Impacts of Mining on Headwater Streams of the Southern Rocky Mountains

Introduction

This study focused on the mining belt within the Southern Rockies Ecoregion, an area where impacts from mining to water quality were suspected of being extensive. It was done under REMAP, the regional component of EMAP (Environmental Monitoring and Assessment Program). REMAP studies generally use the same design and methods as EMAP studies, but are used to answer questions in a smaller geographic area.

This particular study was unique in that the design and methods had not been previously used in the Southern Rockies Ecoregion, nor had it been used to investigate the extent of contamination from mining. Another important aspect of this project was the use of biological and physical measures, along with chemical, to assess the condition of aquatic systems.

Purpose of the Study

Specifically, three major questions were indentified for this study to answer:

1) What is the current condition of biological communities in headwater streams in the mineralized area of the Southern Rockies Ecoregion?

Most previous monitoring in this region had focused on sites upstream and downstream of areas with suspected impacts. As a result, the overall extent impacts from mining in Colorado have been difficult to measure (USEPA,1993a). At time this REMAP study was proposed, 873 miles of streams in Colorado were estimated as having major impacts from metals, with an additional 705 with moderate or minor impacts, for a total of 1578 (WQCD, 1992). More recent estimates are similar. The 2002 draft water quality report for Colorado lists 1557 miles of streams as impacted by metals and pH (CDPHE, 2002). Additionally, according to the Colorado Office of Active and Inactive Mines (1996) there are 21,000 abandoned mines in Colorado impacting 2000 kilometers (1240 miles) of streams. This study sought to estimate the relative proportion of mining-impacted streams using various (chemical, biological, physical) measures.

2) What biological indicators are suitable for detecting the impacts of metals in these streams?

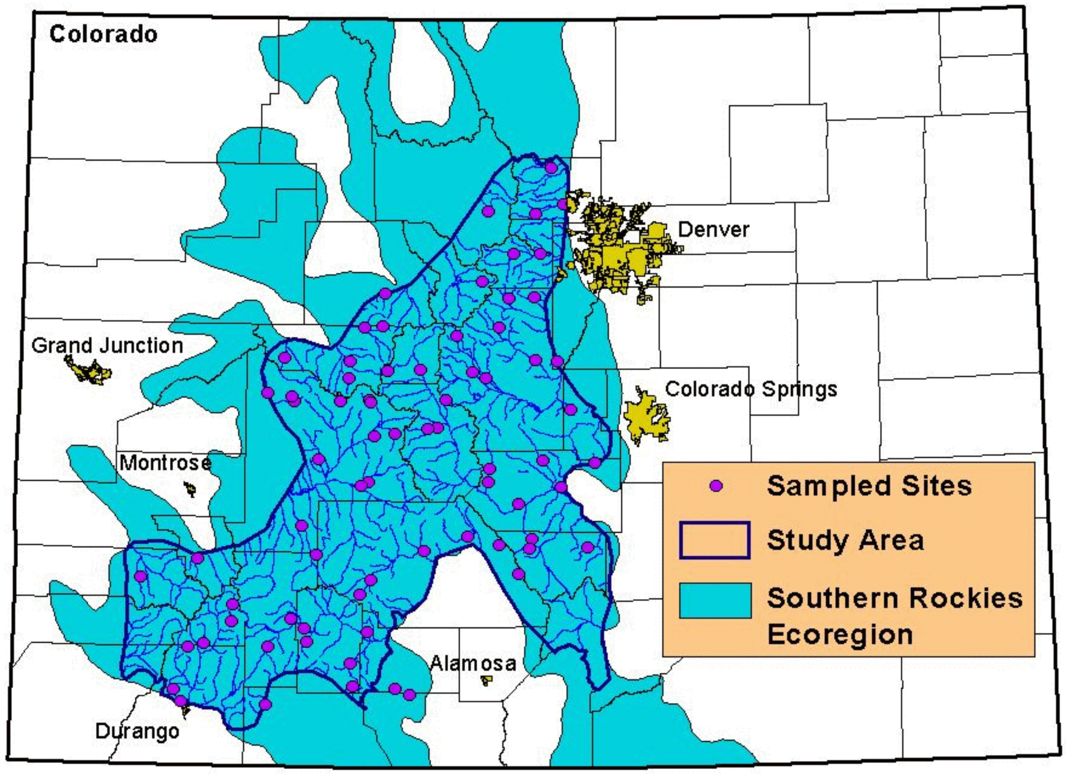
Traditionally, chemical monitoring has been used most frequently to examine mining impacts. This study used chemical, biological and physical habitat measures to determine the effectiveness of each in detecting impacts to streams from mining activities. The usefulness of biological indicators was of particular interest here since this study could provide a good comparison between chemical and biological indicators and among several types of biological indicators.

3) What constitutes a reference (high quality) condition against which to judge the status of streams in the mineralized area?

One objective of this study was to identify the highest quality sites depending on the various measures. These could then be used as a "reference" by which to measure other streams in this region.

Geographic Setting

The Southern Rockies Ecoregion (Omernik, 1987) covers approximately 64,000 square miles, spanning from southern Wyoming to northern New Mexico, with the majority located within central Colorado. The ecoregion is characterized by mountains, foothills and valleys with elevations ranging from about 5,500 feet to over 14,000 feet in elevation. The landcover consists of juniper, pine, spruce and fir forests, with some open park areas and alpine vegetation. This region serves as the headwaters for a number of major rivers, including the Platte, Arkansas, Colorado, and Rio Grande.



Within the ecoregion, the mining belt runs generally northeast to southwest (see map above). This area was delineated using current and historic mine site locations as defined in a GIS database obtained from the U.S. Bureau of Mines. The screening involved locating hardrock, non-placer, mining sites (gold, silver, zinc, lead, copper, and molybdenum) and generating a boundary around high density clusters.

The mining belt has many abandoned and inactive mines, mills and tailings. Adits from abandoned mines are often a source of metal loadings affecting water quality (USEPA, 1993a). Additionally, runoff from waste rock from mining (dumps) and reject material from processing (tailings) can affect water quality. In some cases, depending on the geology, a phenomenon known as acid mine drainage (AMD) can be created. Acid mine drainage is formed by a chemical reaction between water and sulfur-bearing rocks and the runoff from it usually contains high metals and low pH (USEPA, 2000). Mining can also add excess sediment to a stream, impacting aquatic life in a physical manner.

This study focused specifically on headwater streams of second, third and fourth orders. First order streams were not sampled because they were considered too small to support fish populations.

Mining is only one possible threat to these streams, with grazing, logging, water withdrawals, road construction and housing development being others. The predominant impacts associated with many of these threats are sedimentation, alteration of flows, and alteration of riparian areas. Sedimentation can be detrimental to aquatic insects by filling in the spaces between rocks and cobbles. This in turn can affect fish and other vertebrates that depend on insects for food. Alteration of flows can reduce the quality and extent of aquatic habitat and the removal of streamside vegetation can induce a number of effects from increased sedimentation to loss of species.

Sampling Design

A probabilistic sampling design was used, meaning that sites were chosen at random in order avoid biases toward good or poor sites (Hughes, et al 1992; Whittier and Paulsen, 1992). This type of sampling design operates similar to opinion polls, in which a small subsample (in this case, stream reaches) is selected out of a larger population (the headwater streams of the Southern Rockies mineralized area). Through this design, the condition of the larger population can be estimated with a known confidence level.

Another important feature of this study was the use of biological indicators, along with chemical and physical measurements. Monitoring of biota and physical habitat provides information that might be missed when only chemical measures are employed. These indicators may discern impacts resulting from the integration of several pollutants or from impacts that are not chemical, such as sedimentation.

The initial target population for this study was 106 sites. After removing dry, non-wadeable, and access-denied sites, 73 were actually sampled (see map for locations). Of these 73, eight were repeated to determine within and between year variation. The total stream length represented by the 73 sites was 6630 kilometers (4100 miles). This is out of a total stream population of 28,800 kilometers (about 17,900 miles) (Hill, et al unpublished).

Aside from the random sites, six reference sites were chosen using the best judgement of those familiar with streams in the region. Three of these sites were repeated. These sites were assumed to be in excellent condition and represent among the best that streams in this region could attain. Additionally, seven known impacted (test) sites were also chosen, one of which was repeated. Both the reference and test sites were added to ensure that sites at each end of the scale of human influence were included for comparison and the methods were used on a full range of impacts. Percentages reported here do not include these non-random sites.

Sampling was performed in the late summer of both 1994 and 1995. The late summer period (referred to as the index period) was chosen for a number of reasons, including accessability of sites, a lower stream flow to minimize dilution of metals, stabilized macroinvertebrate populations, and was the appropriate time to measure physical habitat characteristics instream and in the riparian zone (USEPA, 1993a). The index period represents the time when there is less short-term variation in the measured parameters and less variation from year to year.

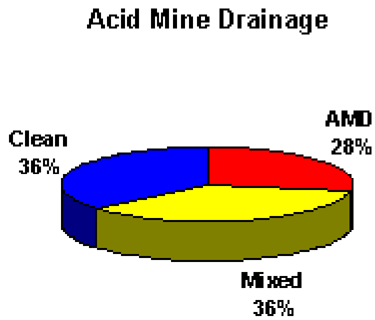
What Was Sampled?

Parameters sampled can be categorized under the broad categories of chemical, biological and physical. *Chemical measures* in the water column included nutrients, total solids, hardness, sulfate, chloride, total metals, dissolved metals, common ions, conductivity, and alkalinity. Common ions and metals were monitored in the sediment. *Biological indicators* measured were fish, benthic macroinvertebrates, periphyton, sediment metabolism, water column toxicity tests and sediment toxicity tests. *Physical measures* included such indicators as substrate size, canopy cover, embeddedness, bank angle, depth, large woody debris, disturbance, fish cover, discharge, gradient, habitat types (pools, riffles, etc.), and riparian vegetation. The sampling and analysis methods used in this study are listed in USEPA (1993b) and USEPA (1988). Additionally, a landscape assessment is being performed using landscape metrics.

Water and Sediment Chemistry

Sites in the data set were classified as acid mine drainage impacted, “clean” (no AMD impacts) or with mixed impacts, based on sulfate and chloride concentrations (Herlihy, et al 1990). Clean sites were those with chloride values of less than 4 mg/L and sulfate less than 5 mg/L. Mixed impacts were sites with greater than 4 mg/L chloride or sulfate between 5 and 20 mg/L. AMD impacted sites were those with sulfate greater than 20 mg/L.

Using this definition, it was determined that 28% of stream miles of headwater streams in the mining belt showed signs of acid mine drainage. Thirty-six percent of stream miles had mixed impacts and 36% were not AMD-impacted.



Aside from acid mine drainage, metal concentrations are also important in determining the presence and severity of mining impacts. In contrast to AMD, in this study, the extent of impacts from metals appears to be smaller. However, these were one-time chemical measurements and may not be representative of what might be found in a more comprehensive chemical monitoring program. Nevertheless, they are an important indicator of mining impacts.

The toxicity of metals is related to the hardness of the water. A higher hardness will reduce the toxicity of a particular metal, although the degree of reduction is specific to each metal. Hardness and metal concentration data were compared to the Colorado water quality criteria (CDPHE, 2001). The following results were obtained.

Fifteen percent of stream miles potentially exceeded either the acute or chronic criteria, or both, for one or more of the following metals: arsenic, cadmium, copper, lead, selenium, and zinc. Zinc had the most exceedances at 9% of stream miles. Arsenic was exceeded in 5% of stream miles. Copper criteria were exceeded in 4% of stream miles, with cadmium, lead, and selenium exceeded in 2% of stream miles each. Nearly 6% of stream miles showed potential exceedances for 2 or more metals, but only 2% of stream miles exceeded the criteria for 3 metals. No sites were found to exceed criteria for more than 3 metals.

Most of the sites with higher water column levels of metals also had higher levels in the sediment. There were only a few sites with relatively high metals in the sediment and low levels in the water column, possibly indicating past contamination. One notable parameter, mercury was detected in sediment at only 3 sites (representing about 4% of stream miles).

Biological Condition

Biological indicators are measures of stream biota and as such represent a direct measure of the aquatic life use classification in state water quality standards. Various biological indicators have advantages and disadvantages. Fish are relatively easy to identify in the field and respond well to effects over a longer time frame and a wider area (Karr, 1987). Macroinvertebrates, on the other hand, while requiring identification in the lab, can respond to effects of shorter duration and smaller area. They also tend to respond to sedimentation impacts sooner than fish (Berkman, et al 1986). Algae (periphyton), especially diatoms, are known to respond to changes in a number of parameters, including metals and nutrients (Bahls, 1993). They are especially responsive to agricultural impacts, with increases in nutrients and light leading to increased biomass and richness (Michael Griffith, personal communication).

Fish

The fish species diversity in this particular region is not high, making the development of useful indexes of biotic integrity difficult. However, the presence or absence of fish, especially trout, says something about the condition of streams, since trout prefer cool, clear, well-oxygenated water. Since a fish index probably cannot be created, using fish to detect mining impacts has limited value. The presence or absence of fish in general, native fish species, or particular trout species does provide information regarding general impacts to aquatic systems, but not necessarily specific to mining.

Eighty-one percent of stream miles had at least one trout species present. Only 43% of stream miles had at least one native fish species present. Only 11% of stream miles had 2 or more native species. No relationship was found between fish assemblages and AMD class or metal criteria, however, the total number of fish and fish species richness was related to water column toxicity tests (Herlihy, et al 1998). Fish in this region do not appear to respond well to environmental impacts until the effect is severe (Herlihy, et al 1998).

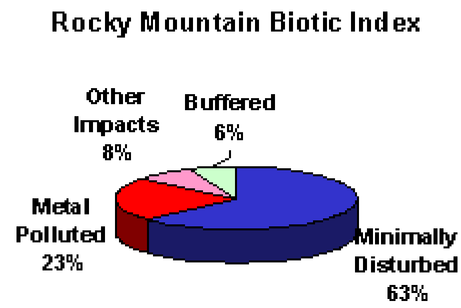
Benthic Macroinvertebrates

Macroinvertebrates may be more useful than fish in this region due to a greater taxa richness. This greater richness allows for more flexibility in creating indexes of biotic integrity (IBI) using a number of metrics. Two such IBIs were developed from the benthic macroinvertebrate data from this study to aid in determining impacts, especially mining impacts.

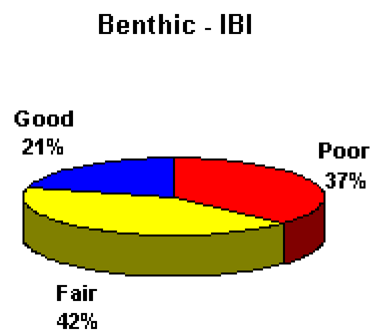
One index, the Rocky Mountain Biotic Index (RMBI) (Clements, et al 1997) is based on 13 metrics (see below).

RMBI Metrics	Total Taxa Richness EPT Richness Mayfly Richness Stonefly Richness Chironomid Richness % Scrapers % Predators % Dominance EPT Abundance Mayfly Abundance Stonefly Abundance Heptageniid Mayfly Abundance Rhyacophilid Caddisfly Abundance
B-IBI Metrics	Total Taxa (ex.Chironomids) Mayfly Richness Stonefly Richness Caddisfly Richness Metal Intolerant Taxa Clinger Taxa % Heptageniid Mayflies

Each individual metric was scored separately and the individual scores were added to create the total index score. Total scores for each site were then analyzed to determine stream condition (higher scores indicating better condition). The RMBI determined that 63% of streams were minimally disturbed, 23% were metal-polluted, 6% were buffered from metal pollution and 8% were impacted by disturbances other than metals (see chart below) (Clements, et al 1997).



The other index, the Benthic-IBI (Fore, 2000), uses seven metrics (see table above) which were also scored individually and total scores divided into categories of good, fair or poor. In the B-IBI, only 21% of stream miles were rated in good condition (see chart below). Forty-two percent were in fair condition and 37% poor.



Toxicity

This study also featured work not typically done with ambient stream samples - toxicity tests performed in the laboratory with stream water and sediment. The tests measured the survival of *Ceriodaphnia dubia* (a water flea) and *Pimephales promelas* (fathead minnow) in water, and the survival and growth of *Hyallela azteca* (an amphipod) in sediment. Toxicity in water was defined as less than 80% survival of *Ceriodaphnia* or *Pimephales.* Sediment toxicity was defined by a significant difference from a control in survival or growth for *Hyallela*.

In the Southern Rockies Ecoregion mining belt, almost 7% of stream miles were defined as toxic to either *Ceriodaphnia* and/or fathead minnows with the water column test. For the purposes of this report, if a site was sampled more than once, the survival percentages were averaged. A little more than 5% of stream miles were toxic to *Hyallela* using the sediment toxicity test (Lazorchak, 1999). The total percentage of stream miles with water and/or sediment toxicity was 11%.

Physical Habitat

In addition to chemical and biological measures, examining the condition of stream habitat can also reveal important clues about the state of the stream. A stream may have no chemical pollutant impacts, yet be dramatically affected by changes in its structure in-stream or riparian zone. Complex in-stream habitat is important for fish and insects in that it creates spawning, feeding, and hiding areas (USEPA, 2000). Riparian vegetation shades streams, providing for cooler temperatures (USEPA, 2000). It also stabilizes banks, reduces siltation, provides migration corridors and nesting areas, and supplies organic matter for aquatic animals (USEPA, 2000).

While habitat impacts might result any number of activities, added sedimentation can be one physical result of mining. One of the ways this study detected this impact was to measure embeddedness. Extensive embeddedness results in loss of habitat for aquatic insects that require spaces between rocks and cobble.

This study found that 36% of stream miles have more than 50% of embedded area. By way of comparison, 61% of sites rated poor, and 96% rated as either poor or fair by the B-IBI had more than 50% embeddedness. Generally, the greater the extent of embeddedness the poorer the benthic macroinvertebrates faired.

There are impacts detected by the physical habitat measures that likely have little to do with mining. For example, of the 31 sites rated as poor in the B-IBI, only 18 could be explained by chemical impacts. In the remaining 13, other processes were affecting the benthic macroinvertebrates, most likely poor habitat, with high or very high embeddedness noted in the majority of those 13. This should be examined in more depth in the future and the development of a physical habitat index would be useful in determining the full extent of impacts from all sources.

Landscape

In addition to the chemical and biological monitoring, a landscape assessment is being performed. The goal of this assessment is to develop landscape-level models that can be used to identify the relative risks to aquatic environments due to watershed-scale (or ecological and regional scales) landscape conditions (Jones, et al 2000). To accomplish this, Region 8 is using remote sensing and Geographic Information Systems (GIS), to understand the quantitative relationships between landscape composition and pattern measurements and biological/chemical/habitat response measurements.

In the Southern Rockies, topographic catchments were delineated for each of the sample locations, and over 70 landscape metrics for each sample site or catchment were calculated. Example metrics include percentage of land cover categories in each catchment, direct catchment metrics such as area and slope, miles of contributing streams, percentage of lithologic units, and number of mines in each catchment.

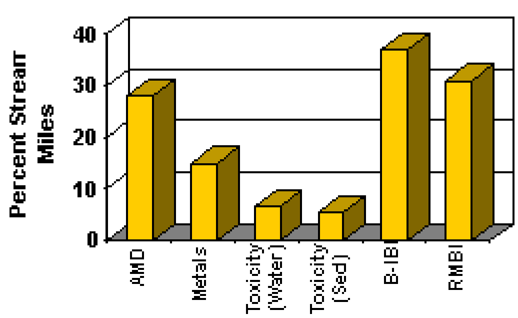
The initial landscape data development and landscape characterization has been completed. The next phase is to determine relationships between landscape measures and chemical, biological, and habitat measures. Preliminary results indicate that several landscape metrics, such as catchment slope, percentage of catchment in forest, and lithology are correlated with the biological/chemical response and may prove useful in predicting aquatic environmental quality (Leland, et al 2002). A complete listing of landscape metrics can be found in Jones et al (2000). Landscape data and information are available in CD-Rom (contact Daniel Heggem, EPA ORD Las Vegas, 702-798-2278).

Summary and Conclusions

Since this study focused on a geographic area defined by mining and does not cover the entire Southern Rockies Ecoregion, the data can only be used to assess impacts within the context of this mineralized area, not the entire ecoregion. This report mainly examines the impacts detected from mining, while acknowledging that the data could be very useful in furthering the understanding of other stressors in the ecoregion.

The number of impacted stream miles was found to be significant, irrespective of measured parameter. Possible acid mine drainage impacts were estimated in 28% of stream miles and toxicity and high metals ranged from 11 to 15%. Using the estimate of 17,900 miles of streams in the total population, this translates into 2000 to 5000 pollutant-impacted stream miles. However, the indexes created from the benthic macroinvertebrate data detected poor quality stream miles in the range of 31-37% (about 5500 to 6600 stream miles). Accounting for the fact that natural factors may play a role at some poor-scoring sites, this is still significant.

Relative Stream Impact by Indicator



The random design used in this study allows for a more accurate estimate of the extent of impacted streams than other studies could achieve. The estimates found in this study are generally higher than ones presently available, indicating that the problem of mining impacts may be greater than previously thought. Past estimates in the range of 1200 to 1600 miles were lower than the lowest estimates in this study (CDPHE, 2002; Colorado Office of Active and Inactive Mines, 1996). There may be a need to reexamine what was previously thought of as the extent of mining impacts in this region.

The macroinvertebrate data revealed a larger universe of impaired streams than the chemistry data, some of which likely resulted from impacts to habitat. The biological data may also be responding to a combination of pollutant factors. Finding a greater response from the invertebrates was not surprising given that the chemical measurements were one-time observations at a given point and in-stream chemical factors can affect metal concentrations over time and space. The biology may be responding to exposure over a longer time frame and a larger scale. Additionally, the geochemical reactions that reduce chemical concentrations often produce fine sediment that can add to embeddedness (Hill, et al unpublished). Other physical impacts, both anthropogenic and natural, unrelated to mining are also likely a part of the noted impacts.

In summary, impacts in this region from mining were found to be extensive and biological measures uncovered more than chemistry alone would. However, not all biological measures are equal. Fish were of limited value and other biological indicators such as periphyton and microbial respiration are still being investigated, although they show some promise. At present, the best biological indicator in this system was determined to be benthic macroinvertebrates. The macroinvertebrates responded to a wider range of impacts and appeared to be a better measure of integrated impacts, both temporally and spatially. This study also showed the value in using a random sampling design for estimating extent of impacts. Additionally, it may be possible to use this data set to develop good criteria for reference sites in the Southern Rocky Mountains Ecoregion. Finally, a repeat of this study in the future would be valuable in evaluating the success of ongoing cleanup efforts.

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