Abandoned Mines and Naturally Occurring Acid Rock Drainage on National Forest System Lands in Colorado

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ABSTRACT

The Colorado Geological Survey completed an inventory of environmental degradation associated with abandoned and inactive mines on National Forest System lands in Colorado. In the course of the inventory, areas with naturally occurring acid rock drainage were also noted. Approximately 18,000 abandoned mine-related features were inventoried, including about 900 features that are considered significant enough environmental problems to warrant further investigation. Water quality data, such as pH and conductivity were gathered at all features where water was present, such as draining adits, seepage at the toe of dumps and tailings, and standing water in shafts. Samples were taken where field tests indicated low pH and/or high conductivity, including several areas with naturally occurring acid rock drainage. Samples were analyzed for dissolved and total metals, and for selected anions. All mine locations and data collected by the field geologists were entered on field forms and, subsequently, into a computer database and GIS format.

With the information provided by the inventory, the Forest Service, in cooperation with other agencies, has been able to prioritize abandoned mines for reclamation. In most cases, cleanup is approached on a watershed basis. Mines in priority watersheds have been selected for reclamation first. Watersheds where studies prerequisite to cleanup are occurring include the upper Animas River, Willow Creek (tributary to the upper Rio Grande), Chalk Creek (tributary to the upper Arkansas River), the Uncompahgre River, and the Alamosa River.

During the inventory, evidence of naturally occurring water quality degradation was found in areas where little or no evidence of mining activity exists. These areas include the upper Alamosa River, the Middle Fork of Mineral Creek, Peekaboo Gulch, and Handcart Gulch. Water from these natural sources has been found to significantly exceed Colorado water quality standards for several metals.

INTRODUCTION

The Rocky Mountain Region (Colorado, Wyoming east of the Continental Divide, and the Black Hills of South Dakota) of the USDA Forest Service (USFS) has recently completed an inventory of abandoned mines. The results indicate that there are approximately 19,000 abandoned mine-related features on National Forest System (NFS) lands in the Rocky Mountain Region of the Forest Service. Of these, about 1,200 are considered environmental problems and 4,500 are considered physical hazards. The

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majority of the problem sites are located in Colorado where 18,382 mine-related features were identified.

The USFS and the Colorado Geological Survey (CGS) completed, under a cooperative agreement, an inventory of environmental degradation associated with abandoned and inactive mines on Colorado's NFS lands. In the course of the inventory, areas with naturally occurring acid rock drainage were also noted. The inventory work began in 1991 and was completed in 1998. The driving force behind the project was the Federal Facilities Compliance Program, which is designed to bring federal facilities and lands into compliance with federal environmental laws including the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Resource Conservation and Recovery Act (RCRA); and the Clean Water Act (CWA) among other laws. The USFS Abandoned Mine Land Inventory Project was a “discovery” process. Identification of environmentally degraded sites may lead to preparation of CERCLA documents consistent with the National Contingency Plan (40 CFR 300). In addition, physical hazards related to abandoned mine sites, such as dangerous shaft or adit openings, were also assessed. Discussion of physical hazards is beyond the scope of this paper.

METHODS

The inventory process began with an office review of existing mining and geologic literature, previous mine inventories, and current and historical maps. Mine locations from these sources were compiled onto a work map. Natural-color, 1:24,000-scale (approximate) aerial photographs were examined to locate potential mine sites not identified by other sources. Water quality information was used to identify streams potentially affected by acid mine drainage or other mine-site contaminants. When the office research process was complete, geologists entered the field with specific mine locations to visit. Additional mines not identified in the literature search were found while performing the field inventory work. Investigated mines were grouped geographically into “inventory areas” that were given identification numbers based on the Universal Transverse Mercator (UTM) coordinate system. An inventory area usually contains one to twenty mine features that can be grouped in relation to geographic features, such as a gulch or hillside. Mine features include adits, shafts, prospect pits, highwalls, quarries, waste rock dumps, tailings, and spoils. All mine features within an inventory area were numbered sequentially. When the feature number is appended to the inventory area number, every mine feature in the inventory has a unique identification number.

Using standardized field-data forms, geologists recorded data on numerous physical and geographic characteristics of the mine features. The quality of any water associated with a mine feature was assessed in the field by determining the pH (acidity), specific conductance (dissolved solids), and observable characteristics of the water. Observable characteristics include precipitates and salts in the effluent drainage, opaque or cloudy water, stressed vegetation, and absence of aquatic organisms. This information was used to assign a qualitative “Environmental Degradation Rating” (EDR) to the individual mine feature. Ratings guidelines (**Table 1**) facilitated consistency in the data set while allowing the field geologists flexibility to consider site-specific conditions such as geology, effluent discharge volume, surface water interactions, precipitation, etc.

The numerical pH and conductivity values given in the ratings are merely guides. Measured values can vary depending on the type of geologic terrane and the location of the mine site within the drainage basin. For example, drainage from areas underlain by sedimentary rocks generally has higher conductivity than drainage from igneous terranes.

Table 1 Guidelines for assigning Environmental Degradation Ratings (EDR)

Rating (EDR)	Feature usually displays one or more of the following characteristics:
1=EXTREME	• Contamination off-site is severe. • Receiving stream is "dead" or sterile at the mine and downstream. • Effluent has extremely low pH (<4). • Effluent has extremely high conductivity (>1500 microsiemens per centimeter - µS/cm; >1000 µS/cm in alpine areas). • High flows of poor-quality water, relative to the receiving stream. • Abundant precipitate at the mine and in the receiving stream. • Very large dumps or tailings piles with evidence of severe erosion, especially if they have abundant sulfides.
2=SIGNIFICANT	• Receiving stream is significantly or obviously adversely affected, but not "dead" or sterile. • Effluent has low pH (<5). • Effluent has high conductivity (>1000 µS/cm; >500 µS/cm in alpine areas). • Moderate flows of poor-quality water, relative to the receiving stream. • High flows of moderate-quality water, relative to the receiving stream. • Moderate to abundant precipitate at the mine and/or in the receiving stream. • Large sulfide-rich dumps or tailings piles with evidence of moderate erosion. • Large dumps with sparse or no sulfides, but evidence of significant erosion.
3=POTENTIALLY SIGNIFICANT	• Evidence of degraded water quality, but serious effects are not obvious or detected. • Effluent has low pH (<5.5). • Effluent has moderate conductivity (>600 µS/cm; >200 µS/cm in alpine areas). • Poor-quality water with low or no flow (standing water). • Moderate flows of moderate-quality water, relative to the receiving stream. • Minor amounts of precipitate. • Very large dumps with little or no evidence of erosion and sparse or no sulfides. • Small and moderate-sized sulfide-rich dumps or tailings piles with evidence of moderate erosion.
4=SLIGHT	• Effluent with slightly acidic pH (<6.5). • Effluent with slightly elevated conductivity (>400 µS/cm; >100 µS/cm in alpine areas). • Sparse or no precipitate. • Small to moderate-sized sulfide-rich dumps or tailings piles with little evidence of erosion.
5=NONE	• No effluent. • Effluent of high quality water. • Small dumps distant from surface water with little or no evidence of erosion.

Water draining from areas of intensely hydrothermally altered rocks often has lower pH and may show elevated conductivity. Sites located topographically higher within a drainage basin may produce water that has relatively lower conductivities because of shorter residence times in the country rock. Water at these sites may still be degraded even though they exhibit lower conductivities than sites topographically lower in the drainage basin. Waters can also have significant concentrations of metals with near neutral pH values. Observable characteristics of the water and the mine site give important clues to the quality of the water in addition to pH and conductivity measurements.

There were some necessary limits on the types of mine features included in the inventory. Generally, prospect pits and exploratory holes were not recorded as their environmental degradation potential is usually negligible. Exceptions were made for deep pits or exploratory shafts that could be physical hazards. As a quantitative guideline, a hole or pit less than 10 feet in depth was not recorded. This guideline was moderated for site-specific conditions such as sloping sidewalls or frequency of site visitation by the public. Dumps, tailings, or spoils piles less than 50 cubic yards in volume were not recorded as their environmental degradation and physical hazard potential are usually negligible. Piles less than this size may have been recorded at the discretion of the field geologist. However, any mine waste interacting with flowing water was recorded, as were all features shown on U.S. Geological Survey 1:24,000-scale topographic maps.

All mine locations and data collected by the field geologists were entered into a computer database. From a computer perspective, both geographic and attribute data were collected. Therefore, the data are well suited for integration into a geographic information system (GIS) creating a geo-referenced data set. Latitude-longitude information for each mine feature and water test was obtained by transferring mine location information from the field geologist's maps to stable-base mylar overlays. Mine locations were then digitized from the mylar overlays. Attribute data that were recorded on standardized field-data forms were keyed into the appropriate database files. The database and GIS files are available from the Colorado Geological Survey.

RESULTS

Abandoned Mine Sites

Tabulations based on the Environmental Degradation Ratings provide useful information for decision- makers. A few factors are important regarding the following numbers. First, these numbers reflect mine features located on NFS lands. Mine features on patented inholdings were not inventoried unless a feature extended onto or obviously affected NFS lands. In the past, promising mining claims or those containing significant economic deposits were usually patented. Therefore, most of the larger mines within National Forest boundaries were patented. These larger mines are more likely to have associated environmental degradation than are the unpatented and generally smaller mines occurring on NFS lands. Secondly, these numbers should not be extrapolated to represent land areas outside of Forest Service administrative boundaries. In many areas National Forest boundaries were deliberately drawn to exclude highly developed mining districts with numerous patented claims. Both of these factors tend to minimize the percentage of mine features with serious environmental degradation problems on NFS lands as compared to privately held lands or lands administered by other land management agencies. The percentages shown on **Figure 1** for extreme, significant, or potentially significant degradation could be viewed as minimum percentages when estimating the number of potential problem sites on non-NFS lands in Colorado.

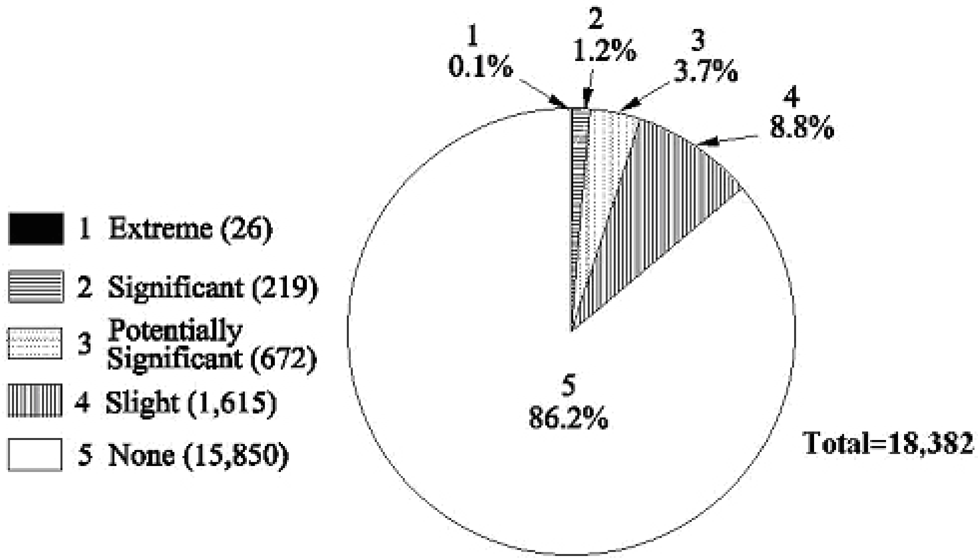

Figure 1 Inventoried mine features by environmental degradation rating (Colorado)

The numbers in Figure 1 reflect all NFS lands in Colorado and reflect varying geologic settings that contain large and small mining districts, within and outside the Colorado mineral belt. **Figure 2** displays the distribution of the abandoned mines in the State of Colorado. As one would expect, the distribution of sites closely approximates the trend of the Colorado mineral belt.

Features exhibiting extreme, significant, or potentially significant degradation (EDRs of 1, 2, or 3) are generally those that warrant further investigation (preliminary assessment, site characterization, etc.) to quantitatively determine impacts to the environment. With the information provided by the inventory, the Forest Service, in cooperation with other agencies, will be able to prioritize abandoned mines for reclamation. In most cases, reclamation is approached on a watershed basis; mines in priority watersheds have been selected for cleanup first. Other involved agencies, such as the Bureau of Land Management, the Environmental Protection Agency (EPA), and the Colorado Department of Public Health and the Environment are working together in priority watersheds to mitigate environmental problems at mines and ultimately improve water quality. The watersheds (**Figure 3**) in which major efforts have been initiated include the upper Animas River, Willow Creek tributary to the Rio Grande Headwaters in the Creede area, Chalk Creek (tributary to the Arkansas River), the Uncompahgre River above Ouray, and the Alamosa River below Summitville. To date, most of the work has been administrative, and little reclamation has been accomplished.

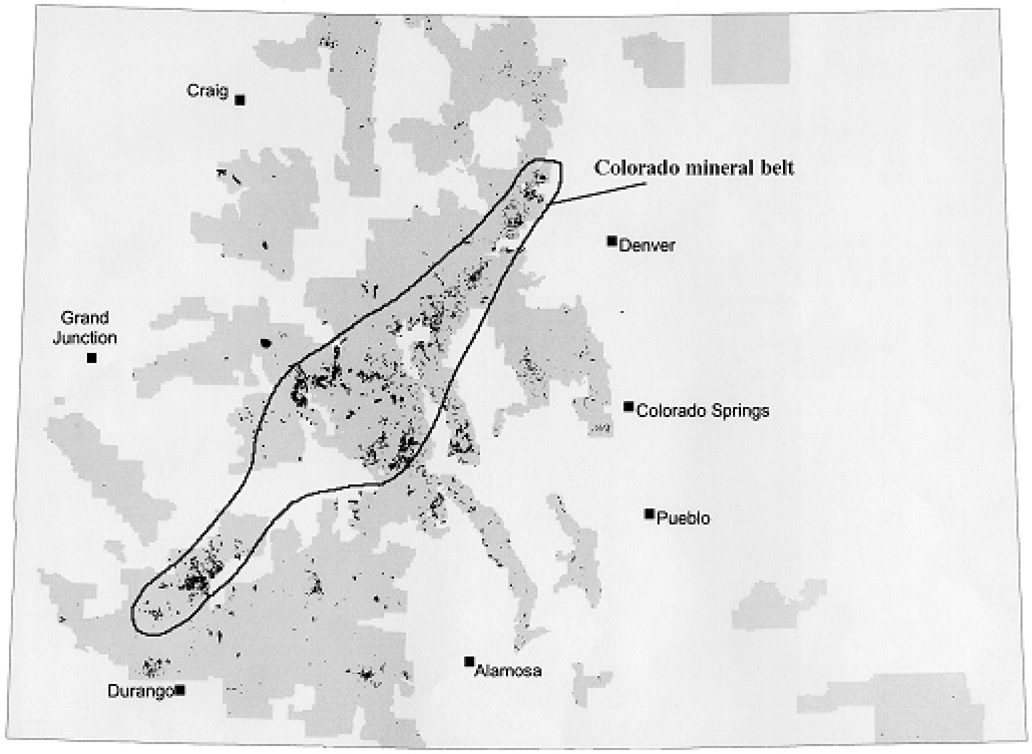

Figure 2 Distribution of Abandoned Mines (black) on National Forest System lands (shaded) in Colorado

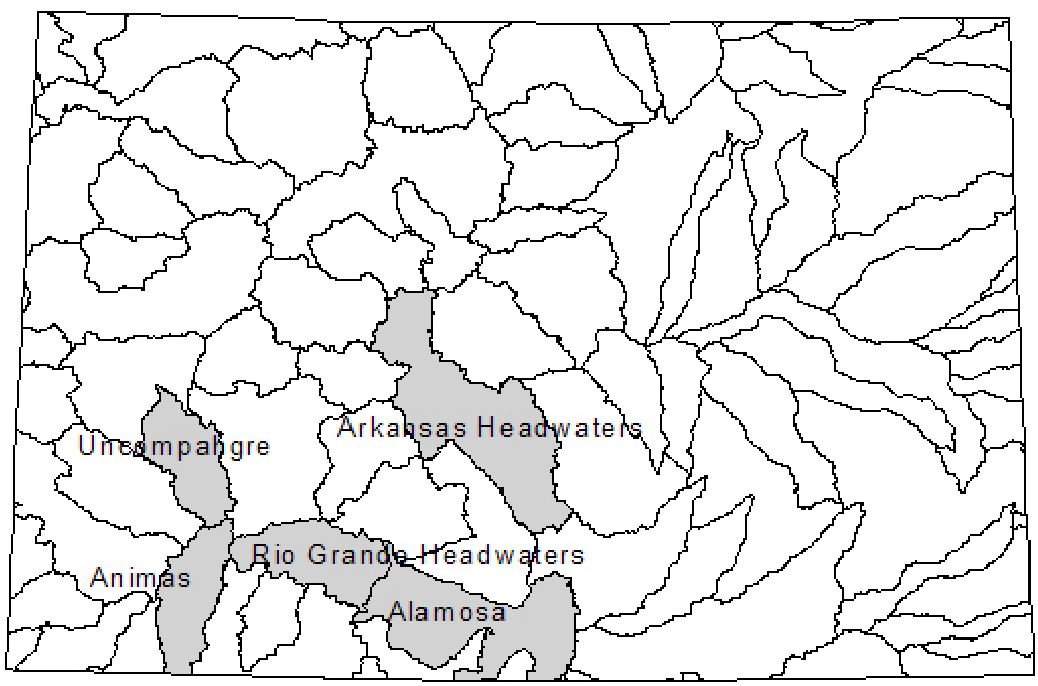

Figure 3 Priority watersheds (shaded) in Colorado discussed in the text

Upper Animas River. The upper Animas watershed, along with the Boulder River watershed in Montana, was selected as a national pilot watershed by the land management agencies in cooperation with other federal and state agencies. The Animas River Stakeholders Group is coordinating efforts by government agencies, private companies, public concern groups, and individuals to identify, characterize, and eventually remediate mining-related sources of metals in the upper Animas River basin. In the upper Animas watershed, Mineral Creek and its tributaries are on NFS lands. Within the Mineral Creek watershed, 20 sites needing further investigation were identified by the inventory. The more notable sites include the Bonner Mine, the Bandora Mine, the Brooklyn Mine, and the Paradise (White Death) Mine.

Willow Creek. The Willow Creek watershed, in the headwaters of the Rio Grande River, lies just to the north of the Town of Creede, Colorado. While most of the degradation in Willow Creek appears to be caused by mines on private lands, the inventory identified nine sites on NFS lands that may be contributing to poor quality water in the vicinity of Creede. These include the Midwest Mine, the Last Chance Mine dump, and the Outlet Tunnel dump.

Chalk Creek. Chalk Creek contains a dozen or more sites in the Arkansas headwaters, south and west of Buena Vista, Colorado in the vicinity of the St. Elmo, Alpine, and Romley mining districts. Most of the mining activity in the Chalk Creek drainage basin occurred prior to the 1940’s. The Mary Murphy Mine was a major producer. Veins in granitoid rocks of the Mt. Princeton batholith host the ore. The Colorado Division of Minerals and Geology has reclaimed many of the worst sites in the drainage basin on non-NFS lands.

Uncompahgre River. This area consists of the Ouray and Red Mountain mining districts. Ore deposits are associated with breccia pipes and veins in volcanic country rock. This area contains the highest concentration of abandoned mine sites needing further evaluation on NFS lands in Colorado. Sixty-four sites were identified with EDRs of 1, 2, and 3. The geology of this area suggests that some portion of the acidic drainage is natural. The Idarado Mine and some others have been reclaimed by the Idarado Mining Company (Newmont) and contributing partners.

Alamosa River. The Alamosa River has been targeted for restoration by the Alamosa River Watershed Restoration Task Force. The Alamosa River basin has several sources of acid rock drainage; some resulting from mining activity and some from natural sources. In this area the inventory has identified nine mine sites on NFS lands needing further investigation. The EPA has spent millions of dollars on the environmental mitigation at the Summitville Mine.

The Forest Service emphasis is on requiring the party responsible for the mining and the subsequent environmental degradation to pay for reclamation. Knowledge of the historical operations and the financial viability of those responsible for the environmental degradation is necessary. Information regarding individual mine sites is usually very limited and has been found to be non-existent at several of the sites investigated. Considering the vast number of sites occurring on NFS lands in Colorado and the limited funding available nationally to reclaim abandoned mine sites, reclamation is likely to take many years.

Naturally Occurring Degradation

During the inventory, evidence of naturally occurring water quality degradation was found in areas where little or no mining activity exists. The geology and hydrology of these areas are conducive to producing waters with relatively high concentrations of metals and low pH's from springs, seeps, and streams. Some areas exhibiting poor water quality unrelated to mining include the upper Alamosa River, Conejos County; Middle

Fork of Mineral Creek, San Juan County; Peekaboo Gulch, Chaffee County; and the upper North Fork South Platte River, Park County. Source areas for naturally degraded water usually exhibit regional hydrothermal alteration of the country rock in addition to vein mineralization. Many of these occurrences are in, or associated with, volcanic rocks.

However, some sources are in metamorphic, sedimentary, and igneous terranes. Samples of natural waters were collected in these areas. **Figure 4** shows their locations and relevant geologic features such as volcanic fields, calderas, and an igneous intrusive stock.

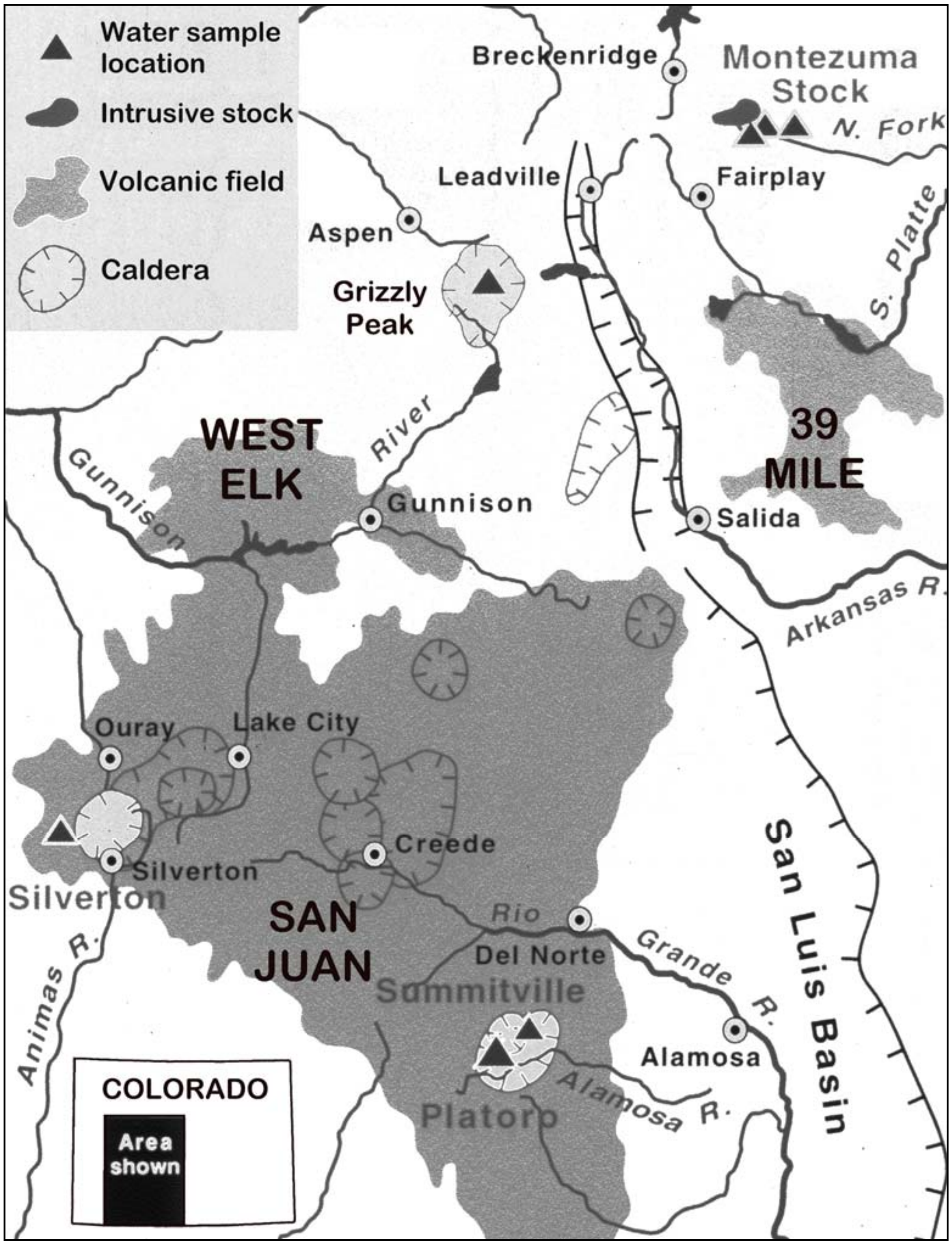

Figure 4 Areas of naturally occurring degradation discussed in the text (modified from Fridrich and others, 1991)

Upper Alamosa River Basin. The upper Alamosa River basin is located within the Platoro-Summitville caldera complex in the San Juan volcanic field **(**Figure 4). The caldera complex and its associated faults served as structural zones of weakness for emplacement of igneous intrusive stocks. Two stocks within the caldera complex, the Alamosa River stock and the Jasper stock, are responsible for extensive hydrothermal alteration affecting the drainage area of the upper Alamosa River and its tributaries (Bove, 1994; Lipman, 1974). Iron, Alum, and Bitter Creeks are underlain by alteration related to the Alamosa River stock. Jasper and Burnt Creeks are affected by alteration related to the Jasper stock.

The Alamosa River drainage basin has been thoroughly studied recently due to environmental problems at the Summitville Mine (Posey and others, 1995). Numerous investigators have recognized the evidence of naturally degraded waters in this area (Moran and Wentz, 1974; Hamilton, 1989; Kirkham and Holm, 1989; Miller and McHugh, 1994; Kirkham and others, 1995). Many tests for pH and conductivity were performed on springs, seeps, and streams in the upper Alamosa River basin during the USFS Abandoned Mine Land Inventory. This was done to document both the mining-related and naturally occurring sources of acidic, metal-rich waters in the area. The relative contribution from each of these sources in the upper Alamosa River basin (excluding Summitville) is discussed in detail by Kirkham and others (1995). Water samples indicate significantly elevated concentrations of aluminum, copper, iron, and zinc at most of these springs and high manganese concentrations at two locations.

Middle Fork of Mineral Creek. Mineral Creek, an important tributary in the upper Animas basin, roughly coincides with the western boundary of the Silverton caldera (Figure 4). The Middle Fork of Mineral Creek extends west of the main stem and lies west of the caldera. Although some mines showing significant environmental degradation lie in the drainage basin of the Middle Fork of Mineral Creek, evidence of natural acidic drainage was found above mined areas. The easternmost significant tributary that drains the slope south of the Middle Fork of Mineral Creek (informally known as the “Red Trib”) is underlain by hydrothermally altered, early Oligocene volcanic rocks of intermediate composition (Steven and others, 1974; Luedke, 1996). The gulch has an obvious red color indicative of disseminated iron sulfides that are now oxidized. Compared to state-wide chronic aquatic life standards for metal concentrations, water in this tributary contains about 115 times the aluminum standard, 1.2 times the cadmium standard, and 27 times the iron standard.

Peekaboo Gulch. Evidence of naturally occurring degradation was observed in the area around the Grizzly Peak caldera, just south of Independence Pass, considerably north of the San Juan-West Elk volcanic field. The Peekaboo Gulch spring is located northwest of the stream about one-half mile below its headwaters. The spring emerges near a fault separating Oligocene Grizzly Peak Tuff southeast of the fault from older Oligocene caldera collapse breccias and lavas northwest of the fault (Fridrich and others, 1991; Tweto and others, 1978). Late-resurgent intrusions caused extensive hydrothermal alteration and metal- sulfide emplacement in the Peekaboo Gulch area (Fridrich and others, 1991). Oxidation of the sulfides has discolored the highly fractured bedrock, hence, the name of Red Mountain that forms the western slope of Peekaboo Gulch.

Four small prospect adits and one moderate size adit are located about one-quarter mile west and upslope of the sampled spring. Three of the mine dumps are less than 50 cubic yards, one is about 270 cubic yards, and the largest is about 1,100 cubic yards. None of these mines were draining water when inventoried (July, 1994). It is possible that water from the Peekaboo Gulch spring is slightly affected by the mines to the west, but the geologic setting and lack of drainage from the mines indicate that the spring produces predominately natural water.

Total concentrations of dissolved metals in the spring water exceed state-wide chronic aquatic life standards by factors of 1,724 for aluminum; 42 for cadmium; 164 for copper; 100 for iron; about 6 for silver; and 21 for zinc. Above its confluence with this spring, Peekaboo Gulch contains clear water with relatively neutral pH (6-7). Below the spring, Peekaboo Gulch becomes red with iron hydroxide precipitate and is very acidic (pH=3.5).

Handcart Gulch and Bruno Gulch. Water samples were taken from Handcart and Bruno Gulches, headwater tributaries to the North Fork of the South Platte River, east of the Continental Divide in central Colorado. The headwater areas of these two streams, including Handcart Peak and Red Cone peak, consist of Precambrian schist and gneiss that have been pyritically altered by hydrothermal fluids (Streufert, 1993). This alteration is regional in scope, related to emplacement and cooling of the Montezuma stock (Neuerberg and Botinelly, 1972). The Montezuma stock forms the central part of the Montezuma mining district located just west of the continental divide in the upper Snake River basin (Figure 4). These tributaries exhibit acidic conditions and were investigated for evidence of mine-related sources. No mining occurred in Bruno Gulch. Only one small prospect adit (200-cubic-yard waste-rock dump) was found in Handcart Gulch. This adit contained a small amount of standing water, but was not draining when inventoried. Acid-metal drainage from the altered areas has created actively forming and extensive bog-iron deposits in Handcart Gulch (Streufert, 1993).

The upper Bruno Gulch sample analyses reveal concentrations above the state-wide chronic aquatic life standards for aluminum (factor of 15), copper (factor of 13), and zinc (factor of 2.7). Water in lower Bruno Gulch is appreciably better due to inflows of good quality water

Analyses of upper Handcart Gulch water show concentrations above standards for iron (factor of 5.6) and zinc (factor of at least 2). Poor water quality persists downstream in Handcart Gulch and the water actually becomes more acidic and laden with metals toward its confluence with the North Fork South Platte River. This may be due to the natural action of acidic stream water on the bog-iron deposits, although some disturbance of these deposits has taken place through placering and minor mining of the bog-iron itself.

CONCLUSIONS

The USDA Forest Service Abandoned Mine Land Inventory Project inventoried 18,382 mine features on NFS lands in Colorado for environmental degradation and physical hazards. Of these, 26 (0.1%) exhibit extreme, 219 (1.2%) significant, and 672 (3.7%) potentially significant environmental degradation.

Areas of natural degradation discussed in this paper are limited to those with no apparent influence by mining on water quality. Country rock in all of these areas exhibits hydrothermal alteration related to volcanic processes and/or intrusion of igneous stocks. Other areas of Colorado would presumably exhibit similar natural degradation of surface water if the hydrologic regimes had not been changed by extensive mining.

This study did not attempt to identify all of the areas showing natural water degradation in Colorado. Investigations regarding natural degradation were tangential to our purpose, and the inventory was restricted to NFS lands. Non-NFS lands with suitable geology probably exhibit natural degradation similar to that described above. Studies focused on identifying regional areas of natural degradation have been completed by Wright and Janik (1995) and Miller and McHugh (1994). A study in progress by the CGS will address many of the known occurrences of this phenomena at a state-wide level.

As inventoried mine sites exhibiting environmental degradation progress from discovery to site characterization and remediation, it will be important to clearly identify the goals of remediation. Sites that occur in areas of naturally degraded water should, if possible, have background conditions characterized in addition to mine-site characterization. Some investigators, such as Wright and Janik, (1995), Taylor and Wheeler (1994), and Bencala and others (1987) are researching methods to estimate amounts of metals contributed by natural sources in streams. If methods to determine relative amounts of mining-generated and naturally occurring water degradation are successful, remediation goals for mine-contaminated watersheds can be set at realistic levels.

REFERENCES

Bencala, K.E., McKnight, D.M., and Zellweger, G.W., 1987, Evaluation of natural tracers in an acidic and metal-rich stream: Water Resources Research, v.23, no. 5, p. 827-836.

Bove, D.J., 1994, Preliminary report on the geology of hydrothermally altered areas within the upper Alamosa River basin, Colorado: U.S. Geological Survey Open-File Report 94-224, 12 p.

Fridrich, C.J., Smith, R.P., DeWitt, Ed, and McKee, E.H., 1991, Structural, eruptive, and intrusive evolution of the Grizzly Peak caldera, Sawatch Range, Colorado: Geological Society of America Bulletin v. 103, no. 9, p. 1160-1177 (September 1991).

Hamilton, J.L., 1989, Investigation of water supply for a private residence southwest of Monte Vista, Rio Grande County, Colorado, in Harmon, E.J., ed., Water in the Valley: Colorado Ground Water Association 8th Annual field trip guide book, p.261-267.

Kirkham, R.M., Lovekin, J.R., and Sares, M.A., 1995, Sources of acidity and heavy metals in the Alamosa River basin outside of the Summitville mining area, Colorado, in Posey, H.H., Pendleton, J.A., and Van Zyl, Dirk, eds., Proceedings: Summitville Forum '95: Colorado Geological Survey Special Publication 38, Denver, Colorado, p. 42-57.

Kirkham, R.M., and Holm, J.D., 1989, Environmental problems and reclamation activities at inactive metal mine and milling sites in San Luis Valley, in Harmon, E.J., ed., Water in the Valley: Colorado Ground Water Association 8th Annual field trip guide book, p.209-227.

Lipman, P.W., 1974, Geologic map of the Platoro caldera area, southeastern San Juan Mountains, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-828, scale 1:48,000.

Luedke, R.G, 1996, Geologic Map of the Ophir Quadrangle, San Juan, San Miguel, and Dolores Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Series GQ-1760, scale 1:24,000.

Miller, W.R., and McHugh, J.B., 1994, Natural acid drainage from altered areas within and adjacent to the upper Alamosa River basin, Colorado: U.S. Geological Survey Open-File Report 94-144, 47 p.

Moran, R.E., and Wentz, D.A., 1974, Effects of metal-mine drainage on water quality in selected area of Colorado, 1972-1973: Colorado Water Conservation Board Circular 25, 250 p.

Neuerberg, G.J., and Botinelly, Theodore, 1972, Map showing geologic and structural control of ore deposits, Montezuma district, central Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-750, scale 1:31,680.

Posey, H.H., Pendleton, J.A., and Van Zyl, Dirk, eds., 1995, Proceedings: Summitville Forum '95: Colorado Geological Survey Special Publication 38, Denver, Colorado, 375 p.

Steven, T.A., Lipman, W.J., Hail, W.J., Jr., Barker, Fred, and Luedke, R.G., 1974, Geologic map of the Durango quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-764, scale 1:250,000. (Reprinted 1977, 1983)

Streufert, R.K., 1993, Symptoms of naturally occurring acid-metal drainage in an area of historic mining: upper North Fork South Platte River, Park and Clear Creek Counties, Colorado, in Richmond, T.C., ed., Proceedings of the Fifteenth Annual Abandoned Mine Land Conference, September 12-16, 1993: Jackson, Wyoming, p.1-7.

Taylor, B.E. and Wheeler, M.C., 1994, Sulfur- and oxygen-isotope geochemistry of acid mine drainage in the western United States in Alpers, C.N., and Blowes, D.W., Environmental geochemistry of sulfide oxidation: Washington D.C., American Geochemical Society, p. 481-514.

Tweto, Ogden, Moench, R.H., and Reed, J.C., Jr., 1978, Geologic map of the Leadville 1° x 2° quadrangle, northeastern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-999, scale 1:250,000.

Wright, W.G., and Janik, C.J., 1995, Naturally occuring and mining-affected dissolved metals in two subbasins of the upper Animas River basin, southwestern Colorado: U.S. Geological Survey Fact Sheet FS-243-95, [4] p.