ENVIRONMENTAL AND WATER QUALITY ISSUES

DECISION-MAKERS
FIELD CONFERENCE 2005
Taos Region

Rio Grande in fall color, near Embudo.

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Public Perspectives on Mining—"There Must Be a Way to Do It Right"

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Mining operations of one type or another have been altering our landscape since the dawn of civilization. Today there is growing evidence that public opinion and the political landscape within which mining operates is altering as well. This is due primarily to conflicts over land use and public values.

> *Pollution…air, water and land pollution-it runs the gamut…the destruction of beautiful mountains and valleys…the Berkeley Pit is one of the biggest toxic waste sites in the country…cyanide…jobs…natural resources…helped build the country…destroys the countryside…its better than it used to be…they haven't figured out a way yet to deal with the harmful byproducts and keep the land healthy…what do we have to show for it…what's it going to do for us once the mine is gone and they've ruined the environment and the jobs are gone…employs a lot of people and I support it but I wouldn't want to live near a mine…there must be a way to do it right.*

These excerpts from focus groups commissioned by EARTHWORKS in 2003 in Billings, Montana, Las Vegas, Nevada, and Seattle, Washington, offer a sampling of public attitudes about mining today. And they match the views expressed in focus groups and polling that we sponsored in 2000, with one significant difference—although mining remains a remote activity for most, there is a growing awareness of its impacts particularly in states with significant current or historical mining activity. The participants in the 2003 focus groups were more able to cite specific mining accidents and even specific types of pollution such as cyanide spills or acid mine drainage.

There is a difference between public awareness in mining regions as opposed to those regions where there is little large-scale mining. For example, people from non-mining urban areas like New York, Baltimore, and Chicago have a vague but somewhat negative impression of mining. Their views are shaped to a great extent by historical images of coal mining. People in the West, even the urban West, have often seen mines, have family members or friends who work in the mining industry, and can draw upon images (from both actual experiences and media stories) of mining and mining accidents and pollution. Their understanding of the role that mining has played economically, either positive or negative, typically comes directly from experience.

The generally negative perception of mining is balanced by an almost unanimous desire for mining, when it occurs, to be done the right way. The public is not anti-mining and is well aware of the material and economic needs that are met by mining the earth's crust. People understand that they benefit from the products created by mined materials, and they want to continue to enjoy those benefits but as one focus group respondent stated: "There must be a way to do it right." This sentiment was shared by virtually every focus group member in every focus group that we have conducted. The public wants tougher mining safeguards, and they want greater corporate responsibility-in fact they expect it.

TOUGHER STANDARDS AND INDEPENDENT VERIFICATION ENHANCE PUBLIC CREDIBILITY

Many in the mining business acknowledge that the industry has a public-perception problem; some even acknowledge that they have a reality problem. In 2000 a number of major mining companies sponsored a multi-year study known as the Mining Minerals and Sustainable Development (MMSD) project and launched a major effort to reposition the industry, including the creation of a new global trade association with a mandate to address issues related to sustainable development—the International Council on Mining and Metals (ICMM). There is, however, a split in the industry as to whether improving public perception is a matter of better performance or just better public relations. Those who look at the issues seriously recognize that better performance is essential to a better reputation. They are therefore focusing their time, energy, and resources on practices and performance first, rather than public relations. They also recognize that an essential component of a better reputation is an acknowledgment of improvements from those outside the mining industry—e.g., non-governmental organizations (NGOs), regulators, academics, investors, insurers, and those that market and sell

Placer Dome's Golden Sunlight gold mine near Whitehall, Montana.

products that use metals such as jewelry retailers and high-tech companies. Many realize that the public is likely to see the cues that come from these groups outside the mining industry as more credible than those that come directly from the mining industry or from mining industry-sponsored groups or trade associations. The public tends to discount self-promotion, as it should. It is always better to have someone else pat you on the back or offer kudos.

Interestingly, the two ingredients that are essential to improving the practice, performance and reputation of the mining sector—stronger government regulations and mechanisms for independent, third-party verification of responsible practices—are fiercely controversial within the mining sector.

In regard to stronger mining laws and regulations, a number of mining companies have asserted to me that they are better corporate citizens but they are not getting credit for it. In the U.S. a number of the major mining companies appear to have become smarter about where they propose mines. Yet, some companies still propose mines near national parks, under Wilderness areas, or in important watersheds. As a result, the reputation of the entire industry is tarnished. Laws or regulations that block irresponsible companies from proposing mines in these areas actually enhance the reputation of the industry and allow companies to focus investment resources for mines in more suitable areas.

In regard to independent certification of performance, instead of movement toward independent standards and verification, there appears to be a preference in the mining industry for self-imposed, first-party standards regarding environmental and social performance. This strategy lacks transparency, credibility, independence, and legitimacy. It would be like Pepsi conducting a taste test to compare itself to Coca-Cola, without blindfolds and using its own employees. Fortunately, there is recent evidence that some leaders in the industry may be willing to participate in the development of an independent, third-party verification scheme, with standards developed through a transparent process and with participants from multiple sectors. This is a potentially significant development.

It is true that the reputation of the entire industry suffers because of the "bad apples," a point made on numerous occasions by leaders in the mining industry. Stronger mining regulations and independent verification schemes could begin to differentiate publicly the leaders from the laggards—and should provide *reputational*, financial, and regulatory rewards to leaders in the industry. Such an approach is a risky strategy only for the laggards. It is a shrewd strategy for those who consider themselves to be industry leaders and are willing to prove it. Those who pursue this strategy may be less popular at trade association sponsored cocktail parties but are likely to find themselves more highly regarded by investors, insurers, and the public.

VALUES VS. TECHNICAL ARGUMENTS ABOUT HOT BUTTON ISSUES

There are today a number of hot-button issues that tend to foster public controversy and push the reputation of mining into the negative column. I will describe two such issues: 1) mine location and land-use conflicts and 2) responsibility for closure and cleanup and the definition of responsible reclamation. In each of these examples the public is listening to arguments that are both technical and value-laden, but the industry is typically making only technical arguments. Mining company officials too often act as if the less-quantifiable values held by the public are irrelevant.

Mine Location and Land-Use Conflicts

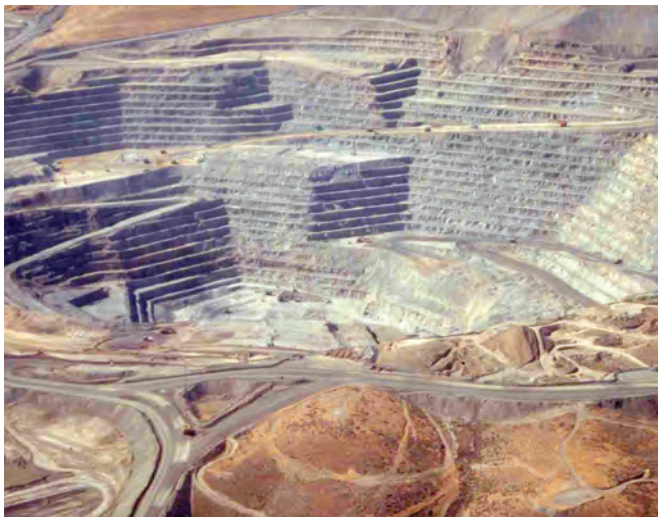
Modern industrial-scale mining can alter landscapes, water systems, economies, and communities, often in ways that are permanent or long-lasting. Therefore, it

should come as no surprise that mining proposals are highly controversial when they conflict with other land uses or preservation.

Near Sandpoint, Idaho, a mining company wants to mine under the Cabinet Mountain Wilderness Area and they want to place the tailings in an unlined pile near the Clark Fork River, threatening clean water, the scenic beauty of the area, endangered grizzly bears, and trout populations. Most people in Sandpoint, and a vast majority of business leaders, oppose the mine; they do not believe this is an appropriate place for a mine or for the mine waste that would result.

However, because of the nature of the laws and the regulatory process, the policy-making process fails to adequately account for the key public concern—the suitability of the location and the fact that the public values keeping the land, and its wildlife and other natural resources, in a protected state. Instead, the debate takes place through competing scientific and technical studies regarding the potential impacts of the mine. These studies are essential, but they fail to address the underlying question of land suitability. The mechanisms that do offer some protection, such as land withdrawals, are not always adequate or effective. Some public officials have had to resort to expensive, complex, and messy buyouts and land exchanges to prevent mine development. What's lacking is a process that allows for the effective and efficient weighing of land uses that should be at the heart of good land use planning and decision making.

Until we begin to develop standards and norms for making appropriate land use decisions, standards and norms that are also accepted by nearby communities, civil society groups, mining companies, and other stakeholders, these conflicts will continue, and the industry as a whole will be swimming against the tide of public opinion and public values.



Open-pit mine.

Defining and Paying for Closure and Cleanup

A prevalent theme in focus groups, particularly in western cities, is that the mining industry has a reputation for walking away from mine cleanup liabilities—to oversimplify, as one focus group participant put it: "They get the gold, we get the pollution mess and the bill for cleaning up the mine."

There is a historical component to the problem. Some of the worst sites on the Superfund National Priorities List are mines. Then there are abandoned mines that are not part of the Superfund program. Several studies, using different definitions of an abandoned mine, have arrived at different estimates for the number of such sites. For example, the Western Governors Association has estimated that there are 250,000 abandoned mines in just the western states, but limited information from some states means the number could be higher. Using a different definition, Mineral Policy Center (now part of EARTHWORKS) has estimated that there may be as many as 500,000 abandoned mines across the entire country. The point is not the debate over the exact number, it's that the problem is significant, particularly as more and more people begin to live or travel near these sites. There is also a contemporary aspect to the problem. In Montana just a few years ago Pegasus Gold walked away from Zortman-Landusky and other mines leaving taxpayers with a bill of at least $30 million. In March 2003 Jim Kuipers authored a report that showed a potential $12 billion gap—the difference between existing financial guarantees and what was likely to be necessary for adequate mine closure—at operating mines in western states.

In the state of New Mexico it took years of citizen-generated pressure and dogged work by regulators to require the mining companies running some of the state's biggest copper mines to update and increase their reclamation bonds so that an adequate financial guarantee would be in place. Mining companies used technical, procedural, and economic arguments to delay complying with New Mexico law requiring them to post an adequate mine reclamation bond. In a narrow sense, these companies may have benefited in that they delayed posting the bond or perhaps decreased the bond amount through torturous negotiations and delays. But in a larger sense the reputation of the min-

Acid mine drainage in Fisher Creek, Montana, from abandoned mine workings.

ing industry suffers. A good part of the public and the groups representing nearby communities in these struggles now believe that all big mining companies will fight paying to clean up the mess that they have made. At its core this is an issue of public trust—as one participant put it: "It's about cleaning up the mess you made; we all learned this value as children."

SCIENCE AS AN ALLY OF PUBLIC VALUES

Drawing a distinction between issues that lend themselves to technical analysis and those that do not is not an effort to paint science as an enemy of good, sound decision making on natural resource issues. Science is essential to good decision making. The argument, however, is for the need to rely on *both* science and values in weighing public policy issues. There is a compelling need for more independent scientific research and evaluation in the mining sector.

Too many of today's mines were approved based upon environmental impact statements that under-predicted impacts on water resources. Sound public policy and sound natural resource planning require sound analysis of the expected impacts—i.e., accurate predictions. Without accurate predictions, the public and regulators are being asked to make decisions in an information vacuum. We now have a data set for modern industrial-scale mines in the western states that spans decades. We should study the data set and learn from it. And that's what we are doing. EARTHWORKS has commissioned an independent analysis of environmental impact statements from major mines in the western U.S., and the predictive models that underpin these assessments. We expect to have results in early 2005.

Accurate predictions will enhance the public image and credibility of the mining industry. It will also increase the confidence of investors, insurers, and regulators. After all, it's not just the environment that suffers if impacts are worse than predicted. The result can be dramatically increased cleanup and closure costs, greater financial liability, costs associated with legal action, government intervention, and a negative impact on corporate reputations. Environmental professionals in mining companies, in the consulting sector, and in academia have a particularly important, and potentially catalytic, role to play in solving the problems related to under-predicting impacts. If they do not address these problems (if they rely upon incomplete or inaccurate predictions), they run the risk of being tarred with the same brush as some of the worst companies in the mining industry.

THE PUBLIC WANTS SOLUTIONS

Ultimately, the public is looking for solutions. What they care about is not mining per se, but the products, resources, and way of life that mining makes possible—e.g., a wedding ring, computers and cell phones, and fuel (whether for their own transportation or to get things to them like food, clothes, books, etc.). They want things that are essential as well as things that are not so essential. They also want to protect people, communities, and the environment. They desire to have these products without doing harm, and they desperately want to believe this is possible. They want to believe that corporations can act responsibly. But they know that without accountability some pretty

nasty things can happen. They are willing to make choices as consumers, particularly in urban areas, to purchase responsibly sourced products. For example, they want to know how to recycle cell phones, computers, and other similar items, and they want the option of knowing that their wedding ring comes from a responsible source, not one that violates human rights or environmental standards.

There are some positive signs. In Montana the Stillwater Mining Company established a good neighbor agreement with nearby communities, agreeing to enhanced water protection provisions and an extensive water testing program. BHP-Billiton, Falconbridge, and Western Mining Corporation have all agreed not to engage in the practice of riverine tailings disposal at future mines. Recently the Newmont Mining Company decided not to pursue its plan to expand its mining operations to Cerro Quillish in Peru, a sacred mountain and key water source in the region, stating that it had underestimated community opposition. In October, Reuters News Service ran a story describing how BHP-Billiton had worked to gain participation and support from community groups and NGOs like Oxfam for its Tintaya Copper mine in Peru. This past April, the world-renowned jeweler Tiffany & Company called for reforms to outdated mining laws and responsible sourcing of metals such as gold and silver as well as diamonds. And Jewelers of America, the national trade association, publicly expressed support for responsible mining practices.

As a practical way forward, there are four reforms necessary in the mining industry:

- A policy that allows for the designation of valuable lands where mining may not be appropriate and the establishment of a mechanism to efficiently and quickly weigh land-use options. This must be determined early, before significant resources have been spent on development.
- An effective regulatory definition of necessary reclamation of lands and other natural resources with a financial guarantee to cover these costs as a pre-condition of mining. And a fee on current mining should be established to begin to tackle the legacy of polluting abandoned mines.
- A company-specific and then industry-wide commitment to independent third-party certification of responsible mining practices.
- The promotion of recycling, re-use, and smart design to lessen our demand for virgin minerals, in order to fully utilize, conserve, and re-use our valuable natural resources. We should mine metals from cell phones, high-tech equipment, and other products.

As a society we will continue to draw resources from the earth for our survival, well being, and enjoyment. We will continue to dig, probe, quarry, shovel, and drill the earth for its resources, to find new materials and new uses for existing materials. But there is growing evidence that we are beginning to alter our views as to how this should be done and under what conditions. And there are signs that a new ethic of *materials responsibility* is beginning to take hold for communities, the business sector, and governments. Materials responsibility begins where we begin to mine the earth's surface resources. And it begins by asking and answering two questions: What is the most sustainable, most responsible, and most efficient way for society to meet its metals or materials needs, and when we need to mine, what are the standards that should and must be met?

The Environmental Legacy of Mining in New Mexico

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The environmental legacy of mining in New Mexico can best be understood by examining human health, water quality, and land use concerns, and regulatory responses that have occurred over time. New Mexico shares approximately the same measure of environmental legacy in terms of historic abandoned mine sites as that of other western states that have similarly undergone extensive exploration and development for minerals over the past 150 years. Today New Mexico has virtually no small to medium-sized hard rock mining industry players, although eight of the 162 major hard rock mines that have operated in the U.S. since 1972 are located in New Mexico. Although these mines only represent less than 5 percent of all hard rock mines in the U.S., it is significant that the attention shown to them as a result of New Mexico's unique environmental regulatory process, both within the state and in the U.S., has made them among the most important mines in the nation, from an environmental legacy standpoint.

HISTORIC MINE IMPACTS

New Mexico is home to possibly the oldest mine in North America in the Cerrillos Hills, where turquoise was first worked by native people at least 1,000 years B.C. It is conceivable that New Mexico is also home to some of the earliest mining-related environmental impacts. The impact of mining in the Cerrillos area is noticeable, and historic mining activities in the region have presented safety issues that attract the attention of the public and regulators today.

In 1820 Josiah Gregg, writing about placer operations south of present-day Santa Fe, noted that in "some places the hills and valleys are literally cut up like a honey-comb." The workings observed by Gregg were created by Spanish miners and differed little from other gold diggings in New Mexico during that time.

In New Mexico, as in most other western states, the primary concern was with jobs and prosperity, and the environmental concerns of today scarcely entered the picture. Prospecting and developing mines were all part of the fulfillment of "manifest destiny" that was so prevalent during the settling of the western U.S. Until the early twentieth century and the coming of larger mines and more obvious impacts, there was little sense of serious environmental problems related to mining. However, in the latter 1800s and early 1900s, aided by the development of modern technologies including nitroglycerin-based explosives and processing techniques, New Mexico's mining industry turned from near-surface placer mining to underground hard rock mining-for silver, gold, lead, zinc, copper, and other minerals. In many cases the prosperous mining towns of that era are today's abandoned mining towns, with the worst of them destined to become Superfund sites.

The Cleveland mill in Grant County, an abandoned lead, zinc, and copper mine and mill is one such example. Although the mine site itself only occupies about 4 acres, tailings have contaminated an additional 10 acres of the bed of Little Walnut Creek, and runoff from the facility had acidified Little Walnut Creek and contaminated it with metals, which may have affected residential wells. Superfund cleanup activities conducted in the 1990s for the Cleveland mill site included removal of the tailings to a repository, in addition to capping and revegetation.

Other legacies were less costly but still significant. In the Socorro area many mine shafts and adits were left open presenting a hazard to public safety. At the same time a significant population of Townsend's long-eared bats was discovered hibernating in the abandoned mine workings. New Mexico's Abandoned Mine Land Bureau secured the mine openings in a way that left them open for bat use.

More recently, New Mexico's response to environmental concerns has been characterized by a slowness to adopt regulations, followed by progress, but accompanied by a failure to address the issue at the state's largest mines. However, in the past five years that obstacle has been removed, although with significant compromise. The following discussions clarify some of the history that has led us to this point as well as where we might go in the future.

Uranium and Human Health Impacts

New Mexico was the scene of some of the earliest vanadium (and later uranium) mining in 1918 near

Shiprock. Despite extensive documentation from European uranium-radium mining districts and from radium watch-dial painters about the health effects among miners and workers who were exposed to uranium decay products, work place protections were not adequate to protect miners and millers. By the early 1960s evidence began to mount of lung cancer among Navajo, Anglo, and Hispanic miners. Following extensive litigation against mine operators and the U.S. government demanding compensation for miners who ended up with lung cancer and other diseases caused by exposure to radioactive materials, the U.S. government agreed to establish a compensation program, acknowledging that workers had not been adequately informed about or protected from known risks at uranium mines operated before 1971.

Since that time New Mexico has served as an example for major changes in mining industry practices in terms of occupational safety and health, and for a unique national compensation program. In addition, New Mexico has developed and demonstrated uranium mill tailings remediation techniques. Although many concerns surrounding this very tragic situation have yet to be satisfactorily resolved, the state has learned a great deal from this issue.

HARD ROCK MINES AND WATER QUALITY IMPACTS

Hard rock mining environmental issues in New Mexico are most often identified with the state's largest hard rock mines-specifically the Questa mine in north-central New Mexico and the Tyrone and Chino mines in southwestern New Mexico. Although very different in terms of metal mined and geography, they have all received their share of attention from the public interest community and individuals who feel they, or their environment, have been affected by the mining operations.

Questa Mine

The Questa mine, now owned by Molycorp, began production in 1918 of molybdenum disulfide ore from underground mines. Open pit development began in 1964 and continued until 1982 by which time some 350 million tons of overburden had been removed and 81 million tons of ore had been mined. The overburden and waste rock was deposited onto steep mountain slopes and into tributary valleys immediately above and along the Red River. In 1983 the mine went back underground using block caving methods.

The resulting impact on the environment has led to one of the most complex and therefore difficult mine remediation projects in North America, and arguably the world. The mine site is characterized by an abundance of acid-generating rock and minerals containing toxic metals located in an environment that ranges from semiarid to relatively wet at the upper elevations. The mine site contains waste rock piles that are nearly 3,000 feet high at elevations that range from 6,000 feet to more than 10,000 feet.

The Red River is located directly adjacent to the waste rock piles and down gradient from the tailings impoundments allowing easy conveyance of pollutants from the mine waste and tailings to the Red River and ground water supplies. Over 3,000 acres of land have been disturbed by mining operations at the Questa mine. Scientific studies have confirmed that significant water quality impacts can occur as a result of contaminated ground water emanating from the mine and mill sites. In addition, steep slopes at the mine site have been determined to be geotechnically unstable with the potential for catastrophic failures. Litigation addressing residents' concern for more than one hundred tailings pipeline spills and tailings site seepage impacts has been instrumental in the evolution of Molycorp environmental management practices and New Mexico environmental programs.

Chino and Tyrone Mines

Lore has it that the Chino mine was first revealed by an Apache Chief to the Spanish in the early 1800s as a turquoise mine. It is now owned by Phelps Dodge Corporation and has become one of the largest copper mines in North America. Some 9,000 acres (more than 14 square miles) have been disturbed by the

The Santa Rita pit and north stockpile at the Chino mine.

open pit mine and associated waste rock piles, leach piles, and tailings impoundments. The site is characterized by a preponderance of acid-generating rock and minerals containing toxic metals, and although located in a semiarid to arid environment, has resulted in the release of significant contamination to ground and surface water. Many tailings spills have occurred in Whitewater Creek, and ground water contamination is evident throughout the mine and tailings sites.

The Tyrone mine, which was not exploited until relatively recently, is also a massive open pit copper mine

The Tyrone mine's numerous open pits, waste rock, and leach piles.

that has resulted in more than 6,000 acres of disturbance. It is characterized by acid generation and the potential for toxic metals leaching from its many open pits, waste rock piles, leach piles, and tailings impoundments. In addition to prevalent ground water contamination, the mine was recently cited for bird deaths at the tailings facility, leading to concern over the potential for mortality to the southwestern willow flycatcher, an endangered species.

Other Mines

Many other mines in the state have been noted for their environmental impacts, including:

- The Cleveland mill site near Silver City
- The Continental pit near Bayard
- The Copper Flat mine west of Truth or Consequences
- The Cunningham gold mine near Santa Fe
- The Asarco Deming mill in Deming
- The Pecos lead-zinc mine and mill complex in San Miguel County
- The ill-fated Earth Sciences, Inc. copper mine near Cuba

More than thirty-five uranium mines and seven mills—two of which were designated Superfund sites—are located between Laguna Pueblo and Shiprock, and the largest potash mining district in the U.S. is in southeastern New Mexico. These mines have been noted for a variety of ground and surface water impacts. In addition, mining often involves the dewatering of large areas, which can create long-term ground water deficits and affect surface water flows as well as seeps and springs.

MINING ENVIRONMENTAL REGULATION

The issue of mining environmental impacts and associated post-mining land use was recognized beginning in the 1960s and had been addressed, in various forms, by most states by the late 1980s. As late as 1993 New Mexico was one of two western states without specific legislation to address either reclamation and closure of hard rock and other non-coal mines or financial assurance to ensure that environmental problems would be adequately addressed at the company's expense. (The other state without such legislation was Arizona.)

However, the problems were recognized by concerned citizens in mining communities, public interest organizations, state government, and even the mining industry itself. The various groups worked together actively during more than three years of negotiations to address the problems The result in 1993 was the passage of the New Mexico Mining Act by the state legislature. This act provides a powerful model of effective mine reclamation policy.

CREATION OF COMPREHENSIVE STATE POLICY

Together with the New Mexico Water Quality Act, the New Mexico Mining Act provides a comprehensive regulatory process to address environmental impacts from mining activities. It does so through a commingling of the authorities of two state agencies: the Environment Department (enforcing the Water Quality Act) and the Mining and Minerals Division of the Energy, Minerals and Natural Resources Department (enforcing the Mining Act). In the end, the process requires the applicant to obtain:

- A discharge permit from the state Environment Department for any discharges into ground water

- A discharge permit (known as National Pollutant Discharge Elimination System or NPDES) from the federal Environmental Protection Agency (New Mexico has not asserted jurisdiction over surface water discharges in the state)
- A financially guaranteed and Environment Department-approved closure plan to assure ground water protection after the end of mining
- A financially guaranteed and state-approved closeout plan from the Mining and Minerals Division

The closeout/closure provisions also require the company to post financial assurance to guarantee the performance of closeout/closure stipulations that address mine reclamation and long-term operations and maintenance.

The enforcement of these laws began with the adoption of New Mexico's innovative Ground Water Protection Regulations, the most significant progress occurring since the passage of the Mining Act. More than one hundred mine sites have been addressed using New Mexico Water Quality and Mining Act regulations, as a result of which significant discharges have been addressed, financial guarantees of post-mining rehabilitation established, and mined land reclaimed, protecting water resources and habitat. The largest mines, facing significant liabilities, lagged behind the rest of the industry, and considerable effort by the agencies, concerned citizens, and public interest groups has been required to get the companies to comply.

Finally, in 2004 nearly all the requirements had been met, with closeout/closure plans and financial assurance being approved for all but a few suspended operations. In doing so, New Mexico has identified the difficulties associated with environmental impacts and reclamation of its mines. The financial assurance amounts for the three largest mines, which are the largest for any mines in the U.S., indicate the enormity of potential environmental impacts. Together they total more than half a billion dollars in potential liability. However, the situation is bittersweet: Although the liability has been recognized, it is mostly covered by corporate guarantees rather than real financial assurance, and the pace of actual reclamation at the largest mine sites still lags behind public expectations.

All seven uranium mills have been reclaimed, the potash facilities remain outside the scope of the Mining Act because of a special exception, and New Mexico has yet to effectively address most inactive and abandoned non-coal mines.

THE ENVIRONMENTAL FUTURE OF MINING IN NEW MEXICO

As New Mexico moves into the twenty-first century, it struggles to reconcile its mining environmental past with its future. A great deal of progress has been made in dealing with the problems recognized in the last century, particularly in the past ten years. It is unclear whether state government and particularly industry have the resolve to face the challenges and to meet the intent of the progressive laws that were passed.

The laws that were intended to protect the state's citizens and resources should provide these citizens the ability to protect their air, water, habitat, and landscapes for the foreseeable future. A critical chapter of New Mexico's environmental legacy of mining is currently being written as mine operators seek “alternative abatement standards” to allow contamination more severe than that allowed by regulation. The citizens of New Mexico have yet to tire in their quest for protection of their water resources and other interests and will continue to work with the present administration to address those issues.

Suggested Reading

Smith, Duane A., 1993, Mining America: the Industry and the Environment, 1800-1980. University Press of Colorado.

Marcus, J., Ed, 1997, Mining Environmental Handbook. Imperial College Press.

Suggested Web Sites

www.amigosbravos.org/molycorpwatch
www.gilaresources.info
www.sric.org

Abandoned Mine Lands in New Mexico

Abandoned mine lands (AML) are a complex issue, not only in New Mexico but throughout the U.S. The following article is intended to provide an introduction to the problem and a look at a number of successful AML programs underway in New Mexico. It was compiled by Greer Price from material provided by Robert Evetts, retired AML Bureau Chief of the Mining and Minerals Division, New Mexico's Energy, Minerals and Natural Resources Department; Virginia McLemore of the New Mexico Bureau of Geology and Mineral Resources; and Melvin Yazzie of the Navajo Abandoned Mine Lands Reclamation Program. Additional information on the Mines Database came from Gretchen Hoffman and Maureen Wilks of the New Mexico Bureau of Geology and Mineral Resources.

Remediation of physical and environmental hazards resulting from inactive or abandoned mines, collectively known as Abandoned Mine Lands (or AML), is one of the greatest challenges to the mining and environmental industries today. Surface and subsurface land disturbance has created serious physical and environmental hazards. Accidental deaths occur every year at old mines across the country. Although some of the more than 500,000 sites in the western U.S. pose little safety or environmental risk, there are many hazardous sites that should be addressed.

Historically miners went about their business much differently than they do today. Exploration commonly involved construction of pits, shafts, and adits that did not yield discoveries and were abandoned. As deposits were found and developed, ore processing facilities (mills, tailings, stockpiles, etc.) were typically located near mine openings. Processing waste was dumped near the processing unit, often into arroyos, rivers, lakes, or other drainages. There were no laws or other guidelines to prevent such contamination. In both underground and surface mining, minimizing costs was a higher priority than safety and stability. Mines generally had few ventilation shafts in order to save money. Upon depletion of the ore, mines were often abandoned and mine waste and tailings piles left as they were, without caps or vegetative cover. Such practices are unacceptable in today's mining industry, but the legacy of these older mines remains.

Although no complete inventory exists, it is estimated that there are more than 15,000 abandoned mine openings (shafts, adits, and pits) in New Mexico with at least 4,000 abandoned mines that have not yet been remediated. Some of these mine features pose significant health and safety issues to the general public. Less than 10 percent of these are coal mines; the vast majority are metal or hard rock sites. Often very little information is available on these mine areas. Many of these sites are on public lands, where they present public land managers with unique challenges related to accessibility and remediation.

PROBLEMS ASSOCIATED WITH AML

The hazardous effects of AML sites on the environment can be broadly divided into the following interrelated and complex categories:

Land Surface Disturbances

Mining by its very nature requires disruption and disturbance of the land surface and/or subsurface. Topography, ore deposit type and shape, economics, and climate all play important roles in determining mining methods and the extent of land surface disturbance. Erosion, sedimentation, subsidence, differential settling of land fills and regraded mine areas, and reshaping of geomorphic features are some of the specific problems that can result. Surface subsidence, such as that occurring above the underground operation at Molycorp's Questa mine, is a natural consequence of some mining and occurs when strata overlying underground workings collapse into mined-out voids, typically as sinkholes or troughs.

Safety

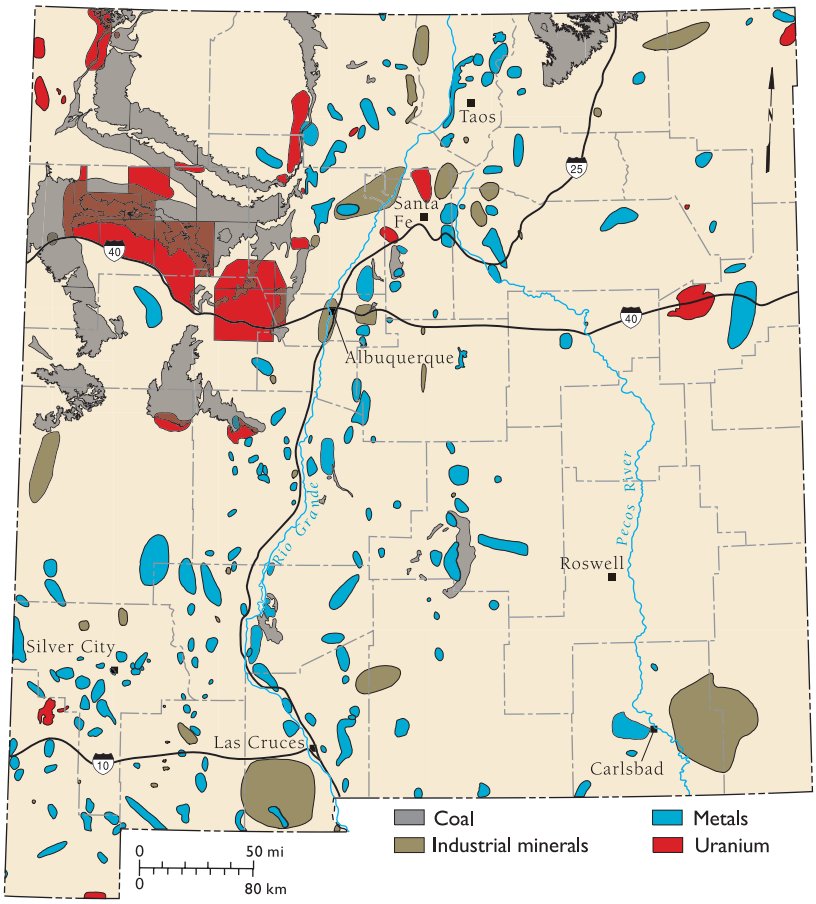
In addition to disturbances to vegetation, wildlife, and habitat, human safety issues associated with AML are a major concern. There are obvious dangers associated with open pits and collapsing shafts and tunnels. There are less obvious hazards associated with abandoned mine workings, including headframes, equipment, poor quality or toxic air, and hazardous materials. In 2004 there were 34 fatalities nationwide associated with abandoned mine lands, nearly all from drowning and ATV crashes. Although the last death in New Mexico associated with an AML was in 2001 (when a high school student fell to his death in a 200-foot deep shaft

near Orogrande), such fatalities and injuries occur regularly.

Water Quality

This is primarily an issue of contaminated runoff from mine sites, but it can be difficult to differentiate natural drainage conditions from those caused by mining. What we considered poor mining practices today, such as dumping mine wastes into drainages, were common in the past. Depending on the contaminants involved, their concentration and contact with living organisms, contaminated water has the potential to harm aquatic organisms as well as other plants and animals. Deposits that most typically cause drainage quality problems are base and precious metals, uranium, and high-sulfur coals, although not all such deposits produce water quality problems. Many others, including some industrial mineral deposits, can impact water quality. The major potential impacts of AML on water quality include:

- Acid drainage
- Metal leaching and resulting contamination
- Release of processing chemicals
- Increased erosion and sedimentation



Mining districts in New Mexico. Although many of these districts are no longer active, this map provides a general idea of where abandoned mines are likely to exist.

The New Mexico Environment Department has identified twenty impaired streams in New Mexico (including the Red River) potentially affected by mining. Various federal and state agencies plan to remediate these areas, where necessary, to eliminate the impact of AML on the affected watersheds.

Societal Effects

Often there are competing societal issues involved with AML sites. The urgent necessity to remediate hazardous AML sites must sometimes be balanced with the historical significance of some sites and their importance to regional tourism. Mineral collecting in southern New Mexico, for instance, is dependent upon access to inactive mines and provides much needed income to communities including Deming, Lordsburg, and Silver City. Some towns are particularly proud of their mining history and do not always seek remediation of their AML sites. The residents of Leadville, Colorado, for instance, insisted on having mine waste and tailings piles remain. Special covers were designed that prevent adverse water quality impacts but maintain the characteristic look of historic mining. The same was true for residents of Madrid, New Mexico. Some historic mines are open for tours. The Harding mine in Taos County, long inactive, is currently maintained as a field laboratory and mineral collecting site.

AML PROGRAMS IN PLACE

There are a number of existing programs throughout the U.S. that address the remediation of AML. They are administered by federal, tribal, state, and local government agencies and private industry. The purpose of such programs is to inventory historic, inactive, and abandoned mines, identify and prioritize hazards associated with these mines, and remediate those hazards.

The primary source of funding for remediation of AML by governmental agencies is through the Surface Mining Control and Reclamation Act (SMCRA), signed into law on August 3, 1977. The act established a coordinated effort between the states and the federal government to fund abandoned coal mine remediation. SMCRA provided funding, through a tax on current coal production, to reclaim land and water resources adversely affected by pre-1977 coal mining. The act also allows funds to be used for remediation of non-coal mines. SMCRA only provides funding for states (like New Mexico) that produce coal. Other sources of funding must be obtained for remediation in non-coal producing states.

SMCRA established successful AML programs in coal-producing states to achieve these purposes. In addition, federal agencies, Native American tribes, and the mining industry also have successfully remediated many AML sites. There exists a proven record of successful mine land reclamation, hazard abatement, and effective management of appropriated AML program funds.

AML programs in place in New Mexico include:

The New Mexico Abandoned Mine Land Program

The New Mexico Abandoned Mine Land Program is administered by the Mining and Minerals Division (MMD) of New Mexico's Energy, Minerals and Natural Resources Department. This is the state program that receives SMCRA funding, usually $1.5–2 million each year. Established in 1980, this program has remediated over 4,000 of the most hazardous coal and non-coal AML features in the state. By law, human safety issues are at the top of the priority list, although environmental problems often are addressed in tandem with safety concerns. For example, backfilling shafts and pits with waste piles from the mine eliminates both features as well as their safety risk. In other cases, underground workings are left open where bats, owls, and other wildlife have taken up residence, but grates are installed over the openings that allow access by wildlife but not humans.

This grate over an abandoned mine shaft near Cerrillos allows bats access to the underground workings but prevents human entry. This feature is part of an award-winning AML project accomplished by the Mining and Minerals Division.

Although SMCRA allows funds to be used on non-coal sites, abandoned coal mines remain the highest priority. New Mexico still has an estimated $10-12 million worth of work to do to remediate its coal sites. These projects include hazardous mine openings, subsidence into old mine workings, and coal mine waste stabilization and reclamation in watershed areas. These cost estimates do not include the safeguarding and/or extinguishing of underground coal mine fires currently burning in the Gallup, Madrid, and Raton coal field areas. The exact location, extent of the area burning, potential loss to the coal resource, and cost of extinguishing these mine fires have not been determined but will be significant.

The program has received federal recognition three times in the past six years for its achievements in reclamation. Most recently, the AML program at MMD received the Best in the Western Region Award for 2004, for the Cerrillos South Mine Safeguard Project, located 25 miles south of Santa Fe. The innovative abandoned mine safeguarding measures in place here were part of the development of the first park in New Mexico dedicated to mining history, the Cerrillos Hills Historic Park. High-strength steel mesh covers with viewing platforms were installed over several shafts to allow visitors to safely view essentially untouched mine workings. Puebloan Indians were mining turquoise and lead in this area as early as 900 A.D., Spanish mining of lead and silver began in 1598, and for several years in the early 1880s there was an Anglo mining boom producing lead, silver, copper, and manganese.

The Navajo AML Reclamation Program

Native American tribes as well as states may establish AML programs and receive funding under SMCRA. From 1988 to 1992 the Navajo Abandoned Mine Lands Reclamation Program (NAMLRP) initiated an on-the-ground inventory assessment on non-coal-related AML sites. The Navajo Nation has jurisdiction

on Tribal Trust Lands only.

In 1989 Navajo AML initiated reclamation work on Priority 1 non-coal sites. Since then Navajo AML has successfully completed approximately 90 percent of the 1,085 inventoried non-coal AML sites. These non-coal sites include uranium, copper, and sand and gravel mines. The mine features include both surface mines such as open pits, rimstrips, and trenches, and underground mines such as portals/adits, and incline and vertical shafts. The terrain and environmental conditions varied widely from the low and dry lands of Cameron, Arizona, to the mountainous, rough, and wetter lands of the Chuska Mountains. Navajo AML has received five Office of Surface Mining awards for its reclamation efforts and numerous partnering opportunities.

After remediation of AML sites, SMCRA allows funding to be used for public works projects. Navajo AML initiated the Public Facility Projects (PFP) Program in 2000. In fiscal year 2002 they funded twenty PFP projects at approximately $4.8 million. This will ultimately account for $16.2 million in completed projects.

Bureau of Land Management, U.S. Forest Service, and National Park Service

The Bureau of Land Management (BLM), U.S. Forest Service (USFS), and National Park Service are responsible for managing most federally owned land, including remediation of AML sites. Each agency is developing inventories of AML sites and, as federal funding becomes available, these agencies have remediated AML sites on their lands. The USFS anticipates that funding will increase in 2006 for completion of inventory and continued remediation of sites on USFS land. The BLM estimates that 3,000 sites on public lands in New Mexico require remediation. These federal agencies work closely with the state AML program.

Other programs not funded through SMCRA include:

U.S. Army Corp of Engineers RAMS Program

The U.S. Army Corp of Engineers initiated the Restoration of Abandoned Mine Sites (RAMS) in 1999 to assist other agencies and industry in remediating AML sites. RAMS funded the New Mexico Bureau of Geology and Mineral Resources to complete an inventory of mines in Sierra and Otero Counties; this report will be released in 2005. RAMS also funded a database of remediation technologies. In addition RAMS is partnering with other agencies in developing plans for remediation of sites in the Red River and Pinos Altos areas. Funding for RAMS is federal, but separate from SMCRA.

Remediation of abandoned sites involves surveying the extent of mine workings and associated hazards, as in this mine shaft near Orogrande.

Industry Programs

Many mining companies have remediated AML sites. Under the 1993 Mining Act any mine in New Mexico that had 24 months of production since 1970 is required to provide a plan for and implement reclamation and remediation. Many mining companies, including Phelps Dodge, Quivira Mining Company, Homestake Mining Company, St. Cloud Mining Company, and Molycorp have remediated historic mines on their permitted areas and in some cases other AML near their mines. Most active mining companies in the state are required to have an approved mine closeout plan, which provides for reclamation to a beneficial use after mining ceases.

REMAINING ISSUES FACING NEW MEXICO

Abandoned Mine Inventory

Most of the western states lack comprehensive inventories of abandoned mine sites, especially non-coal mines. In the early years of the AML programs, abandoned coal mine areas were inventoried extensively as a requirement of the program and in satisfying the development of approved reclamation plans and the prioritization of AML projects. Historical information regarding location, production, and ownership is generally more available for coal mines than it is for non-coal or hard rock mines.

The New Mexico Mines Database

The New Mexico Bureau of Geology and Mineral Resources, a service and research division of New Mexico Tech, serves as the state's geological survey. Since 1927 the bureau has collected published and unpublished data on the districts, mines, pits, quarries, deposits, occurrences, and mills in New Mexico. The bureau is converting that historical data into the New Mexico Mines Database, to provide computerized data that will aid in identifying and evaluating resource potential, resource development and management, production, and possible environmental concerns, such as physical hazards, indoor radon, regional exposure to radiation from the mines, and sources of possible contamination in areas of known mineral deposits. These data will be useful to federal, state, and local government agencies, public organizations, private industry, and individual citizens in order to make land-use decisions. These data are particularly useful in identifying mine sites in a given area and examining the potential for that mine site in contributing metals and/or other contaminants to the watershed.

The database provides information on the mines, quarries, mineral deposits, occurrences, mills, smelters, mine rock piles, tailings, and pit lakes located in New Mexico. Altered and mineralized areas are included because these areas have particular importance in terms of mineral resource development and/or environmental impacts. The database will be linked to other information such as geochemistry of samples collected by the bureau (and others).

The data have been gathered from published and unpublished reports and miscellaneous files in the bureau's mining archive. Information on location, production, reserves, resource potential, significant deposits, geology, well data, historical and recent photographs, mining methods, maps, and ownership are included. The database can be incorporated with other GIS layers, including geologic maps, topography, geophysical data, remote sensing data, the New Mexico Geochron database, and the New Mexico Petroleum database. Eventually the database will be accessible via the bureau's Web page; until then the database is partially available as bureau open-file reports. Although there are many other (and broader) applications for the information contained in this complex database, certainly the cooperative development of an inventory of AML sites in the state is one very important application.

Before New Mexico can fully address its AML issues, especially as they relate to physical hazards, it should have a comprehensive inventory of all abandoned mine sites. This would include locating, classifying, prioritizing, and incorporating mine features into a long-term plan for safeguarding and reclamation. Then a meaningful needs assessment can be compiled and the appropriate reclamation budgets developed. This inventory should be a multi-agency effort, using information already gathered by a number of state, federal, and tribal entities.

Funding

SMCRA fee collections drive the larger AML programs and are scheduled to sunset on June 30, 2005. Congress has not yet passed legislation that would establish a new fee schedule or formally extend the fee collection period. Congress did pass a continuing resolution, which extended the established fee collection temporarily. Without sufficient and predictable funding for the AML programs, many government agencies cannot adequately address hazardous mine features or reclaim and return AML to beneficial use. In addition, western states without coal mines do not receive SMCRA funding.

Baseline Conditions

One of the most difficult tasks in remediating historical mine sites is determining and characterizing the baseline conditions or natural background that existed before mining. A knowledge of baseline conditions is necessary, particularly in complex geologic settings, in order to establish meaningful remediation goals. Methods that may be used for this evaluation include integration of historical information, published values of unmined, mineralized areas, analyses of water from monitoring wells, leaching studies, statistical analyses, isotopic studies, identification of background by subtracting mining influences, and computer modeling. The U.S. Geological Survey has been the primary agency to apply science to identify background conditions. The New Mexico Environment Department contracted with the U.S. Geological Survey to characterize the baseline conditions along the Red River in Taos County to better understand complex interactions between naturally occurring geologic features and mining-related water impacts. The paper in this volume by Kirk Nordstrom outlines much of the work that was accomplished in that study.

Watershed Protection and Restoration in New Mexico—With a Focus on the Red River Watershed

David W. Hogge and Michael W. Coleman, *Surface Water Quality Bureau*
New Mexico Environment Department

The federal Clean Water Act was adopted in 1972 with the objective of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. The Clean Water Act is the basis of most national and state surface water quality standards and regulations. Like the federal act, the New Mexico Legislature provided objectives and policy direction for the protection of water quality when it adopted the state's Water Quality Act in 1967. Monitoring, assessing, and restoring water quality are key to successful implementation of both the federal and state acts, and these responsibilities are the foundation of the work of the Surface Water Quality Bureau of the New Mexico Environment Department.

The term *watershed* refers to the region that is drained by a given stream, lake, or other body of water. It describes the area that contributes water to a given stream or other water body. Any concern over water quality—-or the impairment of water quality—in a given body of water must necessarily take into account the health of the entire watershed. The terms *catchment area* and *drainage basin* are often used interchangeably.

DETERMINING THAT A WATERSHED IS IMPAIRED

In accordance with the New Mexico Water Quality Act, the Surface Water Quality Bureau implements a comprehensive water quality monitoring strategy for surface waters of New Mexico. The monitoring strategy establishes methods to identify and prioritize water quality data needs, specifies procedures for acquiring and managing water quality data, and describes how these data are used to progress toward three basic monitoring objectives: to develop water quality based controls, to evaluate the effectiveness of such controls, and to conduct water quality assessments.

As in most other states, the Surface Water Quality Bureau uses a rotating basin system approach to water quality monitoring. Using this approach, selected watersheds are intensively monitored each year. The goal is to monitor every watershed in the state at least once every eight years. Revisions to the schedule may be necessary based on staff and monetary resources, which fluctuate annually. The Environment Department's monitoring efforts are also supplemented with other data collection efforts, such as USGS water quality gaging stations, which can be used to document long-term data trends.

Data collected during intensive surveys are used to determine whether state surface water quality standards are met and to ensure that designated uses are supported. Assessed data are used to develop the state's list of impaired waters (which is part of the *Integrated CWA §303(d)/305(b) Water Quality Monitoring and Assessment Report*) and Total Maximum Daily Loads (TMDL).

What Is a TMDL and How Is It Developed?

A TMDL, or Total Maximum Daily Load, sets an "allowable budget" for potential pollutants by scientifically determining through rigorous study the amount of pollutants that can be assimilated without causing a water body to exceed the *water quality standards* set to protect its designated uses (e.g., fishery, irrigation, etc.). Once this capacity is determined, sources of the pollutants are considered. TMDLs include both point and nonpoint sources. Once all sources are accounted for, the pollutants are then allocated, or budgeted, among the sources in a manner that will describe the limit (the total maximum load) that can be discharged into the river without causing the stream standard, or budget, to be exceeded. Nonpoint sources are grouped into a "load allocation" (LA) and point sources are grouped into a "wasteload allocation" (WLA). By federal regulation, the budget must also include a "margin of safety." Thus, 100 percent of the budget cannot be allocated to pollutant sources. The margin of safety accounts for uncertainty in the loading calculation. The margin of safety may not be the same for different water bodies due to differences in the availability and strength of data used in the calculations.

Water quality impacts come in many forms. Impacts can be from point sources of pollution—i.e., discharge that flows into a receiving body from a pipe or some other discrete source. Point source discharges include effluent from wastewater treatment plants, industrial discharges, and storm water associated with construc-

tion and industrial activities. Point sources are generally addressed through imposition of National Pollutant Discharge Elimination System permit limits, pretreatment requirements, management of storm water, and other discharge management strategies. Impacts can also be caused by nonpoint sources of pollution. Nonpoint source pollution, according to the U.S. Environmental Protection Agency, "occurs when water runs over land or through the ground, picks up pollutants, and deposits them in surface waters or introduces them into ground water." Sources are often indistinct, such as abandoned mines, agricultural runoff, erosion from denuded hillsides or streambanks, fire scars, overgrazing or overcutting, parking lots, recreational or paved roads, etc. Nonpoint sources of pollution are generally addressed through "best management practices" and other watershed restoration activities. Current estimates indicate that nonpoint sources are the cause of 93 percent of the state's surface water quality problems.

WATERSHED RESTORATION

Watershed restoration activities that address nonpoint sources of water pollution are generally non-regulatory, voluntary initiatives that are driven by a local desire to restore watershed health. Successful watershed restoration efforts rely, for the most part, on the strength of collaborative efforts to build a watershed community among local residents, agencies, and other stakeholders.

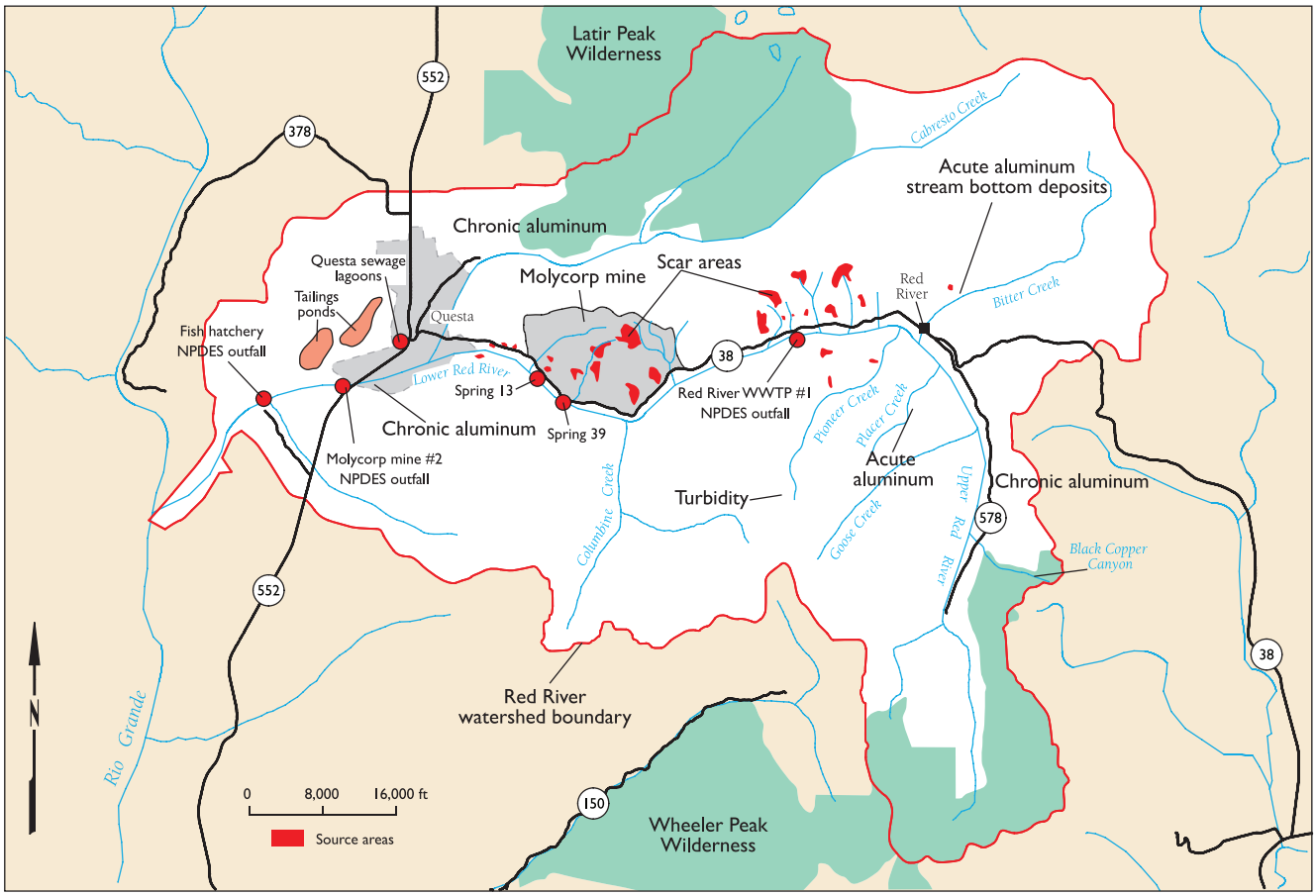
According to New Mexico's 2004–2005 Integrated Clean Water Act Report (section 303d and section 305b), probable causes and probable sources of watershed impairments include on-site liquid waste disposal, roads, recreation, urban storm water runoff, agriculture, ranching, silviculture, and resource extraction. Although no "hard" data exist, wildlife grazing (particularly by elk) is known to also contribute to localized water quality problems in certain areas of the state. Grazing and habitat alteration are the predominant sources of lake water quality impairment.

The implementation of treatment activities that reduce water quality impairment has been an effective tool in addressing watershed impairment. Treatments and controls for nonpoint source pollution are called *best management practices* or BMPs. BMPs can include constructed means of reducing impairments to surface and ground waters, such as inducing a more stable stream channel morphology with structures to deflect flows or installing a sewer system to replace individual septic systems in a community. Nonstructural BMPs are conservation practices related to the way in which we manage our resources. The timing and rate of fertilizer and pesticide application, instituting storm water management ordinances, or creating a rotation system for cattle grazing in areas where ground cover is critical for preventing soil erosion are examples of these. BMPs should realistically represent the best combination of structural or nonstructural management practices working together to reduce impairments to water quality. BMPs should be based on conditions of the site where the practices are to be constructed and/or implemented and should be based on the economics and performance targets associated with the specific problem to be addressed.

RED RIVER WATERSHED RESTORATION EFFORTS

The Red River Watershed is a major tributary to the upper Rio Grande in northern New Mexico. Twenty-one perennial watercourses, draining an area of 226 square miles, originate as very high quality mountain streams. The Carson National Forest manages approximately 90 percent of the area. Elevations range from 13,161 feet at Wheeler Peak (the highest point in New Mexico) to 6,500 feet at the confluence with the Rio Grande. The lowest four-mile reach of the Red River flows through a spectacular canyon of the Wild and Scenic River Area that includes the Rio Grande gorge. The only towns within the watershed are Questa and Red River, which at an elevation of 8,750 feet is the highest incorporated town in the state.

The Red River has long been recognized by state and federal agencies as a high priority watershed. It occupies one of the most popular multiple use watersheds in the state, devoted to recreational activities—chiefly skiing and fishing—along with widespread livestock grazing by U.S. Forest Service permittees. Legacy mining and exploration, as well as development, extraction, and processing of world-class mineral deposits, are other prime features of the watershed. Concerns include: mining (primarily Molycorp, and to a lesser extent legacy mining sites in tributary drainages); septic tank leach fields in the alluvial valley above the town of Red River; unlined sewage lagoons in the village of Questa; leaking underground petroleum storage tanks in the town of Red River; and sediment contributed by steep, bare slopes at the Red River ski area and from many dirt roads, grazing allotments, and hydrothermal scar areas on the national forest.



Map of Red River Watershed, Taos County, New Mexico. Impaired reaches and the pollutants of concern are shown.

RED RIVER WATERSHED PROJECTS

Using Clean Water Act Section 319 grant funding, the Surface Water Quality Bureau embarked upon a series of on-the-ground implementation projects to address impacts to the watershed. These projects began in 1991, and several are underway at the present time.

Beginning in 1995 the Surface Water Quality Bureau helped to initiate the formation of a Red River Watershed Association. Meetings were initially held in Red River and Questa, with attendance and participation by interested citizens, state and federal agencies staff, environmental groups, and municipal representatives. Following reorganization in 1998 the Red River Watershed Group has continued to draw together a broad-based group of watershed residents, agencies, and stakeholders to take on the immense task of restoring conditions that will improve the quality of water—and therefore the quality of life—throughout the watershed. The group addresses a variety of water quality issues throughout the entire drainage—from the headwaters to the Rio Grande—through a collaborative, consensus-based approach in which every voice has equal weight.

The Red River Watershed Group's major focus is:

- To determine pollutants, their sources and effects, and communicate the information to citizens
- To seek opportunities to enhance fish habitat within the watershed
- To bring citizens together to restore, protect, and fully utilize the Red River
- To educate and inform users and citizens about the area and watershed stewardship

Restoration projects in the Red River Watershed have been funded primarily through federal Clean Water Act Section 319 dollars, along with a tremendous effort by local volunteers and local, state, and federal agencies. Projects initiated in the Red River Watershed include:

Mineral Extraction Impacts

This project was initiated in the early 1990s and was one of the Surface Water Quality Bureau's early efforts to use passive limestone anoxic drains to intercept and treat acid mine runoff. This first drain was installed at the Oro Fino mine, along upper Bitter Creek.

Red River Ground Water Investigation

This project identified and addressed, via BMP implementation, several forms of nonpoint source pollution impacting the Red River.

The Red River in the vicinity of Molycorp mine is a gaining stream system, recharged throughout the length of its main stem by shallow ground water. Seeps and springs entering surface water were determined to be virtual point sources of contamination, posing a sizable impairment to the Red River. The primary solution implemented was to install an anoxic alkaline drain along the seep areas, which proved to be effective in neutralizing the acidic, heavy metal-bearing seeps before they could mix with the surface flows of the Red River.

Lower Bitter Creek Restoration Project

This interagency cooperative pollution prevention project was developed on lower Bitter Creek, a perennial-intermittent tributary to the Red River. BMPs to control erosion in the stream channel, along local roads, across unstable slopes, and at the toe of an active hydrothermal scar's landslide zone, were designed by the project cooperators. U.S. Forest Service crews, contractors, Youth Conservation Corps participants, and volunteers completed the on-the-ground work, which resulted in a measured decrease in turbidity, sediment loading, and heavy metal delivery at the Bitter Creek–Red River confluence.

Enhanced Local Involvement for Addressing Water Quality in the Red River Watershed

This ongoing effort to gain broader and more effective local participation from throughout the Red River watershed addresses significant water quality issues, with the goals of developing a cost-effective watershed cleanup strategy, and identifying and prioritizing sites for cleanup. Composed of key stakeholders, the Red River Watershed Group's work will address impacts identified through the TMDL process. Strategies developed will provide a framework for addressing and reducing pollutant loading from both public and private lands.

River Park Stream Rehabilitation Project, Town of Red River

This project is designed to address heavy sediment loads that have caused the active Red River channel to expand horizontally and become very shallow. A heavily impacted 1,500-foot section of the river is being restored to a more functional width/depth ratio and sinuosity using rock flow-management structures, willow plantings, and other BMPs. The project will increase the river's scour energy, enabling it to transport its sediment load, while improving the long-term stability of the channel and bank.

Collaborative Red River Restoration Off Road Vehicle Impact Remediation

This will reduce sediment and turbidity caused by unrestricted off road vehicle use by: implementing and maintaining a series of BMPs: obliterating and reclaiming temporary or unauthorized roads, controlling surface erosion at recreation sites, managing off road vehicle use and enforcing recreation regulations, increasing public outreach and education on water quality protection at recreation areas, and revegetating disturbed areas.

Suggested Reading

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Acid Rock Drainage

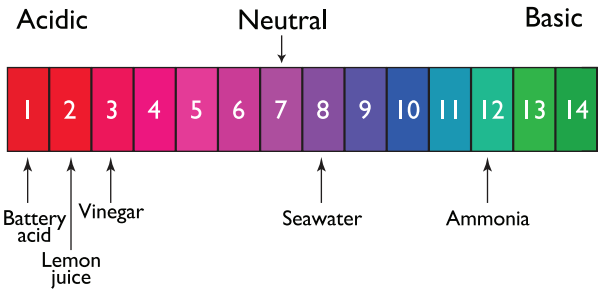
Kathleen S. Smith, *U.S. Geological Survey*

Acidic drainage is a common water quality problem associated with hard rock metal mining and coal mining. Acidic drainage (commonly called "acid rock drainage" or ARD) is formed when rocks containing sulfide minerals come into contact with water and oxygen to create sulfuric acid, which in turn releases metals (e.g., aluminum, manganese, copper, zinc, cadmium, arsenic, and lead) from the rocks. This acidic metal-laden water can negatively impact water supplies used by municipalities, agriculture, or wildlife. Understanding the formation of acidic drainage involves the fields of geology, chemistry, and biology. However, the fundamental source of acid and metals in the drainage is rocks, including the host rocks of a mineral deposit and waste rocks resulting from mining.

There are several phrases used to describe water affected by the weathering (wearing away or erosion and chemical decomposition) of rocks in mining and mineralized areas. The term "acid rock drainage" covers both mining related and naturally formed acidic drainage, and is used in this report to emphasize that not all drainage affected by the weathering of rocks is related to mining. The term "acid mine drainage" (AMD) is limited to drainage that is both acidic and mining related. The term "mining influenced waters" (MIW) is limited to drainage that is mining related, but not necessarily acidic. This term is useful because not all drainage from mining areas is acidic, but non-acidic drainage may still contain significant concentrations of metals.

HOW DO YOU MEASURE ACID?

The pH scale is a measure of the amount of acid, with acids having pH values less than 7 and bases having pH values greater than 7. The pH scale is logarithmic, so water with a pH value of 3 is ten times more acidic than water with a pH of 4, and one hundred times more acidic than water with a pH of 5. Most natural waters are in the pH range of 5 to 9. Rain has a pH of approximately 5.7 because carbon dioxide from the air dissolves in raindrops to form a weak acid. Many familiar liquids also are acidic. For example, lemon juice and vinegar are both acidic and have pH values of approximately 2 and 3, respectively. Mining-influenced waters can have a wide range of pH values and are not always acidic. Young fish and some aquatic insects may be harmed by pH levels below 5. The pH also can affect aquatic life indirectly by changing other characteristics of water chemistry.



The pH scale, a measure of acidity, showing the pH of some common liquids.

WHAT DOES MINING HAVE TO DO WITH ACID ROCK DRAINAGE?

One of the factors that has the greatest influence on the production of ARD is rock type. Rocks are made of minerals, naturally occurring chemical compounds that have specific crystal structures and documented chemical compositions. Different minerals have different properties and weather differently in the presence of water. For example, some minerals, such as halite (table salt), readily dissolve in water, whereas other minerals, such as quartz (found in beach sand), are practically inert (not subject to change). Various metals are contained within the structure of these minerals, and release of these metals into the environment depends on the properties of their resident minerals.

A mineral deposit is an accumulation of metals or minerals in a relatively small volume of the earth's crust. Mineral deposits form as a result of large-scale flow of metal-bearing fluids deep in the earth's crust. The processes involved in depositing the minerals are collectively called mineralization. When mineralized rock is mined, it exposes new surfaces that can be

Photo of the Carlisle mine in the Steeple Rock district of southwestern New Mexico. Geological characterization (below) can be very helpful in predicting potential environmental effects of mined sites.

GEOLOGICAL CHARACTERISTIC	TYPE OF INFORMATION ACQUIRED
Geologic setting	pH buffering capacity Ease of subsurface transport Routes to biological receptors
Mineral deposit type	Which metals are present Acid-generating capacity
Historical mine/mill activities	Predict contaminants of concern (e.g., mercury, cyanide) Efficiency of sulfide removal from wastes

Some aspects of geological characterization. Buffering minimizes pH changes in water when acid or base is added.

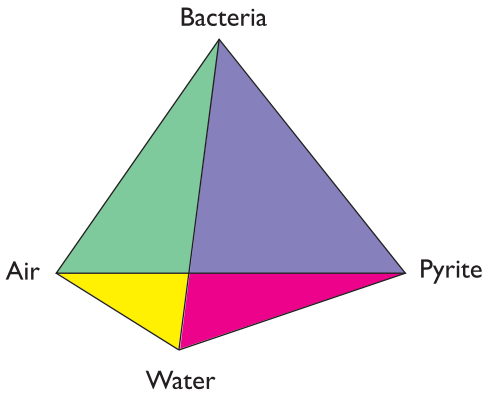
weathered and accelerates the production of ARD.

Mineral deposits can be categorized into different types, defined by characteristic minerals and associated potential environmental impacts. Some kinds of mineral deposits tend to produce very acidic, metal-laden waters, whereas others tend to produce less acidic waters with fewer or different dissolved metals. The particular metals and minerals present in rocks and waste rock are characteristic of how that mineral deposit was formed, and of the regional rock type, hydrology (how solutions move through the rocks), and geologic structures (such as faults). Geologic characterization can be very useful in predicting the potential environmental impact and footprint (impacted area) of a mined site.

Several characteristics of water that are common in drainage from mining and naturally mineralized areas include: low pH (acidic), elevated sulfate concentrations, elevated iron, aluminum, and/or manganese concentrations, elevated concentrations of other metals, and high turbidity, which is a measurement of the amount of small particles suspended in water. These components commonly depend on the mineralogy of the deposit.

WHAT KINDS OF ROCKS MAKE ACID?

Sulfide minerals are common in many types of hard rock metal mining and coal deposits. Many sulfide minerals are relatively unstable under surface conditions, so when they are exposed to air and water they undergo the chemical reactions of weathering. Pyrite, or fool's gold (iron sulfide), is a common sulfide mineral that produces acid when it weathers. The generation of ARD begins with a startup reaction. For example, when pyrite comes into contact with water and oxygen (in air) the result is a reaction that produces dissolved iron and sulfuric acid (a mixture of sulfate and acid). In the acidic drainage generation cycle, once the startup reaction has begun, acid production is self-propagating as long as pyrite, water, and microorganisms (bacteria) are present. The acidic drainage generation cycle involves converting iron from one form (iron II) to another form (iron III). This conversion has been called the rate-determining step (the bottleneck) because it is slow at low pH. However, certain kinds of microorganisms can greatly speed up this conversion of iron by as much as 100 to 1,000,000 times, especially at low pH. Once the ARD reactions have begun, conditions are favorable for microorganisms to speed up the conversion of iron and lessen or eliminate the bottleneck in the acidic drainage generation cycle. This is important because iron III can readily react with pyrite (and some other sulfide minerals) and produce more acid. In fact, weathering via iron III can produce eight times more acid than weathering via oxygen (as in the startup reaction). So, the faster the iron can be converted from iron II to iron III, the more acid can be produced.



The Acid Rock Drainage (ARD) tetrahedron, showing the relationship between the four components that produce ARD. All four components are required to produce ARD.

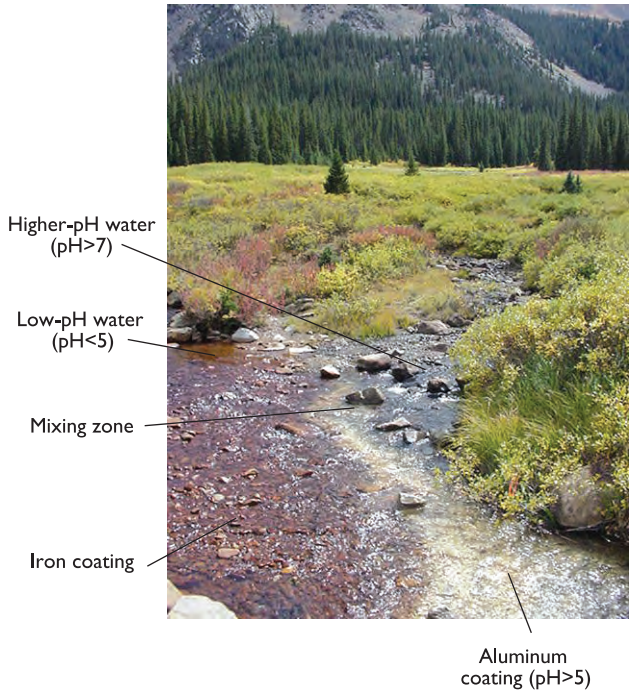
IS ACID THE ONLY PROBLEM?

The acid produced from pyrite weathering can attack other minerals in surrounding rocks. For example, acidic water can attack and dissolve common rock-forming minerals (e.g., mica and feldspar) and produce dissolved aluminum. Manganese and calcium also are common elements that have elevated concentrations in ARD.

In mined and mineralized areas it is common to see solid precipitates (residues) of various colors coating stream bottoms. These precipitates can result in high turbidity, which makes the water cloudy and interferes with sunlight penetration into the water (which in turn interferes with photosynthesis by aquatic plants). Iron forms coatings on stream bottoms over a broad range of pH conditions, and the coatings can vary in color from yellow, to orange, to deep red; these iron coatings are called *yellow boy*. The different colors are different iron-bearing minerals that form under different pH and chemical conditions; these minerals can be used as indicators of the chemical conditions present in the stream. Aluminum forms white coatings on stream bottoms above a pH of around 5. Precipitated aluminum may harm fish by accumulating on their gills. Manganese forms dark brown or black coatings at higher pHs, usually above 7. These various precipitates can form by natural processes in unmined areas, and their colors in stream bottoms were used as a prospecting tool by early miners to identify mineralized areas. Stream-bottom coatings may damage the habitat, inhibit growth, or kill aquatic organisms that live on the bottoms of streams.

WHERE DO METALS COME FROM IN ACID ROCK DRAINAGE?

Trace elements (e.g., copper, lead, zinc, cadmium, arsenic, selenium) are normally present in low concentrations in the earth's crust. However, in mineralized areas certain elements (depending on the deposit type) are present in above-average concentrations. Many of the trace metals in mineralized areas are found in various sulfide minerals. Minerals that contain trace metals can be weathered or attacked by acidic water or iron, thereby releasing metals into the environment. The concentration of a released metal is a function of (1) the concentration of that metal in the mineral, (2) the accessibility and susceptibility to weathering of the minerals that contain the metal, and (3) how easily the metal can be transported through the environment under the existing conditions.



The confluence of Deer Creek with the Upper Snake River near Montezuma, Colorado. As low-pH water containing dissolved aluminum mixes with higher-pH water, the aluminum precipitates to form a white coating on the streambed.

Metals differ from organic contaminants in that they do not break down in nature. Therefore, once metals are released into the environment, they persist. However, metals may be affected by physical and chemical processes that can modify their transport through the environment. Once metals are released from their parent mineral, they can be transported by water or sediment, precipitated, or taken up by solid particles. Generally, metals are more easily transported in lower-pH waters (pH less than 4 or 5), which is why acidic drainage usually contains elevated concentrations of metals. However, some metals (e.g., zinc and cadmium) can be transported in near-neutral pH waters (pH 6 or 7), and some elements (e.g., arsenic, molybdenum, and selenium) can be transported under higher-pH conditions (pH greater than 7 or 8).

In mineralized areas and mining-related rocks, trace metals and acid may be temporarily stored in salts formed from evaporating mineralized solutions. Once wet conditions return, these salts can readily dissolve to release acid and metals. Dissolved metals also may be incorporated into solid particles; later changes in chemical conditions, such as pH, may cause the particles to release these metals back into the water.

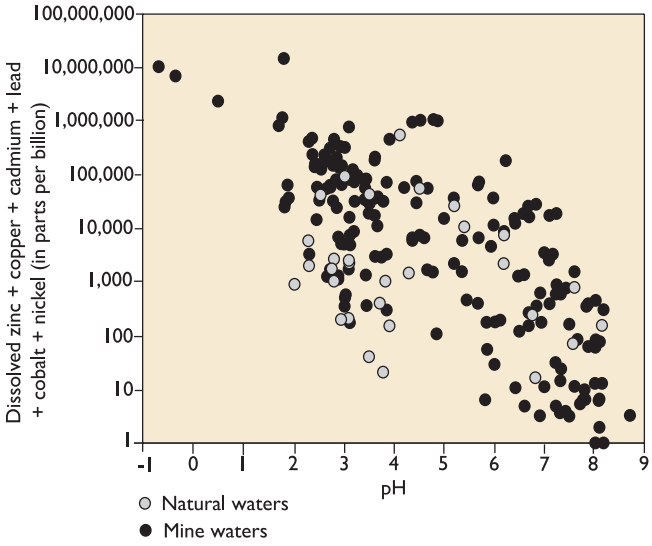


Diagram showing how the concentration of base metals (zinc, copper, cadmium, lead, cobalt, and nickel) vary with pH in natural and mine waters. Diagram courtesy of Geoffrey Plumlee and Sharon Diehl, U.S. Geological Survey.

HOW DO YOU REMEDIATE ACIDIC WATERS?

Most mineral weathering reactions use up acid instead of making acid. Some minerals dissolve better than others or use up more acid when they dissolve. The mineral calcite (calcium carbonate), which is the mineral that makes up limestone, is very effective at neutralizing (counterbalancing) acidic solutions. This is because it dissolves fairly easily in acidic solutions and uses up acid when it dissolves. So, calcite commonly is used in the treatment of acidic waters. Moreover, it is a common mineral in some rocks and can neutralize acidic waters as they flow through those rocks. Other minerals also can help neutralize acidic solutions, but they tend to be less effective than calcite because they dissolve more slowly.

The final pH of the drainage from mining and mineralized areas is a balance between acid-generating reactions (e.g., pyrite weathering) and acid-neutralizing reactions (e.g., calcite weathering). The relative rates of these reactions and the accessibility of the reacting minerals ultimately determines the pH and metal content of the drainage water.

WHAT TYPES OF MINING CAN PRODUCE ACID ROCK DRAINAGE?

Mineral deposits and the ores within them come in a variety of sizes and shapes. Therefore, methods used to mine a particular mineral deposit must be tailored to the size, shape, depth, and grade (richness) of the ore being mined. There are two main types of mining: surface mining and underground mining. In both, as minerals are removed, rock surfaces are exposed to water and air. This presents the opportunity for acid-producing pyrite weathering reactions to proceed and produce ARD. Therefore, openings from underground mines, such as adits, tunnels, and shafts, may drain ARD. Warning signs of ARD near mines include red-orange-yellow coatings on rocks, dead vegetation, and green slime growing in discharge waters. Even though not all discharges from mined areas are acidic, they may still contain significant concentrations of dissolved metals.

Compared to other industries, mining is unique in that it usually discards more than 90 percent of the material that is processed. Therefore, there is a lot of solid waste rock associated with mining, and the characteristics of this rock control its potential environmental impacts. Mining-related rocks from both underground and surface mining may produce ARD. Once fresh rock surfaces are exposed to water and air, the minerals in the rocks can weather. Historic mines generally did not have the technology to efficiently remove or isolate acid-producing minerals or metal-rich minerals from the mining-related rock. In addition, mine rock piles were commonly put in the most convenient place for the miners, generally close to the mining operation, which could be in or adjacent to a stream or drainage, or at the angle of repose on a mountainside. Therefore, many ARD water quality problems are associated with older mines.

WHAT IS OPEN-PIT MINING, AND HOW DOES IT LEAD TO PIT LAKES?

Open-pit mining is a surface-mining technique that is used when the orebody is large and relatively near the surface. Open-pit mining involves repeated removal of layers of rock (both ore and overburden) to form a large open bowl-type structure. Several New Mexico copper and gold mines were mined by open-pit methods. Many open-pit mines exceed 1,000 feet in depth; therefore, most of the large open-pit mines extend well below the ground water table. Once mining and dewatering have ceased, these open-pit mines commonly fill with water to form pit lakes. At some point, pit lakes generally reach the point where the amount of inflow water approximately equals the amount of outflow water.

Pit lakes can receive inflow from both surface and ground water. Ground water models predict most pit

lakes to be terminal basins, which means that they pull in water from all sides and evaporatively concentrate potential contaminants in the lake. During this evaporation process, water is evaporated and contaminants that were in the water remain behind; so, contaminant concentrations increase because there is less water present to dilute them. If this is the case, and there is no outflow from the pit lake (i.e., if it acts like a sump), then potential contaminants from the open-pit mine are contained within the lake. However, if there is outflow from the lake, potential contaminants may flow down gradient from the lake. Once a pit lake is filled, it may persist and fluctuate in elevation with seasonal changes in weather and water flow.

The New Mexico Mines Database includes a table listing thirteen current pit-lake areas in New Mexico. Some pit lakes have water quality that is suitable for recreation, such as the Copper Flat pit lake near Hillsboro, New Mexico. Other pit lakes have acidic waters with elevated metal concentrations, such as the Chino pit lake near Silver City, New Mexico. Many technical questions and issues remain about accurate prediction of the hydrology and water quality of future pit lakes.

Suggested Reading

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A River on the Edge—Water Quality in the Red River and the USGS Background Study

D. Kirk Nordstrom, *U.S. Geological Survey*

Mineral resource production is vital to modern, industrialized societies. Unfortunately, mining and mineral processing can cause serious damage to water, air, soil, and biological resources. Acid mine waters, produced from mines that extract valuable metals such as copper, gold, silver, zinc, and lead, have damaged aquatic life, crops, and livestock. These problems are not irreversible; lands and waters disturbed by mining can be restored, but often at considerable cost.

An important challenge related to mine-site reclamation and cost-benefit analysis is the "natural background" or pre-mining water quality. The pre-mining conditions can provide a justifiable objective for clean-up goals. However, pre-mining water quality rarely was measured at mine sites before the 1970s, and even if it had been measured, the methods of sample collection, preservation, and analysis were likely much less reliable than current methods. Before 1970 detection limits alone would have been higher than most current water quality standards for metals. Consequently, any attempt to determine retroactively the natural background water quality at a mine site today depends on indirect methods using scientific inference.

MINE CLOSURE REGULATIONS AND THE USGS BACKGROUND STUDY

The New Mexico Mining Act of 1993 and the New Mexico Water Quality Act (1967) require operating mines to meet several regulations on closure. One requirement is that ground water must meet New Mexico ground water quality standards *unless* it can be shown that ground water before mining contained solute concentrations greater than the standards. For such a site, the natural background values, rather than the standards, may be used.

One of the largest and most productive molybdenum mines in the U.S. is operated by Molycorp, Inc., near Questa. To provide technical information needed to help settle disputes between regulatory agencies and Molycorp regarding pre-mining ground water quality at this mine site, the U.S. Geological Survey (USGS) conducted a study in cooperation with the New Mexico Environment Department. The project has taken more than three years (2001–2005) and involved an interdisciplinary team of experts in economic and environmental geology, mineralogy, geochemistry, hydrology, geomorphology, and geophysics. It is in the first stage of completion. To the best of our knowledge, this study is the first to estimate pre-mining ground water quality for regulatory purposes at an active mine site by a third party.

THE KEY: A PROXIMAL ANALOG SITE

The approach taken by the USGS was to study a proximal analog site in detail and apply the knowledge gained to the mine site. A proximal analog is located off the mine site but nearby with the same geologic, hydrologic, and climatic conditions as the mine site, and whose water-rock interactions would provide a viable model for the mine site. Any substantial differences between the analog site and the mine site are identified and accounted for with appropriate models of water-rock interactions. The Straight Creek Basin was chosen for the analog site (Figure 1).

During the USGS background study, there was extensive sampling of ground waters and surface waters, especially a detailed chemical survey of the Red River. As the ultimate recipient of ground water flow in the Red River Valley, the Red River water chemistry contains clues on where ground water enters the river, and its composition.

WATER QUALITY OF THE RED RIVER

More than one million years ago, the Red River was the headwaters of the Rio Grande. The Red River begins at an elevation of 12,000 feet near Wheeler Peak, the highest peak in New Mexico, and flows 35 miles to the Rio Grande. A USGS gaging station is located at the U.S. Forest Service Ranger Station at Questa with hydrograph records that date from 1924 to the present. Daily discharges average 46.8 cubic feet per second with a large range of 2.5–750 cubic feet per second. Areas of highly altered rock (known as "scars") erode so rapidly that vegetation cannot be sustained. Acid waters occur naturally in scar areas from

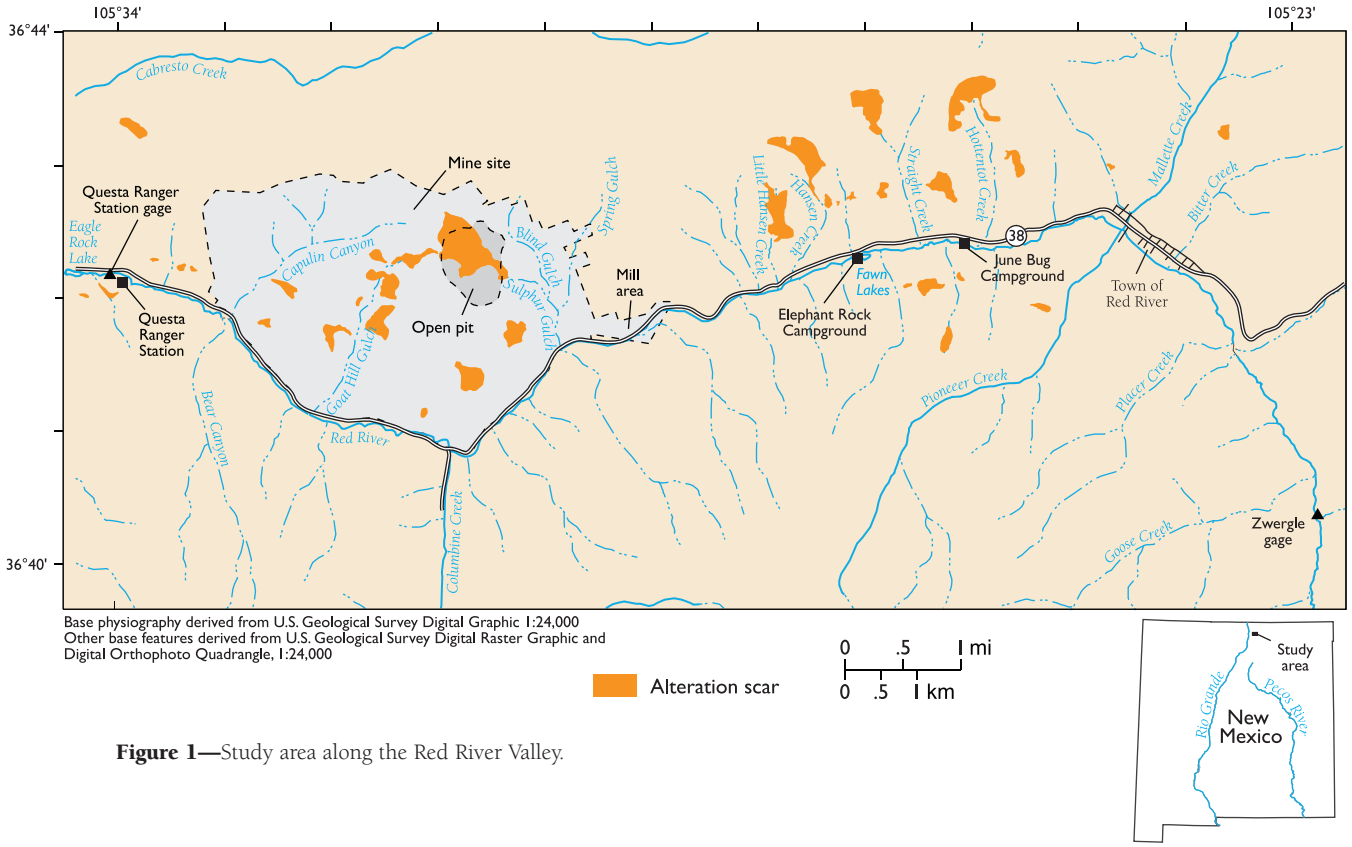


Figure 1—Study area along the Red River Valley.

the weathering of pyrite (iron sulfide).

During August 17–24, 2001, the USGS sampled water along the Red River as part of a constant-injection tracer study to determine the discharge and solute-concentration profile with distance. All major ions and several trace elements were determined on filtered and unfiltered samples including iron, aluminum, manganese, copper, zinc, cadmium, lead, arsenic, cobalt, nickel, molybdenum, and beryllium. These elements are of particular concern because they can be discharged from mining activities and can cause harm to aquatic biota in the river. The analytical results, the most detailed chemical survey ever done for the Red River, are available online at **http://wwwbrr.cr.usgs.gov/projects/GWC_chemtherm/pubs/OFR03_148_QuestaTracer.pdf**.

One indication of the aquatic health of the Red River is shown in Figures 2 A, B, and C. Profiles of discharge, pH, and alkalinity with distance downstream from the town of Red River are shown in Figure 2A. Note that the river flow tends to increase down drainage, not continuously but in steps at specific points in the river. The big step increase at about 13,000 meters is the point at which Columbine Creek enters the Red River. The smaller increase at 6,000 meters, however, has no obvious tributary entering the river and must be from ground water inflows. Note that just upstream from the 6,000-meter point the discharge is decreasing; it is a "losing" stream where the river water is being lost to the subsurface. This loss is caused by stream flow entering the large debris fans that push out from their respective drainages into the Red River and cover part of the river. Water flowing through the debris fans emerges farther downstream. The fans cause a "damming" effect with sediments depositing behind them. Sediments deposited behind the Hottentot fan formed the flat valley for the town of Red River.

The pH measurements provide an estimate of the acidity or basicity of the water. Values of pH less than 7 are acidic and greater than 7 are basic or alkaline. A pH near the neutral point of 7, say 6–8, is healthy for aquatic life and for human health. The pH values for the Red River tend to be in the 7.5–8.5 range and indicate good water quality. Note, however, the distinct decreases, or dips, in pH especially at the three points marked by the vertical dashed lines in Figure 2. These are points where acid ground waters enter. The first pH dip at Waldo Springs is where naturally occurring acid ground waters from the Hansen, Straight, and Hottentot scar drainages enter the Red River. The second dip is near the Sulphur Gulch

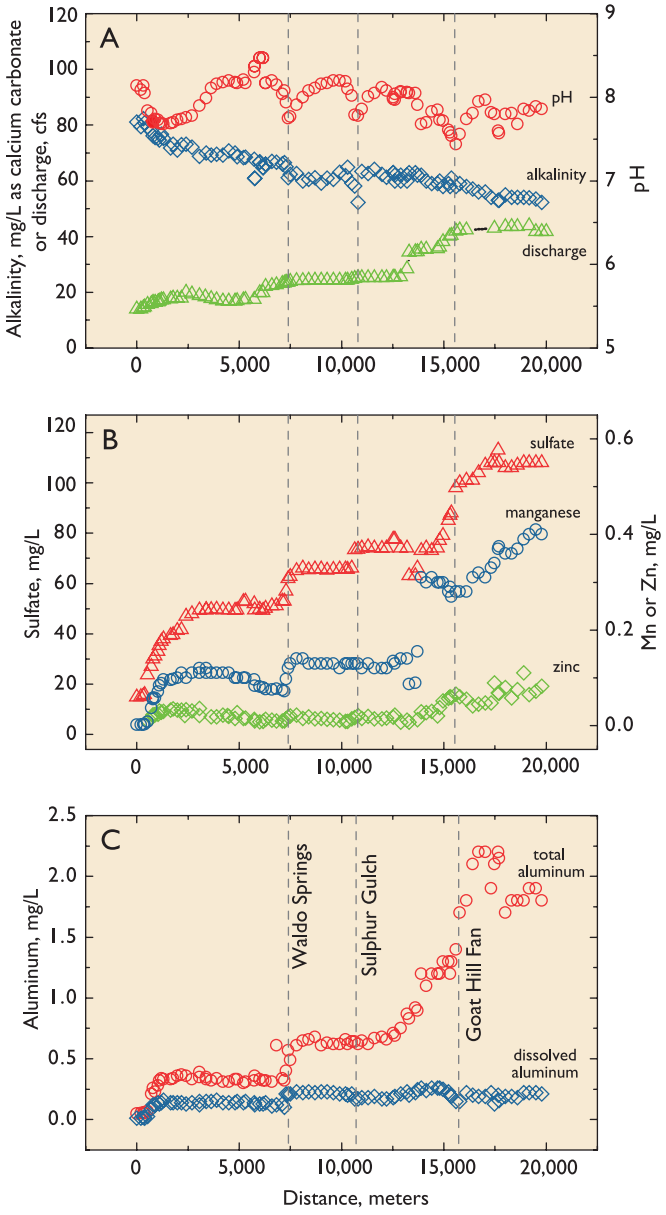


Figure 2— A Discharge, pH, and alkalinity with downstream distance in the Red River from the town of Red River to the USGS gaging station. **B** Sulfate, manganese, and zinc concentrations with downstream distance in the Red River from the town of Red River to the USGS gaging station. **C** Total (dissolved plus particulate) and dissolved aluminum in the Red River from the town of Red River to the USGS gaging station.

drainage where acid waters enter from the mine site (part natural and part related to mining), and the third dip is where acid waters enter from the Goat Hill Gulch area (likely natural). Both natural scar drainage and mine-waste-pile leachates occur at the mine site. However, major seeps are now being intercepted and are no longer entering the Red River.

Alkalinity is another measure of the health of the Red River. Alkalinity is an estimate of the buffering capacity (or neutralizing potential) of the water; the higher the alkalinity, the greater the capacity of the water to resist changes in pH from acid inflows. The profile in Figure 2A shows a steadily decreasing alkalinity with downstream distance. Clearly the addition of acid inflows along the Red River is using up its buffer capacity, making it more susceptible to acidification.

Figure 2B shows distance profiles for concentrations of dissolved sulfate, manganese, and zinc with notable step increases at Waldo Springs, Sulphur Gulch, and Goat Hill Gulch. Sulfate is derived from dissolution of the mineral gypsum (calcium sulfate), which is common in the Red River Valley, and from weathering of pyrite. Only pyrite weathering, however, produces acidic waters, which can occur both naturally and from mine wastes. Hence, pyrite weathering has caused some of the increases in sulfate at these step increases because they coincide with the same places where the pH decreases occur. Manganese and zinc also have step increases in the same places as the sulfate increases, because the minerals from which these elements weather (rhodochrosite and sphalerite) are minerals that accompany pyrite and gypsum. Both of these minerals occur in the Questa ore deposit, rhodochrosite in substantial amounts. Concentrations of most other dissolved metals in the Red River are too low to be of concern for aquatic health standards.

Figure 2C is a distance profile for dissolved and total (dissolved plus particulate) aluminum. Aluminum, derived from common rock-forming minerals, is highly soluble in acid waters but becomes insoluble when the pH increases to about 5. Acid inflows to the Red River are neutralized upon mixing, and a white aluminum precipitate can be seen in many places along the banks. Consequently, the total aluminum concentration in the river builds up as suspended particles, but the dissolved aluminum remains at a low and nearly constant concentration because of the insolubility of this hydrous aluminum precipitate at neutral pH values.

WHEN GOOD RIVER QUALITY GOES BAD

Although the quality of the Red River is affected by acid inflows, most of the time a healthy pH and adequate alkalinity are maintained. Rapid, deleterious changes in the water quality occur when summer monsoonal rainstorms hit the valley. An example is

shown in Figure 3 for a rainstorm event of September 2002. During the early part of the rainstorm, the pH decreased from 7.8 to 4.8, sulfate concentration doubled, and manganese concentration increased fourfold. Another example was recorded in 1986 that resulted in even greater increases in acidity and metal concentrations. These sudden changes in water quality are caused by a surge of acid drainage that usually comes from natural scar areas upstream from the mine site, but which may have come from leaching of mine wastes before remedial action was taken. Large quantities of suspended sediment also are released during these high-flow rainstorm events, which can have a deleterious impact on aquatic life. Fortunately, these are short-term changes, on the order of a few hours or less, and the river does recover. For this short duration, an increase in acid inflow overcomes the buffering capacity of the river, and that is why the water quality is marginal or "on the edge." Although water quality in the river generally is adequate for aquatic life, the river has little resistance to perturbations, such as rainstorms or additions of large quantities of mine waste effluent.

Aluminum precipitation along the north bank of the Red River near the Molycorp mine site.

CONCLUSIONS FROM THE USGS BACKGROUND STUDY

There is no question that in the highly mineralized Red River Valley, acidic ground waters from scar weathering occur naturally with high concentrations of metals, sulfate, and fluoride that can be at least ten times greater than ground water quality standards. There is also no question that mine-waste effluent has contributed additional acidity, metals, sulfate, and fluoride to local ground waters at the mine site. The USGS study of the Straight Creek analog site, combined with other data collected in the Red River Valley, is providing information that constrains pre-mining ground water concentrations and can provide a baseline or reference for setting site-specific standards. These pre-mining ground water solute concentrations vary somewhat from catchment to catchment, and even within different parts of the same catchment depending on the geological characteristics. Hence, a single concentration value (per constituent) for the whole mine site probably is not a feasible approach in such a complex and heterogeneous terrain. A range of concentrations per constituent and per catchment is necessary to characterize the mine site ground waters and to allow for uncertainties in the estimate. Although these conclusions create a more cumbersome regulatory process, they reflect the realities of the complex geology and hydrology in this environment.

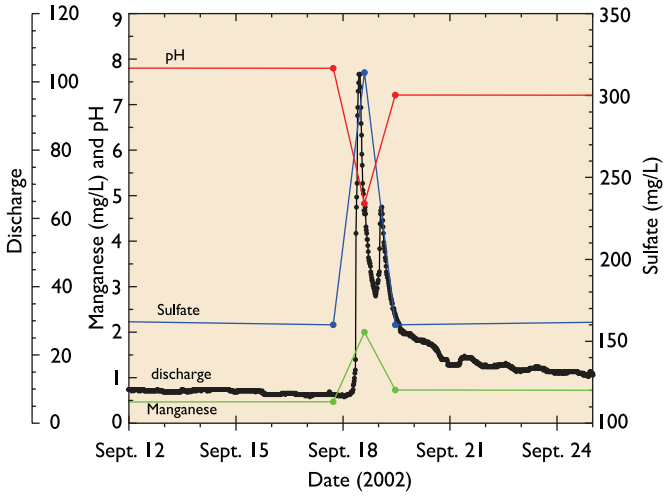


Figure 3—Change in discharge, pH, sulfate, and manganese at the USGS gage during the storm of September 17, 2002.

Water Quality Regulation of Mining Operations in New Mexico

Mary Ann Menetrey, *New Mexico Environment Department*

The New Mexico Environment Department is the primary state agency regulating water quality protection at hard rock mining sites in New Mexico. Over the last several decades there has been increased awareness of the environmental impacts associated with mining operations, including contamination of ground water and surface water resources. Protection of this water is critical, given New Mexico's limited surface water resources and heavy reliance on ground water for public water supplies. Ninety percent of New Mexico's population depends on ground water aquifers for drinking water, and nearly 80 percent of the population is served by public systems derived from ground water sources. Surface water flows in many New Mexico rivers have been significantly reduced due to drought conditions and increased water demands, and New Mexico will continue to rely more heavily on ground water to sustain the state's residential population and business community.

The importance of the state's water resources makes the implementation and enforcement of water quality regulations a top priority. Mining operations are commonly situated in complex and sensitive environments, making water quality protection a challenge. Below is a summary of the water quality regulations that affect hard rock mining operations, as well as a discussion of how the regulations apply to contaminant sources, application of water quality standards, and mine closure.

WATER QUALITY LAWS AND REGULATIONS AFFECTING MINING OPERATIONS

The first water quality protection law in New Mexico, the Water Quality Act, was adopted by the New Mexico legislature in 1967. The Water Quality Act was amended in 1973 to allow the state of New Mexico to adopt regulations requiring that permits be obtained for water quality protection. These regulations went into effect under the jurisdiction of the Water Quality Control Commission (WQCC) in 1977 and provide the current framework for New Mexico's water quality protection programs.

The Water Quality Control Commission regulations include numerical standards for ground water and surface water, and are designed to protect all ground water in New Mexico that has a total dissolved solids concentration of 10,000 milligrams per liter (mg/L) or less. The regulations provide for water quality protection using two methods. The first method is through discharge permits that prevent exceedances of numerical water quality standards by controlling sources of contamination. The second method is through abatement plans that address cleanup of existing contamination. The Environment Department's Ground Water Quality Bureau is responsible for administration of the WQCC ground water regulations as they apply to discharges from mining operations and other types of facilities.

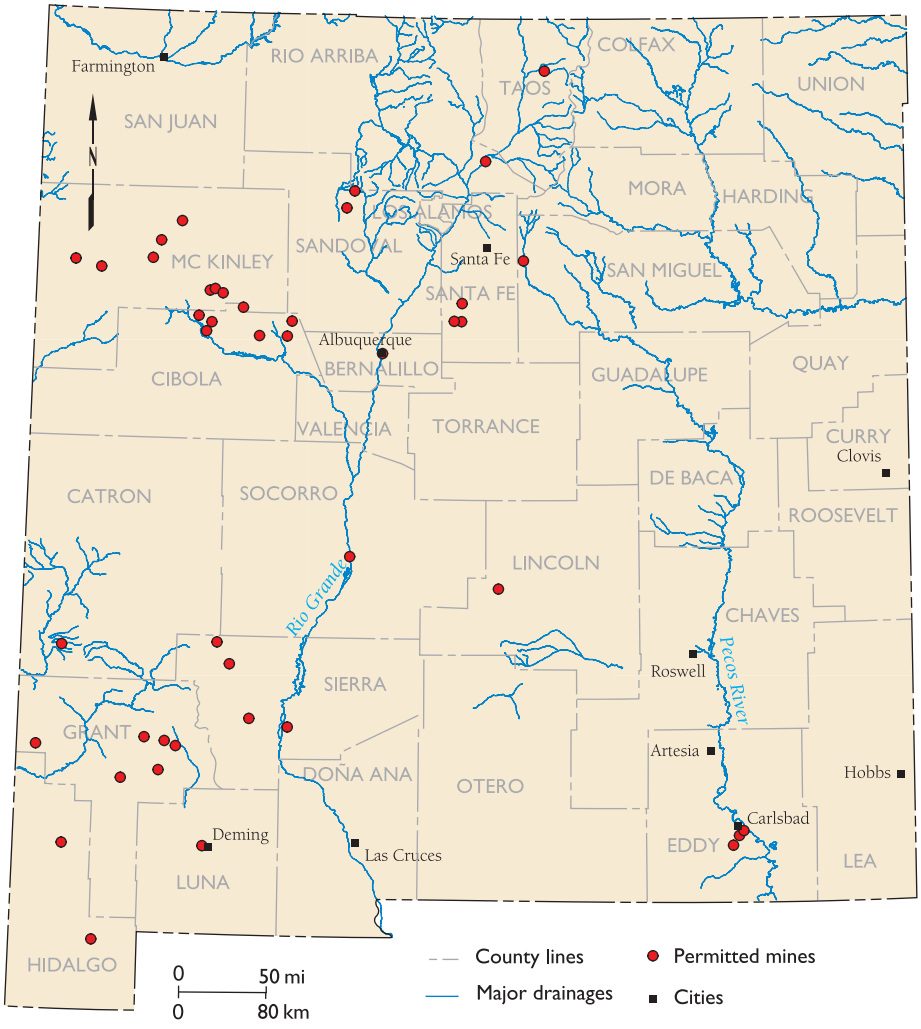
The ground water discharge permit provisions of the WQCC regulations are the foundation of New Mexico's ground water pollution prevention programs. These provisions require that a person discharging onto or below the surface of the ground demonstrate that the discharge will not cause ground water standards to be exceeded at any place of withdrawal for present or foreseeable future use, and will not cause any stream standard to be violated. At mine facilities the regulated discharges can include process solutions, waste rock, mill tailings, leach stockpiles, storm water, and domestic wastewater. The Ground Water Quality Bureau currently has discharge permits for approximately fifty mine facilities, including facilities for mining and/or processing of uranium, copper, molybdenum, gold, and other metal-bearing ores. The primary components of each discharge permit are an operational plan, monitoring plan, contingency plan, and closure plan. The goal of the permitting process is to work cooperatively with operators to keep ground water contaminants contained, and to ensure leaks and spills are detected early and promptly remediated.

The state of New Mexico also works closely with the U.S. Environmental Protection Agency (EPA) in implementing the federal Clean Water Act, Safe Drinking Water Act, and other federal laws that address water quality protection. In particular, the EPA administers the National Pollutant Discharge Elimination System (NPDES) permit program that is applicable to mining

operations pursuant to the Clean Water Act. These NPDES permits are intended primarily to protect surface water quality and address point source discharges to surface waters. The Environment Department's Surface Water Quality Bureau coordinates with EPA in administering the NPDES program by certifying permits, conducting inspections, and providing permit information to the public and operators. The Surface Water Quality Bureau is in the process of obtaining primacy for the NPDES program, which will allow the state to issue NPDES permits to mining and other facilities. Nonpoint source contamination at mine sites is addressed through implementation of best management practices and storm water controls.

SOURCES OF GROUND WATER AND SURFACE WATER CONTAMINATION

Ground water and surface water contamination have occurred at many mining operations throughout the state. Although the sources of this contamination vary, some of the primary contributors include acid rock drainage from sulfide-bearing ore and waste rock, as well as process solutions that have escaped from unlined leach stockpiles and tailing impoundments. Much of the existing contamination from mining facilities is a result of past disposal practices that would not be permitted under the current regulations. Recently issued permits have focused on more rigor-



Mines with ground water discharge permits in New Mexico.

ous contamination prevention measures, such as lining of leach stockpiles and establishing waste rock management plans to reduce the potential for acid rock drainage.

Metals are the primary contaminants at mine sites affected by acid rock drainage. These metal contaminants include aluminum, copper, cadmium, arsenic, chromium, fluoride, and zinc. This contamination is a result of acidic solutions releasing metals contained within stockpiled rocks or tailings exposed to water and oxygen. Acidic solutions are intentionally applied to ore piles at some of New Mexico's copper mines to speed up this acid rock drainage process that dissolves copper so that it can be removed for processing. Total dissolved solids and sulfate are also common contaminants, often found as a precursor to metal contaminant plumes or associated with mine wastes that lack the potential for acid generation.

Open pits associated with mining operations can also be a source of water quality degradation. To facilitate mining, many large open pits have been mined below the ground water table, and dewatering operations are necessary to keep the pits dry. Where the walls of these pits contain sulfide-bearing minerals, oxidation of these minerals causes the release of metal contaminants into surface runoff waters that can accumulate in the pit bottoms. When mining ceases and dewatering of the pits stops, ground water flow back into the pits can create pit lakes that exceed surface water standards for many contaminants.

Pit lake at Nacimiento open-pit copper mine near Cuba.

APPLYING WATER QUALITY STANDARDS AND ABATEMENT

Once ground water or surface water becomes contaminated, cleanup can be very challenging and costly. Many mine facilities are located over fractured bedrock, where it is difficult to install extraction wells to recover the contaminated water. Contaminated waters move through these fractures and can eventually migrate into aquifers that provide a current or future water supply, or they can enter surface waters. Additionally, tailing impoundments and leach stockpiles often contain very large volumes of residual process solutions that can take decades or longer to completely drain from the piles. Where these facilities are unlined and water has become contaminated, it is almost impossible to prevent this drainage from contaminating underlying ground water for years to come.

The Water Quality Control Commission has determined that most ground water in New Mexico with a total dissolved solids or TDS concentration of less than 10,000 mg/L, including the ground water directly underlying mine facilities, has a reasonable and foreseeable future use. Therefore, the ground water underlying tailings, leach stockpiles, and other mine source areas must be cleaned up to water quality standards if it becomes contaminated. Contaminated water beneath these facilities cannot be left unabated because ground water can migrate away from these facilities and contaminate nearby water supplies. Also, many mine sites are candidates for future industrial or residential development, and in either case will need a clean on-site water supply.

The Water Quality Control Commission recognized that there might be situations where it is not technically or economically feasible to fully abate contamination of ground water. The WQCC regulations address these situations by including provisions for operators to petition the WQCC for approval of alternative abatement standards (AAS), which are a type of variance from the numerical ground water quality standards. In order to obtain alternative abatement standards the petitioner must demonstrate that:

- compliance with the applicable WQCC ground water standards is not feasible or there is no reasonable relationship between the economic and social costs and benefits;
- the proposed AAS are technically achievable and cost-benefit justifiable; and
- compliance with the proposed AAS will not create a present or future hazard to public health or undue damage to property.

The Water Quality Control Commission has approved alternative abatement standards for two mine sites in New Mexico, including the L-Bar uranium mill site in Cibola County and the Cunningham Hill mine in Santa Fe County. The Environment Department was able to support the AAS petitions for both these sites because, in part, the mine operators had conducted extensive ground water abatement, characterization, and source control measures before submitting their petitions. Given the difficulties of cleaning up existing contamination at many other mine sites, the Environment Department anticipates that there will be several more AAS petitions coming before the WQCC in upcoming years.

Another important consideration regarding ground water cleanup at mine sites is the issue of background concentrations. Many mine operations are situated in mineralized areas where ground water may be naturally elevated in concentrations of total dissolved solids, sulfate, or certain metals. Under the abatement provisions of the WQCC regulations, where the background concentration of any contaminant exceeds the numerical ground water standard, the responsible person can abate to the background concentration rather than numerical standards. However, determining the background concentration can be extremely complicated at mine sites where the geology is complex and there are multiple aquifers. Due to site-specific differences, the Environment Department does not believe it is appropriate to establish a single method for determining background concentrations. Background concentration investigations are ongoing at several mine facilities, including the Molycorp Questa mine, where the U.S. Geological Survey has been conducting a background investigation since 2001.

WATER QUALITY PROTECTION FOLLOWING MINE CLOSURE

One of the greater challenges facing state regulators and mine operators is determining adequate closure methods for existing operations after mining opera-

Seepage into the Red River at Spring 39 adjacent to the Molycorp mine site.

tions cease. In addition to the long periods needed for drainage of process solutions, acid rock drainage at some facilities is predicted to continue for decades and possibly centuries. Under the WQCC regulations, ground water discharge permits must include closure plans to ensure that water quality standards are met after the mine operation shuts down. The components of the closure plan are a description of closure measures, maintenance and monitoring plans, post-closure maintenance and monitoring plans, financial assurance, and other measures necessary to prevent and abate contamination.

The Environment Department has consistently required that closure plans for mining operations focus on enacting source control measures to reduce or eliminate ongoing contamination of ground water and surface water after operations cease. Containment of contamination without source controls would not meet WQCC requirements and is not practical for sites where contamination could continue for decades or centuries. Measures that are typically included in mine closure plans approved by the Environment Department include long-term stabilization measures such as regrading of stockpiles and erosion controls, covers over stockpiles and tailings that minimize infiltration into contaminated material, and a plan for long-term water treatment of contaminated ground water and surface water.

Due to the large size of some mining operations and extent of existing contamination, there is uncertainty as to whether approved closure measures will successfully protect water resources; therefore, many approved closure plans also include requirements for additional studies to refine the closure plan and allow the mine to plan better for closure. Examples of additional studies include test plots, stability studies, hydrologic investigations, and feasibility studies. Approximately thirty studies related to site closure are currently underway for the Molycorp Questa mine. As more data are collected in the area of mine closure, it is anticipated that permitting for closure under the Water Quality Control Commission regulations should become both more effective and more efficient.

Engineering Challenges Related to Mining and Reclamation

Terence Foreback, *Mining and Minerals Division*
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Mining in New Mexico has been going on for hundreds of years. During this time the public's perception of the concepts of environment, water, economics, and sustainable development has changed. A hundred years ago, mines were not planned, operated, or reclaimed according to today's standards. More recent operations that were planned or operated without sustainable development in mind now are challenged by regulatory requirements to reclaim to a stable landform. With the passage of mining legislation such as the New Mexico Mining Act in 1993 and the Surface Mining Control and Reclamation Act of 1977 (SMCRA), new mining operations in New Mexico are required to integrate planning, operating, and reclaiming activities with a specific post-mine land use in mind. For this reason, the major engineering challenges must be viewed in the context of the age of the operations, and reclamation standards that have changed over time. The New Mexico Mining Act distinguishes between "existing units" and "new units" when applying reclamation standards. Some engineering challenges are unique to older sites. Newer sites can be planned from the beginning to accomplish sustainability of the post-mine land use. Some of the major engineering challenges include:

- Slope stability and reclaiming mined land to landscapes that are geomorphologically stable and self-sustaining
- Design of operations and reclamation strategies to minimize negative public perception issues
- Reclaiming mine sites to geochemically stabilize land without impacting water quality

Successfully reclaimed mined land in New Mexico during the second growing season.

SLOPE STABILITY

Landforms in New Mexico consist of hills and valleys, mesas and arroyos, mountains and canyons, which are all ways of referring to low areas and high areas. Slopes at various angles connect the low and high areas to each other. Slopes are never completely stable because of the effects of gravity and erosion, which are constantly trying to create a flat environment. We've all had some experience with slope stability working in our yards or in a sand pile, and we can understand that we can stack some materials higher and steeper than other materials. The steepest angle at which a pile of material will stand is referred to as the "angle of repose." All materials have an internal resistance or friction. The higher the internal resistance, the better the material's ability to resist the effects of gravity. Materials with higher internal resistance will have a steeper angle of repose, and different materials have different angles of repose. For any material, though, the lower the slope angle, or said another way, the flatter the slope, the more stable the slope.

When we discuss slope stability at mining operations, we are generally referring to the reclaiming of mined landscapes to be geomorphologically stable. Geomorphologically stable means creating a stable topography that soil, slope, and weather would naturally form over time, similar to the natural landform. Mining regulations now require that mine reclamation create a self-sustaining ecosystem that includes the physical stability of the landscape. This has not always been the case. As a result, some older mines have been abandoned and left with unstable slopes. Some active mines must now reclaim unstable slopes that were created before mining regulations required such reclamation.

So what types of slopes are we talking about reclaiming at mining operations in New Mexico?

- Slopes on spoils (in-pit waste rock) at coal mines
- Slopes on out-of-pit waste rock piles at open-pit metal mines (i.e., Tyrone)
- Slopes on tailings dams
- Any slope that was created or affected by the mining operation that must be reclaimed

Overview of Cottonwood pit reclaimed topography in the foreground and undisturbed topography in the distance. Reclamation work is shown prior to revegetation.

Slopes on Spoils at Coal Mines

Reclamation of spoil at coal mines involves restoring natural vegetation and drainage in order to return the mine site to a self-sustaining ecosystem such as farmland, wildlife areas, parklands, or housing developments. The reclamation process actually begins before the first ton of coal is removed. To fulfill mining permit requirements, the coal company must document how sedimentation from the temporarily disturbed areas will be controlled, how ground and surface waters will be protected, and how restoration of the soil and vegetation will be achieved.

Fluvial geomorphic-based design of post-mining topography is an engineering technique that is being used at mining operations in New Mexico. The end product of fluvial geomorphic-based design is a post-mining topography that resembles the natural surroundings. The reclamation grading and recontouring goals of fluvial geomorphic-based design are:

- To provide long-term stability for steep slopes and drainages
- To increase topographic diversity to improve habitat for plants and wildlife
- To reduce the potential for flash flooding of adjacent property as compared to the pre-mine conditions
- To create a functional landform that blends in with the surrounding natural terrain

The fluvial geomorphic approach creates a stable topography similar to what the combination of soil, slope, and weather would naturally form over time and includes sinuous drainage systems that mimic surrounding terrain. Channel dimensions are designed to pass the storm discharges that would be expected from a yearly maximum storm event and to pass the sediment from these annual flow events. These channels are also designed to pass larger events without excessive erosion by allowing overbank discharges to spread out over a flood-prone area as would naturally occur.

San Juan Coal Company, a New Mexico mining operation, received the 2004 federal Office of Surface Mining's National Award for Excellence in Surface Coal Mining, Best of the Best Award for its application of fluvial geomorphic-based techniques. Although this procedure has been pioneered at New Mexico's coal mines, it can be applied to other types of mines where conditions allow.

Slopes on Out-of-Pit Waste Rock Piles at Open-Pit Metal Mines

When open-pit metal mines remove non-economic material overlying an orebody, the material must be placed somewhere out of the way of the mining operation. This out-of-pit material is referred to as waste rock. Waste rock piles can vary in size depending on the mining operation, but some waste rock piles can be quite large.

Waste rock piles in the past were placed in the most convenient location determined solely on economics. They were typically dumped at their angle of repose on pre-existing hillsides near the mining operation. Sometimes these hillsides were not stable. In some locations waste rock was deposited on material that trapped ground water flowing through the waste rock piles or contained clay and developed into a sliding surface. These factors have all contributed to unstable

waste rock piles that now must be addressed. Mitigation of the waste rock piles that were not designed to be geomorphologically stable is difficult. Mitigation is a process of lessening (reducing) the slope of the pile, combined with ensuring adequate drainage.

There are two ways to reduce the slope of a waste rock pile. Earthmoving equipment can start at the top and extend the toe of the stockpile in length, thus creating a flatter surface. If this is not possible because of constraints such as highways, topography, structures, streams, or environmental concerns, then the material must be removed starting at the top and placed in another location.

Ensuring adequate drainage lessens the effects of surface and sub-surface water. Constructing surface interception ditches can reduce infiltration by preventing surface water from flowing onto rock piles and by preventing ponding of water on rock piles. Mitigation of ground water effects is difficult on rock piles that were not properly engineered.

Waste rock piles at new operations can be designed to be geomorphologically stable. Slopes can be constructed at an angle much less than the angle of repose. Rock pile locations can be selected so that material is not placed on areas that are already unstable. Drainage under rock piles can be established by constructing gravel underdrains that can prevent the buildup of ground water pressures. Surface drainage can be designed to prevent any ponding of water on rock piles, and diversions can carry water away from the pile.

Many mining operations can also be designed to place some or all of the waste material back into the open pit. The advantages of partial backfill are possible reduction of disturbed area, containment of waste rock piles, and partial reclamation of the open pit. The backfilled material can then be graded as described above in order to achieve stability.

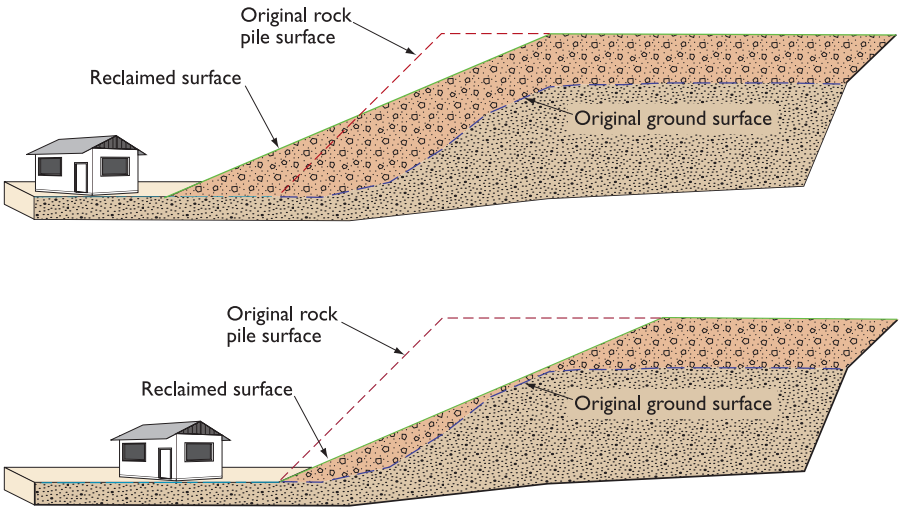
Slopes on Tailings Dams

Tailings dams are man-made structures used to contain the non-ore material that is left after ore is processed. Typically, this waste material is very fine and has a high moisture content.

The same types of considerations discussed above apply to slopes on tailings dams. The major engineering design difference is that tailings dams are structures containing large volumes of material consisting of water and very fine material created during the processing of the ore. The slopes on the tailings dams must be not only geomorphologically stable, but the dam must hold back material that has low internal strength. For this reason, the state of New Mexico has regulations and standards on the design and construction of these structures.

Other Slopes at Mining Operations

There are other types of slopes at mining operations such as slopes on leach stockpiles. Current regulations require that these slopes be designed to be geomorphologically stable upon reclamation. The guiding



Grading waste rock piles to obtain more stable slope angles.

principles for the engineering design are creating flatter slopes and ensuring adequate drainage.

DESIGN TO MINIMIZE NEGATIVE PUBLIC PERCEPTION ISSUES

Public perception issues related to mining are often the concerns most frequently dealt with by regulators and legislators in New Mexico. These concerns are related to how the public comes into contact with mining issues such as:

- Dust from mining operations
- Blasting and its effects
- Traffic from mining operations, particularly from trucks
- Visual effects

Mining operations usually cannot eliminate these effects, but mines can be planned, operated, and reclaimed to minimize them.

Dust from mining operations can be controlled through a variety of engineering practices. Roads can be designed using materials that create less dust. There are environmentally friendly substances that can be applied to road surfaces to suppress dust. One of the simplest procedures is to apply water to the road surface. Mineral processing plants can use cyclones or other collection methods to capture dust rather than emitting it to the atmosphere.

Mining operations where blasting is performed can use blasting techniques that minimize its effects. Using blast delays that reduce the amount of explosives that are shot at one time can greatly reduce the effects of ground vibration. Reducing ground vibration can eliminate damage beyond the mining property boundary and minimize the perception of damage. Using blasting methods that reduce noise can greatly influence the public's perception of blasting. Proper planning, design, and operations can greatly reduce the public's perception of the consequences of blasting.

Traffic from mining operations almost always creates public perception issues. Usually the issue is trucks carrying the mined material, and the problem is particularly evident with aggregate (sand and gravel) operations. Solutions to this problem may be solicited in public meetings with affected stakeholders and could include minimizing dust from roads, carefully planning the hours of operation, monitoring the speed and size of the trucks, and minimizing (to the degree possible) the number of trips by processing on site.

Visual effects are often a concern to the public. But mines can be planned, operated, and reclaimed to minimize visual effects. Operations can be planned to minimize the amount of surface disturbance by mining only the required area to meet production requirements and by reclaiming areas expeditiously after mining. Planning should be given to the permanent mine facilities relative to their siting. Proper reclamation techniques previously discussed, such as fluvial geomorphic-based design, can also create a post-mine environment with a pleasing visual effect.

RECLAIMING MINE SITES TO GEOCHEMICALLY STABLE LAND WITHOUT IMPACTING WATER QUALITY

Another engineering challenge is reclaiming mine sites to be geochemically stable without impacting water quality, specifically:

- Soil problems related to coal mines
- Acid rock drainage from waste rock piles
- Soil problems related to reclaiming areas with low pH and high metal content.

To a large degree, if a mine is not reclaimed to be geochemically stable, it will not be geomorphologically stable.

Soil Problems Related to Coal Mines

Two major problems encountered during coal mine reclamation are salinity and clay content of topsoil and spoil material. Reclamation at some mines in New Mexico was problematic because vegetation could not be established in soils that contained a high salt and clay content. Regulations now require that mine operators sample the available topsoil material before mining. Both quality and quantity of the material must be addressed to ensure that both are adequate for reclamation. The material that will be mined must also be analyzed for problems in soil chemistry, which must be taken into account prior to reclamation.

Acid Rock Drainage from Waste Rock Piles

Waste rock piles may contain materials that create acid drainage. This usually is caused by water reacting with waste rock of material containing the mineral pyrite. The water flows through the rock pile, reacts

with the pyrite, and then flows out of the rock pile as acidic ground water. Acidic water can dissolve metals and other substances and may contain unacceptably high levels of these contaminants. The acid rock drainage (ARD) can remain beneath the surface, causing contamination of ground water, or surface as springs and contaminate surface water.

The effects of ARD from rock piles can be minimized, particularly when mining operations plan, operate, and reclaim with mitigation in mind. Surface water can be diverted around rock piles to minimize the amount of water that will infiltrate into the pile. Soil layers placed on top of the rock piles can be properly designed and vegetated to use the precipitation that naturally falls on the rock piles without allowing infiltration. This is referred to as a "store and release cover." In extreme cases, systems can be designed and constructed to collect ARD that flows from rock piles so that it can be pumped and treated.

Soil Problems Related to Reclaiming Areas with Low pH and High Metals Content

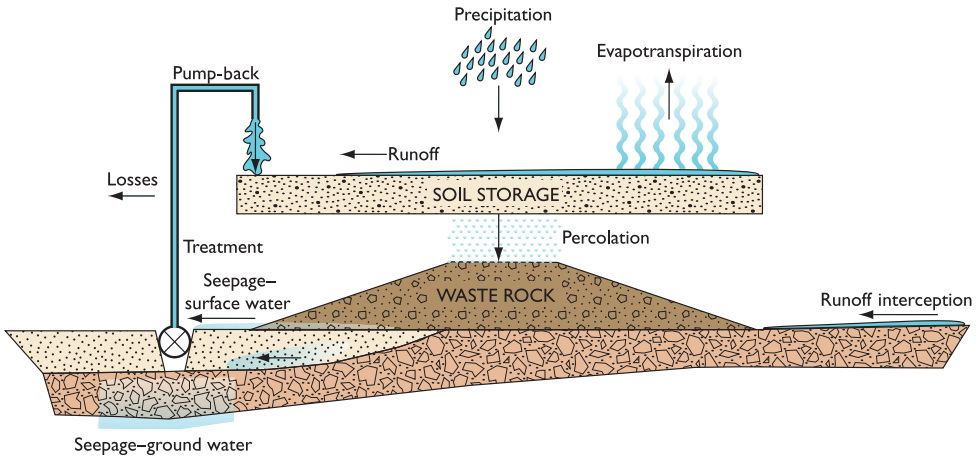
Metal mining operations sometimes have unique engineering challenges reclaiming areas with low pH (high acidity) and high metals content. Two areas usually of concern are tailings areas and waste rock piles. There are several challenges with ensuring that proper engineering is done in these areas including:

- Limiting water infiltration and ARD by establishing a store and release cover.
- Ensuring that neutral cover material is placed over material that would inhibit plant growth. The concern here is that plants may not grow adequately in the acidic material or they may absorb metals through the roots.
- On areas that were not regulated and designed according to current standards, interceptor systems for ARD may need to be constructed after problems have been encountered.

REQUIRING ADEQUATE FINANCIAL ASSURANCE

Mining has left an unfortunate legacy of abandoned, unreclaimed sites in New Mexico. For this reason the New Mexico Mining Act and the Surface Mining Control and Reclamation Act require that mining companies calculate the cost of reclamation and post a bond for that amount in the event the company becomes insolvent and cannot meet its regulatory responsibilities.

The calculation of the cost to reclaim is an important engineering challenge. Engineers working on the calculation must have an adequate understanding of the principles of reclamation. There must be regulatory oversight of the calculation in order to ensure that adequate reclamation funding is available. This is one of the most important engineering challenges and one that ensures that unreclaimed sites will not be an issue of the future.



Conceptual design of an acid rock drainage collection system.

Environmental Impacts of Aggregate Production

William H. Langer, *U.S. Geological Survey*
L. Greer Price and James M. Barker, *New Mexico Bureau of Geology and Mineral Resources*

Our nation's infrastructure—streets, highways and bridges, houses and buildings, sidewalks, sewers, power plants, dams, just about everything—requires huge volumes of aggregate. The main sources of aggregate in the United States are sand and gravel (43 percent) and crushed stone (57 percent). These materials are commonly used with a binder in concrete, mortar, and blacktop. About 2.66 billion metric tons of natural aggregate worth $14.5 billion (exceeding the total value of all metals) were produced in the United States during 2003.

Many agencies advocate that resource extraction be sustainably managed. This approach commonly requires that decisions regarding resource extraction include best management practices and other environmental management tools that consider health, economic prosperity, and social well-being.

Most aggregate is used in its natural state, except perhaps for crushing, sizing, and washing. Unlike most metallic resources, aggregate is not concentrated from an ore. Quality aggregate is chosen specifically to avoid metallic and other minerals that react with water to create acid.

Because aggregate is expensive to transport, it is quarried near the point of use, commonly a population center. Resource availability and conflicting land use issues severely limit areas where aggregate can be developed. The siting of aggregate quarries depends primarily upon where the geology is favorable and not necessarily where it is needed most.

Most environmental impacts from aggregate quarrying are benign. The impacts are generally close to the quarry and can be largely mitigated. Impacts from most extraction activities relate to the geology of the site, and geologists can help identify impacts and design plans to avoid them. Aggregate production may alter geologic conditions, altering the dynamic equilibrium of the site. Specific impacts and their mitigation are outlined below.

CONVERSION OF LAND USE

The most obvious environmental impact of pit/quarry operations (which is what most aggregate "mines" consist of) is the conversion of land use, generally from undeveloped or agricultural lands. Surface pits and quarries are dramatically different from most other land uses. Careful selection of a pit or quarry site minimizes the amount of surface area that must be disturbed by resource extraction. In some cases, the post-quarry use is more acceptable to the public and more environmentally or economically valuable than the original, pre-quarry use.

Conversion of land use may impact features of special interest or significance. Conducting a pre-quarry inventory of the site for scenic, biological, historical, archaeological, paleontological, or geological features minimizes this impact. Ironically, such features are sometimes recognized as unique only when aggregate operation begins. Aggregate extraction uncovers a relatively large area at a relatively slow pace, which can lead to serendipitous discoveries to which many organizations are able to respond rapidly.

STATE	SAND & GRAVEL PRODUCTION (10^3 metric tons)	SAND & GRAVEL AS A % OF AGGREGATE PRODUCTION
Arizona	59,800	84.8
Colorado	33,500	73.0
New Mexico	13,900	77.0
Oklahoma	9,890	17.3
Texas	81,500	43.5
Utah	26,100	77.3
United States	1,140,000	42.9

Sand and gravel production for the year 2003, and sand and gravel as a percentage of the total aggregate production by states in the New Mexico region and for the United States.

CHANGE TO VISUAL SCENE

Conversion of land use often changes visual character, viewed either from the site or toward the site. The change, temporary or permanent, is subjective; what is acceptable to some is objectionable to others. Visual impact depends on the topography, ground cover, and the nature of the quarry operations.

Visual impacts can be mitigated through careful quarry planning and design. The process may include limiting extraction areas and unnecessary disturbance (such as road widths), staining fresh rock faces to

resemble weathered rock, creating buffer zones, and visual screening such as berms, tree plantings, fencing, or using other landscaping techniques. Overburden and soil can be stockpiled out of view. Good housekeeping practices, such as maintaining equipment and locating equipment below the line of sight or in enclosed structures, are also effective.

LOSS OF HABITAT

Site preparation often results in loss of habitat for some species. Pre-production site inventories identify rare or endangered species so that habitat can be set aside, or so that extraction operations can be suspended during critical breeding or migrating seasons. Creation or improvement of habitat off site can offset the loss of habitat on site. Selected animals or plants can be relocated. After closure, the site may be reclaimed to look and function like the original habitat. Reclamation during quarrying, rather than waiting to the end of operations, can speed habitat recovery.

Many aggregate operations preserve existing habitat through creation of buffer areas. The buffer areas of many aggregate operations retain all the characteristics of the original habitat or may be planted to increase vegetative cover. In some populated areas, quarry buffers are a significant part of the total available open space. Wildlife from the surrounding area may seek the protection afforded by such buffers. Some active aggregate operations and their buffer zones can serve as habitat for rare or endangered species. Water is a major limiting factor in arid and semiarid climates. Irrigation may be necessary to establish new vegetation.

NOISE

The most frequent complaint from the public about aggregate operations is noise. Tolerance to new noise depends upon the background noise to which one has adjusted. In an urban or industrial environment, background noise may mask noise from an aggregate operation. In contrast, the same level of noise from an operation in a rural area or quiet residential neighborhood is noticeable to those accustomed to quiet settings.

Ambient noise generally is an accumulation that does not have a single, identifiable source. If noise can be identified as coming from a quarry, the perception of this noise may be enhanced. Noise impacts are highly dependent on the sound sources, the topography, land use, ground cover, and climate. Sound travels farther in cold, dense air and during atmospheric inversions.

The primary sources of noise during aggregate extraction are engines, processing equipment, and blasting. Aggregate producers are responsible for ensuring that the noise emitted from the pit or quarry does not exceed regulated levels. Regular inspections and maintenance can help ensure effective noise control for equipment.

Noise generated during quarrying can be mitigated through various engineering techniques. Topography, landscaping, berms, and stockpiles can form sound barriers. Noisy equipment (such as crushers) can be located away from populated areas and can be enclosed in sound-deadening structures. Conveyors can be used instead of trucks for in-pit movement of materials.

Trucking of aggregate is a significant source of noise. The proper location of access roads, the use of acceleration and deceleration lanes, use of engine-brake mufflers or avoidance of engine-brake use, and careful routing of trucks all can reduce this noise or at least its detection. Noisy operations can be scheduled or limited to certain times of day.

DUST

The impact of dust is determined by proximity of the operation to residential areas, ambient air quality, moisture, air currents and prevailing winds, the size of the operation, and interaction with other dust sources. Regulations strictly limit the amount of dust emitted during quarrying. A carefully prepared and implemented dust control plan reduces impacts. Controlling fugitive (non-point source) dust commonly depends on good housekeeping more than on elaborate engineered controls. Techniques of dust control include applying water and chemicals to haul roads, sweeping, reduced vehicle speed, windbreaks, and ground cover. Point source dust can be controlled using dry or wet suppression equipment. Dry suppression includes conveyor covers, vacuum collection systems, and bag houses. Wet suppression systems consist of pressurized surfactant-treated water sprays throughout the plant. Lack of an adequate water supply can present a problem for large operations in the arid west and thus water is often trucked or piped long distances.

BLASTING

Quarry blasting may occur daily or as infrequently as

Aerial view southward of the Taos Gravel Products gravel pit near the edge of the Rio Grande gorge. This operation was closed in 2002 because it was determined to be too close to the Rio Grande Wild and Scenic River Corridor and was situated (in part) on un-permitted land. The site has since been reclaimed.

once or twice a year. Potential impacts include ground vibrations, noise, dust, and flyrock. Geology, topography, and weather all affect the impacts of blasting. Buffer zones, tree belts, and berms may serve multiple purposes in reducing noise and dust levels between the mine site and community, while improving the visual quality of the area.

The modern technology of rock blasting is highly developed, and when blasting is properly conducted, the environmental impacts should be negligible. By following widely recognized and well-documented limits on ground motion and air concussion, direct impacts are mitigated.

CHEMICAL SPILLS

Routine equipment maintenance and blasting may result in the accidental spillage of solvents, fuels, and blasting agents, which can contaminate surface or ground water. Leaking underground storage tanks can pollute ground water. Minimizing chemicals used, properly storing all hazardous chemicals and petroleum products carefully within bermed areas, monitoring water for nitrates, and providing workers with training in safe operation and maintenance procedures are all part of best management practices.

GROUND WATER

Predicting the environmental impacts of these operations on ground water is highly dependent on an understanding of local geology, hydrology, and climate. Precipitation may flow into a quarry and recharge ground water. In dry climates, evaporation of water in pits or quarries may actually lower the water table. Removing vegetation from the quarry reduces evapotranspiration, which may ultimately increase ground water. In highly permeable deposits, impermeable subsurface (slurry) walls are sometimes necessary to isolate the pit from the water table. Water removed from pits through pumping can be returned to nearby streams, which may recharge the ground water supply downstream.

In some areas of aggregate production, changes in ground water quality have been attributed to the removal of soil that previously acted as a protective layer that filtered or otherwise reduced contaminants reaching the ground water. Many heavy metals, easily degraded organic substances, and bacteria are retained relatively well in the natural soil layer. If an underlying gravel layer is exposed, this retention is much weaker. The level of impact depends on the thickness and character of material removed, the surface area involved, and the total volume and recharge of the aquifer. Impacts can be mitigated by controlling water recharge in quarries or by locating quarries outside of recharge areas.

SURFACE WATER

Aggregate operations entail removal of vegetation that may retard runoff. Aggregate extraction may create impervious land that prevents infiltration or may change runoff patterns in other ways. Pits and quarries may affect surface water chemistry, but these subtle changes are primarily local. The ability to predict flooding and deposition at a pit or quarry largely depends on how well the hydrology and history of the adjacent stream and surrounding watershed are known.

Water from aggregate processing and storm runoff over pit/quarry sites can increase the suspended rock particles (turbidity) in stream runoff. Turbidity is generally greatest at pit/quarry and wash-plant water discharge points and decreases downstream. Turbidity can be controlled by filtering, or by containing runoff or wash water at recharge basins.

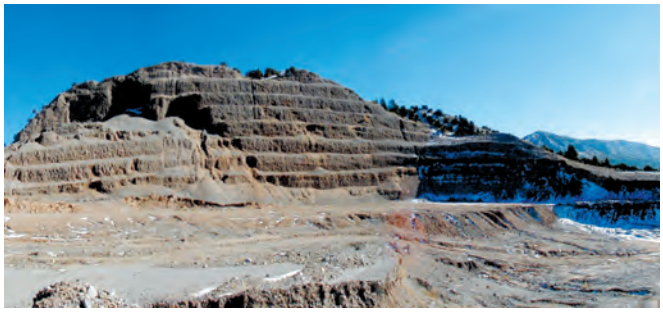
Aggregate production within stream floodplains may impact stream-channel morphology. Flooding streams

may flow through a pit or quarry in an active floodplain resulting in permanent changes in channel position that cause bank erosion and undercutting. This can substantially alter the distribution of the energy and force of the stream. Levees or dikes protect pits/quarries from flooding and keep water and sediment in the main channel. Engineered spillways allow controlled flooding and prevent deposition of sediment in pits/quarries.

Few aggregate operations in New Mexico occur within active streams. Careful hydrologic studies and application of best management practices can allow aggregate to be extracted from active stream channels with little environmental impact. The type and severity of impacts are dependent on the geologic setting and characteristics of the stream. The main impact occurs if more sediment is removed than the stream can replenish. Sediment removal may be at one site or be the total of many smaller operations. Sediment removal changes the stream cross section and increases gradient at the pit, which may cause widespread upstream erosion and loss of riparian habitat. A decrease in stream sediment by deposition in a pit can cause the stream to erode, resulting in similar effects. After aggregate extraction ceases, stream recovery can be quite fast or take many years.

EROSION AND SEDIMENTATION

Quarrying can promote erosion, which can result in increased sediment in nearby streams. Slope stability, water quality, erosion, and sedimentation commonly are controlled by sound engineering and geologic decisions. Appropriate slope angles are important. Roads, drainage ditches, and operational areas must fit the particular site conditions. Disturbed areas can be protected with vegetation, mulch, or other cover. They can be protected from storm water runoff by the use of dikes, diversions, and drainage ways. Sediment can be retained on site using retention ponds and sediment traps. Regular inspections and maintenance help ensure continued erosion control.



Aggregate extraction site on the north end of Velarde that created an unstable highwall. Such sites can create problems for nearby communities including dust, truck traffic, infrastructure damage, noise, and safety hazards. The back side of this highwall is currently being mined, which will eliminate the steep slope and allow revegetation so the site will more closely resemble the surrounding terrain.

LAND SURFACE

Aggregate operations should avoid areas of known landslides and areas favorable for mass movement. Aggregate operations on an existing landslide or near the toe or head of a landslide can remobilize the slide. In areas where natural factors are not conducive to slope failure, aggregate extraction can cause landslides if the pit or quarry is poorly located.

If a landslide does occur, it is likely to be near (but not necessarily at) the quarry. Landslides are likely to occur after quarrying starts, usually triggered by precipitation. This could be a single event or a series of landslides over an extended period of time. Geologic engineering techniques can identify existing landslides and landslide-prone areas, but they cannot predict precisely where or when a landslide will occur.

POST-QUARRYING IMPACTS

Most aggregate permits issued today in the United States require a formal reclamation plan and some form of guarantee (i.e., financial assurance) that reclamation will be done. Forward-looking quarry operators plan well in advance for the post-quarrying use of the site. Closed pits or quarries can be reclaimed as natural habitat, especially if they intersect ground water. Other uses include golf courses and other recreation, residential or commercial development, and parks. In many cases, post-closure uses equal or exceed the value of the pre-quarry use.

Wisely restoring the environment after aggregate production requires a design plan that responds to a site's physiography, ecology, function, artistic form, and public perception. Operating and reclaimed pits/quarries are no longer isolated from their surroundings. Analysis of a pit/quarry must go beyond the site-specific and relate to its context in the regional environment so a sustainable approach is useful. Understanding this aesthetic turns an industrial site typically perceived by the public as being undesirable into a positive feature for the entire region.