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Historic Hardrock Mining: The West's Toxic Legacy

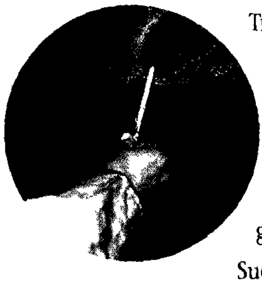
The Critical Link between Water Quality and Abandoned Mine Sites

"Drainage from hardrock mine sites is a major water quality problem in our state. This is true for many Western states. We need to stay focused on cleanup of the sources of severe water contamination— for restoration of our natural systems, and maintenance of our environment."

Geoff Harvey
Senior Surface Water Analyst
Division of Environmental Quality

The Trouble with Historic Mine Sites

Historic hardrock mining activities in the West have created hundreds of thousands of geological disturbances. Drainage and runoff from mine sites impact water quality in streams throughout the Rocky Mountain states. While cleanup of mine sites is a high priority, the sheer number and geographic distribution of these disturbed areas make addressing them a formidable task.



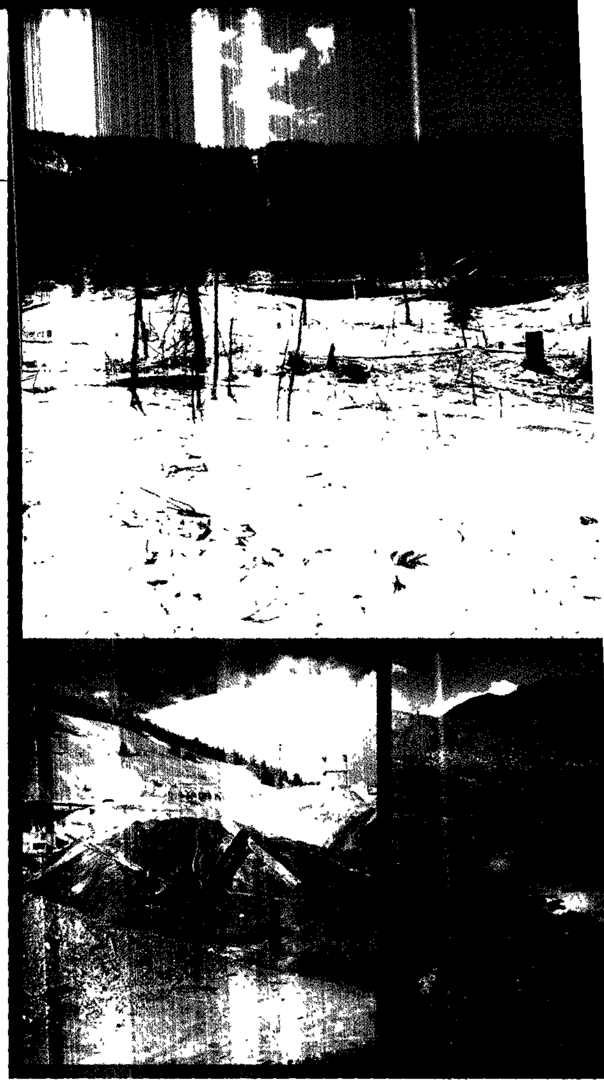
This metals deposit on the wall of a mine shaft is nearly pure zinc.

Traditional metals mining usually involves digging tunnels and adits to reach lodes of mineral-rich ore. Rock is removed from deep within the earth, and milled to extract desired minerals. When the ore is exhausted, miners move on leaving behind finely-ground tailings and waste rock above ground, and tunnels underground.

"If we don't understand what is going on and how the water moves through the earth, we'll end up spending a lot more money and getting a lot less done."

Bruce Stover
Senior Geologist and Project Director
Division of Minerals and Geology
Colorado Department of Natural Resources

Such mining activities expose part of the earth's crust to water, oxygen, and bacteria. Layers of metals-rich rock that have been underground become oxidized and chemically altered. When water flows through and over the newly-disturbed material, metals that were once locked within rock can dissolve in the water. Zinc, iron, cadmium, copper, lead—metals that are toxic to aquatic life and can damage human health—end up contaminating surface waters and ground water.



Top: **The eerie effects of windblown tailings near the former Mary Murphy Mine and Mill in Colorado.** ***Bottom Left:*** **Tailings and the remains of historic mine workings exhibit the characteristic reddish-brown color of iron oxide leaching.** ***Bottom Right:*** **Blocked by mine waste dumped in the stream channel, the flow in French Creek was reduced to ponding near the former Wellington-Oro Mine near Breckenridge, Colorado.**

Investigate, Investigate:

The Importance of Detective Work

The activities that created the mine workings, residual wastes, and other impacts to the environment at inactive and abandoned mine sites are generally poorly documented. Consequently, little or no useful information is available as the reclamation specialist steps onto the site to determine specific water quality impacts, their origins, and remediation strategies.

Since every mine site is unique, using "off-the-shelf" characterization strategies can lead to an improper or incomplete understanding. Remedial actions based on a partial picture of a site may overlook important contaminant sources or pathways, resulting in no improvement to water quality. With limited financial resources available to address mine sites, failure of remediation will only be tolerated to a limited extent.

Adequate resources and time must be dedicated to extensive site characterization before remedial activities are proposed and undertaken. Characterization includes five steps: 1) reconstructing pre-mining conditions, 2) inventorying what has been deposited above ground, 3) mapping what has occurred underground, 4) monitoring the movement of water, and 5) estimating the impacts of mining disturbances.

Far Left: **Gathering data on water from a mine pond.** ***Top Right:*** **Collecting ground water from a well for sampling purposes.** ***Bottom Right:*** **Water quality analysis can sometimes be performed on site, from the back of a truck equipped with laboratory equipment.**

Taking a Closer Look:

Two Colorado Mine Sites Shed Light on Future Cleanup Projects

Staff and managers involved in cleaning up mining-related sites have begun to realize that traditional site remediation can be tremendously expensive, running into the millions of dollars. There are simply not sufficient funds to approach every site that needs cleanup in the traditional manner. This realization led the teams working on Chalk Creek and French Gulch to look for more cost-effective ways to meet environmental goals.

To tackle the immense task of characterization at these two historic mine sites in Colorado, it was critical to have a team representing a diverse but complementary mix of expertise and experience. The teams working on these sites include geologists, mining engineers, hydrogeologists, biologists, water quality engineers, mined land specialists, and public relations specialists. The ability and willingness of these experts to work together was a definite factor in the current successes of the projects.

The map on page 8 shows the locations of the Chalk Creek and French Gulch sites.

Chalk Creek:

Getting Our Feet Wet

In 1986, the Colorado Division of Wildlife's Chalk Cliffs Fish Rearing Unit experienced widespread death among its fingerling trout. Located on the lower reaches of Chalk Creek, the unit uses water from the creek. This fish kill prompted the Colorado Department of Public Health and the Environment (CDPHE) to conduct water quality sampling along Chalk Creek. Results revealed elevated levels of zinc and cadmium. The highest concentrations of the metals occurred near the former Mary Murphy Mill site, upstream from the fish rearing unit.

Looking south from the top of Chrysolite Mountain toward the Chalk Creek site—a vast expanse of barren hillside covered by tailings.

In 1990, the Chalk Creek site was selected for Colorado's Nonpoint Source Program. The Division of Minerals and Geology (DMG) within Colorado's Department of Natural Resources took the initial lead in the cleanup. Other primary partners include CDPHE, EPA's Region 8, the U.S. Bureau of Mines, the Colorado Division of Wildlife, and private businesses and volunteer organizations.

Chalk Creek received high priority for remediation for two major reasons:

1) Its extreme level of impact to fish habitat in Chalk Creek.
2) Its contribution to water quality degradation in the Arkansas River.

Ground and Surface Water Investigations Used to Characterize the Site

In order to determine contaminant sources, the project team established a network of ground water monitoring wells at the site and surface water monitoring stations along Chalk Creek. Under an annual monitoring program, members of the team collected surface and ground water samples in spring, summer, and fall. These samples established baseline information for the area.

Initial water quality sampling and geophysical investigations identified three primary sources for metals and sediment loadings: 1) mill tailings piles, 2) discharge from a prominent adit (the Golf Tunnel), and 3) some unknown source.

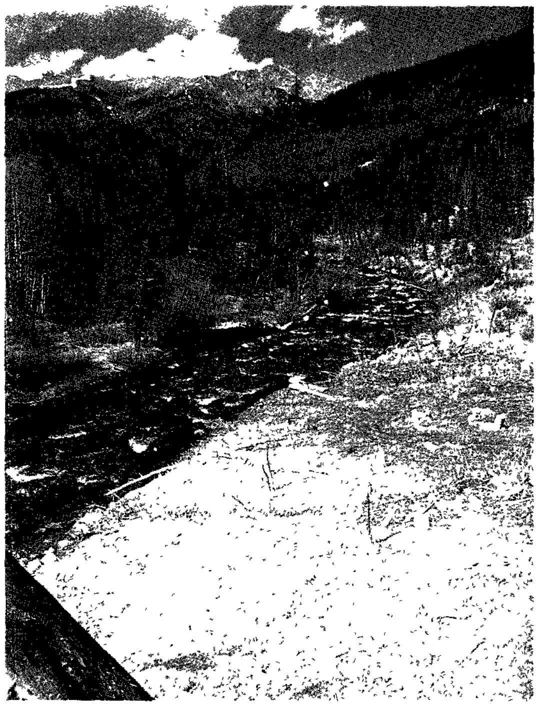
With this knowledge, the team established ambitious objectives for improving local water quality:

1) 50-100% reduction in metals and suspended sediment loadings.
2) Sufficient reductions in instream metal concentrations to allow an increase in salmonid abundance in South Chalk Creek.
3) Reduction of chronic metal stress to aquatic organisms in South Chalk Creek.
4) Elimination or significant reduction of acute lethality to fingerling trout at Chalk Cliffs Fish Rearing Unit.

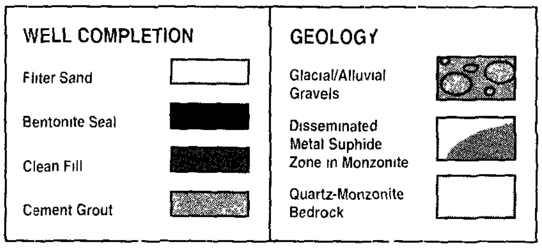
In order to address the determined sources of contamination, two major remedial activities were conducted during the summer and fall of 1991. First, five tailings piles were consolidated into one, and then covered with waste rock from the site to reduce the potential for further erosion. Second, the Golf Tunnel was unplugged, with drainage from the adit redirected through a settling pond.

Disappointing Results Underscore Importance of Full Characterization

Water quality in Chalk Creek did not improve after these remediation activities were completed. Why? Several possibilities exist. First, metals-laden ground water is suspected as a previously unidentified source of contamination. Remediation focused solely on surface water

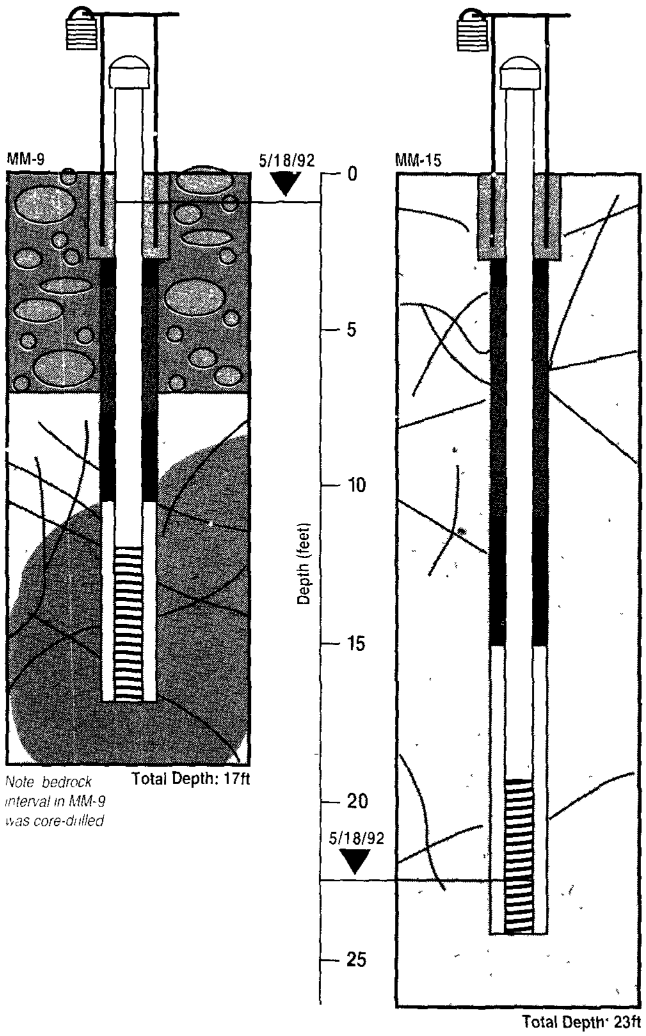


After a constructed wooden barrier deteriorated, tailings once retained by it drifted directly into Chalk Creek



GEOLOGY AND WELL COMPLETION DIAGRAMS

1992 Chalk Creek Drilling Project



sources. Second, metals from mine operations have been washing into Chalk Creek for more than 100 years. Regardless of remediation activities taken today, metals accumulated along the creek bottom could contribute to contamination for years to come.

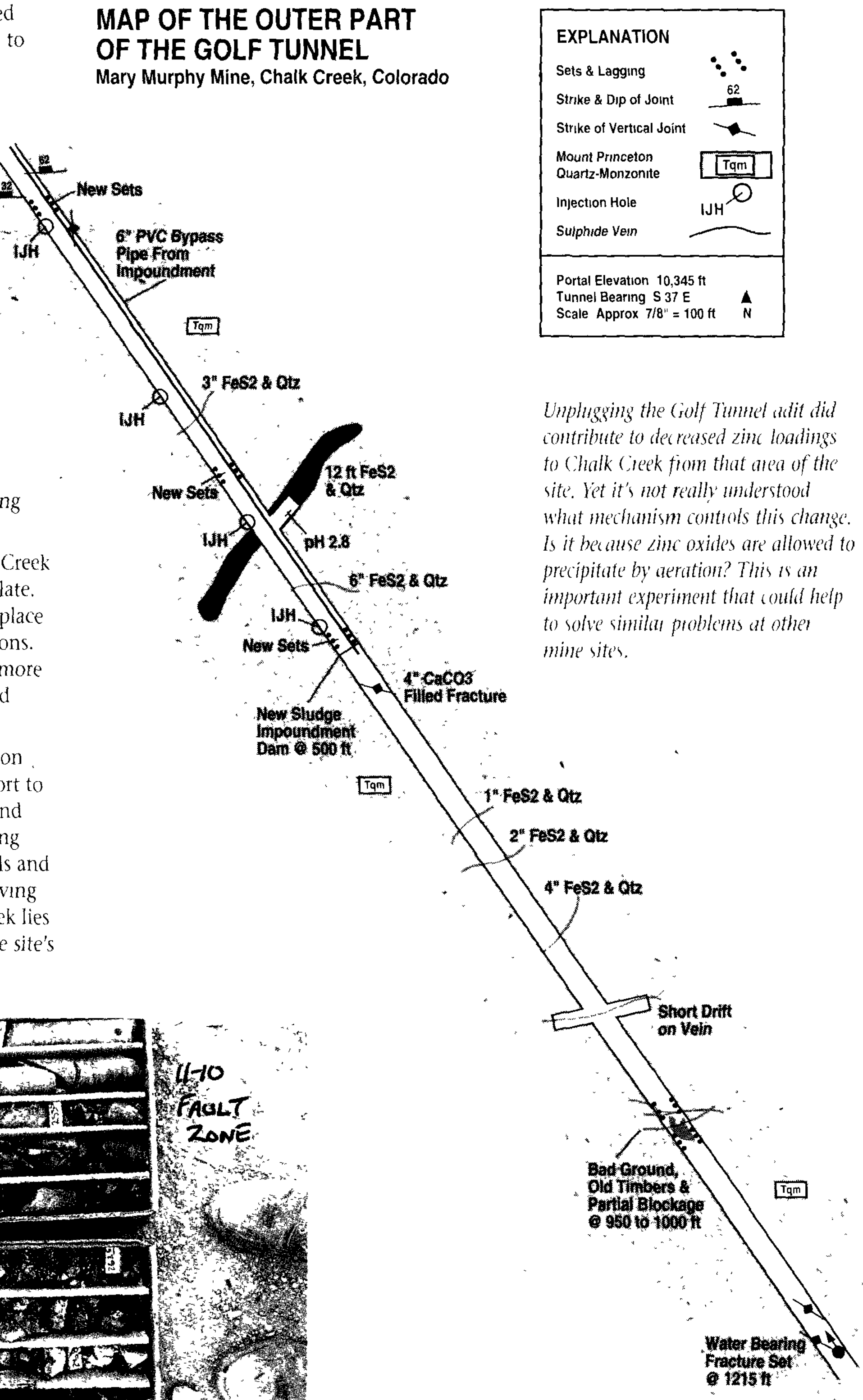
Continued problems of metals leaching may also be due in part to residual tailings left behind during the consolidation effort—these are now exposed to mobilization through leaching and erosion. Seeps were not taken into consideration when planning for the consolidation efforts. Nor were wetlands at the site properly studied prior to remediation decisions. Once hailed as natural passive water treatment systems, wetlands may act as metal sinks during the growing season only to release stored metals during fall and winter.

The major problem in the case of Chalk Creek is that characterization efforts came too late. The reclamation concept was already in place when the project team began investigations. In addition, the site proved to be much more complex than any of the participants had anticipated.

Future actions at Chalk Creek will focus on continued site characterization in an effort to better understand the pathways for ground water movement. This will include drilling additional ground water monitoring wells and conducting tracer studies. The key to solving the water quality problems at Chalk Creek lies in a more thorough understanding of the site's geochemistry and hydrology.

MAP OF THE OUTER PART OF THE GOLF TUNNEL

Mary Murphy Mine, Chalk Creek, Colorado



Unplugging the Golf Tunnel adit did contribute to decreased zinc loadings to Chalk Creek from that area of the site. Yet it's not really understood what mechanism controls this change. Is it because zinc oxides are allowed to precipitate by aeration? This is an important experiment that could help to solve similar problems at other mine sites.

Samples of core drilling taken from a fault zone at the French Gulch site. From top to bottom, notice how the rock becomes increasingly fractured.

French Gulch:

Implementing the Lessons Learned from Chalk Creek

Beginning high in the mountains, French Creek flows near the City of Breckenridge and into the Blue River through a prime tourist and recreation area. In 1989, concern over water quality in the area was raised when fingerling trout released into the Blue River downstream of French Creek died. The Colorado Department of Public Health and the Environment (CDPHE) conducted extensive water quality sampling in response to this fish kill.

Results showed acutely toxic conditions in a stretch of French Creek from the site of the Wellington-Oro Mine to the Blue River. Metals loadings have completely eliminated the trout population in this stretch of water, and have severely reduced trout populations in the Blue River for an undetermined distance.

These sampling studies determined the Wellington-Oro Mine to be the primary cause of water quality impacts to the French Creek and Blue River drainages. The French Gulch site was selected for the Colorado Nonpoint Source (NPS) program for three primary reasons:

1) Its significant impact on the Blue River trout population.
2) Its high public visibility.
3) Its negative economic impact on Summit County and Breckenridge.

The State of Colorado's Division of Minerals and Geology (DMG) assumed responsibility for implementation and management of the French Gulch NPS project. Other primary participants in the project include: CDPHE, EPA's Region 8, the U.S. Bureau of Mines, and Summit County. Initial objectives set in this case were less ambitious than for Chalk Creek. Rather than setting specific targets for remediation, these objectives remain broad and focus on characterization.

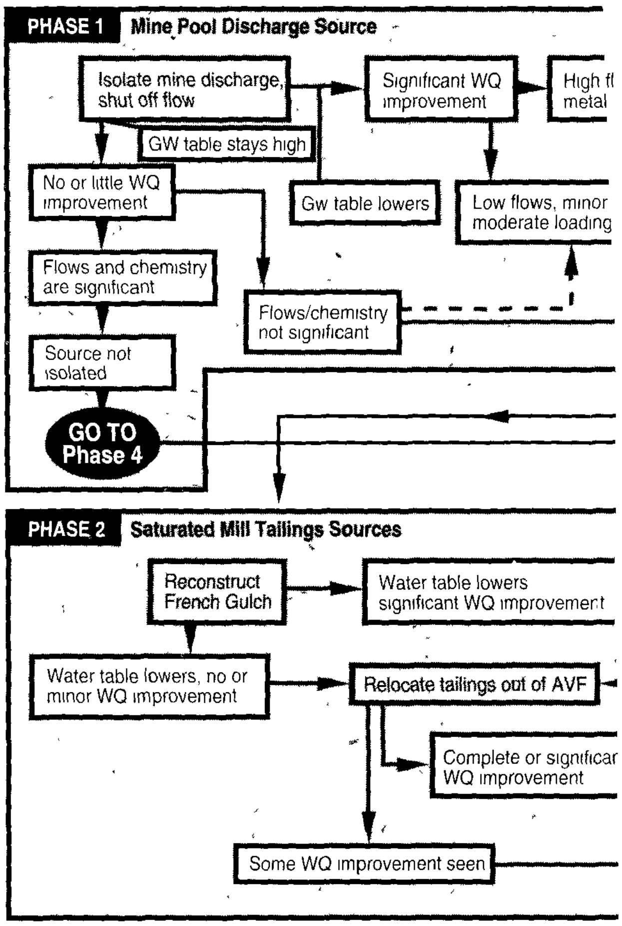
Objectives:

1) Establish baseline physical, chemical, and biological conditions (pre-remediation)
2) Identify primary toxic metals sources, transport, and fate through physical, chemical, and biological sampling.
3) Evaluate remedial alternatives for possible isolation, removal, containment, and treatment of priority sources.
4) Reduce heavy metals loading from the French Gulch project site to levels which would not produce acute or chronic toxicity to aquatic life in the Blue River.
5) Minimize contaminant loadings to the Blue River during project remediation activities.
6) Document the development and benefits of the French Gulch project and establish a long-term water quality and aquatic life monitoring and contingency plan that will assure design integrity of the French Gulch site area of the watershed

Early sampling at the French Gulch site revealed three primary sources of metals loadings:

1) Saturated tailings adjacent to the stream. Some tailings below the water table. Seepage from the tailings rust-colored.
2) Discharge of mine water through fractures in shale bedrock into the alluvium.
3) Runoff from roaster fines and mine waste rock piles exposed to normal precipitation. Extremely acidic pH levels measured in samples of runoff from these piles

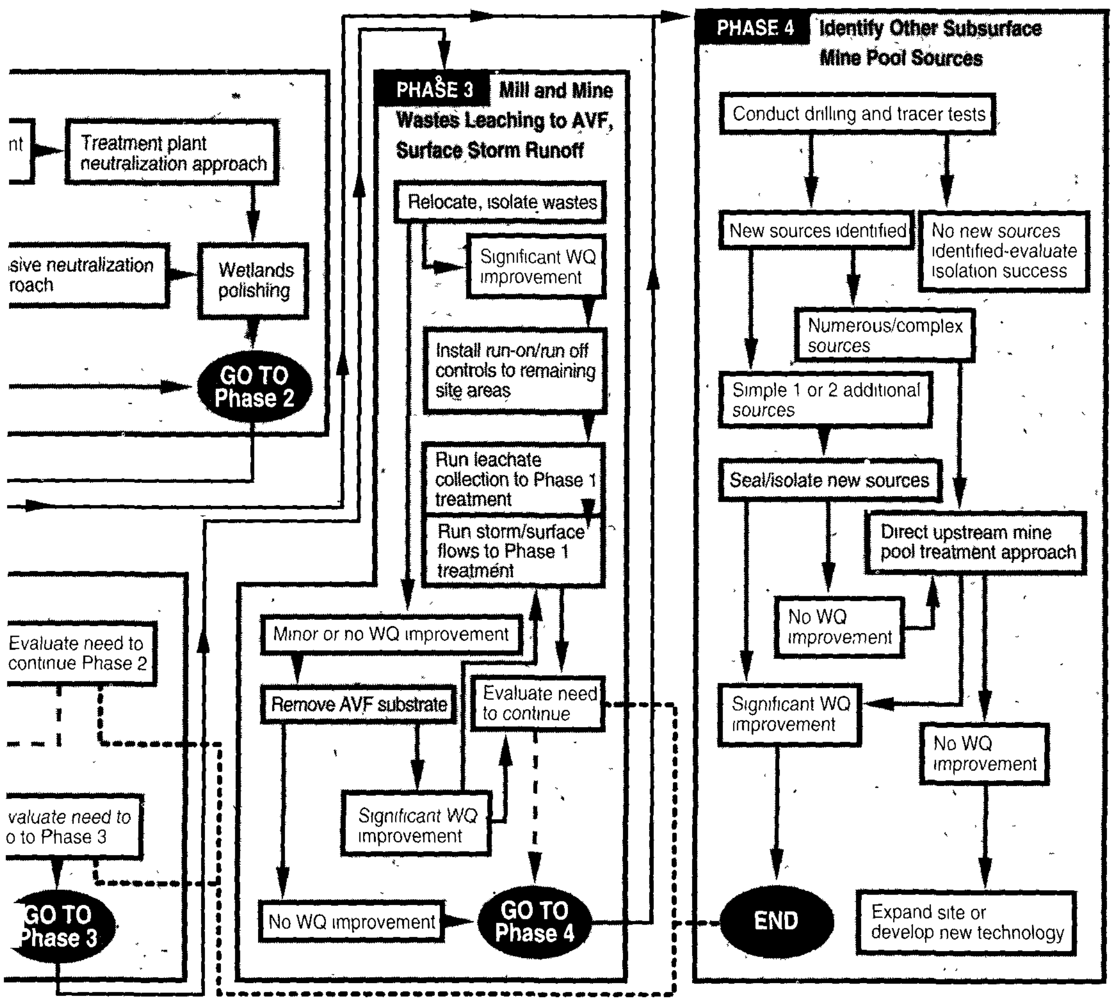
Further study of these sources led to several intensified characterization study actions



AVF=Alluvial Valley Floor GW= Ground Water WQ=Water Quality

Toxicity of dissolved metals in French Creek and the Blue River was evaluated using Ceriodaphnia in 48-hour acute toxicity tests. Little or no mortality was found upstream of the Wellington-Oro Mine site. From the site to French Creek's confluence with the Blue River, however, 100% mortality was observed. One mile downstream from the confluence, again no acute toxicity was found. The site team also conducted habitat testing using EPA's Rapid Bioassessment Protocols, with similar results. Biological tools such as these are proving tremendously useful at mine sites in testing hypotheses and establishing priorities for further study.

Grouting Shaft No. 3 at French Gulch



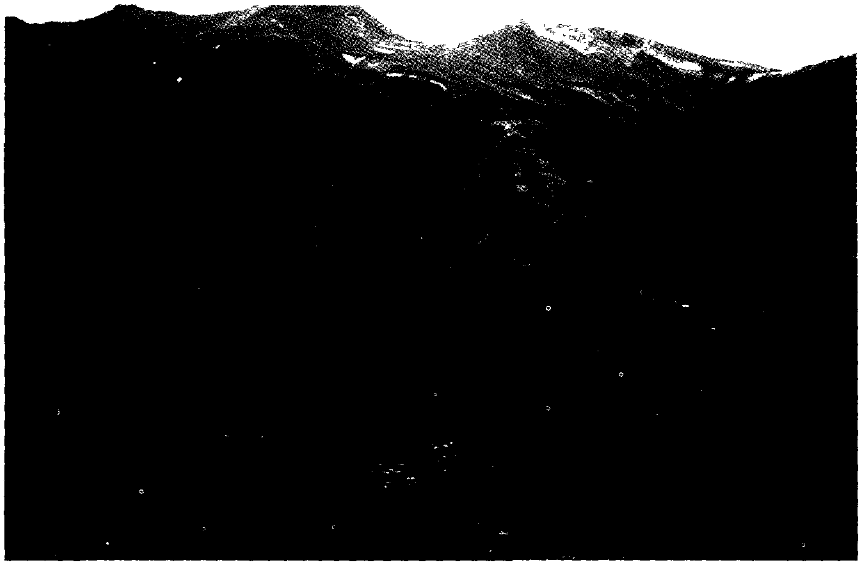
PHASED PROJECT APPROACH PLAN, FRENCH GULCH

Phased approach assumes each metals source is a significant contributor. (Best Management Practices alternatives are in shaded boxes.)

Characterization Efforts and Their Effects

During operation of the Wellington-Oro Mill, tailings were deposited directly into the French Creek drainage. Thus, the tailing disposal area became hydraulically connected to the alluvium and the flow in French Creek. Over the years, placer tailings and mine tailings effectively dammed the creek. In fact, placer dredge tails created artificially high water levels all around the mine site.

Efforts to restore the creek's flow by removing tailings from the stream bed succeeded in dropping water levels in the tailings, and seepage volume decreased. However, the elevation of the reconstructed French Creek drainage is still above the lowest level of tailings, and some tailings remain saturated. The ultimate effects of this remediation activity on water quality have not yet been determined.



The French Gulch site from a nearby ridgetop. Notice the ski runs of Breckenridge Ski Resort in the background.

A significant portion of the underground mine workings remains flooded. Because of the high water table, it was determined that this "mine pool" flows directly into the alluvium. The key to keeping contaminated mine pool water out of the creek lies in discovering this exact hydraulic connection, and then determining the best remediation method.

When members of the French Gulch team suspected Shaft No. 3 to be a problem, they developed a plan to seal the shaft. The objectives of this action were:

- To eliminate seepage of mine water into the alluvium.
- To better quantify and characterize the discharge from the mine pool.

Shaft No. 3 was grouted, and then a pipe was inserted to allow for drainage of mine pool water to the surface. The team also constructed a drainage ditch on the surface for collected mine water. However, the water level in Shaft No. 3 did not rise, meaning that this shaft is not the only pathway of mine pool water to the alluvium.

Further investigation revealed numerous hydraulic connections via fractures in the rock and highly-fractured, subsidence zones above the mine workings. The 11-10 fault, the largest in the area, extends from ground level through all levels of the mine, including those below the water table.

In order to address contamination from precipitation through roaster fines and mine waste rock, a plan was developed to encapsulate these waste piles. The encapsulation unit would be capped and lined, with a leachate collection and treatment system. Though planned and designed, this activity has been temporarily suspended until further data are gathered. Questions about whether to proceed include projected costs and the amount of metals loading that would ultimately be controlled by this action.

Future Characterization Activities

Continued work at the French Gulch site will focus on characterization. Planned activities include:

- Drilling additional ground water monitoring wells.
- Continuing ground water sampling and tracer studies.
- Mapping previously-undefined features.
- Conducting geophysical surveys.
- Sampling all waste piles.
- Undertaking further investigation of the 11-10 fault.

Several future remedial activities have been discussed and may be undertaken, depending on the outcome of the characterization efforts outlined above. These are:

- Recontouring the site with runoff directed to collection and necessary treatment.
- Leaving waste piles in place and managing runoff, and construction of a subsurface barrier.
- Returning waste rock to the mine.

Experience as Teacher

Probably the most important lesson learned from cleanup efforts at Chalk Creek and French Gulch is that characterization and remediation of mine sites are much more complex than imagined. The amount and level of scientific information needed to characterize a pathway (e.g., ground water flow to a stream) are magnitudes greater than had been expected—planned for, budgeted for, scheduled for. As a result, these projects have taken longer to understand and ultimately remediate than was originally thought.

Pressures for a Quick Fix Come from Many Directions

While cleanup of mine sites demands a thoughtful, step-by-step approach, a host of constraints can hinder this. Interested parties and the general public typically call for taking swift action to improve water quality. Yet sites like Chalk Creek and French Gulch are extremely complex. Observing and quantifying the impacts of contaminants may be quite straightforward, but determining exact pollutant sources is much more involved.

In addition to these obstacles, limited financial resources make extensive site characterization difficult. And decisions are often driven by funding sources available. The Nonpoint Source Program, for example, requires development and implementation of Best Management Practices to mitigate identified impacts. Unlike other types of nonpoint source projects, though, mine sites tend to require more complex solutions.

Down the Road: Tips for Other Mine Sites

- Metals accumulate in the topsoil or peat layer due to absorption by organics in these layers. Further characterization of the organic materials that are naturally-occurring on site (such as in wetlands or peat bogs) is necessary.
- Take care when recommending hydraulic controls (e.g., tunnel or adit pluggings) as a final site remedy. The evidence suggests that this type of solution is temporary at best. Instead, try to understand the hydrologic system at a site and deal with the water that is there.

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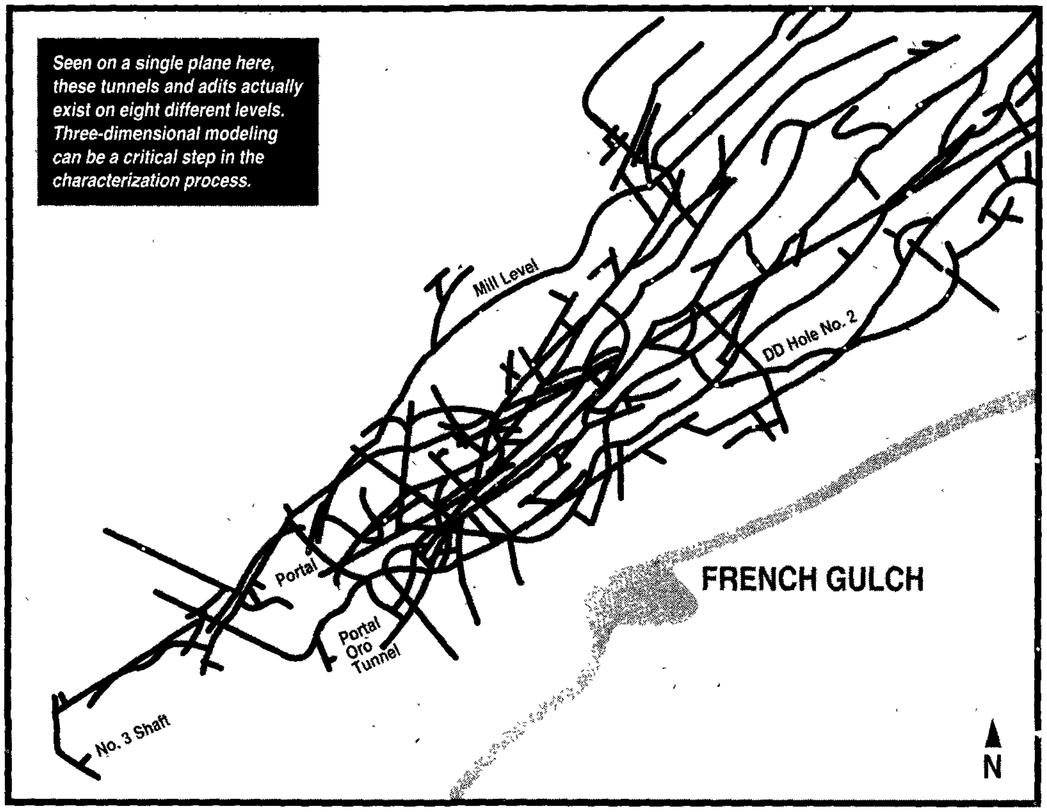
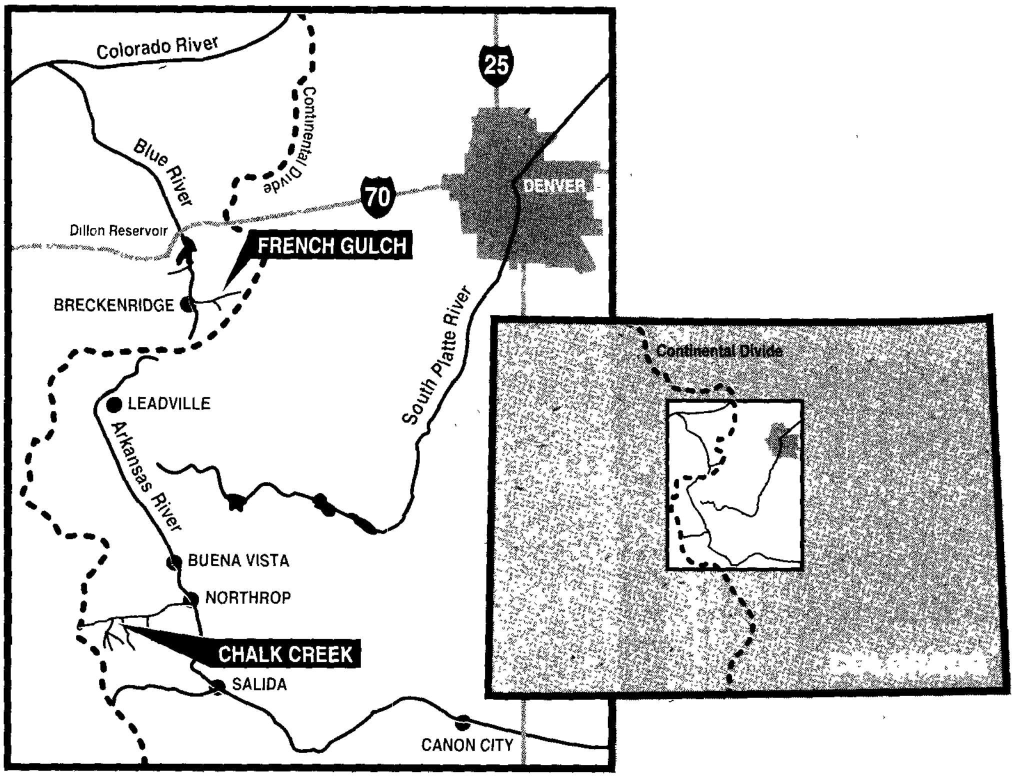
Knowledge Gained:
Chalk Creek and French Gulch as Practical Models

PARTIAL RECONSTRUCTION OF UNDERGROUND WORKINGS
Wellington-Oro Mine, French Gulch NPS Site, Colorado



Location of Study Sites
French Gulch and Chalk Creek, Colorado



(Tips continued from previous page)

- Governmental agencies need to learn to work together as a team. Pooling resources and expertise yields better results.
- At some sites, obvious point source discharges can be remediated. Bioreactors using sulfate-reducing bacteria substrates (SRB's) are showing some promise as one means of treating mine water discharges containing heavy metals at acid conditions. These treatment systems may need to be housed in structures to perform more optimally in harsh weather conditions.
- Site remediation should focus more on impacts to the aquatic ecosystem and less on other endpoints, such as human health impacts. If one understands the impacts that a site and remediation actions have on ecosystems and their sensitive aquatic life, then cleanup levels necessary to protect human health will usually be exceeded.

A Better Toolbox: What's Needed for More Effective Site Characterization and Remediation

- A standardized screening process (written methodology) that gives direction on how to characterize or assess sites. We need the right data to calculate an accurate metals balance.
- A committed leader. The person/agency in charge must have a commitment to seeing the project through, and be willing to ask for help when necessary.
- A team approach, with the right mix of the right people. No one person has the background or experience to understand all of the complex processes going on at abandoned mine sites.
- Personnel trained in the specifics of metals mining reclamation, including: water chemistry, ground water hydrogeology, stability of metals species, and metals mobilization.
- Institutional flexibility to approach mining sites somewhat experimentally.

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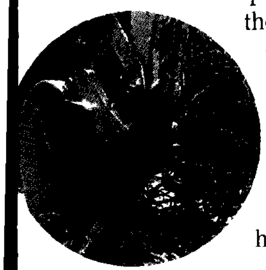
Chalk Creek and French Gulch:

Two Colorado Test Sites

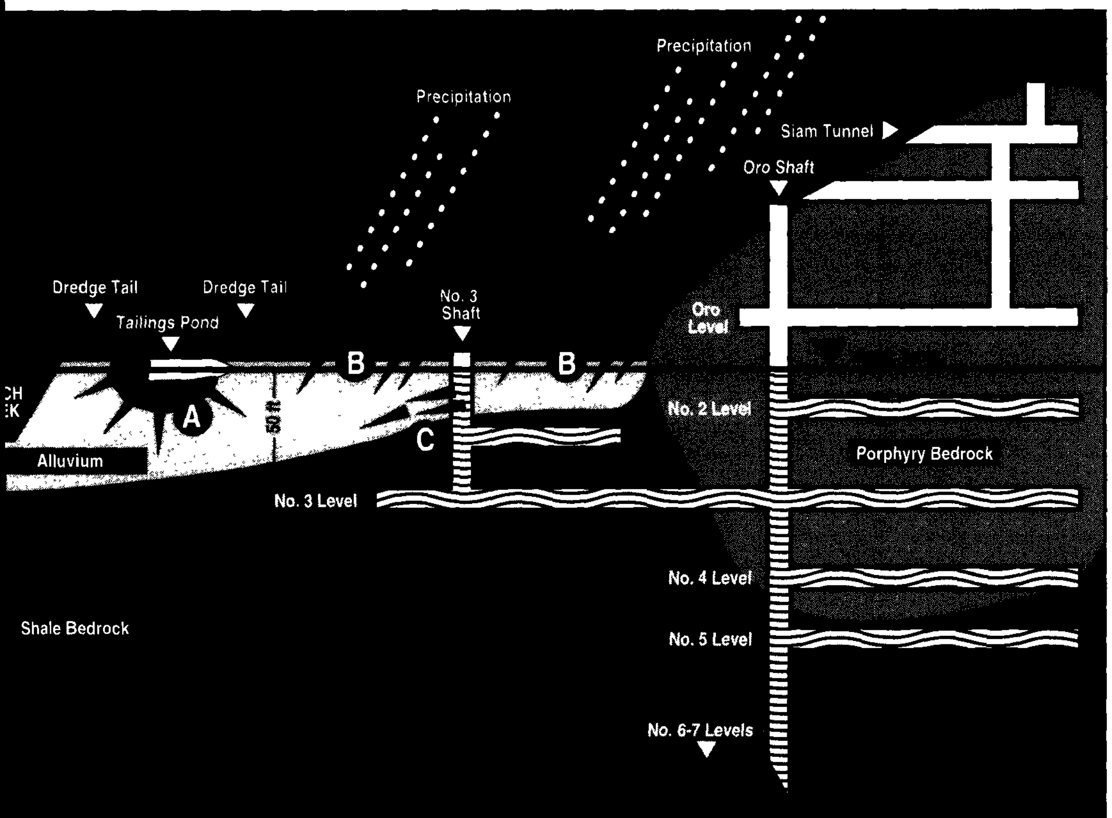
Chalk Creek and French Gulch are typical of the many inactive and abandoned mining and ore processing sites in the Rocky Mountain West. Neither site has produced the catastrophic environmental damage that might place it on the Superfund priority list. Yet from the perspective of the Colorado Department of Public Health and Environment, these two sites—like hundreds of others across the state—pose definite threats. As such, these sites were recognized as possible test cases for using experimental characterization techniques at mine sites.

To tackle the task of characterization at these two sites, specialists from several complementary disciplines came together to combine their expertise. The teams approached Chalk Creek and French Gulch with few preconceptions about the geologic, hydrologic, and physical systems operating at each site.



Water quality improvement goals at Chalk Creek and French Gulch have not yet been achieved. Yet these two sites have been extremely valuable laboratories for agencies and reclamation specialists involved in characterization and remediation efforts. Ongoing work will help to better understand and solve the impacts to water quality at the sites.

Far Right: **Water draining from a mine tunnel in the Chalk Creek area runs bright red with dissolved metals.**
Top Left: ***Just upstream from a fish hatchery intake gate, the stream bottom reveals the tell-tale whitish-gray coloring of tailings.*** ***Bottom Left:*** **A moonscape caused by mine tailings contrasts starkly with the natural alpine vegetation.**



Cross Section through French Gulch at Wellington-Oro Mine, High Flow Conditions

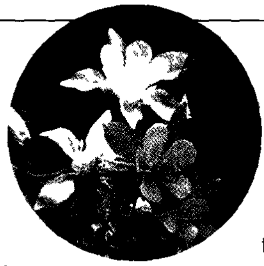
Potential Sources of Heavy Metals Contamination

- **A** **Mill tailings in alluvium, saturated by French Creek**
- **B** **Precipitation leaches metals from mine and mill waste to water table**
- **C** **Mine pool from Wellington-Oro complex drains to French Creek alluvium**

KEY

- **Alluvium**
- **Porphyry Bedrock**
- **Shale Bedrock**
- **Waste Rock**
- **Roaster Fines**
- **Dredge Tails**
- **Flooded Workings**
- **Precipitation**
- **Direction of Seepage**

Lessons Learned from Chalk Creek and French Gulch



■ Sites can be far more complex than they appear—hydrologically, geologically, and physically. Obvious metals sources may not be the only ones contributing to water quality problems.

■ Without appropriate levels of human resources and the ability to commit them in a concentrated effort, mine sites can take an extremely long time to characterize.

■ It is nearly impossible to plan work in advance because it's a "learn as you go" process.

■ After remediation activities, water quality may actually get worse before it gets better. Follow-up work is essential to achieve objectives.

■ Even with a total cleanup, it could take decades to see complete restoration of water quality at a site. Additional causes of contamination are likely to become apparent only after cleanup of obvious sources.

■ Securing funding for characterization work continues to be a challenge.

The Road Map:

Steps for Understanding Effective Site Characterization and Cleanup

■ Ask—and answer—the hard questions before beginning cleanup at any site.

1) Why should this site be cleaned up?
2) Will it make measurable differences in water quality to clean up the site and leave other nearby sources as they are?
3) How much time and money will the cleanup take?

■ When attempting cleanup of a mine site, pay attention to available technology, institutional commitment, and financial resources. Failure to manage any one of these could derail good effort in the others.

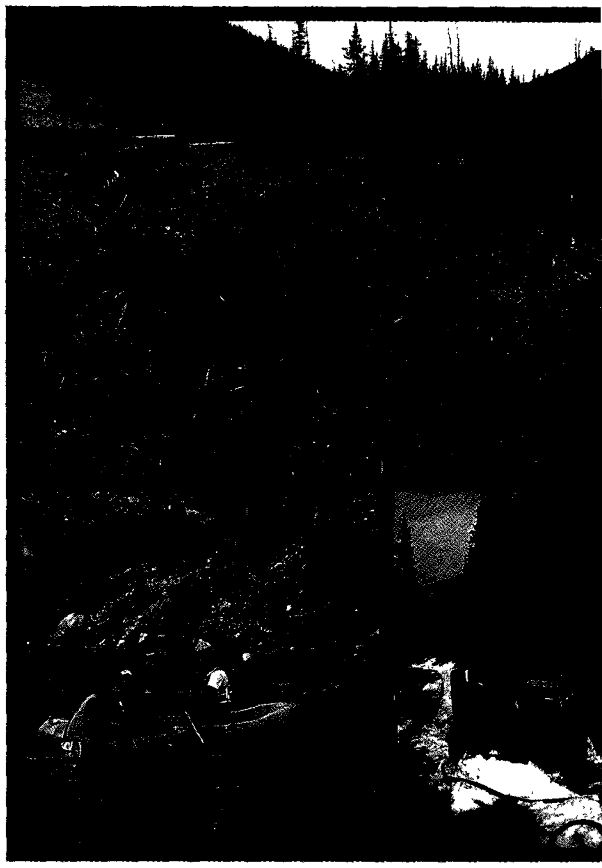
■ Set achievable goals and objectives. Remember: one size does not fit all.

■ Do a good job of analyzing the data collected. Use information on flows, concentrations, water levels, and contamination to forecast trends or see anomalies.

■ Follow up once surface reclamation is completed. Which techniques were successful? Which were not? Why?

"Using the tools currently available for use in mine site characterization feels like conducting an autopsy with a butter knife. We need more sophisticated, more reliable tools. Experience together with better tools is the winning combination."

Carol Russell
Environmental Scientist
Environmental Protection Agency, Region 8



Top: Revegetated wetland area, formerly covered by tailings and barren of any life. **Bottom Left:** Fly fishing and rafting on the Arkansas River in Colorado—reminders of why cleaning up abandoned mine sites is so important. Good water quality makes possible *many* uses of our Western streams. **Bottom Right:** Drilling a ground water well near the French Gulch site.

Into the Future

Initially, EPA and other agencies approached mine site investigations in a relatively simplistic manner. Experience has proven, however, that a minimalist approach does not provide the complete story. Reaching a thorough understanding of what causes water quality problems at a mine site can take significant resources, money, and time. Yet many people—from agency managers to the general public—continue to expect cheaper, quicker fixes than are possible to deliver. Solving problems related to mine sites must be considered a long-term effort.
In addition, the overall structure must allow for experimentation and learning. Instead of regarding an activity that doesn't work as a "failure," it must be seen as a valuable lesson to be transferred to other situations. An important tenet of the scientific process remains true: You don't always prove a theory by conducting experiments; rather, you disprove false hypotheses.

Many of the West's inactive and abandoned mine sites have been around for a hundred years or more. Five, ten, even twenty years of remediation efforts probably won't undo all the damage done. Nevertheless, it's important to remember why we continue to try: for clean water. If not today, then perhaps tomorrow.

Photographs by Paul Osborne, Mike Wireman, Colorado Division of Minerals and Geology, and ECOS Communications (Boulder, CO)
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COLORADO DEPARTMENT OF NATURAL RESOURCES

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