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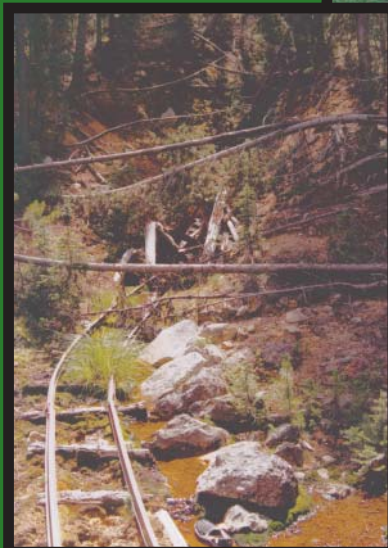
Forest Service

**Technology &
Development
Program**

7100 Engineering
August 2003
0371-2801-MTDC



Investigative Methods for Controlling Groundwater Flow to Underground Mine Workings



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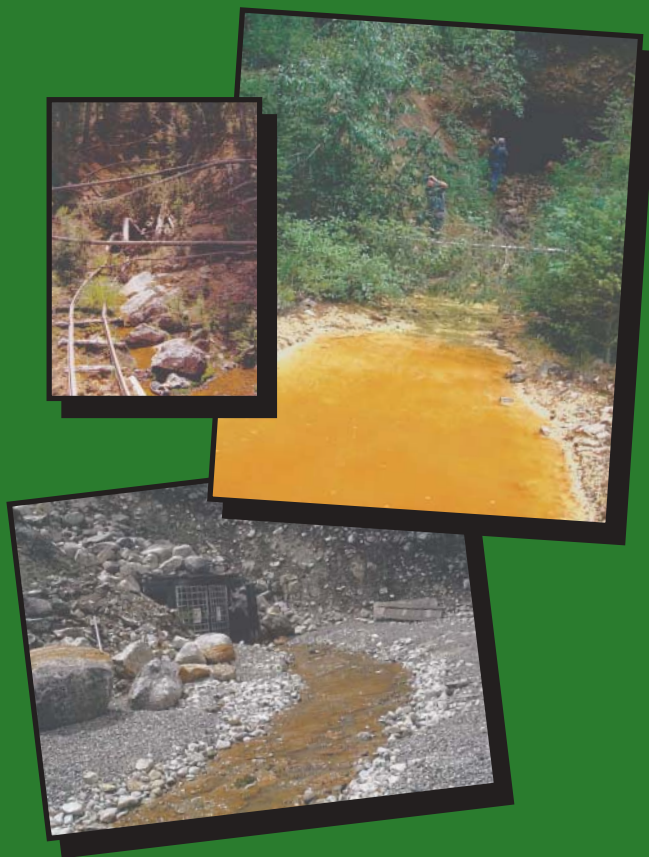
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Investigative Methods for Controlling Groundwater Flow

to Underground Mine Workings



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Introduction

In 1998, an adit discharge water-quality and quantity monitoring project began at the Elkhorn and Charter Oak Mines in Montana. These mines were chosen as representative of hard-rock mines with discharging adits (horizontal entrances) throughout the United States. Three reports have been published detailing the findings of this project:

- ✕ Adit Discharge Monitoring Summary for the Elkhorn and Charter Oak Mines, MT (0071–2858–MTDC)
- ✕ Using Recharge Control to Reduce Mine Adit Discharges: A Preliminary Investigation (0071–2804–MTDC)
- ✕ Treating Acid Mine Drainage From Abandoned Mines in Remote Areas (9871–2821–MTDC)

This report, the fourth in the series, discusses continued investigations at both sites showing how additional data from conventional resources available to USDA Forest Service staff can be used to help determine a specific recharge control method for a particular mine discharge.

Application of the various methods of controlling groundwater flow into mine workings requires knowledge of the source and pathways of the portion of the aquifer that is hydrologically connected to the mine. The following discussion is meant to provide an overview of the investigation. Information from several sources must be compiled to compose a conceptual model of the groundwater flow system near the mine. No one method will provide all the necessary information. The case-study portion of this report is divided into two sections: one for the Elkhorn Mine and the other for the Charter Oak Mine. Each section provides details of the methods that were used to investigate environmental problems at the mine.

Controlling groundwater recharge to the workings requires identifying, characterizing, and controlling surface water and

groundwater that may infiltrate mine workings. Good-quality water is diverted from the workings to prevent it from interacting with pyrite and metal-bearing minerals. Infiltration controls may include grouting from outside the workings, soil or stream-bed treatment to reduce infiltration capacity, storm water and runoff management, and recontouring or regrading natural recharge areas. This discussion explores methods for controlling groundwater flow into mine workings. Many of the methods should be applied to investigations of all three treatment categories: capture, treatment, and disposal; adit plugging or grouting; and controlling groundwater recharge to the mine workings.

Numerous investigations of mining sites throughout the Western United States have identified thousands of discharging mine adits. Many of these adits discharge poor-quality water that is created when groundwater circulates through the mine workings and interacts with mineral-rich rock exposed by mining. Many mines also contain abundant iron pyrite. Interaction of pyrite, oxygen, and water can produce

acidic waters quickly as the water circulates through the rock and mine workings. A pyrite content of only a few percent by volume can produce acid for hundreds or thousands of years. Other metal-bearing minerals dissolve in the acidic water, producing high concentrations of metals in the discharging waters.

Hargrave and others (2000) identified about 336 discharging adits in Montana based on work conducted by the Montana Bureau of Mines and Geology, the USDA Forest Service's Northern Region, and the Montana office of the U.S. Department of the Interior, Bureau of Land Management. Although the quality of the discharging water varied widely, nearly all discharges indicated elevated concentrations of metals. The rate of discharge from the adits ranged from less than 1 gallon per minute to more than 100 gallons per minute. However, the vast majority of the adits discharged water at a rate of 5 to 10 gallons per minute. This report will review methods of investigation for controlling groundwater flow to underground mine workings.



The acid mine discharge at one of the adits at the Charter Oak Mine southeast of Elliston, MT, in the Helena National Forest.

Groundwater Flow to Underground Mine Workings

Economic deposits of precious and base metals are found in a variety of geologic terranes (series of related rock formations). A region's geology strongly controls the emplacement and deposition of ores and the mechanism of transporting and depositing the ore-bearing fluids. Mining methods used to extract the ore reflect the nature of the deposit. Underground base- or precious-metal deposits are often found in veins formed when metals-rich hydrothermal fluids are injected along fractures or joints in the preexisting rock. Extracting the ore (rock mined at a profit) requires a shaft or adit for access and workings or tunnels to excavate the rock. During the active period of mining, groundwater is often encountered; the groundwater must be pumped or drained throughout the life of the mine. In the case of a mine that used an adit or shaft for access, drainage may occur long after mining has ended.

Mineralized and unmineralized discrete fractures, joint sets, and faults may control groundwater flow in and near the underground workings. The fractures' hydraulic conductivity (ability to transmit water) depends on factors such as the degree of alteration or weathering of the rock, the presence or absence of fault gouge, and the connectivity of the fractures. The type of host rock (rock surrounding the ore)—igneous intrusive, metamorphic, volcanic, or sedimentary—controls the density, orientation, and connectivity of fractures. The Boulder Batholith in Southwest Montana, for example, is an igneous intrusive rock hosting a variety of ore bodies. Vertical and horizontal joint sets and faults are common in both mineralized and unmineralized intrusive rock. Although nearly all of the batholith has been slightly altered by hydrothermal activity, intense

alteration is found near fractures, faults, and veins. More than 900 underground hard-rock mines have been active in the batholith during the past 140 years. Generally, the mines within the batholith range from small mines limited to small groups of veins with workings that extend only a few hundred feet to larger mines whose workings extend several thousand feet and produced several thousand tons of material. However, the Summit Valley mining district at Butte, MT, has hundreds of mines and thousands of miles of workings. Although groups of individual mines may exploit the larger vein systems, the mines are rarely connected by workings. Adit discharges from most of these mines are recharged from unmined host rock—the recharge area for the smaller mines is likely to be small. The discharge rate is often less than 10 gallons per minute.

Mitigation Methods

Mitigation of poor-quality adit discharges tends to fall into three general categories as described in Metesh, Jarrell, and Oravetz (1998):

- ✂ Capture, treatment, and disposal
- ✂ Adit plugging or grouting
- ✂ Controlling groundwater recharge to the mine workings

Treatment and indirect control of adit discharges have been investigated frequently. Metals-laden, acid discharge can continue for many decades, so these methods require a long-term commitment to year-round maintenance and monitoring. Because sites on lands administered by the Forest Service commonly do not have electrical power and have limited access, such treatment is especially difficult.

Adit plugging or grouting can be very effective in reducing or eliminating adit discharge. Often, the two methods are combined. Construction costs are considerable because the work is done within the mine workings. Grouting or plugging active mines nearing closure is often the best approach. Long-inactive mines may have to undergo extensive rehabilitation for safety and for proper application of the grouting or plugging.



Old mine working from the upper adit at the Elkhorn Mine and mill site near Wise River, MT.

Methods for Investigating Groundwater Source Areas

Applying the various methods of controlling groundwater flow into mine workings requires knowledge of the source and pathways of the portion of the aquifer hydrologically connected to the mine. The following discussion of methods is an overview of the investigation. No single method will provide all the information. Compiling information from several sources and integrating the information into a conceptual model of the groundwater flow system near the mine is necessary.

Hydrological and Geohydrological Methods

Water Balance

Changes in groundwater chemistry and flow paths induced by mine openings sometimes can be observed throughout the watershed—certainly within the vicinity of the mine. Several methods can help quantify these changes and develop a conceptual model of sources and pathways. Precisely measured, detailed seepage measurements of streams and springs near the mine may show a net loss that should approximate the adit's discharge rate. In addition to surface flows, precipitation throughout the watershed and measured or estimated evapotranspiration are used to determine the overall water balance.

Age Dating of Springs

The age of a given volume of groundwater is the time that has elapsed since the water infiltrated the ground surface to become part of the groundwater flow system. The age is related to how far and how deeply the water has traveled. Determining the age of a given volume of groundwater, along with the hydraulic characteristics of the aquifer, will provide a means of locating the recharge source for that groundwater.

Tritium (^3H) is a radioactive isotope of hydrogen that has a half-life of 12.45 years in the atmosphere. Nearly all of the

tritium in the atmosphere and water worldwide is a result of aboveground nuclear weapons testing that began in the 1950s. Atmospheric tritium levels in rainwater before the 1950s have been estimated to be 5 to 10 tritium units. The level increased to over 1,000 tritium units in the United States during the peak of testing in 1963 and has since declined to less than 100 tritium units. Tritium is unaffected by chemical reactions, and sources other than nuclear weapons are rare. The decay process essentially stops when the tritiated water leaves the atmosphere and enters the groundwater. These qualities make tritium particularly useful in determining the age of groundwater. The concentration of tritium in a sample of groundwater can be compared to the historic concentrations of tritium in rainwater. Using tritium as a tracer, the age of groundwater can be estimated with a precision of a few years.

One of the decay products of tritium is helium-3 (^3He), a stable, inert isotope. In the atmosphere, ^3He escapes and does not accumulate. In groundwater, ^3He accumulates and is referred to as excess ^3He . The ratio of tritium and the excess ^3He can be used to determine the time elapsed since the groundwater was in contact with the atmosphere (Poreda, Cerling, and Solomon 1988) with a precision of a few weeks to a few months. This technique is particularly useful in determining the age of groundwater in shallow-flow systems. Helium-tritium age dating has been used in conjunction with other information related to the aquifer when identifying recharge areas.

In addition to helium and tritium, other isotopes can be used for dating, including anthropogenic chlorofluorocarbons, oxygen (^{16}O and ^{18}O) and deuterium (^2H). Kendall and McDonnell (1998) have compiled investigative methods used in catchment studies.

Tracer Tests

Tracer studies have been applied at the watershed scale to estimate metals loading from various contaminant sources (for one example, see Kimball and others 1994). In general, a chemical unique to the local environment is introduced to sur-

face water or groundwater. Streams and wells are monitored to determine when and where the tracer travels. Choices for the tracer include bromide (usually sodium bromide or potassium bromide), fluorescent dyes, and isotopes. Tracer tests are used commonly, but the failure rate is quite high. Reasons for failure vary, but often tracer studies are begun without sufficient knowledge of the fracture density, fracture orientation, and so forth. Tracer studies should be applied toward the end of the overall investigation rather than during an initial investigation, as is often the case.

Water Quality

"Natural" tracers associated with unmined host rock and acid rock drainage may be used to define flow paths in and around the mine. This method requires rather specific information on the mineralogy of the ore, gangue minerals (waste rock), alteration and weathering products, and the host rock. If available, detailed sampling and analysis of waters inside and outside the mine's suspected zone of influence can produce information. In areas where there are many rock types, each rock type often is fingerprinted by its water chemistry. Computer-based geochemical equilibrium modeling programs can be used to estimate concentrations based on mineralogy, and to define water quality resulting from the mixing of two waters (such as host-rock water and acid rock drainage). For example, a model could be based on the chemistry of the adit discharge and the mineralogy of the ore body to help define the "required" chemistry and relative quantities of the different waters flowing into the mine.

Drilling

Often, the type of drilling required to develop a thorough understanding of the groundwater system near a mine opening is used in the final phase of an investigation when grouting is being considered. Drilling targets should be based on other less intrusive and less expensive methods. A thorough discussion of the many drilling methods, tools, and strategies is beyond the scope of this paper. Mobilization, road

building, and the logistics of any type of drilling are expensive and often are reserved for larger, more complex mine sites. Core drilling to determine such parameters as fracture density, orientation, and hydraulic conductivity can add to the expense.

Soils and Vegetation Methods

Remote Sensing, Photo Interpretation, and Field Mapping

Remote sensing provides a relatively inexpensive, efficient process for mapping hydrologic features of the landscape. Remote sensing often relies on images obtained by a low- to moderately high-elevation aircraft flight or by satellites.

Image Scale—Various scales of imaging are available with fixed-wing flights, ranging from large scale (for example, 1:2,000) to fairly small scale (for example, 1:63,000).

The larger the scale, the more detail that can be extracted from the images, assuming that high-quality equipment and imaging techniques are used. However, costs generally increase as the scale of imaging increases. Because wetlands and riparian areas associated with groundwater sources to mine workings are often quite small, large-scale images will improve mapping accuracy. Generally, an image scale of 1:3,000 to 1:7,000 is adequate for delineating small areas.

Smaller scale images such as 1:16,000 to 1:24,000 are still quite useful for mapping wetlands and riparian areas. However, images at scales greater than about 1:50,000 provide only marginally useful detail for the needs discussed in this paper.

Satellite imaging such as the *Landsat* and the French *SPOT* series provide various image scales, along with a variety of

spectral capabilities that can be quite useful for mapping wetland and riparian areas at a coarse scale. The ability to discern small wet areas depends on the electronic resolution associated with the image. Applicable *Landsat* bands for vegetation mapping have 30-meter pixel resolution, while the *SPOT* black-and-white panchromatic band has 10-meter resolution and the color bands have 20-meter resolution. *Landsat* image resolution may not be adequate for locating small areas related to the recharge of mine workings.

Other innovative remote-sensing methods include using hand-held or video cameras to record landscape features during overflights in small, fixed-wing aircraft and helicopters. Distortion, relatively poor image quality, and difficulty orienting images make these methods less desirable as a primary mapping resource. However, they can be useful when interpreting other remotely sensed images.

Another similar—but less expensive—method is to photograph or videotape from various fixed points on the landscape, preferably high-elevation, open areas, such as peaks. Even though heavy forest cover and intervening ridges may obstruct the view of some areas, these photos can be used to improve understanding of other images and maps. Tripod-mounted cameras can provide excellent image quality, but georeferencing the images is difficult.

Imagery—A popular type of imaging is conventional color film in a large-format mounted camera, such as the 1:16,000 resource photos used by the Forest Service. These photo sets also allow stereo viewing, which is especially helpful when the image is magnified using a stereoscope. The three-dimensional (3-d) image shows the relief of the land and allows interpretation of landforms, an important part of identifying wetlands and riparian areas. These resource photos are readily available, are fairly inexpensive for small assessment areas, and are reimaged about every 5 years by the Forest Service. Image quality is excellent.

False-color infrared photography is even better for mapping wetlands and riparian areas. The photos are similar to the resource photos and can be viewed as 3-d images. The colors of the printed image are drastically different from those the eye sees when viewing the landscape. This is difficult for some viewers to get used to, but for an experienced mapper, the information is much improved over conventional color photos. These false-color infrared images are especially useful for locating vegetation associated with wet areas, such as wetlands and riparian areas.

Because of the spectral sensitivity of the film in the very near infrared portion of the electromagnetic spectrum, vegetation that is well supplied with water, such as vegetation growing in wet areas, shows up as brilliant red on the print. This is especially true for the wet-site deciduous trees and shrubs, as well as forbs and grasses.

Vegetation growing in relatively dry soil and unhealthy, diseased vegetation reflects very little of the red wavelengths and shows up as gray to grayish pink. Experience is required to properly interpret these photos, because healthy vegetation on upland, well-drained sites may also appear quite red on the photo. Viewing in 3-d helps interpret these images properly.

Both the color and the false-color photo series contain significant distortion, particularly toward the edges of the photo. Wetlands and riparian areas can be delineated on these photos, but for project planning and implementation, the delineations are best transferred to a georeferenced, distortion-free image. Orthophotos provide such a base-photo series. They are available in the same size, scale, and coverage as the U.S. Geological Survey 1:24,000 topographic maps. Perennial and intermittent streams, as well as topographic contour lines, can (and should) be added to these orthophotos. The combination of a distortion-free, georeferenced photo image and contour

lines is a very powerful mapping tool. These images also serve as useful field tool, especially when combined with global positioning system (GPS) capabilities.

The Landsat satellite images are available in a variety of spectral bands, including very near infrared, which is useful for identifying vegetation associated with wet areas. Black-and-white photography has limited application for mapping wetlands and riparian areas. If the only available images are black and white, a well-trained mapper can do fairly well with these images, preferably using good-quality stereo pairs.

Compiling the pertinent spatial information narrows the geographic area that may be contributing water to mine workings. This compilation can include delineating the surface watershed boundary and circumscribing lands at elevations higher than the mine portal, both within and adjacent to the watershed. Local knowledge of groundwater pathways and bedrock permeability, as well as time and budget constraints, are factors that may determine the geographic limits of the area where wetlands and riparian zones are mapped.

If color or false-color infrared stereo photos are available, they should be used to delineate areas that are likely to be wetlands or riparian areas. At this point, it would be helpful to adapt an existing wetland and riparian area classification system (see *Soil and Wetlands Interpretation* in the *References* section). These choices include classification based on potential natural vegetation (plant associations), existing vegetation (community types and riparian-dominance types), hydrogeomorphic features and functions (U.S. Army Corps of Engineers), and on various combinations of hydrologic systems, soils, and vegetation types (U.S. Fish and Wildlife Service's wetlands classification and the U.S. Army Corps of Engineers' *Wetlands Delineation Manual*). The U.S. Fish and Wildlife Service's *Classification of Wetlands and Deepwater Habitats of the United States* is especially useful. This classification is hierarchical, allowing the user to select the appropriate level or rank that works best for the project.



Acid mine discharge from the lower adit at the Elkhorn Mine.

The more detailed levels of classification allow a better understanding of the hydrologic regime. The Corps of Engineers' manual is not a classification system, but it does present a well-recognized system for identifying jurisdictional wetlands.

Both polygons and line segments may be needed to delineate the wet areas; polygons are most appropriate when the area is large enough to circumscribe at the mapping scale being used. Line segments are appropriate for long, narrow areas, such as along minor streams. These delineations can be transferred to a field map, such as an orthophoto with contours and streams, by referring to common landscape features in the stereo photos and the orthophotos. Map symbols for the various classification units that reflect the classification hierarchy should be developed. Human-caused sources of water,

such as irrigation and drainage ditches, stock ponds or other impoundments, and mine portals should also be located and mapped. Both the stereo photos (preferably large scale) and the orthophotos are useful field references for locating wet areas on the ground and for choosing sampling sites.

Field Investigations for Soil and Vegetative Mapping

Some field time should be devoted to correlate remotely sensed image features with on-the-ground data. Remotely sensed data is often quite good, but is incomplete by itself. Depending on the landscape and the particular needs of the project, field study may become a major part of the identification of wetlands and riparian areas. Fieldwork can greatly improve the accuracy of remotely sensed delineations. Fieldwork is also needed to understand

the relationships of wet areas to hydrologic features, flow paths, and patterns. Field documentation is required to understand water discharge, recharge, and storage.

Once the mapped delineations have been classified as categories of wetland and riparian types, the field sampling strategy can be developed. The classification and mapping can reduce the amount of field documentation needed to verify the mapped delineations and to characterize their hydrology, soils, and vegetation. Based on the degree of confidence needed in the mapped delineations, as well as the time and money available for fieldwork, delineations representative of the classified map units may be selected for field study. In other situations, the needs of the study may require that every delineation be field checked.

The following is a suggested methodology for field investigations that should produce the data needed to characterize the wetland and riparian area map units for mine workings recharge studies. The specific needs of the map user should determine how much field data to collect.

Traverse representative portions of the mapped polygon or line segment, noting the various landforms and positions on landforms. Streams commonly have a low, active, poorly drained floodplain and a higher, older, better drained stream terrace. Slumps may have a shallow, ponded basin near the base of the head scarp with poorly drained slide debris below. These different topographic features should be characterized individually as follows.

Topographic Features

Site Features and Supplementary Information

- Slope.
- Aspect.
- Elevation.
- UTM or latitude/longitude coordinates (using GPS, if available).
- Date.
- Resource or other photo source number.
- Name of orthophoto.
- Examiner name or initials.
- Standard or digital photos of site (record image number).

Hydrologic Features

- Stream size (visual estimates of width and depth may be adequate).
- Estimates of stream flow in cubic feet per second.
- Changes in flow along stream length.
- Depth of ponded surface water.
- pH (as needed).
- Reduction-oxidation potential (as needed).

Vegetation

- Identify and record at least those plant species that dominate the various tree, shrub, and grass/forb layers. If possible, identify plants to the species, rather than to the genus or family. Species can be compared to lists of wetland indicator plants, such as the *National List of Plant Species that Occur in Wetlands: 1988 National Summary*, by the U.S. Fish and Wildlife Service. The plant species can be related to their affinity to wet areas. If plants cannot be identified to the species level, record the plant's genus, or its life form, such as tree, shrub, graminoid, or forb.
- Estimate and record the canopy cover for each species, genus, or life form. Cover estimates can be expressed as percentages, or as classes such as few, common, abundant, and so forth.
- Classify the vegetation using climax plant associations, dominance types, or community types as desired (see *References*).

Soils

For the dominant vegetation classes of a given landform or landform position, describe the major features of the upper portion of the soil profile. Initially, to develop correlations between landforms, vegetation, and the soil taxa or soil moisture regime, the upper 30 to 40 inches of soil should be described. Once the correlation of landscape features, soil drainage, and permeability is better understood, the soil may need to be characterized only for the upper 12 to 24 inches. Descriptions of the soil profile should include:

- Recognized designators and thickness of major organic and mineral soil horizons (U.S. Department of Agriculture, Natural Resources Conservation Service, *Soil Survey manual* 1993).
- Soil texture, including modifiers such as rock fragments, and mucky or ashy soil.
- Moist matrix color using standard Munsell color charts.
- Redoximorphic features, noting abundance, size, and Munsell color (see *References*).
- Depth to freestanding water (water table).
- Depth to saturated soil.
- Soil moisture condition (as needed: dry, moist, wet).
- pH (as needed).
- Reduction-oxidation potential (as needed).

Geoscientific Methods

Geoscientific methods use existing information, which can usually be obtained at low cost. Some historical information, such as underground mine maps of collapsed mines, could not be gathered today.

Literature Review

Before going into the field, review the literature. The amount of geologic information about a particular area may vary greatly. Some mines with a great deal of development were never documented—neither in published materials nor in proprietary, unpublished materials. Other highly speculative properties may have numerous reports written on them, but with embellished information. Mine maps are a great asset when they are available, but the level of detail varies greatly from mine to mine. Some maps include notes detailing where water was encountered. Other geologists only sketched in major structures and rock types.

Aerial Photography in Relation to Fracture and Structural Studies

Many of the techniques applied to soil and wetland delineation also apply to structural and geologic mapping. Aerial photo interpretation before and during field mapping can help analysts interpret geologic features that may control the flow of groundwater. Geologic features that may be differentiated through aerial photos include lithologic changes such as alluvial rather than bedrock substrate, intrusive

rather than sedimentary rocks, or well-jointed rather than unfractured formations. Recent landforms such as landslides may control, or be controlled by, groundwater and are usually easy to discern on aerial photos. Interpretation includes studying vegetation differences, lineations, locations of seeps, and rock types.

Aerial photos are relatively inexpensive and are available in a variety of scales. Aerial photos have been taken for the past 50 years, allowing changes to be documented over time (Sciacca and Ault 1993). Because most aerial photos date from the 1950s and later, older mine activity may not be documented.

The scale of most publicly available aerial photos ranges from 1:62,500 to 1:15,000. You may have to arrange your own flights to get larger scale photos, but they will show more detail. Orthophotographs (a compilation of aerial photos that have the qualities and position of maps) can be used to plot features seen in stereographic projections.

Factors to consider in photo interpretation include tone, texture, and pattern. Tone is related to the amount of light reflected by an object. It is influenced by the location of the sun, the amount of haze, the latitude (and the time of year), the sensitivity of the film used, the camera filters used, and the type of image processing. Texture is a tonal change within the image produced by an aggregate of unit features too small to be resolved or distinguished individually. Texture may also be a function of the drainage density. Pattern is an orderly

spatial arrangement of geologic, topographic, and vegetation features. Patterns may be a result of faults, joints, dikes, or bedding. Faults tend to be single and more striking or intense when they have more offset. Joints are more numerous and less intense.

Lineations caused by fracturing and faults may be evidenced by the locations of springs, angular drainage patterns (especially with abrupt directional changes), changes in the type and health of vegetation, and unexplained changes in soil color and texture. Joint patterns in rocks can be observed on some aerial photos, especially in granitic terranes. Aerial photos are not perfect tools. In heavily vegetated areas, vegetation may mask lineation produced by fracturing of bedrock.

Aerial views may show the presence of highly permeable surface materials or show vegetation growth that indicates the presence of water. To some degree, the amount of plant material may be used in the water-budget calculations of transpiration in an area.

Sometimes the recharge area is so extensive that flow will be unaffected by plugging, grouting, or other local control measures. Large geologic structures sometimes can be discerned from aerial photographs, even when they are not recognizable from the ground. Drainage patterns and, more specifically, their offsets, often reveal fault traces. Other subtle differences in tone, texture, or patterns may reveal geologic differences.

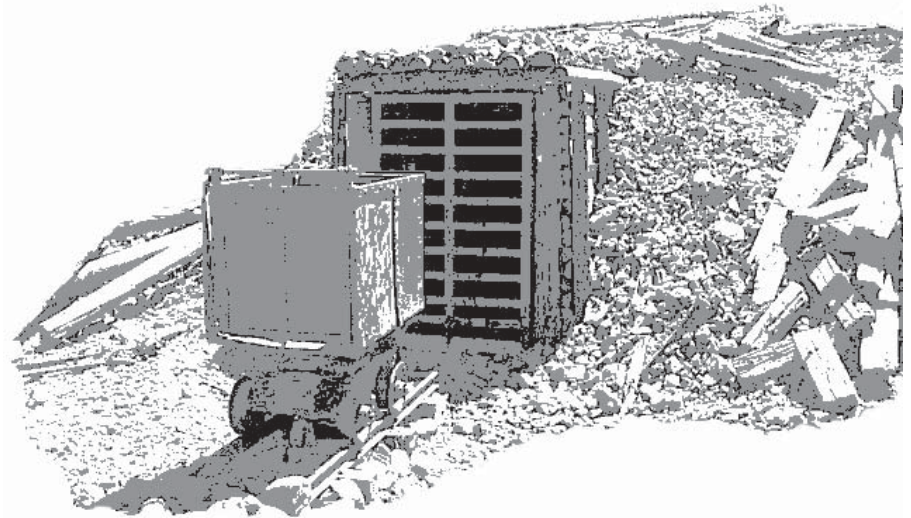
Field Mapping

Field reconnaissance and detailed mapping are also an important part of a regional interpretation. They are used to ground truth the interpretation from aerial photographs and to add details that are not evident from even the largest scale (and most detailed) aerial photographs.

Field mapping is essential to discovering the sources of discharge and recharge in mine areas. Underground mine mapping is one method of gathering data for adit discharge control. Ideally, the sources of water would be mapped while the mine is still open. Although rare, opportunities do exist in active operations. Examples would be the recently inactive TVX Gold, Inc., Mineral Hill Mine in Jardine, MT. A large quantity of water was encountered in the crosscut driven to the Crevasse deposit in 1997. Individual fractures and faults could be recognized easily and mapped as discharging the majority of the water.

Abandoned workings of varying ages are sometimes accessible if properly trained personnel can enter them. Recent U.S. Geological Survey wilderness mineral resource study reports contain maps produced while the study was underway, even though the mines had been abandoned for years (Stotelmeyer and others 1983).

A third possibility would be to rehabilitate mine workings that have caved in or become unsafe. Although costly (often cost prohibitive), the information gleaned



from such an exercise would be invaluable in planning mine reclamation and, later, in the actual process of adit plugging, grouting, or implementing another method for controlling adit discharge.

Geophysics

Consider using a geophysical program to locate fractures and the water they may carry. Various electrical methods may help identify voids created by mining and the presence of water in fractures and mine workings. This option would be preferred to amass more detail where fractures are the primary water conduits. Bither and Tolman (1993) found that a combination of aerial photo interpretation and geophysics (specifically, very low-frequency electromagnetics or terrain conductivity) were useful in locating the preferred sites

for drilling water wells. Well yields were greater when the two methods were combined than when fracture-trace studies based on aerial photo interpretation alone were used. This combination of methods may be useful in discharge and recharge studies.

Ground-penetrating radar may help detect voids left by mining that may be filled with water, so long as the voids are not more than 100 feet underground. Ground-penetrating radar can provide a cross section of soils and subsurface features by measuring transmitted energy reflected by differing medias and buried objects. Steep and uneven terrain provides a physical challenge for the implementation of surface geophysics.

Case Studies

Two sites in southwestern Montana were selected for investigation using basic information and personnel whose expertise is commonly available to most national forest ranger districts. The three areas of investigation for the case studies were hydrology and hydrogeology, soil and vegetation, and geology. The sites were chosen because both had existing water quality data, they differed

in their geologic setting, and they represented a range in the size of the mine and the quantity of adit discharge. The emphasis in both case studies was to use existing information and moderate-level field reconnaissance to understand the nature and extent of the adit-discharge problem. The objective of the studies was to apply basic information and evaluate the potential for source controls to reduce the adit discharge.

The Elkhorn Mine and Mining District

Introduction

The Elkhorn mining district is on patented and unpatented mining claims and on land administered by the Beaverhead-Deerlodge National Forest in T. 4 S., R. 12 W., sec. 14 (tracts AADD), and sec. 11 (tracts DDDDB) near the ghost town of Coolidge, MT (figure 1). The lower (or 1,000-foot-

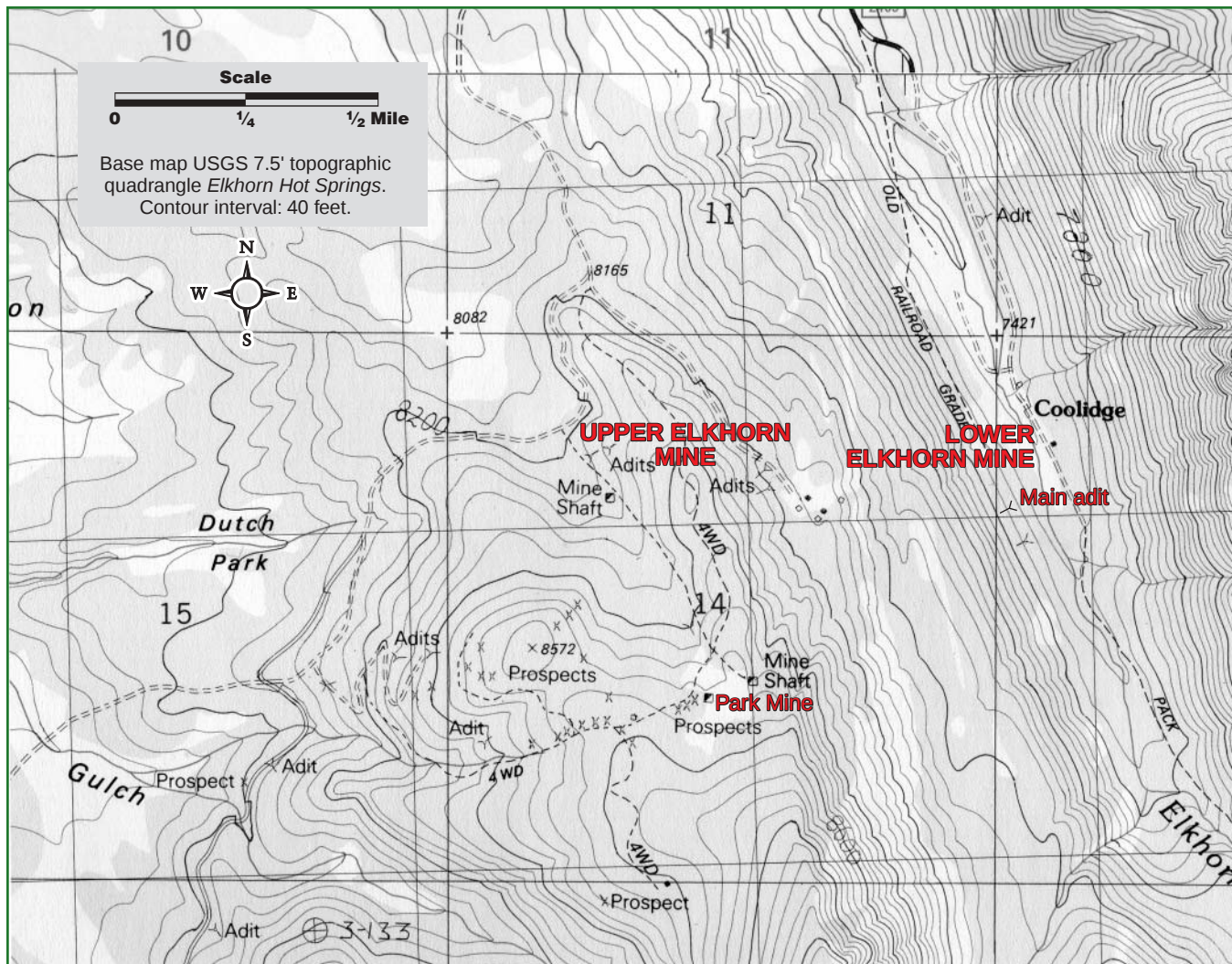


Figure 1—The Elkhorn Mine is in the Elkhorn Creek drainage south of Wise River, MT. The surrounding area is generally small, swampy valleys separated by steep valley walls.

level) adit discharges a bright-orange, iron-stained discharge that flows into Elkhorn Creek. An upper camp (or 300-foot level) at Elkhorn has a small discharge that infiltrates into the ground. This upper camp is located on the former Idanha unpatented mining claim and is referred to as the Idanha tunnel. It produced much of the ore processed at the mill. The Park Mine lies on the same side of the drainage divide as the Elkhorn Mine and may be hydraulically connected to the Elkhorn workings.

History

The mining district was first worked from 1872 to 1874. The first 50 feet of shaft produced 15 tons of high-grade ore that

contained 500 to 800 ounces of silver per ton and 15-percent copper. Many of the early workings were prospects, shallow shafts, and short adits. After a period of inactivity from 1893 to 1906, the mine was operated by the Boston-Montana Development Co., which consolidated the claims, built a narrow-gauge railway, extended the high-tension electric line to the mine, built a 750-ton-per-day mill, and significantly developed the underground workings that included the upper and lower adit. Production from the Elkhorn mining district was estimated at 851,725 pounds of lead, 4,100 pounds of zinc, 370,799 pounds of copper, 180,843 ounces of silver, and 1,013 ounces of gold.

Geology

Ruppel and others (1993) reported that the ore is hosted in Late Cretaceous or Tertiary granitic rocks associated with the Pioneer Batholith. One set of veins strikes N. 50° E. and dips 65° to 85° SE. The other minor set of veins strikes generally east-west and dips steeply to the north (Evans 1946). Vein minerals included quartz, pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and molybdenite.

The two main veins, the Park and Idanha, are coincident with a general north-south trend of mineralized faults in the area. Two large faults, the Mono and Comet, were mapped along with the workings (figure 2). Both the upper Elkhorn and

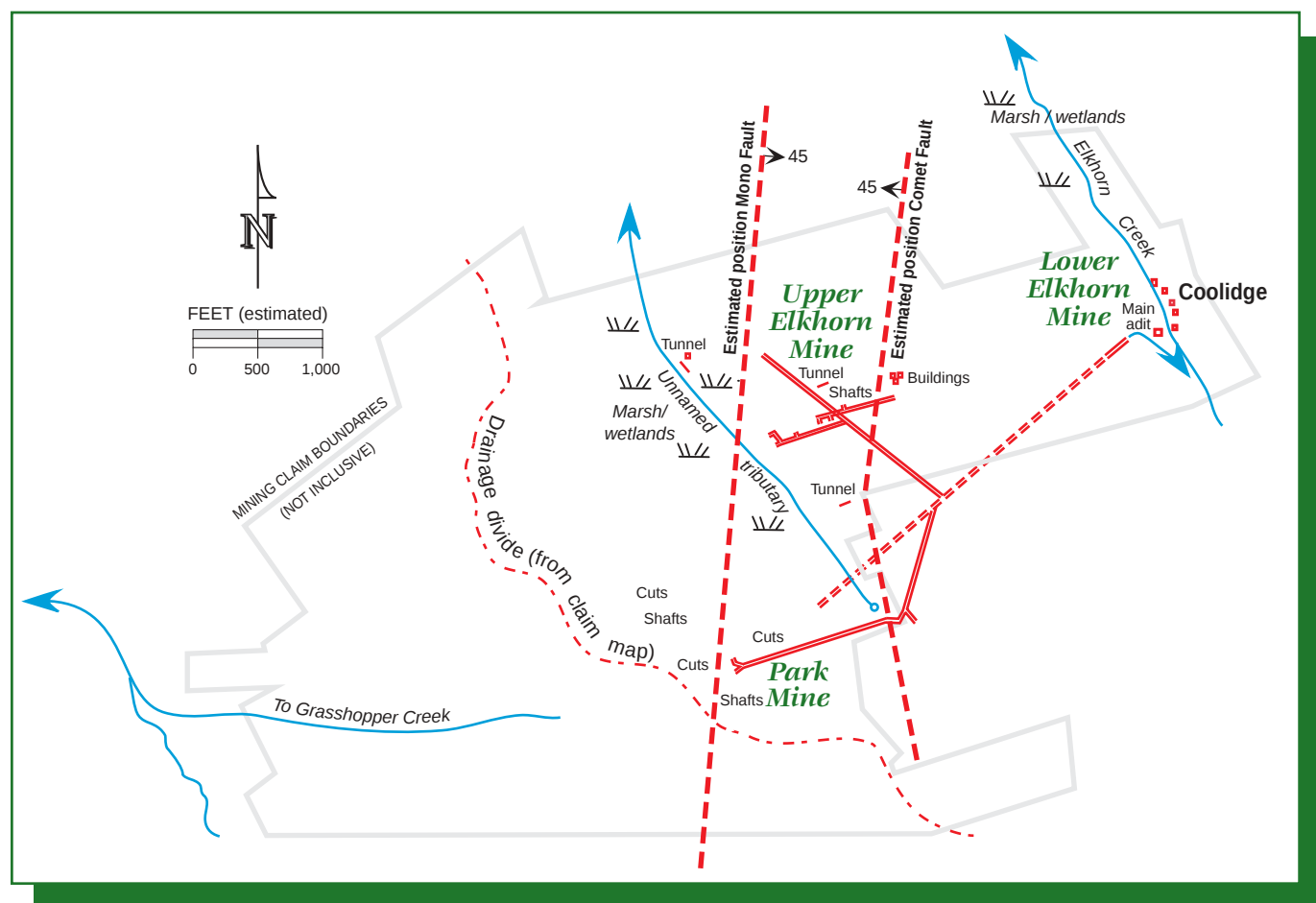


Figure 2—The Elkhorn Mine is one of several mines in the area. The lower Elkhorn workings extend toward the upper Elkhorn Mine and the Park Mine. The map shown is a composite sketch based on unpublished maps in the Montana Bureau of Mines and Geology mineral property files.

Park Mines are within the graben (depression between two parallel faults) formed by the faults. Drifts branching off the main tunnel of the lower Elkhorn breached the Comet fault at least twice. The Comet fault trends north-south along the eastern border of the mineralized zone. It passes near the portal of the 300-foot level and dips 45° NW. The Mono fault is 1,200 feet east of the Comet fault. The Mono fault dips east 45° and makes a sort of trough or graben with the Comet fault. There is minor movement or displacement on the Mono fault. In addition to the two major faults, several other faults are described in the geology of the mines. There is a 300-foot-wide zone of fracturing. According to Evans (1946), the geology of the rock is simple (granitic or quartz monzonite), but the area is structurally complex. The mineralized zone was reported to be 3,000 feet wide by 7,000 feet long. Throughout this zone is a network of “compact inter-related system of fissures” (Evans 1946). These fissures may be a source of water.

Environmental Conditions

The site was identified in 1998 by the Montana Bureau of Mines and Geology and the Forest Service as having several potential environmental impacts to water and soil (Marvin and others 1998). At the lower site on Elkhorn Creek, the adit was discharging over 100 gallons per minute of poor-quality water. Additional flow and chemistry data were collected from the lower adit in 1998 and 1999. The concentration of several dissolved constituents in the main adit discharge (figure 3) exceeded secondary and primary drinking water standards as well as acute and chronic aquatic life criteria (table 1).

The Park Mine is also associated with the Boston and Montana group of mining claims forming the Elkhorn mining district. The mine is included in this investigation because the workings of the Elkhorn Mine extend toward the Park Mine. Loen and Pearson (1989) listed the mine as being associated with the Cretaceous granodiorite or quartz monzonite of the Pioneer Batholith. Winchell (1914) stated that the Park Group’s fissure veins are 20 to 30 feet thick, striking northeast and dipping



Figure 3—The discharge from the lower Elkhorn Mine adit ranges from 80 to 135 gallons per minute. The discharge stream eventually reaches Elkhorn Creek, a tributary to the Wise River.

Table 1—Selected water quality data for the lower adit discharge of the Elkhorn Mine. Bold text indicates that water quality standards have been exceeded.

Elkhorn Mine Water Quality Data										
Sample date	pH	Iron (mg/L)	Sulphate (mg/L)	Aluminum (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Copper (µg/L)	Nickel (µg/L)	Lead (µg/L)	Zinc (µg/L)
9/09/96	4.83	1.6	130	851	4.0	21.5	1,115	4.2	66.9	3,812
11/25/98	6.11	0.04	111	<30	4.20	12.6	264	5.8	<2.0	2,380
6/02/99	5.88	0.316	105	110	4.01	10.2	381	<2.0	16.3	3,520
7/30/99	5.52	0.334	103	360	3.44	17.2	526	2.2	80.2	2,860
9/02/99	5.61	1.490	118	232	3.29	14.9	483	2.4	36.9	2,810
10/05/99	6.17	0.309	103	126	3.39	13.1	283	2.6	7.8	2,380
11/09/99	6.06	0.193	103	108	3.36	11.9	263	2.5	9.8	2,390

75° NW. He said the veins are associated with aplite dikes in the quartz monzonite. One sample taken by the U.S. Bureau of Mines (1995) ran 3.8 ounces per ton gold, 0.67-percent copper, 2.7-percent lead, and 3.9-percent zinc. Another ran 0.07 ounces per ton silver, 4.7 ounces per ton gold, 0.17-percent copper, 0.59-

percent lead, and 0.60-percent zinc. A third sample ran 1.05 ounces per ton gold, a fourth ran 5.8 ounces per ton gold, and a fifth ran 2.6 ounces per ton gold—all with minor copper, lead, and zinc. Workings at the site consist of two adits, three shafts, and several small prospects. They are presently flooded. At certain times of

the year, the area has standing water in many of the depressions resulting from mining. Table 2 presents selected water quality data for the Park Mine.

Underground Workings

The Elkhorn Mine has been described as consisting of 15 miles (almost 80,000 feet) of tunnels (in a Montana Bureau of Mines and Geology mineral property file), 40,000 feet of tunnels (Sassman 1941), or 24,000 feet of workings on two levels—each exploiting a large vein (Evans 1946, Geach 1972). The discrepancy reflects the reliance on company records and promotional articles. Unpublished maps in the Montana Bureau of Mines and Geology files are probably incomplete, but they do give some indication of the extent of the workings. A compilation of these maps (figure 2) shows workings extending from the main adit of the lower Elkhorn Mine to the upper Elkhorn Mine west of the main adit, and toward the Park Mine southwest of the main adit. Only a small amount of information is available on the underground workings for the mine. There was no information indicating that the workings of the Elkhorn Mine had reached the workings of the Park Mine. The No. 1 raise, a 700-foot working, was driven from the 1,000-foot level through the Idanha vein system to the 300-foot level (Evans 1946). It was reported to be open and in good condition in 1946. A 400-foot level and an 800-foot level were driven off of this raise. These workings not only may serve as conduits for water, but also may serve as storage reservoirs.

Unpublished reports from the time the mines were operating described the conditions encountered in the mine. Information gleaned from the Montana Bureau of Mines and Geology mineral property files found reference to water in the workings from the early days of mining. The shaft at the upper Elkhorn was “unwatered” as early as 1909 to allow work in the mine to resume (Montana Bureau of Mines and Geology mineral property file, no author, no date). The 2,300-foot-deep shaft was full of water to within 250 feet of the mouth. Evans

Table 2—Selected water quality data for the adit discharge at the Park Mine. Bold text indicates that water quality standards have been exceeded.

<i>Park Mine Water Quality Data</i>									
pH	Iron (mg/L)	Sulphate (mg/L)	Aluminum (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Copper (µg/L)	Nickel (µg/L)	Lead (µg/L)	Zinc (µg/L)
<i>9/12/96, at adit discharge</i>									
6.4	0.55	19.5	<30	2.1	<2	47.3	<2	21.9	348.6
<i>9/12/96, upstream of mine</i>									
6.1	0.14	2.8	<30	<1.0	<2	<2	<2	<2	12.7

(1946) stated that workings were “sunk as deep as excessive flows of water would permit.” W.R. Butler (no date) mentioned an 8- by 7-foot tunnel driven to access the veins that had been worked from above (this would be the lower Elkhorn adit). The 300-foot level and the 1,000-foot-level tunnels were not only drilled to develop the ore bodies, but also to drain the workings. Of at least 24,000 feet of tunnel at the Elkhorn Mine, 10,000 feet were on the 300-foot level and 14,000 feet or more were on the lower, 1,000-foot level. The report says that development “served to drain all the vast area above the 1,000-foot level and to dry up the water in many of the vein fissures.” The same report describes the “excessive downpours of water over the stopes.”

A report on the Park Mine (Dickman 1913), stated that groundwater in the mine “has proven an obstacle to development by shaft work.” This report describes the mineralization filling “breaks” or fissures in the host rock. These fissures trended east-west and northwest-southeast. A third set of fissures were crosscutting. These fissures were a series of faulted and mineralized zones. The report does not state that these are water-bearing openings, but there is a strong possibility that they are.

These references to water in the workings as they were being mined leads to the conclusion that the flooding and subsequent discharges in the Elkhorn mining

district are directly related to groundwater flow along the numerous faults and fractures in the area. Controlling the discharge through surface remediation may not be feasible.

Mine Discharges

The discharge from the lower adit at the Elkhorn Mine was monitored over a period of about 1 year. The discharge ranged from a minimum of about 80 gallons per minute to a maximum of about 135 gallons per minute during the period of record (figure 4). The greatest discharge occurred in May and June during snowmelt and spring storms. Discharge generally declined throughout the rest of the year. Field parameters such as temperature, pH, and specific conductivity (SC) show some seasonal trends, particularly in the spring months. Water temperature is lowest in late winter. The annual range in temperature is less than 2 degrees Celsius, suggesting a deep groundwater flow source. Overall, water quality appeared to be best just before the spring snow melt and poorest during higher flows. The range of values throughout the year is small.

A second, much smaller adit south of the lower Elkhorn Mine discharged about 3 gallons per minute. With one exception, the discharge showed little variation based on four visits at various times of the year over a period of 2 years. In the late summer of 2000, a particularly dry year, there was no discharge.

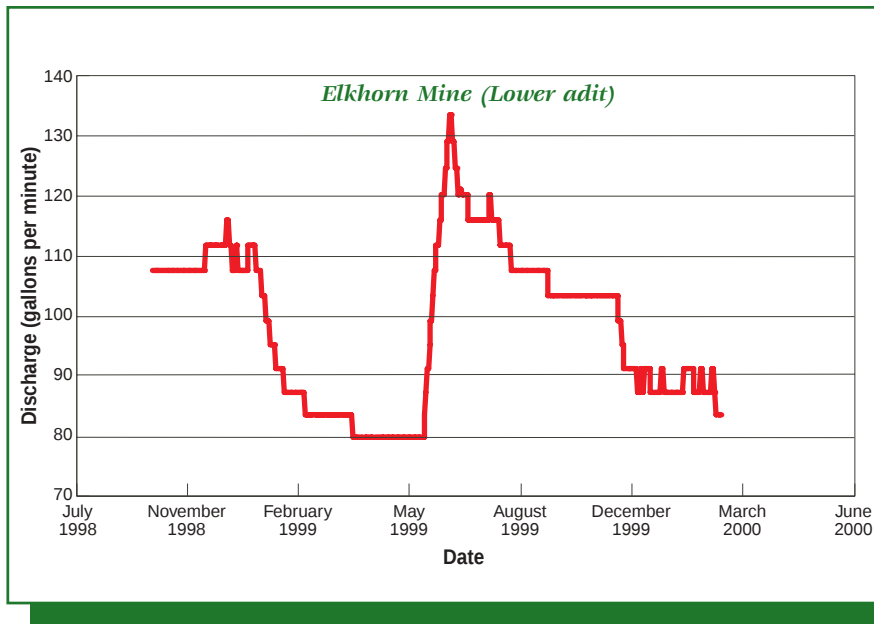


Figure 4—Discharge from the main adit of the lower Elkhorn Mine ranged from 80 to 135 gallons per minute over the period of record.

The workings of the Park Mine are near the head of a small tributary of Elkhorn Creek. A flooded shaft and several cuts and prospect pits are flooded throughout the spring and during most of the summer. A spring originates near the surface workings and flows throughout the workings most of the year (figure 6).

The upper Elkhorn Mine adit discharge (figure 5) ranges from less than 1 gallon per minute to about 5 gallons per minute. As with the smaller adit at the lower Elkhorn Mine, this site was measured four times over a period of 2 years. Water from the area drains through the waste-rock dumps and down a small tributary. A second adit in the area of the upper workings does not show any evidence of discharge at any time of the year.



Figure 5—The upper Elkhorn shaft/adit (center of photo with lumber over it) discharges a small amount of water throughout the year.



Figure 6—The workings at the Park Mine include a flooded shaft and several flooded cuts and prospects. The area is especially wet during snowmelt, but the workings are flooded throughout the year.

Surface Water

Springs that were apparently unrelated to mining activities were found throughout the area around the upper and lower Elkhorn Mines and the Park Mine (figure 7). The largest spring originates on the scree slope between the upper and lower Elkhorn Mines and flows onto the waste-rock dump of the lower adit. During the spring months, this spring flowed more than 20 gallons per minute, but it was dry by late summer during the 3 years of observations. The other springs had much lower flows. By late summer, many springs were dry and none was found to flow more than about 1 gallon per minute. Field chemistry (pH, specific conductance, and temperature) was unremarkable. All of the springs had nearly neutral pH and low specific conductivity (less than 50 micromhos per centimeter). A visit in late 2000 found springs and wet areas paralleled the west side of the Elkhorn Creek drainage at a consistent elevation. They were apparent at the toes of the scree slopes that commonly formed on the west side of the valley.

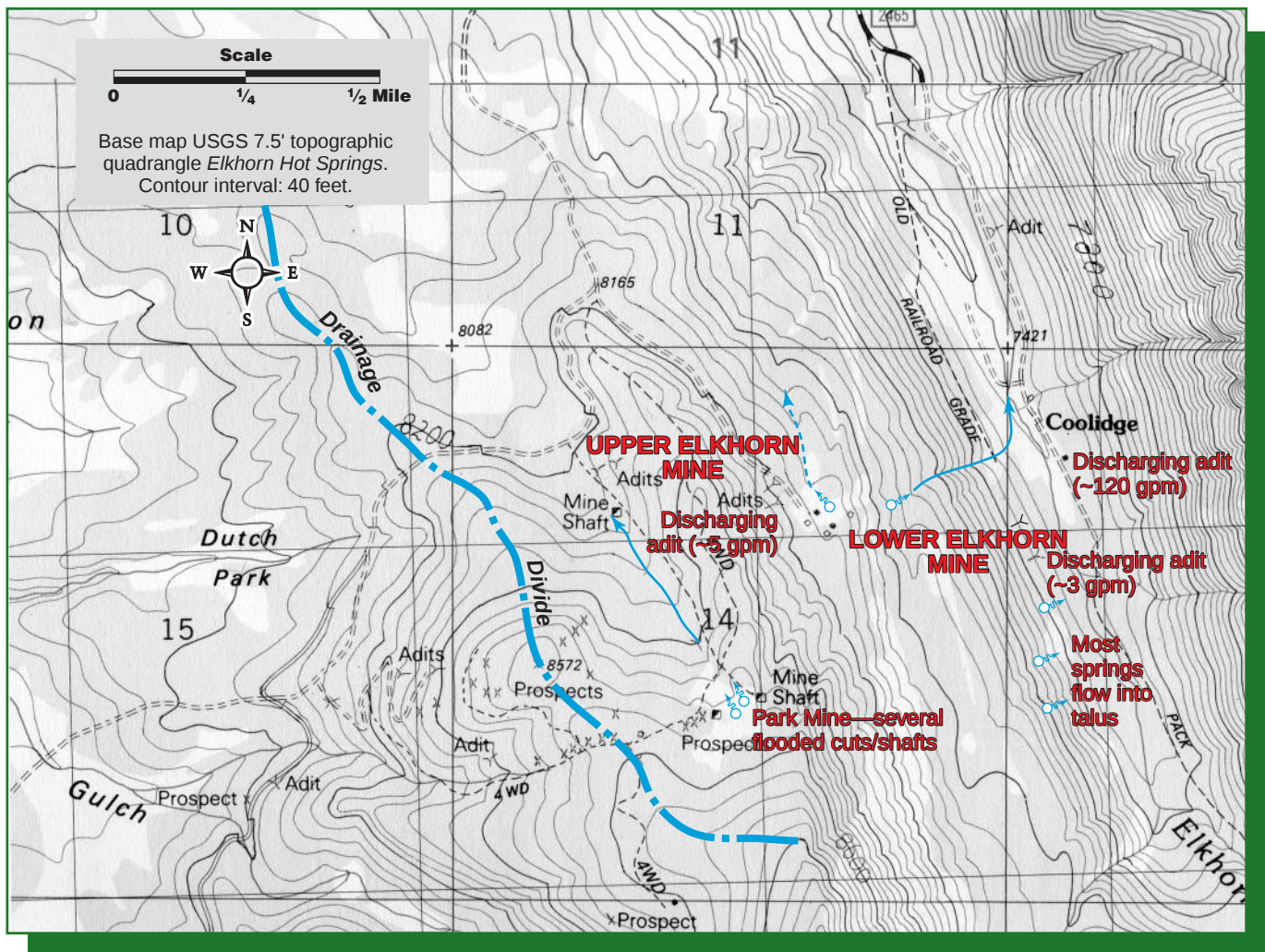


Figure 7—Adits at the upper and lower Elkhorn Mine—as well as shafts and cuts at the Park Mine—discharge water. Symbols indicate the approximate location and direction of flow for the larger springs. Sustained surface-water flow (measured in gallons per minute, gpm) near the adits is also indicated.

Regional Structure (Aerial Photographs)

Two sets of aerial photos were interpreted for the Elkhorn area: a black-and-white set taken from high altitude (at 1:24,000 scale) and a set of color photos at a larger scale (about 1:48,000). The smaller scale photographs were more useful for mapping the regional structures in the area. A large north-south structure (figure 8) was inferred to pass between the lower and upper Elkhorn Mines. That structure would correspond with the Comet Fault as shown on the unpublished map in the

Montana Bureau of Mines and Geology mineral property files. A lineament was drawn east-west through the lower Elkhorn workings that may reflect the vein system. Areas showing a sudden change from upland vegetation to vegetation indicative of wet environments were also mapped on the aerial photos. The regional structures at the Elkhorn area extended thousands of feet. Aerial photos at commonly available scales were of limited use in mapping the smaller structures in the area. When known geology was transferred to the aerial photos, the large

structures could be discerned, but it was difficult to pick them out when the geology was unknown.

Characterization and Mapping of Riparian Areas and Wetlands

Wetland and riparian sources of groundwater entering mine workings can be identified using several levels of mapping intensity. These include remote sensing, field verification and delineation, and physical and chemical characterization

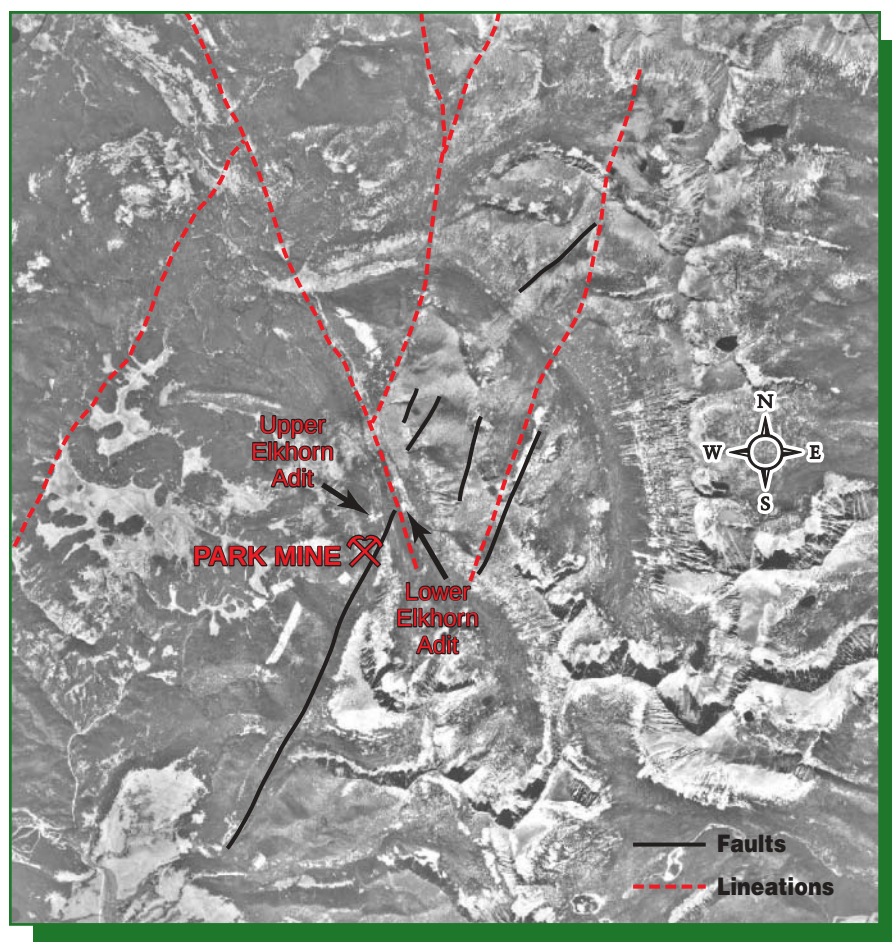


Figure 8—Several faults have been mapped in the Elkhorn Mine area. Solid lines indicate faults mapped previously and documented in published and unpublished reports. Dashed lines indicate lineations (fractures).

of the hydrological features of the study area. Depending on time and funding available for identifying the source areas, various levels of these methods may be preferred. The discussion that follows summarizes a full study (McBride 2002).

Office Procedures

The assessment area for the riparian and wetland characterization was designed to follow roughly the 7,600-foot-elevation contour; 7,600 feet is the approximate elevation of the lower workings of the Elkhorn Mine. Lands higher than 7,600 feet were presumed to be potentially contributing groundwater to the underground mine workings through bedrock fractures.

Some subjective judgment was used to adjust the assessment area boundary, based on broad landscape drainage patterns. The assessment area encompasses about 12,000 acres, extending about 2 miles north of the Elkhorn Mine area, 4.5 miles to the west, and 4 miles to the south. This large area ensured that all potential sources of water were included. It is unlikely that locations farthest from the mine are contributing groundwater to the mine's underground workings.

The characterization and mapping of riparian and wetland areas included stereoscopic review of standard 1:16,000-scale color aerial photography, commonly called

resource photography in the National Forest System, as well as field documentation of soil profiles, soil moisture status, plant species, plant associations, slope hydrology, and landforms.

The initial stereoscopic review of aerial photographs was used to select sampling sites that would be representative of various combinations of vegetation, soil parent material, landforms, and landform positions observed on the photos. In the photos, nearly all of the sites that were selected appeared to be moderately wet or wet near the surface. About 10 to 15 sampling sites were located to represent each unique combination of vegetation type, landform, soil parent material, and landform position to characterize the variability of the soils, vegetation, and hydrology.

Field investigations documented these sites as well as others that would provide useful information. After field operations, these landscape and ecological parameters were formulated into map units that represent a unique combination of features that recur in patterns across the assessment area. The map units were designed to keep variability low and to be different enough to allow meaningful map unit interpretations.

The assessment area was satisfactorily characterized and mapped using a total of seven map units. Once these map units had been described, a stereoscope was used to produce a preliminary map of the assessment area on clear acetate overlain on the color aerial photos. Based on field data and a review of these preliminary riparian/wetland delineations, adjustments were made to the characterizations of the map units. A followup step in this iterative process was to correct the delineations on the aerial photos. These delineations were transferred to a clear acetate film registered to a paper black-and-white orthophoto that included all of the assessment area. This orthophoto was retrieved in digital format from the Natural Resource Information System

database at the Montana State Library in Helena, MT. The digital file was printed at 1:24,000. This paper map became the base map for the transferred polygon delineations. The orthophoto allowed the riparian and wetland polygon lines to be located precisely on a base corrected for distortions. The acetate map of these polygons was scanned. Map unit symbols were added to provide digital files for the project's final report. Locations of field sampling stops and discharge or recharge areas also were mapped and scanned.

Field Investigations

A total of 102 field sites were documented. Nearly all of the sites were in areas with moderately high to high water tables at some time during the growing season. The soil profile and soil moisture conditions were characterized on 60 of these sites. Soil was excavated with a shovel, or where feasible, samples were retrieved using a hand-operated soil auger. Depth of sampling depended on site characteristics and site-specific data needs. Typically, soil was sampled from 12 to 40 inches deep. Soil-related data included horizon designations, textures, clay content, color, redoximorphic features (Vepraskas 1992, USDA NRCS 1998), soil moisture status, and the depth to saturated soil. Not all parameters were determined at each site.

Data collected on vegetation included dominant and characteristic plant species and the potential natural plant community (referred to as plant associations). Other field data collected included slope, aspect, pertinent landform or landscape features, and whenever feasible, latitude and longitude determined with a GPS receiver. The data collector also made observations of slope hydrology, including determinations of water discharge out of the soil (to become surface water) or recharge into the soil (to become groundwater). Rough visual estimates of flow rates of small perennial and intermittent streams also were noted. About 40 sites were assessed for hydrologic conditions. In addition, 15 determinations of the pH of stream and pond water were made using a field meter.

Mapping Results

Three digital map layers were produced from the field data and aerial photo interpretations:

- ✕ A layer with polygons of seven map units that partition the area into distinct, relatively homogeneous ecosystems based mainly on soil wetness and natural vegetation (figure 9).
- ✕ A layer showing locations of groundwater discharge, recharge, and of complex patterns of discharge and recharge. As used here, discharge refers to groundwater becoming surface water as typically occurs along streams, seeps, and springs. Recharge occurs where surface water becomes groundwater. Because of the large size of the assessment area, some discharge or recharge areas were not inventoried in the field.
- ✕ A layer showing the locations of all field sampling points.

These three layers can be overlain on the geologic structure layer to help locate potential connections of groundwater or surface water with the mine's underground workings. Appendix A has detailed descriptions of the map units.

The map of riparian and wetland ecological units shows that much of the assessment area has soils that are saturated to the surface or to within a few inches of the surface at some time during the year. These wet areas are generally associated with valley bottoms, alluvial basins, stream headlands, and pitted glacial deposits (see appendix A).

Discharge and Recharge Areas

Most of the riparian and wetland areas are associated with groundwater discharge in which the groundwater becomes surface water associated with streams, seeps, and springs. During the latter part of the growing season, some areas have complex patterns of alternating discharge and

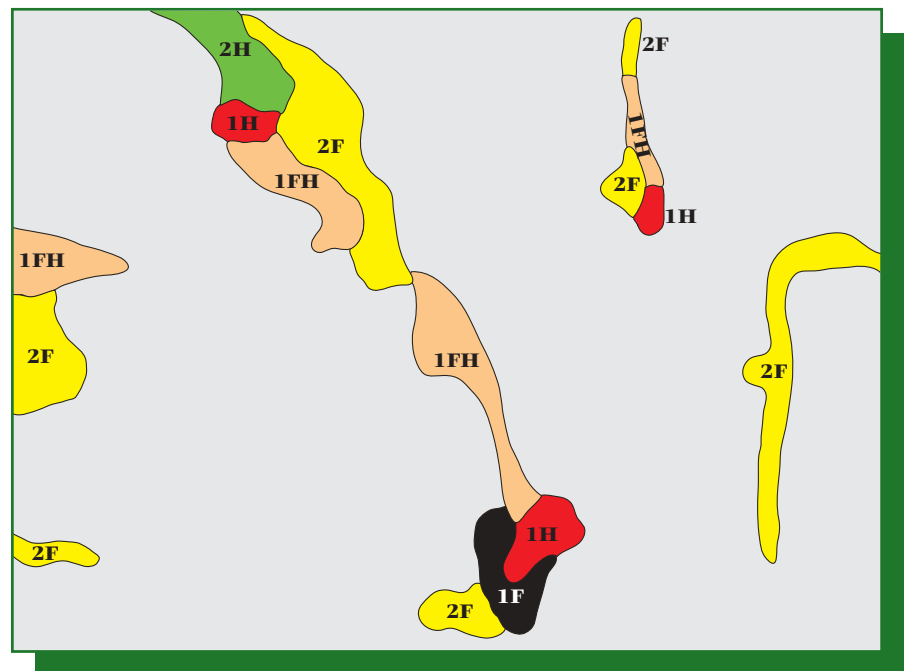


Figure 9—A portion of the riparian and wetland map unit delineations for the Elkhorn Mine study area (see appendix B for the detailed map unit descriptions).

recharge. Although these patterns are not documented, these areas are likely to be dominated by discharge during the wetter, early part of the growing season and during snowmelt. Indications of 10 sites of discharge, 12 sites of recharge, and 8 sites of complex discharge and recharge were observed in the study area.

This study focuses on the recharge areas as potential contributors of groundwater to the mine's underground workings. Of particular interest are a few areas near the mine workings. One site is the partially collapsed portal of the Park Mine in the southwest corner of section 14. Standing water occurs at a depth of about 20 to 25 feet in the vertical opening. Another excavated depression has a couple of feet of standing water. The small grassy meadow to the east of these sites has several ditches that apparently were constructed to divert water away from the downslope shafts and workings, possibly for domestic use at the cabin sites in the meadow (stop 29 on the maps and in the notes of the project file at the Montana Bureau of Mines and Geology). One of these ditches runs roughly along the contour at the top of the meadow heading north-northeast. Near the north edge of the meadow, this ditch enters a drainage-way that flows into the Elkhorn valley below. The increased flows from this ditch have destabilized the old channel, leading to considerable erosion and sediment deposition. It appears that at least some of this drainage water becomes groundwater about 300 to 400 feet from the edge of the park before it heads down the very steep glacial trough wall of Elkhorn valley. At this point, the Elkhorn Mine adit portals are only about $\frac{1}{3}$ mile away.

Along the upper reaches of St. Louis Gulch, the workings of a remote, small, collapsed mine was observed. At the time, a trickle of water was draining from the collapsed opening. After flowing about 30 feet, this trickle disappeared into the ground. The pH of the surface water was 4.2. The water was depositing bright red iron coatings on the soil and rocks of the channel.

Water Samples

The pH of surface water of the lower adit and various locations in Elkhorn Creek was collected on Aug. 30, 2002 (table 3).

Table 3—The pH of surface water at the lower adit of the Elkhorn Mine. Redox is the reduction-oxidation potential of the water.

<i>Surface Water pH at Elkhorn Mine</i>			
Location of discharge	Surface water pH	Redox (millivolts)	Temperature (°F)
<i>Adit discharge water within several feet of the entrance</i>	6.1	+129	45
<i>Adit discharge water about 3 feet before entering Elkhorn Creek</i>	6.1	+176	68
<i>Elkhorn Creek about 6 feet upstream of the junction with the adit water</i>	7.1	+220	62

These data indicate that the lower adit water is 10 times more acidic than Elkhorn Creek water that is unaffected by the adit discharge. The adit water lowers the pH of Elkhorn Creek from 7.1 to 6.8, and 6.5 downstream of the junction with the adit discharge. The pH values of the adit discharge water are higher than those reported in a previous Montana Bureau of Mines and Geology report in which the discharge water had a pH of 4.8, compared to a pH of 6.1 in 2002. The use of a relatively inexpensive field pH meter for these field samples may account for some—but probably not all—of this difference.

Charter Oak Mine Site

Introduction

The Charter Oak Mine (figure 10) and nearby mill, T. 9 N., R. 7 W., sec. 36 (tracts CCB), are on land administered by the Helena National Forest along the Little Blackfoot River south of Elliston, MT. Although the Charter Oak Mine's mill tailings and some waste have been removed and placed in a repository, two small adits

continue to discharge. The southernmost adit's discharge has been monitored. The levels of many metals exceed water quality standards. The discharge contributes

arsenic, cadmium, copper, zinc, and other metals to the environment. Methods by which the flow could be reduced, if not eliminated, were considered.

History

From 1916 to 1966, the mine and mill intermittently produced 9,127 tons of ore that yielded 382 ounces of gold, 39,146 ounces of silver, 10,041 pounds of copper, 672,046 pounds of lead, and 168,270 pounds of zinc (McClernan 1976).

Geology

The dominant rock type at the Charter Oak Mine is an andesite that hosts two main veins: one, at least, is vertical; the orientation of the other is unknown (Pardee and Schrader 1933). These veins are referred to as the *front* and *back* veins. Mineralization consists principally of argentiferous galena and boulangerite (a lead-antimony sulfide) (Pardee and Schrader 1933) along with arsenopyrite, sphalerite, and plumbogjarosite in quartz. McClernan (1975) reports 300 feet of underground workings were accessible in 1968. A northwest-trending drift split as it encountered the northeast-striking, 88 degrees southeast-dipping, fault-controlled vein. Elliot and others (1992) say that five adits were driven along shear zones in

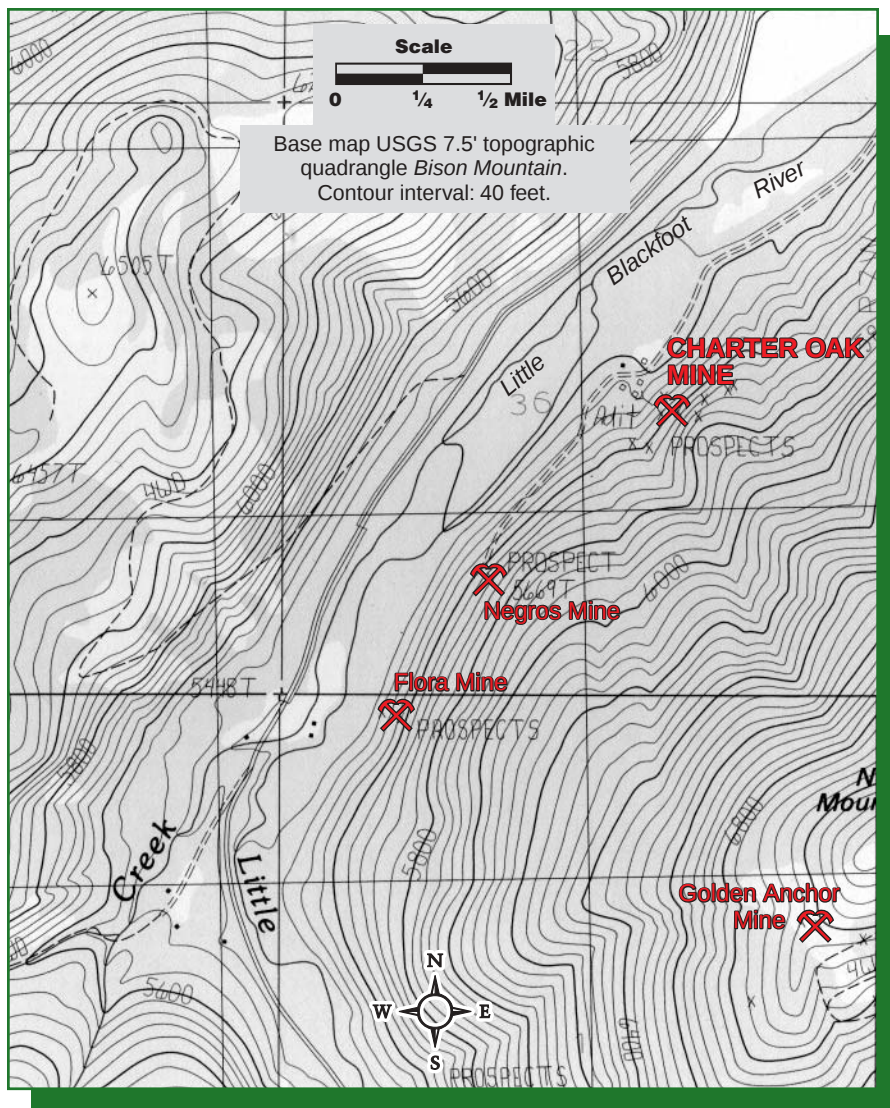


Figure 10—The Charter Oak Mine in the lower reach of the Little Blackfoot River south of Elliston, MT, is one of several mines and prospects in the area.

Cretaceous andesite. A major northeast-trending fault known as the Dog Creek Fault parallels the Little Blackfoot River and Hat Creek to the southwest (Schmidt and others 1994). The southeast block has only 427 feet (130 meters) of downward displacement. Movement postdates the Elkhorn Mountains volcanics but predates the younger volcanics to the southwest.

Environmental Conditions

The mine and mill were identified in 1998 by the Montana Bureau of Mines and Geology and the Forest Service as having several potential environmental impacts (Hargrave and others 1998). Additional flow and chemistry data were collected from the lower adit in 1998 and 1999. The concentration of several dissolved constituents in the lower (west) adit discharge exceeded secondary and primary drinking-water standards as well as acute and chronic aquatic life criteria (table 4). The main adit discharge and the small stream flowing through the site also exceeded several standards but generally had much better water quality.

Underground Workings

The area immediately around the mine is steep and covered with trees. Above the mine, bedrock crops out and talus slopes are common. The mine has at least six adits, but only the lower two adits discharge water (figure 11). A third adit, the Kineo vein and drift, may contribute water to the unnamed tributary that has been partially reclaimed. Seeps emerge from the northeast side of the unnamed tributary but it was not evident whether they were the result of a buried adit discharge.

Table 4—Water quality data for the Charter Oak Mine. Bold text indicates that one or more water quality standards were exceeded.

Charter Oak Mine Water Quality Data										
Sample date	pH	Iron (mg/L)	Sulphate (mg/L)	Aluminum (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Copper (µg/L)	Nickel (µg/L)	Lead (µg/L)	Zinc (µg/L)
West (lower) adit										
6/06/95	3.17	51.5	500.0	1,541	4,568	35.1	369	9.2	68	353
11/23/98	2.93	31.5	433.0	2,109	1,450	28.5	287	21.7	34	2,810
6/01/99	3.14	76.6	502.9	2,270	7,210	34.6	555	8.8	145	3,520
6/28/99	2.55	136.0	764.7	3,790	13,000	69.6	1,170	13.4	210	6,680
8/30/99	3.13	64.8	531.9	221	4,170	45.1	608	14.1	84	4,370
10/06/99	2.63	45.4	469.5	2,620	2,340	36.3	454	11.6	53	3,440
11/01/99	2.85	37.6	431.9	2,490	1,670	33.3	419	11.7	40	3,230
East (main) adit										
10/6/95	7.86	0.7	450.0	<80	107	<2	2.3	9.4	<2	353
Stream onsite										
10/6/95	7.45	0.1	40.0	<80	60	<2	<2	<2	<2	121

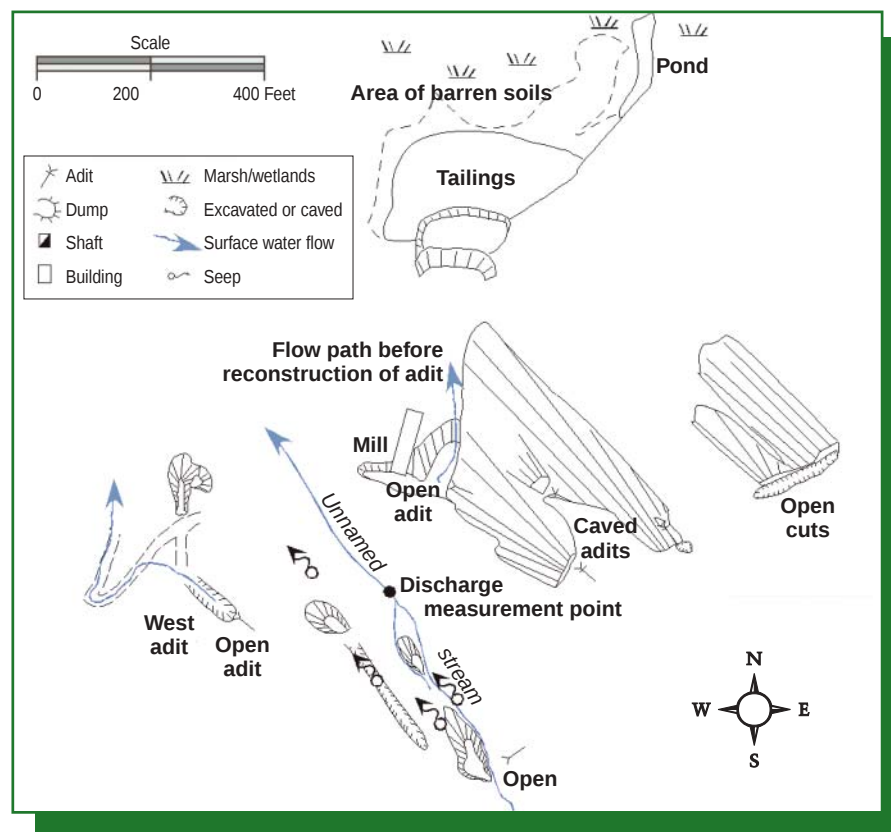


Figure 11—Two adits discharge water throughout the year at the Charter Oak Mine and mill just south of the Little Blackfoot River. A stream originates above the site and flows into the disturbed area. Springs near the stream flow only during spring and early summer.

Unpublished maps in the Montana Bureau of Mines and Geology files provide some indication of the extent of the workings and their geology. The plan map (figure 12) was drawn at a reported scale of 1 inch equals 30 feet. It conservatively estimates 2,350 feet of workings on at least three levels in 1943. Similarly, the accompanying cross section (figure 13) shows three or four levels with several stopes and raises. Four adits on the 1943 map include:

- ✕ The lower, discharging adit, trending south 62 degrees east, southeast of the mill that was designated as "0.0" elevation
- ✕ One adit at 146 feet relative elevation
- ✕ Two adits at 206 feet relative elevation

The map also shows a shaft at 275 feet relative elevation. The Kineo workings or adit (north 55 degrees east-trending) has about 1,000 feet of drifts and crosscuts. A fault was noted in the Kineo crosscut. The same fault was the terminus for the 146-foot-elevation adit and the two drifts off of the shaft. Raises and stopes helped to connect the various levels. Between 1904 and 1908, most of the Kineo drift that followed the vein was driven at a relative elevation of 130 feet. This adit correlates with the partially reclaimed portal to the northeast of the unnamed tributary that flows to the northeast into the Little Blackfoot River, south of the main mine area.

If the notes on the map are accurate, the workings are shallow—most are less than 200 feet below the surface. As noted, the mine operated for about 20 years after

the date of the maps, so they probably represent the minimum extent of workings. The lower discharging adit south of the unnamed tributary is not shown on the mine map. The small size of the waste-rock dump indicates that the tunnel is fairly short, probably less than 50 feet.

Mine Discharges

The discharge from the lower (west) adit at the Charter Oak Mine (figure 14) was monitored with a weir (small dam used when measuring water flow) and recorder for about 1 year. The discharge ranged from a minimum of about 0.4 gallons per minute to a maximum of about 10 gallons per minute during the period of record (figure 15). The greatest discharge occurred in early May during snowmelt and storm events. A small portion of the discharge was due to runoff outside the portal, but most appeared to come from

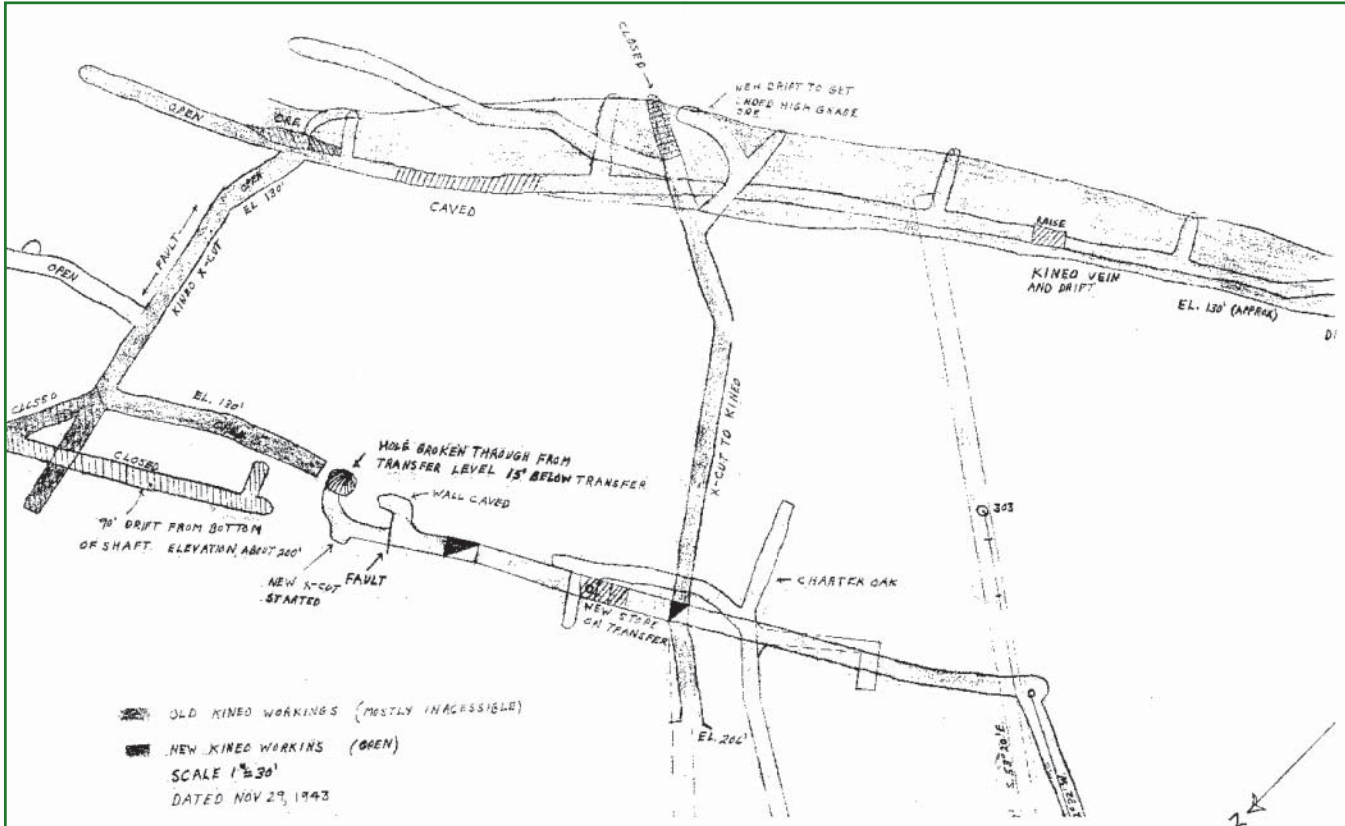


Figure 12—An unpublished sketch map from the Montana Bureau of Mines and Geology files provides some detail of the Charter Oak Mine workings. Although the map does not follow convention, the orientation of the map was preserved (note north arrow).

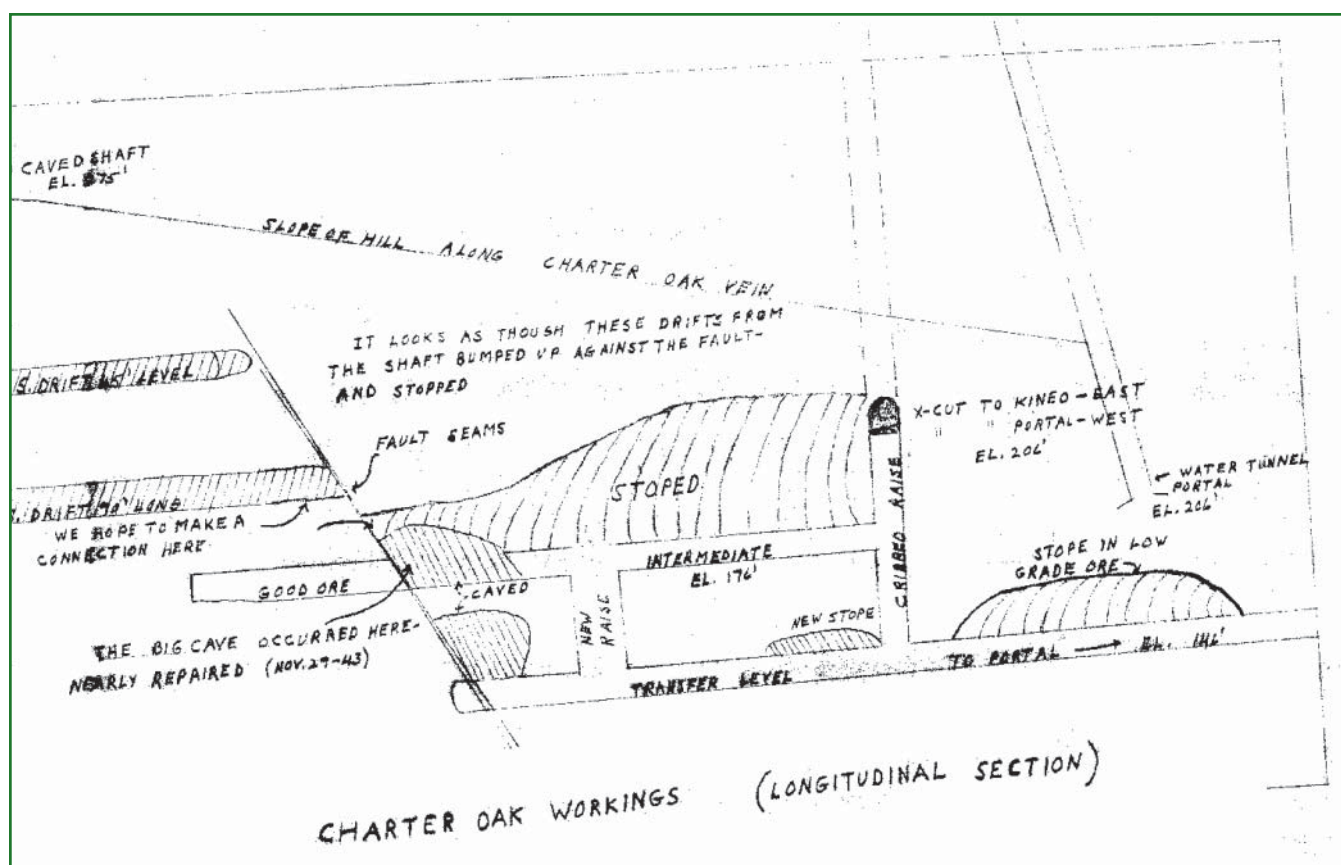


Figure 13—The unpublished work in the Montana Bureau of Mines and Geology files included a cross section of the Charter Oak Mine workings. The scale of the maps and cross section had to be estimated because they did not include a bar scale.



Figure 14—The lower (west) adit of the Charter Oak Mine discharges 0.4 to 10 gallons of water per minute. The extent of the workings and their relationship to other workings could not be determined.

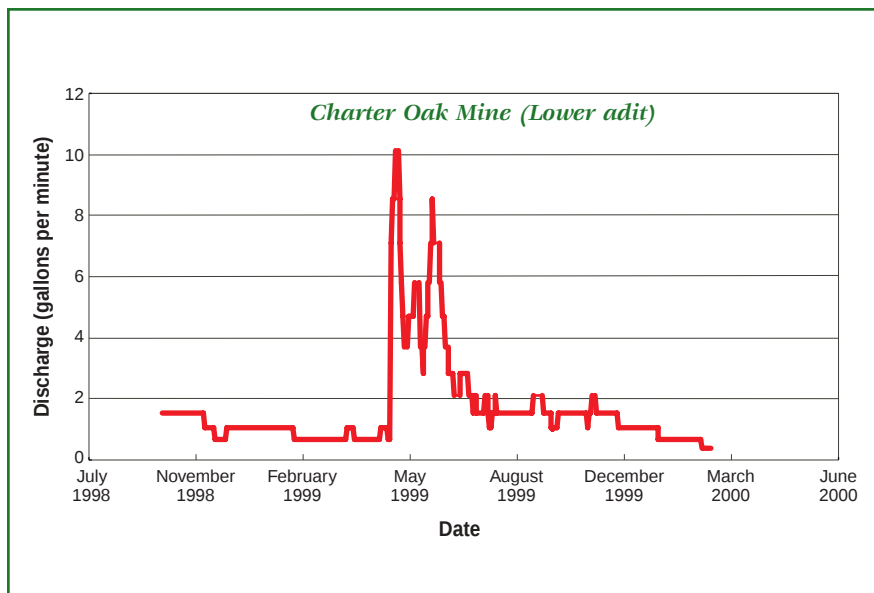


Figure 15—The lower (west) adit of the Charter Oak Mine discharges water throughout the year. The flow ranges from about 0.4 to 10 gallons per minute.

within. The discharge generally declined through the rest of the year. The rapid response to snowmelt, and possibly storm events, suggests a close proximity to the groundwater recharge area and fits well with the shallow mine workings indicated on the sketch maps (figures 12 and 13).

The main (east) adit was not monitored, but flow measurements were made during several visits, mostly during late summer and early fall. Flow from this adit is always about 10 gallons per minute or less. The discharge stream disappears into the scree within a few tens of feet from the adit. When the adit was reconstructed in 1999, gravel was used to “bury” the discharge stream before it exits the portal (figure 16). It does not resurface.

Surface Water

The workings of the Charter Oak Mine are well above the floodplain of the Little Blackfoot River. The only surface water that is likely to be in contact with the workings is a small unnamed tributary of the

Little Blackfoot River that flows through the disturbed area. The stream originates several hundred feet uphill. It flows through and around several waste-rock dumps and small pits. This stream's flow is a direct function of snowmelt and storms. Its base flow in the late fall was estimated to be about 20 gallons per minute at a point midway through the disturbed area (figure 17). The stream is contained within a straight reconstructed channel with some ponding only in the disturbed area. Seeps emerge on the north side of the creek in the recently reclaimed area. These seeps did not have iron oxide staining, vegetation appeared normal, and based on water quality data, the seeps did not contribute metals to the creek.

A series of catch basins or trenches have been bulldozed across the face of the scree slope into which the workings were



Figure 16—The main adit of the Charter Oak Mine is just uphill from the mill. A small discharge flows from the portal (entrance) and infiltrates the coarse material near the portal.



Figure 17—A small stream originates well above the uppermost workings of the Charter Oak Mine and flows in a nearly straight path through the disturbed area. Seeps like the one in the right center are common near the workings. The uppermost adit, the Kineo, is just to the right of this photograph.

driven. The trenches serve to stop rock slides from the unvegetated hill above and limit the formation of erosional channels down the steep face. One minor result of the basins formed by these grassy benches may be the increase of snow retention. Snow is also caught in the road cuts on the top and sides of the ridge east of the mines. The portal areas of the adits (especially the collapsed area at the unnamed discharging adit) also provide an area in which snow may accumulate.

This snow accumulation contributes to the water available to be discharged.

Aerial Photography

The aerial photos in the area were of limited use. The volcanic rocks that host the ore body do not have a strong joint pattern. The Dog Creek Fault (Schmidt and others 1994) follows the Little Blackfoot River (figure 18). The trace follows the valley up Hat Creek to the southwest. It is the only regional structure that has

been mapped in the immediate area. The unnamed tributary to the Little Blackfoot River follows an east-west lineation. Its course also may be locally fault controlled. Vegetative changes reflecting the presence of groundwater are not evident.

Characterization and Mapping of Riparian Areas and Wetlands

A brief study of the topography and possible discharge and recharge areas indicated that the area adjacent to the Charter Oak Mine is much smaller and less complex than the area adjacent to the Elkhorn Mine. The riparian and wetland areas associated with the Charter Oak Mine are primarily down-gradient from the mine along the Little Blackfoot River. One unnamed tributary to the Little Blackfoot River flows through the area. It may be a direct source of recharge to the mine. Negro Mountain, almost a mile away, forms the drainage divide to the southeast. No other tributaries or possible source areas were detected from the topographic maps or aerial photos. A preliminary field investigation revealed no springs or wet areas on the slope above the mine. The only catchment basins were from recontouring to inhibit erosion on the steep face where the workings were driven and on exploration roads high on the hill. These areas held snow in the late spring, but were not large enough to be significant. The apparent simplicity of the drainage, and the lack of distinguishable wet areas on the aerial photos, led to the decision to concentrate time and funding on the more complex Elkhorn Mine area.

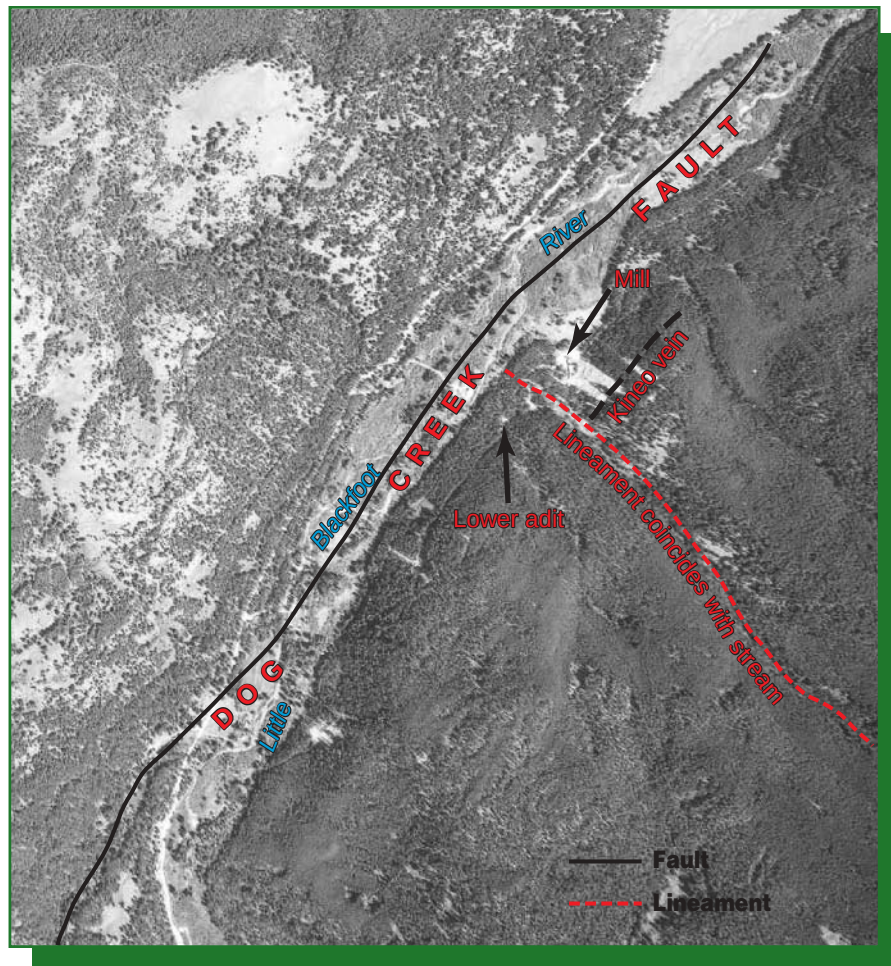


Figure 18—The Charter Oak Mine is near a small tributary of the Little Blackfoot River. The stream flowing through the site may be controlled by the lineament (fracture). The mine apparently explored the Kineo vein as the main source of ore.

Summary

Application of the various methods of controlling groundwater flow into mine workings requires knowledge of the source and pathways of the portion of the aquifer that is hydrologically connected to the mine. The previous discussion of methods provides an overview of the investigation. No single method will provide all the pertinent information. It will be necessary to compile information from several sources and compose a conceptual model of the groundwater flow system near the mine.

Elkhorn Mine

The discharge of 80 to 130 gallons per minute from the main adit of the lower Elkhorn Mine far exceeds that of most mines in Montana. Discharge from most adits is in the 5- to 10-gallon-per-minute range (Hargrave and others 2000). The Elkhorn Mine is also one of the largest abandoned mines in Montana with acid mine drainage problems. The mine has a reported 24,000 feet of workings. This investigation was limited to a survey of surface features, surface water, soils, vegetation, and existing information on geology and workings.

Although information is incomplete and sometimes contradictory, the mine probably intersects a number of faults and well-jointed granitic rock capable of transmitting groundwater. The volume of rock available for groundwater recharge to the mine is quite large. This is evidenced, in part, by the high sustained discharge from the adit. The workings of the Elkhorn Mine extend toward the Park Mine. Flooded shafts and prospects prevent us from knowing whether there is a direct connection between the two mines, but there could be some contribution of groundwater from the Park Mine to the Elkhorn Mine workings.

Any attempt to control or eliminate adit discharge from the lower Elkhorn Mine would have to include an investigation of the underground workings. The true extent of the workings, the effects of the faults on groundwater flow, and fracture/joint orientation and density are unknown. Extensive tree cover severely limited the use of aerial photos or field mapping to identify fractures and joints on the surface.

The unnamed tributary flowing through the disturbed area, along with several closed depressions throughout the area, probably contribute a significant portion of the groundwater recharge to the adjacent

underground workings. Infiltration controls on the streambed and surface disturbances may reduce discharge from the adits. Further investigations are warranted, particularly investigations to identify the recharge area. For example, age-dating the adit discharges would provide a means to estimate flow paths and residence times. Similarly, tracer tests and detailed flow measurements of the stream may identify segments losing water.

Charter Oak Mine

A portion of the discharges at the Charter Oak Mine site may be the result of fault-related flow; faults were described in the underground workings on the unpublished maps of the area. No mention of water in the workings was made in the sparse information available for the mine. However, the amount of water contributed from these fault conduits is probably small. The seasonal response in adit discharge and the shallow workings suggest a similarly shallow groundwater flow system that may be a good candidate for source control.

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Appendix A—Elkhorn Mine Riparian and Wetlands Characterization and Mapping

Methods

The office procedures, field investigations, and mapping results are discussed on pages 17 and 18. Figure 1 shows the points where data were collected for the wetland and riparian characterization and mapping.

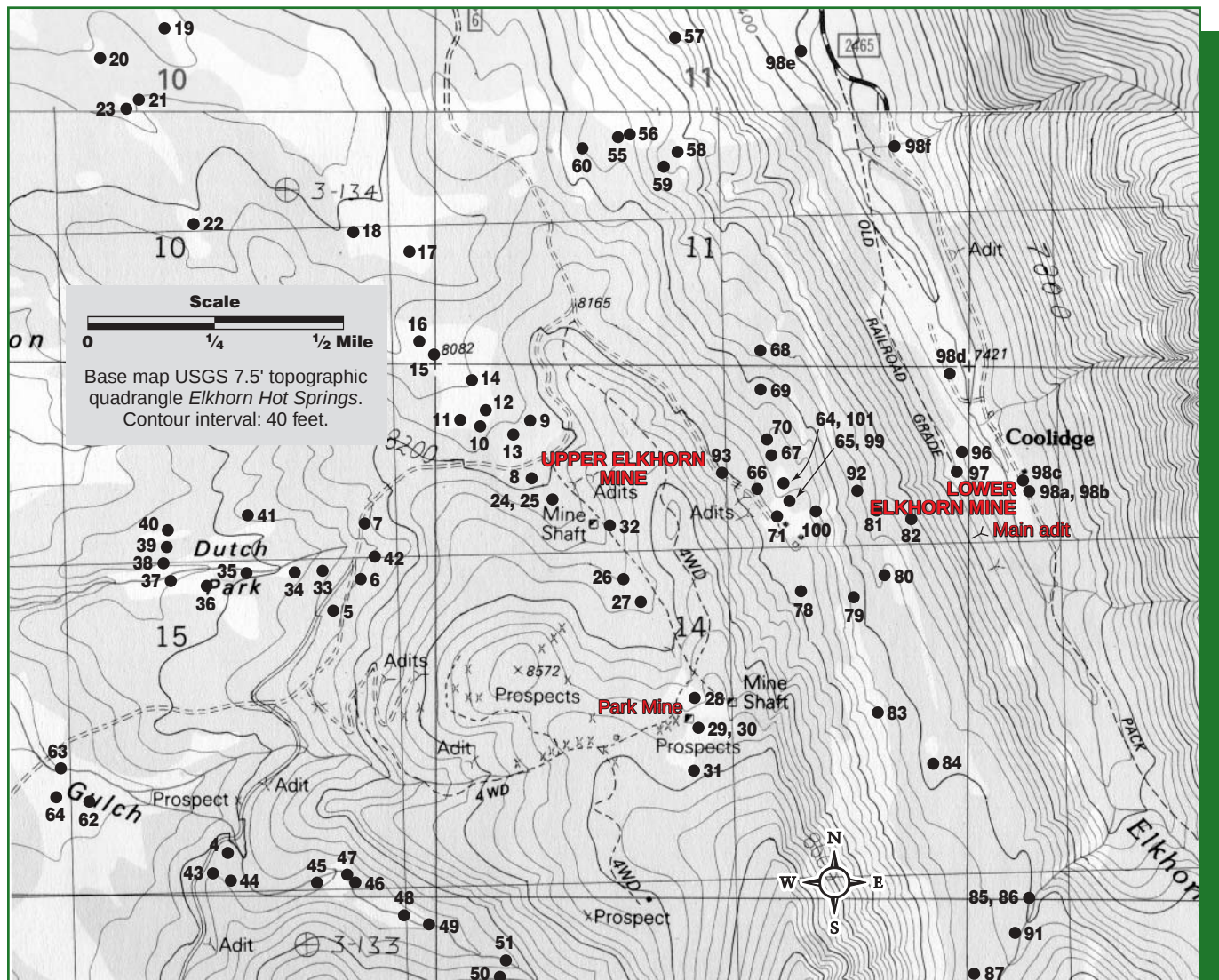


Figure 1—Stop points (data collection sites) for the wetland and riparian characterization and mapping in the Elkhorn Mine area.

Appendix A—Elkhorn Mine Riparian and Wetlands Characterization and Mapping

Brief descriptions of the major ecological units follow.

The large grassy parks to the southwest, west, and northwest of the mine surface workings reflect a combination of clay

soils and seasonally to yearlong saturation of the upper soil profile. Within the parks closest to the mine sites, the wettest areas occupy the lowest parts of the valley bottoms along small intermittent and perennial streams (figure 2).

The somewhat drier sites border these areas slightly upslope (figure 3). These sites are bordered upslope by upland forests dominated by lodgepole pine growing on coarse glacial till or colluvium (map unit 3U). Farther west (lower in elevation), the parks are dominated by the very wet map unit. Characteristic soils on the wettest portions of the large parks are Histic Cryaquolls, Typic Cryaquolls, Cryohemists, and Cryofibrists (U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff 1999). Soils are saturated above the 12-inch depth throughout the year in most years. Dominant plant associations are water sedge, wolf willow/water sedge,



Figure 2—Map unit 1H: A wet meadow ponded at the surface. Beaked sedge and water sedge dominate the plant community. Soils have an 8-inch-thick fibric organic surface layer.

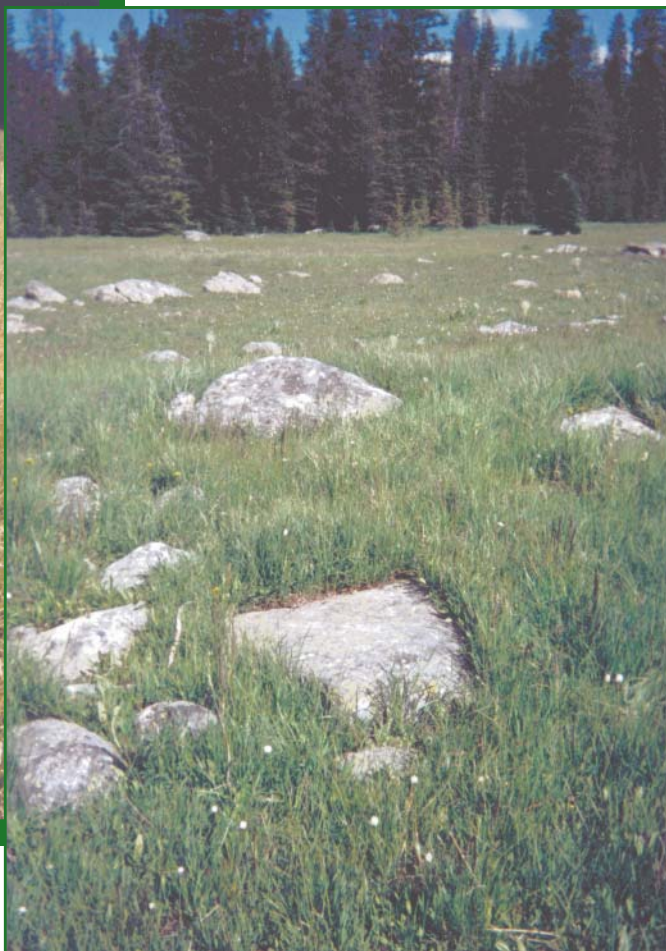


Figure 3—Map unit 2H: A meadow in extremely bouldery glacial till, seasonally saturated in the upper 12 inches of soil which has a thick, dark mineral surface. The plant community is dominated by tufted hairgrass and American bistort.

and tufted hairgrass (Hansen and others 1995). Characteristic soils on the somewhat drier portions of these large parks are Cumulic Cryaquolls, Aquic Argicryolls, and Aquic Haplocryolls. Soils are saturated to the surface during snowmelt and the early part of the growing season. The depth to saturation drops to 20 to 35

inches at the end of the growing season. The dominant plant association is tufted hairgrass.

Very wet Engelmann spruce and subalpine fir areas are associated with coarse stream alluvium and glacial till (figure 4).

Dominant soils are Histic Cryaquepts, Typic Cryaquepts, and Typic Cryaquolls. The depth to saturated soils is to 18 inches throughout the year in most years.

Characteristic plant associations are Engelmann spruce/Holm's Rocky Mountain sedge (an undescribed type), subalpine fir/Labrador tea-bluejoint reedgrass, and Engelmann spruce/bluejoint reedgrass. Slightly drier forested areas form transition zones between these wet forests and the dry upland forests (figure 5).



Figure 4—Map unit 1F: A wet slump deposit at the base of a steep glacial moraine. The soil has 17 inches of saturated hemic (partially decomposed) organic material at the surface. The plant community is mainly Holm's Rocky Mountain sedge, Engelmann spruce, and Jeffrey's shooting star.



Figure 5—Map unit 2F: Foreground is a moderately wet inclusion (too small to map as a separate unit) dominated by common camas, tufted hairgrass, and American bistort. The forested background is the major part of the map unit, dominated by Engelmann spruce, subalpine fir, arrowleaf groundsel, and Labrador tea.

Characteristic soils of the slightly drier forests are Aquic Dystrocrypts and Typic Cryaquepts. Seasonally, the soils are saturated within the upper 12 inches of the soil profile, but the depth to saturation drops to 24 to 40 inches at the end of the growing season in most years. The dominant plant association is subalpine fir/Labrador tea-Labrador tea. Small, grassy, wet meadows included in the wet forests are the wettest sites observed in the assessment area. In these small meadows, shallow ponding of water on the surface was observed. The ponded meadows occur along low-gradient drainageways, slumps, and in seepage areas (figure 6).

In some locations, small areas of the wet forests and very wet, grassy meadows are intermixed in a fine, complex pattern that did not permit mapping the two types separately at the mapping scale used. These areas were mapped as a complex of the two types (figure 7).

The soils and plant associations that characterize these areas are similar to those of their respective components (map units 1F and 1H). The minor differences are described in appendix B.

All areas that were not mapped as water, or as any of the five riparian and wetland map units discussed above, were mapped as upland areas (map unit 3U). The unit includes forested and nonforested lands, and areas of rock outcrop and talus/scree. The soils of the upland meadows and forests are well-drained to excessively drained Typic Dystrocrypts, Andic Dystrocrypts, and Lithic Dystrocrypts. They formed mainly in colluvium (a loose deposit of rock debris that accumulates at the base of a cliff or slope) and glacial till. Water tables and saturated soils may occur below the 40-inch depth examined in this study, but this could not be ascertained from the soil profiles, vegetation, or aerial photos. The dominant plant associations are subalpine fir/grouse whortleberry-pinegrass and subalpine fir-whitebark pine/grouse whortleberry.



Figure 6—A wet meadow slump in map unit 1F. The slump headscarp is in the background. The slump deposit is saturated to the surface and has areas of surface ponding. The soil has 9 inches of fibric organic material over gleyed loam. Holm's Rocky Mountain sedge, beaked sedge, and seep-spring arnica dominate the plant community.

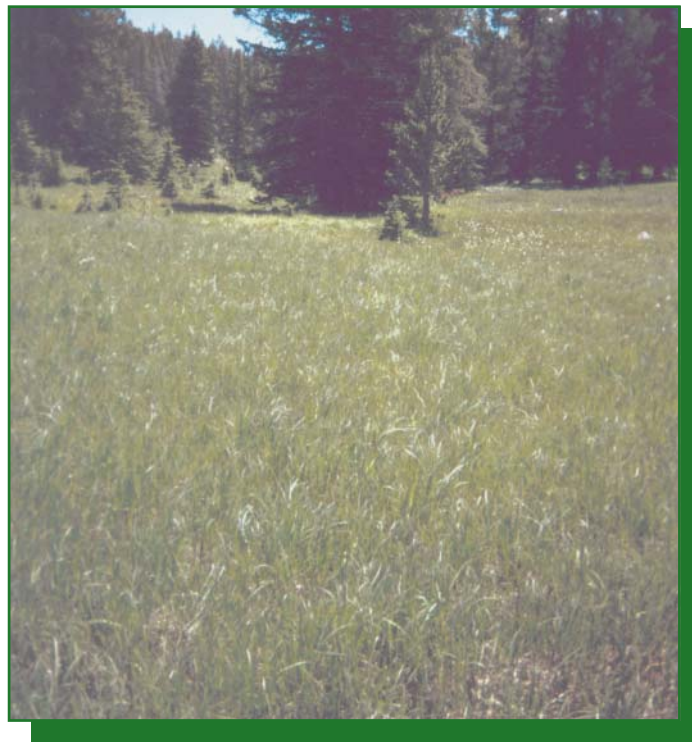


Figure 7—Map unit 1FH: A complex of small areas of wet meadows, saturated to the surface yearlong (foreground). Holm's Rocky Mountain sedge and water sedge mixed with small, wet forested areas (background) having soils saturated within the upper 6 inches yearlong, dominated by Engelmann spruce, subalpine fir, bluejoint reedgrass, and willow. Soils of both components have thick organic surface layers.

Discharge and Recharge Areas

General information about the discharge and recharge areas, including St. Louis Gulch (figure 8), is included in the *Discharge and Recharge Areas* section

(pages 18 and 19). Another area with several sites of apparent groundwater recharge is around the Upper Camp of Elkhorn Mine. A 100- by 300-foot wet sedge meadow (figure 9) is at the toe of the flat, large fill immediately east of the collapsed upper adit portal.

This meadow consists of about 5 inches of saturated organic soil material over 8 inches of extremely acidic, fine sandy loam and silt loam alluvium which is saturated and gleyed. These recent deposits of alluvium buried the native wetland soil. The buried soil profile is still intact and consists of buried organic horizons over dark, gleyed silty clay loam, which overlies gleyed very cobbly sandy loam, likely from glacial till. The recent alluvium is probably associated with the mine operations. Part of the alluvium collected behind a

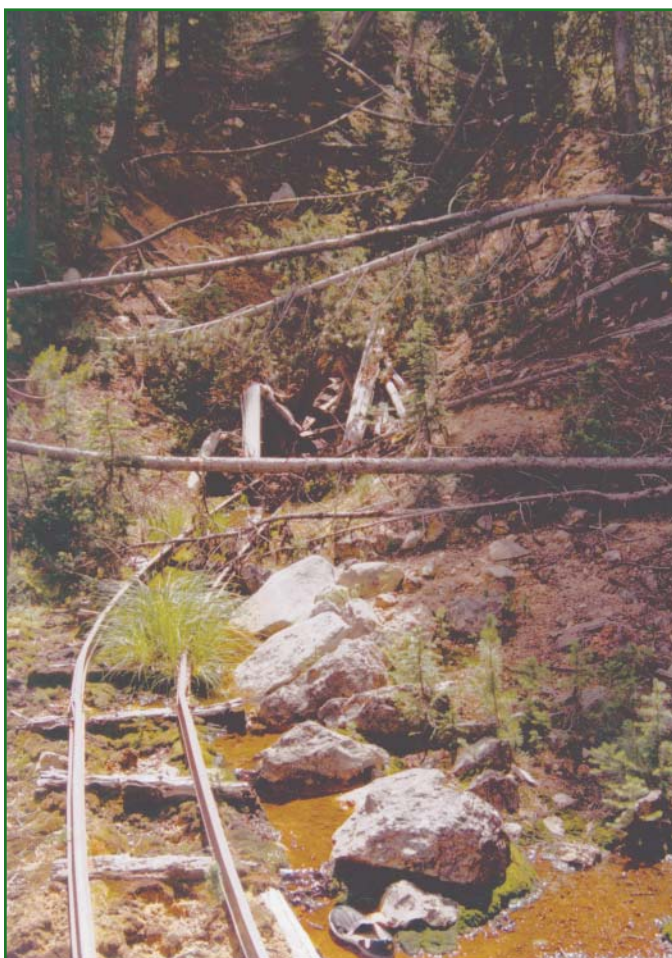


Figure 8—Looking upslope into collapsed hillside mine workings about $\frac{3}{4}$ mile south of the Elkhorn Mine upper adit. A small, very acidic flow (pH 4.2) emerges from the workings, then becomes groundwater 30 feet downstream. The water deposits thick iron coatings on soil and rocks in the shallow channel.



Figure 9—Buried wetland soil at the Elkhorn Mine's upper adit. The upper 13 inches of soil is saturated and covers the original saturated wetland soil. The upper 5 inches has dark brown to reddish fibric organic horizons overlying gleyed, mucky silt loam. The original soil surface (below 13 inches) is fibric to hemic organic material. The tape measure shows inches.

constructed dam at the base of the wet meadow (a complete soil profile description of this site is in the project file). Immediately above this dam is a deposit of saturated silty clay loam that appears to be bentonite or drilling mud with 30- to 35-percent clay. It varies from red to buff grey or black. This is not native material, but its purpose in the mine operation is unknown—perhaps it is drilling mud that was used for exploratory drilling. This clayey alluvium continues in the wet meadow below the dam (stop 67). The native wetland was buried by the clayey alluvium in this lower meadow. The pH of the recent organic deposits and the recent alluvium ranged from 4.3 to 5.5 at a ratio of 1:1 as soil: distilled water. Surface water adjacent to the meadow is pH 4.3.

At the upper end of this wet meadow is a small pond about 7 by 10 feet with several inches of standing, stagnant water (stop 65). This spot appears to have been previously excavated. The pH of the pond water is 2.9 and the pH of the exposed sediment adjacent to the pond ranges from 2.5 to 4.4 (stops 65 and 101). Sediment in the bottom of the pond is less acidic (pH ranged from 4.5 to 6.0) and more reduced (redox potential ranged from +39 to +186 millivolts) than the exposed sediment next to the pond (redox potential ranging from +249 to +341 millivolts). It appears that the surface of the pond represents the level of the water table under the wet meadow discussed

above. The source of the acidity of the pond and adjacent wet meadow is unknown. The pH of the fillslope soil, as well as the soil in the large cutslope above the buried upper adit portal, is about 6.3 to 7.4 (stops 65 and 71).

To the east of the large, flat fill area in the Upper Camp is a large deposit of sandy loam to gravelly sandy clay loam waste-rock material that has very steep sideslopes (stop 100). This material apparently came from the upper workings underground system and was dumped from a rail system. The deposit is about 200 feet wide and 400 feet long. This material was excavated to 52 inches for study. Seven layers were described regarding pH, color, texture, redox potential, percent clay and gravel, temperature, and soil moisture status (stop 100). The pH of this material ranged from 2.9 for red soil to 3.5 for light yellow soil. The redox potential ranged from +433 (light yellow soil) to +543 millivolts (red soil). Colors to 52 inches are red (surface), grayish-yellow, and light yellow. The observed red soil only occurred in the first 16 inches, where it is about 70 percent of the soil volume. Water leaching through this extremely acidic deposit could become quite acidic. If such water reached the underground workings, it would contribute to the problem of acid drainage from the lower adit.

This acidic waste dump is bare of vegetation and shows signs of serious erosion in the form of numerous rills and several

gullies. The eroded material was deposited on the forested slope (15-percent gradient) immediately below the waste dump (stop 92). Much of the sediment is deposited within 200 to 250 feet of the toe of the dump. The thickness of the overburden south of the tramway is about 5 to 8 inches. Some sediment was carried another 200 feet through the tramway corridor before spilling over the steep slope below. Some of the surface water probably becomes groundwater in these deposition zones as the flow rates decrease and surface water flows across the native volcanic ashcap soils of the area. The pH of the overburden and of the buried silt loam volcanic ash soil is 4.2. This contrasts with a pH of 5.2 for native silt loam volcanic ash surface soil in an adjacent area that was not affected by the acidic sediment. A 10-fold increase in the acidity of the native buried soil has occurred since its burial. Acidification and burial of this area south of the tramway has resulted in the death or severe defoliation of most lodgepole pines. North of the tramway, the overburden occurs in patches and is less than 2 inches thick. In this area, the tree canopies appear healthy. Acidification of the buried native soil by water leaching through the acidic overburden indicates that this area has the potential to supply acidified water to the groundwater.

Near the bottom of the tramway corridor is a recent, long narrow slump scar (stop 92). In the forested site nearby, there is a

second slump in extremely bouldery glacial till. The slumps are probably due to a seasonally high water table as evidenced by several large Engelmann spruce trees and a few alder shrubs.

Soil pH of the lower workings below the lower adit were alkaline, ranging from a pH of 7.8 at a depth of 4 to 6 inches, to a pH of 8.5 at 12 to 24 inches (stop 93). The upper 6 inches is gravelly, sandy clay loam that overlies very gravelly sandy loam. Evidence of seasonally saturated soil (fine reddish iron masses) begins at about 12 inches. The upper 10 inches of the profile appear to be topsoil that was added to the site as part of previous reclamation.

Water Samples

The pH of surface water of the lower adit and various locations in Elkhorn Creek was measured on August 30, 2002. The results follow:

- ✕ **Stop 97**—Adit discharge water within several feet of the entrance: pH 6.1, redox +129 millivolts, 45 °F.
- ✕ **Stop 98b**—Adit discharge water about 3 feet before entering Elkhorn Creek: pH 6.1, redox +176 millivolts, 68 °F.
- ✕ **Stop 98a**—Elkhorn Creek 6 feet upstream of the point at which adit discharge water enters Elkhorn Creek: pH 7.1, redox +220 millivolts, 62 °F.

✕ **Stop 98c**—Elkhorn Creek 100 feet downstream from its junction with the lower adit discharge water: pH 6.8, redox +228 millivolts, 62 °F.

✕ **Stop 98d**—Elkhorn Creek about 300 feet upstream from the mill site: pH 6.5, redox +176 millivolts, 65 °F.

✕ **Stop 98e**—Elkhorn Creek near the parking lot and trailhead, downstream from the confluence with the diversion channel: pH 6.6, 58 °F.

✕ **Stop 95**—Elkhorn Creek where forest road 2465 crosses the creek in the northwest corner of section 2: pH 6.4, 45 °F.

✕ **Stop 98f**—A small tributary that crosses the trail to Coolidge about 200 yards upvalley from the parking lot and trailhead that drains the east wall of Elkhorn trough: pH 7.3, 58 °F.

These data indicate that the lower adit water (stops 97 and 98b) is 10 times more acidic than Elkhorn Creek water that is unaffected by the adit discharge water (stop 98a). The addition of the adit water lowers the pH of Elkhorn Creek from 7.1 (stop 98a) to 6.8 and 6.5 (stops 98c and 98d) downstream of the junction. The pH values of the adit discharge water are higher than those reported in a previous

Montana Bureau of Mines and Geology report. The use of a relatively inexpensive field pH meter on the field samples mentioned above, may account for some—but probably not all—of this difference.

The adit discharge water is more reduced (redox +129 millivolts at stop 97) than that of Elkhorn Creek above the junction with the adit discharge (redox +220 millivolts at stop 98a). The redox potential of the adit water increased from +129 millivolts (stop 97) to +176 millivolts by the time it reached the junction with Elkhorn Creek (stop 98b). This discharge water runs across several hundred feet of wetland before reaching this junction. The wetland appears to influence the redox potential as well as water temperature, which rises from 45 °F at the adit portal to 68 °F by the time it reaches Elkhorn Creek. The adit discharge water does not appear to affect the redox potential of Elkhorn Creek 100 feet downstream from this junction (+228 millivolts at stop 98c), but within another couple hundred feet downstream, the redox drops again to +176 millivolts at stop 98d. The pH drops from 6.8 to 6.5 and the water temperature increases from 62 to 65 °F between these two points of Elkhorn Creek. Perhaps unidentified underground sources between the adit and the mill sites are responsible for these changes in water characteristics.

Appendix B—Elkhorn Mine Riparian Area and Wetland Map Unit Descriptions

The riparian and wetland areas surrounding the Elkhorn Mine site are characterized by various combinations of soils, vegetation, and seasonally high water tables. Five riparian/wetland map units were developed to delineate these moist areas. Additionally, an upland map unit was developed for areas that were not riparian or wetland areas. These six map units are described here. Bodies of surface water large enough to be mapped comprised the seventh map unit. The map unit symbols are appropriate combinations of soil wetness and vegetation types as follows:

First digit of the map symbol:

✕ **1** represents the wettest soil conditions.

✕ **2** represents slightly drier soil conditions.

✕ **3** represents the well- to excessively-well-drained soil conditions of uplands.

Second digit of the map symbol:

✕ **F** represents forested areas.

✕ **H** represents areas dominated by shrubs or grasses, sedges, and forbs.

✕ **U** represents upland areas.

✕ **W** denotes mappable bodies of surface water.

Map Unit 1F—Forested sites with soils typically saturated within the upper 18 inches throughout most years.

This map unit mainly occurs adjacent to ponds and on floodplains of small perennial streams. It also occurs in sloping areas where groundwater surfaces as seeps and springs and in areas of recent slumps that have not yet developed mature drainage systems. The tree canopy is closed to fairly open and consists of conifers such as Engelmann spruce, subalpine fir, and lodgepole pine. Where the canopy is open, a luxuriant, diverse understory of hydrophytes develops, including species such as bluejoint reed-

grass, Holm's Rocky Mountain sedge, and Labrador tea. These are very wet sites and qualify as wetlands under most wetland classification and delineation systems (Cowardin and others 1979; U.S. Army Corps of Engineers 1987; U.S. Fish and Wildlife Service 1989; Brinson 1993; Committee on Characterization of Wetlands 1995; Hansen and others 1995). Soils are hydric, vegetation is hydrophytic, and water tables are at the surface or within a couple of inches of the surface for long enough and frequently enough to affect the surface soil layers and the vegetation types. Evidence of a fluctuating water table occurs within the upper 5 inches of soil in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion.

Less than 10 percent of the areas mapped as this map unit consist of drier soils having seasonally high water tables deeper in the soil profile. The vegetation on these areas reflects the drier soil conditions. Small areas of wet meadows similar to the ecological conditions of map unit 1H are also included in this map unit.

Dominant soils: Typic Cryaquolls, Histic Cryaquepts, and Typic Cryaquepts.

Minor soils: Typic Cryohemists, Histic Cryaquepts.

Depth to saturated soil: 0 to 18 inches, season long in normal or wetter years.

Depth to redoximorphic features: 0 to 5 inches.

Dominant soil textures from 0 to 40 inches deep: organic peat and muck 2 to 20 inches thick, overlying mucky silt loam that overlies very cobbly to very gravelly sandy loam derived from glacial till.

Soil parent material: organic deposits and coarse alluvium over glacial till.

Dominant plant associations: Engelmann spruce/Holm's Rocky Mountain sedge (undescribed type), subalpine fir/Labrador tea-bluejoint reedgrass, and Engelmann spruce/bluejoint reedgrass.

Minor plant associations: Engelmann spruce/common horsetail.

Plant species: Highest frequency of occurrence: Engelmann spruce, Holm's Rocky Mountain sedge, Labrador tea.

Moderate frequency of occurrence: subalpine fir, brook saxifrage, arrowleaf groundsel, Jeffrey's shooting-star.

Lowest frequency of occurrence: small-winged sedge, common horsetail, alpine timothy, water sedge, tufted hairgrass, seep-spring arnica.

Species occurring on the drier site inclusions: green false hellebore, western twinflower, western meadowrue, sickletop lousewort, swamp currant.

Map Unit 2F—Forested sites with soils typically seasonally saturated within 2 to 12 inches deep in most years; depth to saturated soil drops to 24 to 40 inches during the latter part of the growing season.

This map unit occurs mainly on somewhat poorly to poorly drained terraces, on low, gently sloping glacial moraines, and on the slopes of moderately steep, colluvial stream headlands. Narrow bands of this riparian/wetland type can also be found at the edges of areas mapped as wetter types, such as map units 1F and 1H.

These bands are transition zones between the lowland and upland areas and are too narrow to map at the mapping scale used for this project. The tree canopy of this map unit is mostly closed with some small openings. Tree species include Engelmann spruce, subalpine fir, and lodgepole pine. Many of these areas would qualify as wetlands under the U.S. Fish and Wildlife Service system (Cowardin 1979). Some sites might meet the U.S. Army Corps of Engineers (1987) and the Federal Interagency Committee for Wetland Delineation (U.S. Fish and Wildlife Service and others 1989) definitions of wetlands. Most of these areas would not meet the definitions because the soil is not saturated to the surface frequently

enough or long enough to meet the criteria for hydric soils. In addition, the vegetation is marginally hydrophytic to nonhydrophytic, depending on local conditions. Evidence of fluctuating water tables occurs mostly at depths of 2 to 36 inches in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion.

Moderately dry, upland sites and wetter sites that are similar to map units 1F and 1H occupy less than 10 percent of the lands in this map unit.

Dominant soils: Aquic Dystrocrypts and Typic Cryaquolls.

Minor soils: Typic Cryaquepts.

Depth to saturated soil: seasonally high, 2 to 12 inches; seasonally low, 24 to 40 inches.

Depth to redoximorphic features: 2 to 30 inches.

Dominant soil textures from 0 to 40 inches deep: silt loam over silty clay loam or sandy clay loam.

Soil parent material: alluvium, colluvium, and glacial till.

Dominant plant associations: subalpine fir/Labrador tea-Labrador tea.

Minor plant associations: subalpine fir/bluejoint reedgrass-bluejoint reedgrass.

Plant species: Highest frequency of occurrence: Engelmann spruce, subalpine fir, Labrador tea, arrowleaf groundsel, grouse whortleberry, pinegrass, western meadowrue.

Moderate frequency of occurrence: bluejoint reedgrass, heartleaf arnica, *Lupinus* species.

Lowest frequency of occurrence: lodgepole pine, glacier lily, one-sided wintergreen, green false-hellebore, bracted lousewort, Jeffrey's shooting-star, swamp currant, broadleaf arnica, red mountain-

heath, whitebark pine (the last two species occur only at the highest elevations in this map unit, generally above 8,400 feet).

Species occurring on the hydric soil inclusions are: common camas, tufted hairgrass, Holm's Rocky Mountain sedge, and small-winged sedge.

Map Unit 1H—Graminoid- and forb-dominated wet meadows with soils typically permanently saturated to the surface.

This map unit is a major component of the large meadows that occur to the southwest, west, and northwest of the Elkhorn Mine site. It occurs in the wettest portions of these grassy parks. It also occurs on low floodplains of small perennial streams and in alluvial basins adjacent to or near ponds. These soils formed in relatively fine-textured alluvium and colluvium. This fine soil material is found in slowly to very slowly permeable layers that tend to perch water tables (hold at unusually high levels). A weak artesian system was observed at one location. These areas lack tree canopies. However, a few widely scattered, stunted Engelmann spruce, lodgepole pine, and subalpine fir trees can be found growing on small, raised hummocks. At some sites there is a shrub canopy of wolf willow. Other sites lack this willow component and are dominated chiefly by sedges, grasses, and forbs that have an affinity for very wet soils. Essentially all of these areas would qualify as wetlands using any of the commonly used wetland classification or delineation systems. Soils are hydric and the vegetation is hydrophytic. Wetland hydrology is prevalent throughout the map unit with soil saturated to the surface or surface water ponding, at least seasonally. Most areas within the map unit are saturated to the surface yearlong. The soils often have a 5- to 12-inch-thick layer of peat and muck at the surface. Some soils have peat and muck deeper than 40 inches and are classified as organic soils (Histosols). This accumulation of organic plant matter is caused by conditions of prolonged and frequent

saturation to the soil surface. These organic materials serve as sponges, storing many times their own weight of water.

Small areas of wet forest are included in this unit. These areas have ecological conditions similar to those discussed in map unit 1F. Also included in the large parks are areas similar to map unit 2H. These occur on portions of map unit 1H that are slightly higher than the very poorly drained main part of the unit. These grassy inclusions are seasonally saturated to the surface, but the depth to saturation drops 6 to 12 inches during the latter part of the growing season.

Dominant soils: Histic Cryaquolls, Typic Cryaquolls, Cryohemists, Cryofibrists.

Minor soils: Aquic Haplocryolls, Typic Cryaquepts.

Depth to saturated soil: normally saturated to the surface yearlong, some local ponding.

Depth to redoximorphic features: 0 inches.

Dominant soil textures from 0 to 40 inches deep: peat and muck over mucky silt loam to silty clay loam over sandy loam or sandy clay loam.

Soil parent material: organic deposits over alluvium or colluvium.

Dominant plant associations: water sedge, Holm's Rocky Mountain sedge, and wolf willow/water sedge.

Minor plant associations: tufted hairgrass, beaked sedge, Drummond willow/beaked sedge.

Plant species: Highest frequency of occurrence: water sedge, tufted hairgrass, and beaked sedge.

Moderate frequency of occurrence: Holm's Rocky Mountain sedge, wolf willow, elephanthead.

Lowest frequency of occurrence: bluejoint reedgrass, small-winged sedge, Oregon saxifrage, seep-spring arnica, sweet-marsh butterweed, showy fleabane, Drummond willow.

Species growing on slightly raised hummocks include Engelmann spruce, sub-alpine fir, and lodgepole pine. The spruce and fir trees also occur as inclusions of wet, forested sites in the map unit. The slightly drier grassy meadow inclusions are dominantly tufted hairgrass communities having reduced sedge components. Inclusions comprise less than 10 percent of this map unit.

Map Unit 2H—Graminoid- and forb-dominated plant communities growing on soils seasonally saturated to the surface; depth to saturated soil drops to 20 to 35 inches during the latter part of the growing season.

This map unit occupies major portions of the large meadows that occur to the southwest, west, and northwest of the Elkhorn Mine site. It encompasses the somewhat poorly drained to poorly drained soils of these meadows. These soils typically occur upslope from areas of the parks mapped as the wetter map unit 1H and downslope from the dry upland forested areas mapped as 3U. It is rare to find this map unit in settings other than these large, grassy parks. The soils formed in relatively fine-textured alluvium and colluvium. This fine soil material is found in slowly to very slowly permeable layers that can perch water tables. Glacial till probably underlies some areas of this

alluvium. Low moraines formed basins into which the alluvium was deposited. The soils have humus mixed with the mineral soil material in the upper foot or so of the profile, reflecting abundant fine root production of graminoids and forbs along with adequate soil moisture. In most years, the depth to saturated soil is about 0 to 8 inches during the wettest periods of the year, dropping to 20 to 35 inches during the dry periods of July, August, and September. Evidence of fluctuating water tables exists in the upper 3 inches of the soil profile as redoximorphic features such as reddish iron masses and low chroma iron depletions. Except for small areas of forested land included in this unit, it has graminoid- and forb-dominated plant communities. The plant species characteristic of this map unit have a moderate affinity for saturated soils; they are fairly tolerant of soils that are seasonally saturated to the surface. Many of these species would not tolerate soils permanently saturated to the surface. Most areas within this map unit would meet the definition of wetlands in most commonly used classification and delineation systems. Soils are hydric, vegetation is hydrophytic, and the soil is saturated to the surface frequently enough and long enough to meet wetland hydrology criteria.

Forested areas with somewhat poorly drained soils are included in this mapping unit. These areas also have seasonally high water tables, but the depth to saturated soils is greater than for the grassy portions of the unit. Small areas that are wetter than the characteristic grass/forb sites occur in slight depressions and on floodplains of small streams that traverse the map unit. These sites are ecologically similar to those of map unit 1H.

Dominant soils: Aquic Argicryolls and Cumulic Cryaquolls.

Minor soils: Typic Cryaquolls and Aquic Haplocryolls.

Depth to saturated soil: seasonally high depths of 0 to 3 inches, dropping to seasonally low depths of 20 to 35 inches.

Depth to redoximorphic features: 0 to 3 inches.

Dominant soil textures from 0 to 40 inches deep: silt loam to bouldery silt loam overlying sandy clay loam or bouldery sandy clay loam.

Soil parent material: alluvium and colluvium over glacial till.

Dominant plant associations: tufted hairgrass.

Minor plant associations: beaked sedge and subalpine fir/bluejoint reedgrass-bluejoint reedgrass occurring as inclusions.

Plant species: highest frequency of occurrence: tufted hairgrass, American bistort, small-winged sedge, alpine timothy.

Moderate frequency of occurrence: lodgepole pine in areas of inclusions.

Lowest frequency of occurrence: common camas, little larkspur, arrowleaf groundsel, showy fleabane.

Map Unit 1FH—Lands including wet forested areas and wet shrub/graminoid/forb areas.

This map unit occurs mainly on floodplains along moderately wide drainageways (typically 100 to 300 feet wide) and in local areas of low glacial moraines dotted with kettle depressions. The wet, forested areas within this unit resemble those in map unit 1F, but minor differences in vegetation were observed. Similarly, the wet shrub/graminoid/forb areas resemble those in map unit 1H, with minor variations in vegetation. The two types are intermixed in complex patterns at a scale too small to delineate separately at the mapping scale used. The soils are similar to those of map units 1F and 1H. The soils of the wet forested areas have organic surface horizons up to 6 inches thick overlying silty alluvium. The substratum is loamy sand. The soils of the wet shrub/graminoid/forb areas have organic surfaces up to 17 inches thick that overlie silty and clayey alluvium. The temporal patterns and duration of soil saturation are also similar to 1F and 1H. In the wet forested sites, evidence of a fluctuating water table occurs within the upper 4 inches of soil in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion. Soils of the wet nonforested areas are saturated to the surface yearlong in most years. Both components qualify as wetlands in commonly used wetland classification and delineation systems.

Less than 5 percent of this map unit has inclusions of areas with soils that have slightly greater depths to seasonal soil

saturation; these small areas are similar to those mapped as map units 2F and 2H elsewhere.

Dominant soils: Typic Cryaquolls and Typic Cryaquepts.

Minor soils: Histic Cryaquepts.

Depth to saturated soil: 4 to 20 inches seasonlong in normal or wetter years.

Depth to redoximorphic features: 0 to 4 inches.

Dominant soil textures from 0 to 40 inches deep: organic peat and muck 3 to 6 inches thick, overlying silt loam, which overlies loamy sand.

Soil parent material: organic deposits and coarse to moderately fine-textured alluvium.

Dominant plant associations: subalpine fir/bluejoint reedgrass-bluejoint reedgrass.

Minor plant associations: Engelmann spruce/Holm's Rocky Mountain sedge (undescribed type), subalpine fir/Holm's Rocky Mountain sedge (undescribed type).

Plant species, highest frequency of occurrence: Engelmann spruce, Holm's Rocky Mountain sedge, bluejoint reedgrass.

Moderate frequency of occurrence: subalpine fir.

Lowest frequency of occurrence: Labrador tea, willow.

Map Unit 3U—Forested and nonforested upland areas having no evidence of soil saturation within 40 inches of the soil surface.

This map unit occupies all areas of the riparian/wetland assessment area that were not mapped as units 1F, 2F, 1H, 2H, 1FH, or W. It includes areas with soil cover and nonsoil, miscellaneous areas of rock outcrop, and talus/scree. Both in the field and on color aerial photos, these areas show no evidence of riparian/wetland vegetation or soil conditions. The exceptions are areas that are too small to delineate at the mapping scale used. The soils of these upland forests and meadows are well drained to excessively drained Typic Dystrocryepts, Andic Dystrocryepts, and Lithic Dystrocryepts that formed mainly in colluvium and glacial till. The vegetation mostly consists of forests of lodgepole pine, Douglas-fir, subalpine fir, and whitebark pine. The understory consists of plant species indicative of upland soil conditions and includes grouse whortleberry, heartleaf arnica, pinegrass, and elk sedge. The dominant plant associations are subalpine fir/grouse whortleberry-pinegrass and subalpine fir-whitebark pine/grouse whortleberry.

Information about soil depths below 40 inches is not available. Water tables and saturated soils may occur below this depth, but they could not be ascertained from the soil profiles, vegetation, or aerial photos.

Map Unit W—Bodies of water large enough to delineate at the mapping scale used, including lakes and glacial ponds.

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Ken McBride graduated from the University of Wisconsin with a degree in botany. Graduate studies in soil science led to a position conducting soil surveys in southern Colorado for the Natural Resources Conservation Service (then known as the Soil Conservation Service). Three years later he transferred to the Rio Grande National Forest, where he continued soil mapping. In 1988 he became a soil

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Library Card

Hargrave, Phyllis; Metesh, John J.; McBride, Ken; Oravetz, Steve. 2003. Investigative methods for controlling groundwater flow to underground mine workings. Tech. Rep. 0371–2801–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 42 p.

Controlling groundwater recharge to mine workings requires identifying, characterizing, and controlling surface water and groundwater that may infiltrate mine workings. This document's premise is that good-quality surface water and groundwater can be diverted from the workings to prevent the water from interacting with pyrite and other metal-bearing

minerals that cause acid mine drainage. Infiltration controls may include grouting from outside the workings, streambed or soil treatment to reduce infiltration capacity, storm water and runoff management, and recontouring or regrading the natural recharge areas. Although this paper describes methods for collecting data for controlling groundwater recharge to the mine workings, many of the data collection methods could be applied when investigating other treatments, such as adit plugging, grouting or capture, and treatment and disposal of acid mine drainage. This is the fourth report on acid mine drainage produced through a partnership between the Montana Bureau of Mines and Geology and the Missoula Technology

and Development Center. The other reports are:

- ✕ Adit Discharge Monitoring Summary for the Elkhorn and Charter Oak Mines, MT (0071–2858–MTDC)
- ✕ Using Recharge Control to Reduce Mine Adit Discharges: A Preliminary Investigation (0071–2804–MTDC)
- ✕ Treating Acid Mine Drainage From Abandoned Mines in Remote Areas (9871–2821–MTDC)

Keywords: acid mine drainage, ground water, groundwater, mined land, recharge control, remediation, water quality

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