Best Practices in Abandoned Mine Land Reclamation:

the remediation of past mining activities

Colorado Division of Minerals and Geology

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This manual is also available as a Printable
Document Format (PDF) file on the Internet
at www.mining.state.co.us/bmp.pdf

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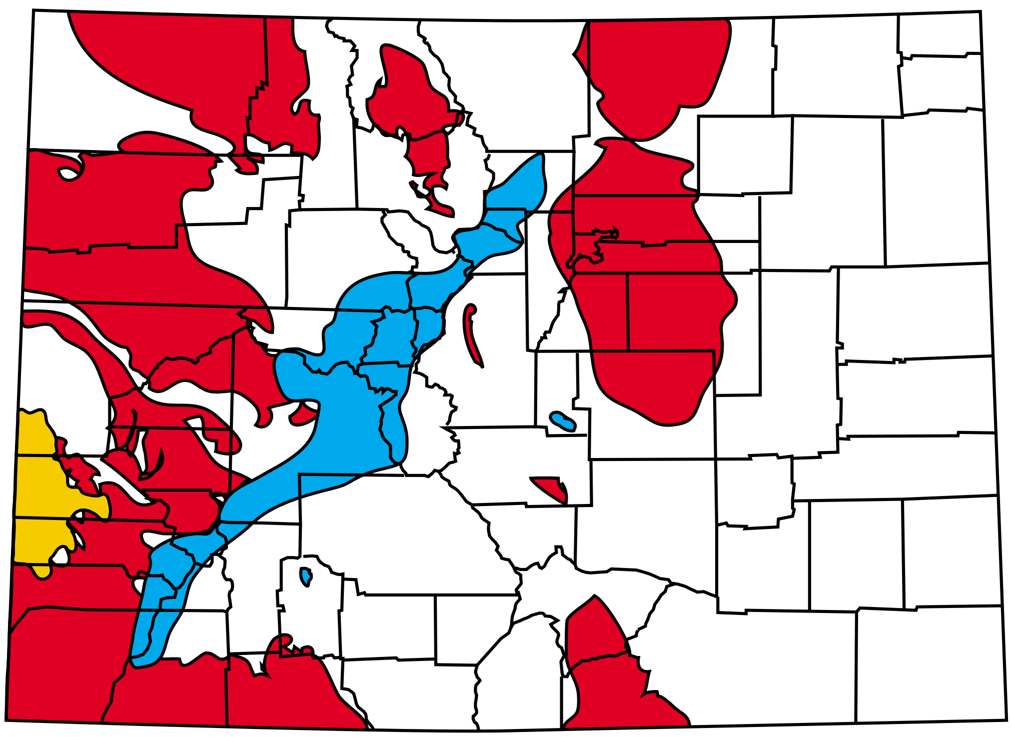
Introduction

Most of the mining of gold, silver, lead, zinc and other metals occurred in the Colorado Mineral Belt from 1860 to 1975, although some mining operations are still active today. Mining practices during the early days allowed the mine owners to simply abandon their mines without consideration of the impact on streams, water quality, slope stability and safety. Often old mining properties within the Colorado Mineral Belt contain abandoned mine workings, mine waste and/or mill tailings.



Map of minerals found in Colorado

● *coal* ● *uranium* ● *other minerals*

Accessible mine openings and associated mine workings can be a safety hazard and a liability on the part of the landowner if someone is injured or killed in them.

Mine waste is the rock taken from a mine that is of no economic value. Although some consider mine waste piles to be aesthetically pleasing because of their historic nature, these piles are generally difficult to vegetate and may pollute adjacent streams.

Mill tailings are the waste product of ore-processing facilities. Mill tailings generally exit the mill as slurry and in the past were deposited wherever convenient, usually in a stream valley. Because mill tailings consist of very small particles they are highly susceptible to erosion or removal by wind and water. In addition, areas covered by mill tailings are generally difficult to vegetate, due to the high concentration of heavy metals and acidity associated with waste materials high in pyrite.

Purpose of this Manual

This manual was compiled to assist people in:

- determining if an area has been impacted by past mining;
- determining the extent of environmental problems caused by past mining;
- providing options to address the environmental and safety problems caused by past mining, especially those posed by waste rock dumps, mill tailings piles, and hazardous openings;
- providing a list of contacts to acquire additional information about reclamation practices and current regulations governing environmental problems associated with properties mined in the past.

How do you determine if an area has been impacted by past mining?
Walk the area and look for evidence of past mining activity, such as

accessible openings into the rock or soil;

drainage from suspected mine openings (even if collapsed);

piles of barren, unnatural-looking discolored rock (often yellowish or reddish);

drainage from the base of a waste rock pile;

large areas of barren, brown or gray sandy or fine-grained material;

drainage from the low point of a mill tailings pile;

pools of discolored (often orange/red) water on barren, sandy or fine-grained soil;

waste piles in winter after snowfall, when snow melts more quickly than on surrounding areas;

areas of dead vegetation;

If you suspect past mining activity, additional information can often be obtained from the following sources:

- the town or county in which the property lies;
- mining/environmental groups in the area;
- county health departments;
- local watershed groups;
- local libraries;
- Colorado Division of Minerals and Geology, Inactive Mine Reclamation Program (303-866-3567)
- Colorado Department of Public Health and Environment, Water Quality Control Division (303-692-3500)
- Bureau of Land Management Mineral Claims Database (Public Room, 303-239-3600)

Old mine maps and maps showing locations of old mills are sometimes available through these sources. Water quality information from previous testing is available through the Colorado Department of Public Health and Environment, the county health department, local stakeholders groups and the state government agencies listed above.

If you suspect that past mining has occurred in an area but cannot locate any information about mining in the area, it does not necessarily mean no mining occurred. Thousands of unpatented claims and small exploratory mining operations throughout Colorado exist, most of which were never recorded in state or local government offices.

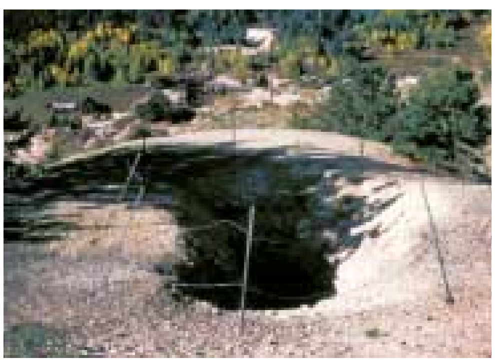
Past Mining and its Impact on You

Why should you be concerned if your property was impacted by past mining?

In some cases, the impact of past mining on your property may affect adjacent properties and/or nearby streams. In many cases, this initiates complaints from the local government or adjacent landowners. In other cases, government agencies may be involved in investigation and clean-up of a property adjacent to yours. Additionally, if your property has been impacted by past mining, you may be required to participate in the clean-up plan.

Both state and federal agencies have regulations pertaining to abandoned and active mines.

Regulations are continually revised. Contact the Colorado Department of Public Health and Environment, Water Quality Control Division and the Environmental Protection Agency for details on the current regulations pertaining to mine and mill sites.



Abandoned mine shaft with ineffective fence and collapsing walls

What are the problems caused by past mining?

Historical mining operations cause problems in three general areas:

Unsafe mine openings: Underground mines are accessed either by vertical shafts, inclined shafts or horizontal portals. A vertical shaft can be hundreds of feet deep and may not be obvious until you are standing next to it. In addition, the ground next to the shaft may be unstable. Inclined shafts and portals are somewhat less hazardous, but the ground around them may also be unstable.

Inactive mines are not ventilated, and therefore are likely to contain stale, oxygen-deficient air and possibly poisonous and even explosive gases. Old mine workings should NEVER be entered without properly trained personnel equipped with the proper safety equipment.

Drainage from an abandoned mine adit

Contamination of streams by acidic drainage: Acidic water (commonly called acid mine drainage) forms from the chemical reaction of surface and ground water with rock containing sulfur. The product of this reaction is sulfuric acid, which then leaches metals (iron, copper, zinc, manganese, cadmium and lead) from mineralized rock and keeps the metals dissolved in the water. This acidic metal-laden drainage can adversely impact aquatic and human health when it enters the surface and groundwater systems. Elevated levels of metals can cause fish and other aquatic life to die and drinking and agricultural water sources to be contaminated.

Much of the rock associated with mines and ore deposits in the Colorado Mineral Belt contains pyrite, a sulfur-bearing mineral, so acid mine drainage from past mining operations is common. Acid mine drainage can form in mines and in water percolating through waste rock dumps and mill tailings piles.

Acid Mine drainage containing heavy metals

Contamination of streams by excess sediment: Sediment related to mining and milling activities consists of small particles that often contain high concentrations of heavy metals. Because of the toxic nature of this sediment, plants do not readily grow on it, and as a result, it is easily removed and transported by water and wind. Mining-related sediment can contaminate streams, rivers, wetlands and other riparian areas. Heavy metals in the sediments are released into the water in streams and ponds, poisoning the fish and other aquatic creatures. The mill tailings particles can destroy aquatic habitats by covering the stream bottom and suffocating the fish eggs, by filling in pools which serve as fish habitat. Sediment can also affect suitability of the water for human uses such as agriculture and drinking water.

Mill tailings being eroded by an adjacent stream

What is the extent of the problems caused by past mining on your property?

Unsafe Mine Openings: Any open mine workings on your property are a potential liability. Such openings can be unstable and possibly contain oxygen-deficient air or poisonous gases. These openings should be approached with caution. Investigation of these openings should begin with a search for information at the local library, county offices, local mining/environmental groups or the Colorado Division of Minerals and Geology, Inactive Mine Reclamation Program. If access into an abandoned mine is necessary, the investigation should be conducted by someone properly trained and familiar with the necessary safety precautions.

Draining Mine Openings: If drainage is coming from a mine opening on your property, it may be contaminating adjacent streams. Warning signs that the drainage may be acidic and contain metals include dead vegetation or red/orange staining on the rocks and soil in the area where the drainage exits the mine. This drainage water should be tested to evaluate its pH (acidity) and metals content. Two simple inexpensive tests are described later and will provide a preliminary assessment of the nature and extent of contamination in the drainage at your site.

Waste Rock Piles: The extent of the problems caused by waste rock piles or dumps depends largely on their location.

A waste rock pile located away from streams and ponds that are well or moderately-well vegetated with no visible staining of the ground at the lower end, is probably not a significant problem to the environment and needs no further action.

A waste rock pile located away from streams and ponds that are not well vegetated and shows signs of staining and/or dead vegetation at the lower end, may be contributing metals to the groundwater system.

A waste rock pile located in a stream or drainageway may be contributing metals and lowering the pH of the stream as it percolates through the rock.

A waste rock pile located directly below a collapsed or uncollapsed mine opening that is draining may be contaminating the mine drainage further as it flows through and leaches the waste rock.

If there is drainage from a waste rock pile, the drainage should be tested to evaluate its effect on adjacent streams and groundwater. Samples from above or upstream of the waste dump and below or downstream of the waste

Ineffective Barrier at an abandoned coal mine allowing access to the workings

Snowmelt and rainfall percolating through old mine waste has killed the vegetation downhill dump should be tested using the simple inexpensive tests suggested later for pH and metals. The results should then be compared to assess the impact of the pile on the drainage.

Mill Tailings: Because mill tailings were generally in a slurry form when originally deposited, they are almost always located in a stream valley or depression where water collects. Evaluating the extent of the problem caused by tailings requires determination of their exact location, current condition and whether they are being eroded and transported off the site by wind or water. Some questions to be considered are:

Are they wet or dry?
Are they located directly in a flowing stream?
Are they sitting in a depression filled with water?
Is there vegetation on the mill tailings? Is it alive or dead?
Are there drainage paths on the surface of the tailings?
Are there pools of discolored water on the top of the tailings?
Is there drainage coming from the lower end of the tailings?
Is the water in the stream below the tailings cloudy?
Is there white, gray, or light brown fine sediment (tailings) in amongst the rocks and pebbles of the stream below the tailings?
Do the tailings create dust when the wind blows?

Tailings escaping from their present location: tailings can escape either by erosion into a stream or by blowing in the wind, posing a problem. Likewise, if the water coming from the tailings is contaminated, the tailings may be a problem. Water pooled on the tailings and draining from the lower end of the tailings and in the stream below the tailings should be tested to evaluate the impact of the tailings on the surrounding environment. The pH and metals content of the tailings should also be tested. Three simple, inexpensive tests are described on the next page. These will help you do a preliminary assessment of the nature and extent of the problem.

Three Simple, Inexpensive tests to Evaluate the drainage and Tailings in Previously Mined Areas

MOST IMPORTANT FOR ALL TESTS: For any test, be sure to write down the date, time, exact sample location, results of your test and any observations you make at the sample location or during the test and save that information. It could save you money in the future.

1. A simple test of pH (how acidic the water is):
This test will provide an estimate of the pH of the water. The pH scale ranges from 0 to 14. A pH of 7 is neutral. A pH reading below 7 indicates the water is acidic. A pH reading above 7 indicates the water is alkaline. Rainwater is naturally between pH 6 and 7 in most areas. Drainage directly affected by mining is often low pH indicating that it is acidic, although in some drainages the pH is high, indicating alkaline conditions. This test can be done by purchasing pH or litmus paper at a drugstore, hobby shop, hardware store or scientific supply store. Follow the directions on the litmus paper package and stick the paper into the drainage water. If the resulting pH is either less than 5 (acidic) or greater than 9 (alkaline), this drainage may be causing problems to the environment. If the water you are testing is in a fast-moving stream, get a small sample of the water in a clean jar and then put in your pH (litmus) paper.

HINT: You probably will want to test during both low-flow (fall) and high-flow (spring) conditions and compare the results. Be sure to write down the date, time, exact sample location and results of your test.

2. A simple test to evaluate whether metals are present in the water:
Often, a visual inspection of the drainage will indicate metals in the drainage. A red/orange coating on the rocks indicates that the drainage contains high iron. A black coating on the rocks indicates high manganese. A green/blue coating indicates either high copper or high silver. A white coating indicates high aluminum. Note that other metals may also be present in lesser quantities, but their signature may be masked by high iron or some other metal.

The following simple test of the drainage water can be performed to indicate the presence of metals (however, it will not differentiate which metals are present and which are not):
Obtain about one cup of the drainage in a clean dry glass jar or coffee cup. Add about one teaspoon of baking soda, swirl the mixture around, then let it sit and watch to see if the baking soda will completely dissolve. it will do so in good, clean water. However, if a fluffy sediment forms (precipitates) and collects at the bottom of the sample jar, that is an indication that there are metals in solution in the water.

If metals are present, the next step is to have a more comprehensive test performed on the drainage water by a water-testing lab. Call the lab to find out about the procedure for sampling the drainage. The new sample should be tested for at least cadmium, copper, iron, lead, manganese and zinc. This test is generally about $125.

3. A simple way to evaluate the contamination of the tailings:
This method will allow you to test the pH and metals content of mill tailings. Collect a sample of tailings (about one cup) and place it in a doubled coffee filter over a strainer over a clean glass or ceramic dish, jar or bottle. Pour about one cup of distilled water into the tailings and collect the drainage that exits from the base of the coffee filter in the dish, jar or bottle. Test this drainage using the two tests discussed above for pH and metals. Because the tailings will vary in degree of mineralization, you should collect and test samples from at least 10 locations in the tailings pile. Samples should be taken from

within the tailings (dig a hole!), as well as from the surface of the tailings.

What are feasible solutions to problems caused by past mining?

Feasible solutions to the impacts of past mining are called "Best Management Practices" or BMPs. Often, incorporation of only one BMP will solve a particular problem. Sometimes, several BMPs must be incorporated. A list of commonly used BMPs is shown below. This list offers many different solutions that can apply to a wide variety of problems and involve varying amounts of construction and maintenance, and a range of costs. Each of these solutions is described at the end of this brochure. In some cases, a description of the construction of the BMP is included.

Hydrologic Controls: Most hydrologic controls are preventive measures. The goal of these BMPs is to inhibit the process of acid formation and/or heavy metal dissolution. If hydrologic controls can minimize or even eliminate water from entering a mine or coming into contact with sulfide rocks, waste rock or tailings, they can be the best, most cost-effective reclamation approach because they eliminate the cause of the problem rather than treating the symptoms.

- BMP #1: diversion ditches
- BMP #2: mine waste rock/tailings removal and consolidation
- BMP #3: stream diversion
- BMP #4: erosion control by regrading
- BMP #5: capping
- BMP #6: revegetation

Passive Treatment: Passive treatment generally refers to a range of drainage treatment techniques that do not require continuous electrical or chemical inputs or frequent maintenance. These methods do not eliminate the cause of the problem, but in many cases, may be the only feasible alternative to address the problem.

- BMP #7: aeration and settling ponds
- BMP #8: sulfate-reducing wetlands
- BMP #9: oxidation wetlands
- BMP #10: other BMPs to treat acid mine drainage

Costs: Costs of BMPs vary widely from year to year and location to location, however, a sheet showing the general range of costs for some of the elements of the BMPs discussed in this booklet is available from the Colorado Division of Minerals and Geology, Inactive Mine Reclamation Program.

What is the best solution for your problem?

General flow charts for determining possible solutions for mine waste and tailings pile problems are provided in the next two pages. These charts are designed to guide you to possible alternatives. Conditions at each site, however, will vary.

Who can you contact if you have questions?

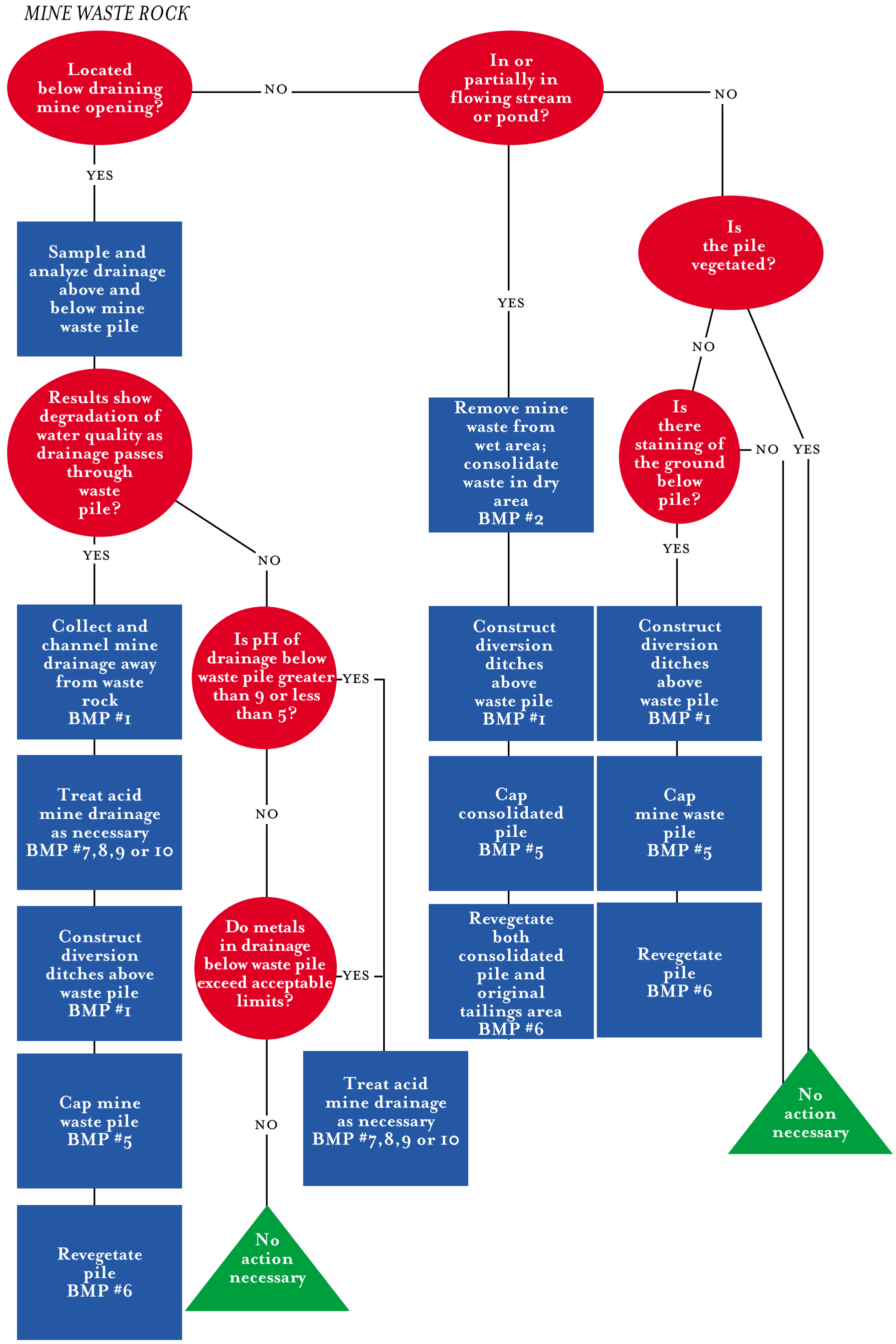
Questions about the mining-related problems discussed in this booklet should be directed to the following agencies.

Colorado Division of Minerals and Geology
Inactive Mine Reclamation Program
303-866-3567

Colorado Department of Public Health and Environment
Water Quality Control Division
303-692-3500

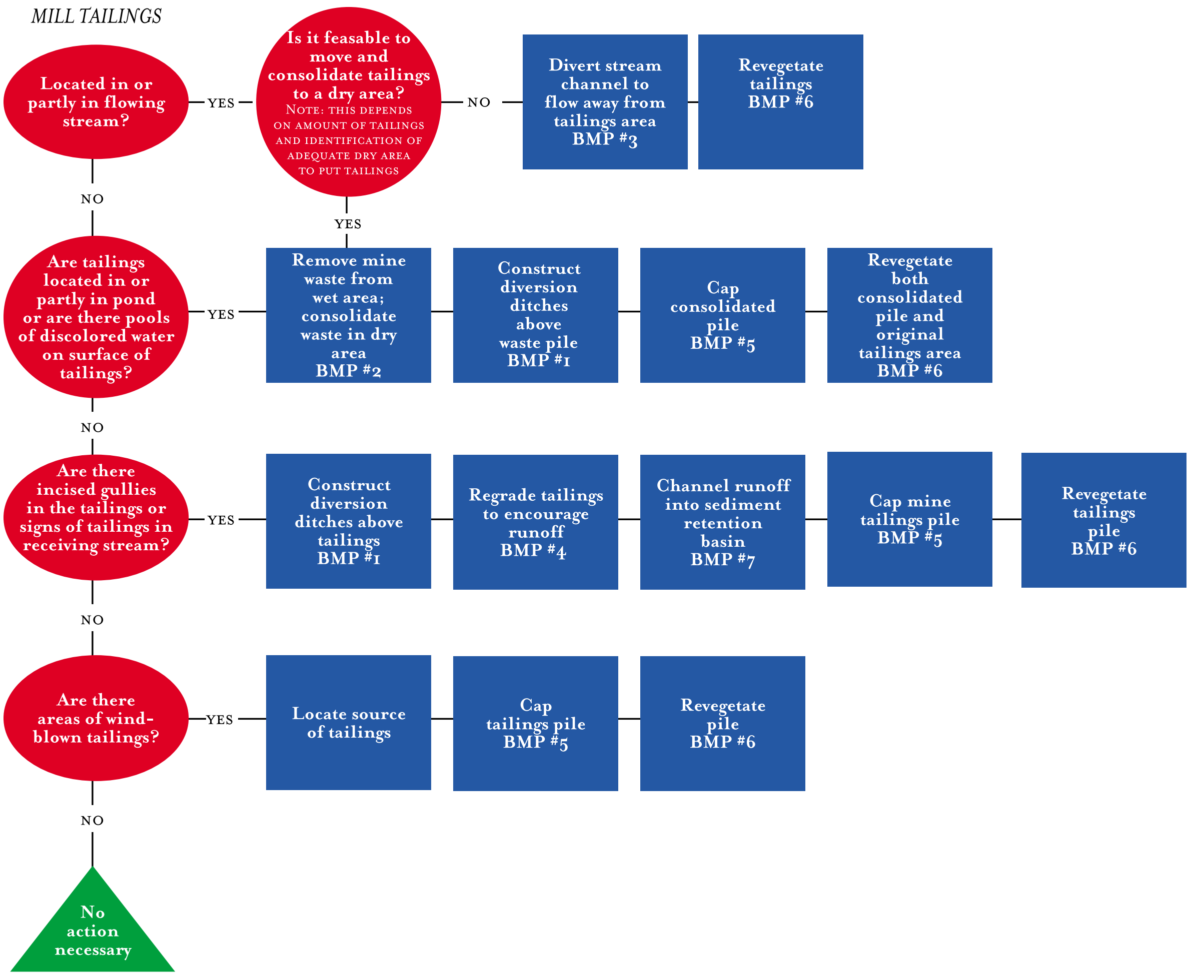
MINE WASTE PILE REMEDIATION

Goal: Keep water away from mine waste



MILL TAILINGS REMEDIATION

Goal:Keep water away from mill tailings



Best Management Practices

BMP #1 – DIVERSION DITCHES

Applicable situations:

- waste rock piles
- mill tailings
- draining mine openings

Description and purpose

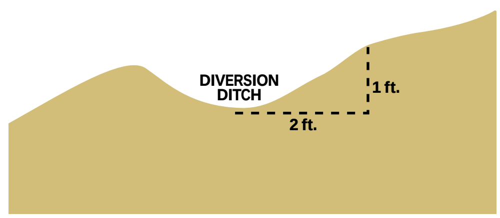
Diversion ditches are effective where the quality of rainwater, snowmelt or surface flow is degraded by flowing over or through mine waste, tailings or into mine workings. Diversion ditches can also be used to intercept shallow groundwater that may enter a mine waste or tailings pile.

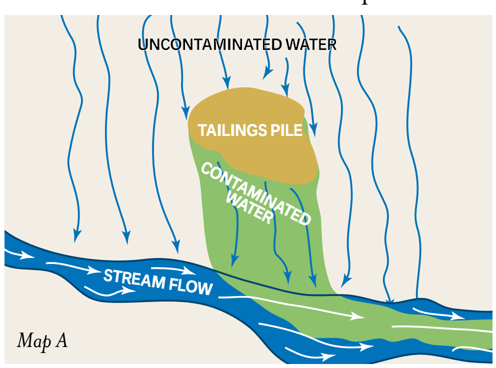
How to do It

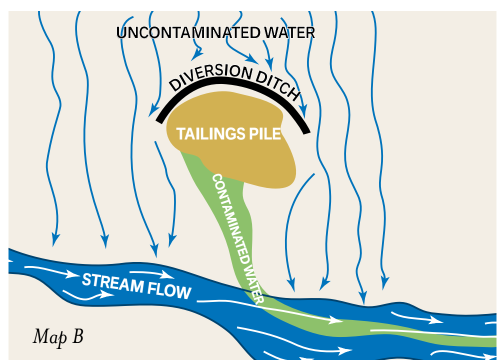
A diversion ditch should be located upstream of the contaminated waste rock or tailings pile, and should capture and channel the clean water from uphill around the problem, as shown in Maps A&B. Because the only goal of the ditch is to keep clean water away from contaminated rock or tailings, the length of the ditch depends on the size of the contaminated pile and the topography of the site. The ends of the ditch should be in a place where clean water will flow away from, and not come in contact with, the contaminated pile.

The size of the ditch generally depends on how much water is expected. The simplest ditches are dug either by hand, using a backhoe, or using the corner of a bulldozer blade to make a triangular cut. Care should be taken to dig deep enough to catch incoming shallow groundwater as well as water flowing on the surface when using any of these methods. The side walls of the ditch should be smoothed to a slope of 2:1 (two feet horizontal to one foot vertical) or flatter to maintain stability, as shown in Drawing 1.

Ideally, the slope or gradient of the bottom of the ditch should be designed to encourage water to flow freely, while not ponding, but







DRAWING 1 (at top right)– Cross section of a diversion ditch showing side slopes at 2:1. To maintain stability, side slopes should be at 2:1 or flatter. MAPS A & B (above)– Simplified views of a tailings pile and the quality of surface water flowing into a nearby stream. (Also applies to waste rock piles.) Map A shows that uncontaminated surface water originating uphill of the tailings pile will become contaminated after flowing across or through the contaminated pile. Map B shows that a properly placed diversion ditch will channel the water originating uphill of the pile away from the pile to avoid becoming contaminated. The amount of contaminated flow downhill of the tailings pile entering the stream is then greatly reduced.

not flow so fast that water erodes and scours the ditch walls. In order to accommodate this, a minimum slope of 100:1 (100 feet horizontal to one foot vertical) and maximum slope of 33:1 (33 feet horizontal to one foot vertical) is recommended. The bottom of the ditch should be smooth with no pits or holes.

The ditch should be vegetated to slow the water flow and decrease the opportunity for erosion of the ditch by moving water. Seeding of the ditch walls and bottom is easiest during low flow times of the year such as late summer or fall. Recommendations for vegetation are discussed in BMP #6 of this brochure.

If the slope of the ditch must be greater than 33:1, then the ditch should be lined with riprap (medium to large rocks) to slow the flow of water and decrease the erosion and scouring along the ditch walls. If riprap is used, it is important to select rocks that are not contaminated by mining and will not degrade the water in the ditch. Often in high-altitude areas, suitable rocks can be found at the base of steep talus slopes.

When to do it

Construction is generally easiest when performed during low flow times of the year, such as late summer or fall.

Considerations

Although in most cases, water that flows through a mine waste pile will degrade in quality, in a few cases water quality will remain the same or even improve. Therefore, it is important to sample the water above and below the pile to determine the changes in water quality before doing any ditch construction.

Initial costs

Cost of diversion ditches will vary depending on their length and the equipment used to construct them.

Maintenance

Periodic inspection and maintenance is required for continued effectiveness of diversion ditches. Water should flow smoothly along the base of the ditches and should not overflow the ditch walls. Ditch maintenance should include cleaning debris out of the ditches, checking that there is a constant drop in slope of the ditch bottom, and repairing erosion along ditch walls. Generally, inspections should be conducted before and after spring runoff and after major storm events.

Diversion ditch in rocky area

Diversion ditch lined with riprap

Best Management Practices

BMP #2 - MINE WASTE ROCK/TAILINGS REMOVAL AND CONSOLIDATION

Applicable situations

- waste rock located in direct contact with flowing water or pond
- mill tailings located in direct contact with flowing water or pond

Description and purpose

The purpose of this BMP is to move the reactive material in the waste rock dump or tailings pile away from water sources. Reducing the potential for water flow through the dump or pile will decrease the formation of contaminants, thereby reducing contamination to nearby water sources.

Removal and consolidation are effective where there are several small waste piles in an area, or where there is a large pile in direct contact with flowing water. The method is simply to isolate reactive material away from water sources.

How to do it

An area must be found that is away from water sources and avalanche chutes that can hold the volume of waste rock or tailings to be relocated. The area must be cleared of topsoil and organic material and contoured to hold the waste rock or tailings. A compacted berm or small dam may be required on the downstream side if the material to be relocated is saturated or will tend to flow. Material excavated during preparation of the consolidation area can be used to build the berm or set aside to be used later as a cap for the consolidated pile. Relocation of the waste rock or tailings may require the use of backhoes, excavators, loaders and dump trucks depending on the amount of material to be removed and the distance between the original site of the material and the consolidation area. The consolidated pile should be capped, preferably using topsoil and excavated material, and vegetated to prevent erosion. Capping and vegetation techniques are discussed in BMP#5 and #6.

Regrading and vegetation of the original site of the waste rock or tailings should also be performed to minimize erosion on the disturbed area. These are discussed in BMP #4 and 6.

When to do it

The optimum time to do this BMP is during the driest time of the year (generally late summer or fall), simply for ease of excavation and transport.

BULLDOZER CREATING A PIT FOR RELOCATING WASTE ROCK

RELOCATED MINE WASTE PRIOR TO FINAL GRADING AND CAPPING

Considerations

There are two major considerations in this BMP:

- the amount of waste rock or tailings to be moved; and
- the identification of an adequately large, relatively nearby, dry and safe area in which to place them.

Careful evaluation of both of these considerations is necessary to determine the best course of action. Waste rock and tailings relocation can be expensive, depending on how much must be moved, how moist it is, and how far it must be moved.

The other alternative in the case of waste rock or tailings located in a flowing stream is to move the stream (see BMP #3 in this brochure). However, this is often also very expensive and may not provide a permanent solution, depending on the configuration of the valley and the stream dynamics.

The other alternative in the case of waste rock or tailings located in a pond is to drain the pond, thus drying up the area.

Initial costs

Cost of this BMP will vary greatly depending on the volume of material to be moved and the distance between the original site and the consolidation area.

Consolidated waste rock site after capping and revegetation

Maintenance

Periodic inspection of the consolidated pile, especially the cap and berm or dam holding the material, should be conducted to ensure that excessive erosion is not occurring. Prompt repair in eroded areas is essential to maintaining this BMP.

Occasional visits to the site of the original pile should be made, especially if the entire pile was not removed. Additional work to protect the remaining waste rock or tailings pile may be necessary to reduce its exposure to water.

Best Management Practices

BMP #3 - STREAM DIVERSION

Applicable situations

- waste rock pile in direct contact with flowing stream with no place to remove and consolidate pile;
- mill tailings in direct contact with flowing stream with no place to remove and consolidate pile.

Description and purpose

Stream diversion involves relocating a stream away from a waste rock dump or tailings pile. Reducing the potential for water flow through the reactive materials in the dump or tailings pile will decrease the input of contaminants into the stream.

How to do it

The construction of this BMP depends largely on the configuration of the stream valley. In general, the valley must be wide and flat to maintain a reasonable distance between the stream and the contaminated rock or tailings when finished. Also, the new stream alignment should not be placed on bedrock and should be slightly deeper than the existing streambed to encourage the stream to stay in its new channel. Stabilizing measures may be needed along the bank of the new streambed and could include willow plantings, emplacement of tree stumps, riprap and berms.

An effort should be made to make the environment of the new stream segment similar to that of the abandoned stream segment. Native vegetation should be planted or transplanted along the new stream segment. Depending on the length of the new stream alignment, meanders should be incorporated, especially if there were meanders in the original stream segment.

The waste rock or tailings that is now in the abandoned streambed will still be susceptible to erosion from rainfall, snowmelt and wind, and therefore should be capped and vegetated to minimize erosion (see BMP #5 and 6) .

When to do it

The optimum time to construct this BMP is during the lowest flow of the stream (generally late summer or fall), simply for ease of construction.

Considerations

Initially, the major consideration for this BMP is the presence of a suitable place to reroute the stream. With time, streams will find the easiest way down a slope. Moving a stream generally requires major excavation work and often construction of stabilizing measures, such as extensive planting, berms and riprapped banks. In addition, rerouted

Mine waste being eroded by a stream

New stream channel under construction

streams will often move back into their original configuration during high flow events, because it was the easiest route down originally. Therefore, in most cases it is preferable (in terms of initial construction costs and long-term maintenance costs) to move the waste rock pile or tailings pile away from the stream rather than to move the stream.

If stream relocation is the best option, the Army Corps of Engineers should be contacted at the beginning of the planning process to obtain a 404 permit. The effect of stream relocation on the surrounding area is an important consideration and will be addressed as part of the 404 permit.

Initial costs

Costs for this BMP will vary depending on the configuration of the valley and the location of the waste rock or tailings with respect to the stream.

Maintenance

The new configuration of the stream should be checked several times during the year, especially after high-flow events, such as spring run-off and flooding due to summer/fall thunderstorms, to ensure that the stream is remaining in its new alignment. Areas of excess erosion and possible break-through into the old stream alignment should be repaired immediately.

Stream in new channel separated from waste rock by relocated road

Points of drainage from the old waste rock or tailings should be identified and sampled through time. Tailings would be expected to continue to dewater over several years because of their small grain size. If the drainage does not decrease over time, the possibility of a buried spring or mine opening should be considered, and the appropriate BMPs should be installed.

Best Management Practices

BMP #4 – EROSION CONTROL BY REGRADING

Applicable situations
- waste rock piles
- mill tailings

Description and purpose

Erosion occurs as a result of many things including water, wind, frost and animal action. Generally slopes with less than three feet horizontal to one foot vertical are stable from erosion and conducive to vegetation growth.

Often an area that has been barren for a long time is highly dissected by water erosion and may be susceptible to wind erosion and frost action. An area such as this requires regrading to make the surface more uniform and gently sloping.

How to do it

Because the ultimate goal is to have a gently sloping surface, natural debris, such as tree trunks and stumps, and metal debris should be removed prior to regrading. If the natural debris is regraded into the new slope, the dirt above the debris will settle as it decays and could leave a hole or low spot allowing water to pond. Pooled water can seep in and leach through the reactive waste rock or tailings, and result in acidic drainage with high metals content being discharged into the surrounding environment.

Regrading generally requires the use of heavy construction equipment, such as bulldozers, scrapers, loaders, backhoes and excavators to fill the holes and grade the slope. Note that the surface of the final slope should be moderately roughened to help in establishing vegetation, but not so rough as to promote pooling of water.

When to do it

The optimum time to construct this BMP is during the driest time of the year (generally late summer or fall), simply for ease of construction. Experience shows that wet tailings are not conducive to heavy equipment traffic.

Considerations

This BMP is generally followed by vegetation of the waste rock or tailings if the waste rock or tailings is not too toxic and can support the establishment and growth of vegetation (see BMP #6). In cases in which the waste rock or tailings is toxic and cannot support vegetation, regrading is followed by capping and vegetation (see BMP #5 and 6).

The potential for erosion can be reduced by creating grooves across the slope (or perpendicular to the slope direction). This can be done easily on the last pass of the heavy equipment

MIRED DOWN IN WET TAILINGS!

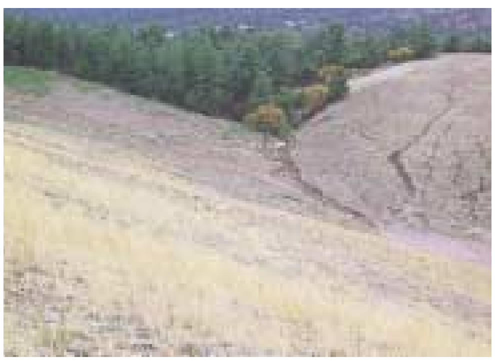
NEWLY-RECLAIMED SLOPE ROUGHENED TO HELP IN ESTABLISHING VEGETATION using a track vehicle running up and down the slope.

Initial costs

Costs for regrading vary depending on the size and slope of the area, how much debris is present, and the wetness of the soil or tailings.

Maintenance

Periodic inspections should be conducted to identify holes, pits and areas of erosion that may have formed due to scouring water, wind or burrowing animals. These areas should be repaired quickly to minimize the chances for further erosion.



Gullies in a regraded slope

Best Management Practices

BMP #5 - CAPPING

Applicable situations
- waste rock piles
- mill tailings

Description and purpose

Capping of waste rock or tailings is a protective layer of soil, graded to promote runoff rather than infiltration into the reactive materials. Any minor water or wind erosion that occurs will remove soil from the cap and should not disturb the contaminated waste rock or tailings. This will ultimately improve the water quality downstream of the waste rock or tailings pile, by eliminating the source of contamination.

The cap will also provide an uncontaminated soil layer in which vegetation can grow. Vegetation of the cap will further protect the soil and decrease erosion of the cap by slowing the speed at which raindrops hit the soil.

How to do it

Caps range from simple to complex in design and vary widely in cost. The different types of caps depend on the toxicity of the material to be capped and what materials are available at or near the site. In the majority of cases, simple covers are adequate. Composite covers are used when the material is highly reactive if mixed with surface water. Complex caps are used in situations of highly toxic materials and are often combined with liners under the toxic material.

Simple cover: The simplest, least expensive type of cap consists of soil obtained at the site. A minimum of six inches is desirable, because some erosion may occur before vegetation is established. One foot or greater is optimum. Often, the excavation of diversion ditches will provide the necessary soil for a cap. Glacial till or a good mix of clay, sand and organic matter is ideal. Sometimes a site will have sand in one area and clay in another, which can be mixed. The cap should be graded to a gentle slope to encourage runoff. No extra effort should be made to compact the soil. The material will be sufficiently compacted by the equipment used to grade the cap. The surface of the slope should be left moderately roughened to enhance vegetation, but not so rough as to promote pooling of water. Once in place, the cap should be vegetated (see BMP #6).

Composite cover: A composite cap has at least two layers of different soil types. The lower layer lying next to the waste rock or tailings is fine-grained, high density and low permeability. The purpose of this layer is to inhibit water from the surface from seeping into the contaminated pile and forming acid drainage. The upper layer consists of coarser material and is lower in density. The purpose of this layer is to encourage plant growth. This cap should be vegetated once it is in place (see BMP #6).

Complex cover: A complex cover consists of interlayered synthetic filter fabrics and fine and coarse material. The principles of this cap are the same as the simple and composite caps, that is to inhibit water infiltration into the

Grading waste rock prior to capping

reactive material below and encourage plant growth on the top. The actual design and installation of these caps is site-specific and generally costly. If your site requires such a cap, contact one of agencies listed in this brochure for assistance.

When to do it

Capping of the waste rock or tailings should be performed immediately after regrading of the pile in order to minimize the opportunity for erosion. Construction at high altitudes is generally easier in the dry seasons, such as late summer or fall.

Considerations

Any type of cap will be susceptible to water and wind erosion, penetration of tree roots, animal burrowing, and frost action. Consideration should be given to minimizing the effects of these processes, such as fencing if animals are expected to be a problem. Generally, a vegetative cover on the cap helps to minimize these effects.

The potential for erosion can be reduced by creating grooves across the slope or perpendicular to the slope direction. This can be done easily on the last pass of the heavy equipment using a track vehicle running up and down the slope.

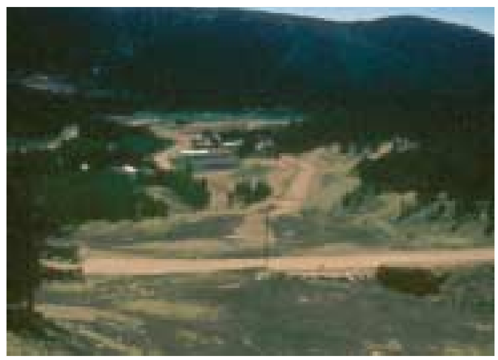
Placing material on a composite cover

Initial costs

Costs vary depending on site topography and location of the capping material relative to the location of the pile. The primary cost is based on equipment usage and may include dump trucks, excavators, bulldozers, backhoes or loaders.

Maintenance

Periodic maintenance requirements include an occasional walk-through of the capped area to identify problems caused by erosion, tree root penetration, and animal burrowing. Prompt repair of any problems will increase the effectiveness and lifetime of this BMP.



Tailings capped, graded, and vegetated

Best Management Practices

BMP #6 – VEGETATION

Applicable situations

- waste rock piles
- mill tailings

Description and purpose

Vegetation planted on a waste rock or tailings pile helps to contain the reactive material by protecting the pile from erosion and reducing the amount of water that can infiltrate into the pile. In addition, vegetation growth provides nutrients to the soil cover and improves the wildlife habitat. Vegetation is often used in combination with other BMPs, protecting the soil from erosion along diversion ditches and on areas that have been regraded and/or capped.

First-year growth at coal waste site

How to do it

Ideally, the surface to be vegetated should consist of good uncontaminated soil, moderately roughened to allow the seeds to hold and some moisture to collect. Roughening can simply be the caterpillar tracks of heavy equipment that has been used at the site for regrading. However, if the material beneath the soil cap is toxic, care must be taken not to roughen the surface too much which could promote ponding and subsequent infiltration and leaching of the reactive material into the environment.

Fertilizer should be applied to enhance the soil. If good uncontaminated soil is to be vegetated, a commercial grade diammonium phosphate (18-46-0) is generally adequate. This can be broadcast by hand or machine at a rate of 300 pounds per acre. If vegetation is to be performed directly on tailings with no soil covering, mixing crushed limestone into the tailings or using a super phosphate fertilizer (0-58-0) at the same rate of 300 lbs. per acre is generally sufficient. Dry cow, horse or sheep manure, which is not caked or lumpy and has been stockpiled for at least one year, can be used instead of fertilizer, in which

TABLE OF SEEDS, THEIR MIXES, AND PLANT TYPES

Seed Name (*Scientific Name*)	Percent of Seed Mix	Plant Type
Tufted Hairgrass (*Deschampsia ceaspitosa*)	20	Bunch grass
Smooth Bromegrass (*Bromus inermis*)	20	Sod grass
Intermediate Wheatgrass (*Agropyron intermedium*)	20	Sod grass
Kentucky Bluegrass (*Poa pratensis*)	15	Sod grass
Creeping Foxtail (*Alopecurus arundinaceous*)	15	Sod grass
Hard Fescue (*Festuca ovina*)	10	Bunch grass
Crested Wheatgrass (*Agropyron cristatum*)	10	Sod grass
Cicer Milkvetch (*Astragalus cicer*)	less than 1	Leguminous forb
White Clover (*Trifolium repens*)	less than 1	Leguminous forb
Indian Paintbrush (*Castilleja spp.*)	less than 1	Forb
Shrubby Cinquefoil (*Potentilla fruticosa*)	less than 1	Shrub

case it should be applied at a rate of 30 tons per acre.

The seed mix used should be specific to the climate of the site and should be similar to the native vegetation. It should include a variety of bunch grass, sod grass, legumes, forbs and shrubs, so that if one type fails, there will still be some vegetative cover on the area. Many options are available. The scientific names of the seeds are given for ease of ordering. For other seed mix options, contact your local County Extension Agent or Soil Conservation Service representative.

After seeding, mulch should be applied over the entire area to protect the seeds from water and wind erosion while they sprout. A covering of mulch will also retain moisture for the seeds, insulate the seeds from extreme temperatures and help to hold the seedlings in place, so that they are less likely to be pushed out of the ground by frost in the fall. Certified weed-free hay, alfalfa or straw can be used for mulch, depending on what is available and the cost. It should be applied uniformly at a rate of two tons per acre. It is best to crimp the mulch into the soil to prevent it from blowing away. This can be done using a shovel to simply push ends of the mulch into the ground, or by the caterpillar tracks of a bulldozer or loader.

Regraded mill tailings site after mulching

When to do it

Vegetation can be done anytime, although spring and fall are better because there is more moisture available. Vegetation should be performed soon after construction in an area is completed to protect the soil. Unprotected soil or tailings will quickly erode.

Considerations

Any vegetation program will be susceptible to water and wind erosion and frost action. The use of mulch will help to keep the seeds in place and minimize the effects of frost on the new seedlings.

Initial costs

Costs of vegetation will vary depending on acreage.

Maintenance

Periodic maintenance requirements include an occasional walk-through of the area to identify problems caused by erosion and areas of non-growth. Prompt repair or reseeding of problem areas will help to stabilize the site and will increase the effectiveness of this BMP. If you suspect noxious weeds in your vegetation, contact your County Extension Agent for information on identification and control methods.

Best Management Practices

BMP #7 - AERATION AND SETTLING PONDS

Applicable situations

treating drainage from a mine opening

Description and purpose

Aeration and settling ponds promote the precipitation of heavy metals such as iron, zinc and manganese through oxidation processes. This BMP is particularly effective for treating mine drainage water that is high in total suspended solids (TSS) but has a pH close to neutral (7.0). Aeration is accomplished by channeling the mine drainage over a series of small waterfalls or drops, which will increase the oxygen content of the water into a quiet settling pond, where the metals will drop out.

How to do it

Aeration is accomplished by making the water turbulent. Turbulence can be initiated by channeling the drainage down a steep slope, over rough slopes (such as ditches lined with riprap or large rocks) or over a series of drops or small waterfalls.

A settling pond should be located at the base of the aeration channel. Ideally, it is in a naturally low area, but not along or in flowing water. An embankment at the lower end of the pond holds the water in the pond. This allows clean water to flow over the top of the embankment back into the main stream without eroding the dam. The embankment is generally composed of a mix of rock and soil with larger rocks lining the upstream side and smaller rocks on the top to discourage erosion as the water flows over the top.

SETTLING POND AT A MILL TAILINGS SITE

Settling ponds should be designed so that the water entering the pond will remain in the pond for a minimum of 24 hours before being discharged. A 24-hour retention period will allow the oxidized metals to precipitate. In order to design the pond for 24-hour retention, the expected flow into the pond must first be measured. This can generally be done with a bucket and stopwatch. Using that flow rate (probably measured in gallons per minute), the amount of water that will flow into the pond in a 24-hour period can be calculated. The pond should be large enough to hold at least that amount. An example calculation for a settling pond is shown. (Note: one gallon equals 0.134 cubic feet.)

If, given the area on your site, it is not possible to have a settling pond large enough to retain the water for at least 24 hours or the ground is too rocky or hard to excavate to the necessary depth and size, consider several smaller settling ponds at different elevations, which together will provide a total retention time of at least 24 hours.

When to do it

Construction of this BMP will be easiest during the lowest flow of the mine drainage. That is generally in the late summer or fall, however, flow at your site may differ.

Considerations

This BMP is best used in situations in which the mine drainage water is high in total suspended solids (TSS) and has a pH of near neutral (7.0). Therefore, sampling and testing to determine the pH and suspended metals content of the drainage is advisable to decide if this BMP will work at your site.

Because this is a two-part system, consisting of an aeration channel and settling pond, requirements for space are greater than for other BMPs.

Initial costs

Costs for this BMP vary depending on the depth of soil cover and the topography of the site. Construction of a settling pond at a rocky site may be difficult. A steep site may offer good possibilities for aeration of the drainage, but limited possibilities for a settling pond. A flatter site may require creative thinking to aerate the drainage but provide plenty of area for a settling pond.

Maintenance

The aeration channel should be periodically inspected to confirm that the drops and waterfalls are effectively producing turbulence in the mine drainage. Prompt repair of any problems along the channel should be made to ensure that the suspended metals in the drainage are adequately aerated and subsequently dropped out.

Because metals will be precipitated or dropped out in the settling pond, the pond will occasionally need to be cleaned out. Whenever the pond is half full of sediment, it should be cleaned out and the sediment disposed of in an environmentally sound way. The metals content of the sediment from the pond should be tested. Based on that value, the sediment can be taken to a hazardous waste site or buried in a lined and capped disposal trench on the site.

EXAMPLE CALCULATION FOR SIZING A SETTLING POND FOR 24-HOUR RETENTION OF INFLOW

step 1: *Measure expected flow rate.*

10 gallons/minute (gallons per minute or gpm)

step 2: *Convert gallons to cubic feet.*

10 gallons x 0.134 cubic feet/gallon = 1.34 cubic feet (cu.ft.)

step 3: *Calculate expected flow for 24 hour period.*

1.34 cu.ft./min. x 1440 min./24 hr. = 1930 cu.ft. flow in 24 hours

CONCLUSION: The pond must be able to hold 1930 cubic feet of water for 24-hour retention of 10 gpm flow. Therefore, width x length x depth of the pond in feet must be equal to or greater than 1930 cubic feet. One possible pond configuration is: width =20 ft., length = 25 feet, depth = 4 ft., so the pond can hold 2000 cubic feet. However, there are countless possible pond configurations. The area available at your site to build a pond will determine the dimensions of the pond.

Best Management Practices

BMP #8 - SULFATE-REDUCING WETLANDS

Applicable situations

- treatment of drainage from waste rock piles
- treatment of drainage from mill tailings
- treatment of drainage from a mine opening

Description and purpose

Sulfate-reducing wetlands will improve the quality of acid mine drainage using common bacteria found in decomposing organics to remove the heavy metals. Sulfate-reducing bacteria (SRBs) utilize the oxygen in sulfates for respiration, producing sulfides. The sulfides combine with heavy metals in the drainage to form relatively insoluble metal sulfides, which precipitate or drop out. The bacteria derive their energy from a carbon source, most commonly cow manure or mushroom compost.

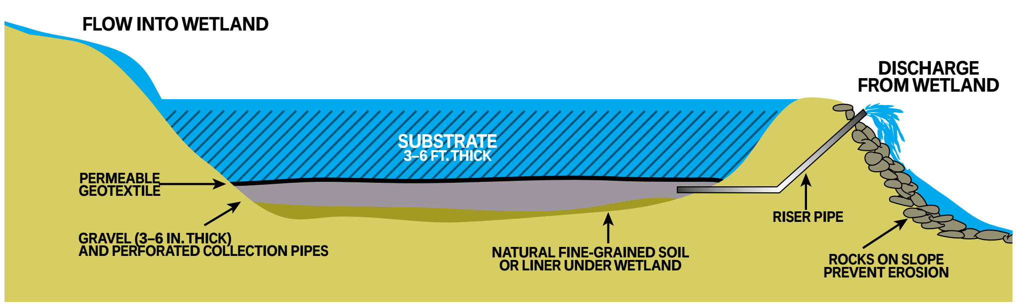
How to do it

Generally, a sulfate-reducing wetland is placed behind a berm or small earthen dam. Depending on the grain size of the soil, the wetland cell behind the berm may need to be lined with either compacted clay or a PVC or HDPE geomembrane liner. If the soil is fine-grained with very little rock, no liner is necessary. The system may leak temporarily, but should seal off in a period of weeks.

A thin layer of gravel (about 3 to 6 inches) is placed on the bottom of the cell (or on the liner) and perforated collection pipes are buried within this layer. A highly permeable geotextile fabric, such as a loose weave erosion fabric, is placed on top of the gravel layer. This fabric must allow drainage into the gravel, while keeping the finer material above the fabric from piping into the gravel. The substrate or treatment layer is placed on the geotextile to a depth of about three to six feet. The substrate can consist of cow manure, mushroom compost, sawdust or in some cases soils from the site depending on their permeability.

The drainage enters at the top of the system but must exit at the base of the system to ensure that the drainage flows through the substrate material and is exposed to the SRBs. Mine drainage enters the system through a pipe buried just beneath the top of the substrate or can simply be pooled on the surface of the substrate. A riser pipe, through which treated water will exit, is installed starting in the gravel layer at the low end of the wetland and angling up through the berm where it discharges. A schematic cross section of a sulfate-reducing wetland is shown in Drawing 2.

The size of the wetland depends on the amount of metals and pH of the drainage, the volume of the drainage and the area available to install the wetland. A general rule of thumb



Drawing 2 - Schematic cross section of sulfate-reducing wetland. Not to scale.

is that five cubic yards of properly designed and installed wetland will treat one gallon per minute of mine drainage. Therefore, if the depth of your wetland is three feet, and you are treating 10 gallons per minute of drainage, the total area of the wetland should be about 150 square feet. The wetland can consist of one large cell or be broken into several smaller cells in order to achieve the necessary area to treat the drainage.

When to do it

Construction of this BMP will be easiest during the driest time of the year.

Considerations

Sulfate-reducing bacteria prefer an environment with a pH above 4.5. In situations where the pH of the drainage is below 4.5, design modifications are necessary, such as channeling the drainage through a lined buried trench filled with two- to six-inch chunks of limestone prior to entering the wetland, or adding limestone to the substrate in the wetland.

Some pooling on the cells is desirable, because it discourages plant growth. Plants will introduce an additional source of oxygen and the system works best in an oxygen-deficient environment. However, pooling should not approach the top of the berm.

Sulfate-reducing wetlands with HDPE liners

Sulfate-reducing wetlands should generally not be constructed near population centers, because these systems commonly produce excess hydrogen sulfide, which can cause undesirable odors up to 1/2 mile away from the system. Note that when the system is first installed, the treated water will be discolored and may look worse than the untreated water entering the system. This is normal and should change after a few months.

Initial costs

Costs for installation of a sulfate-reducing wetland will depend on the size of the wetland and the cost of obtaining and delivering the substrate materials.

Maintenance

Metals will precipitate as the drainage is treated in the wetland. Wetlands, properly designed for the metals content of the drainage being treated, generally have a life of 20 to 30 years, after which time the accumulated metals will begin to slow the flow and the treatment will not be as effective. This metal sludge must be removed and properly disposed of in either a landfill or an on-site lined and capped trench, or it can be sold for remining if the metals content is sufficient.

Best Management Practices

BMP #9 - OXIDATION WETLANDS

Applicable situations

- treatment of drainage from waste rock piles
- treatment of drainage from mill tailings
- treatment of drainage from mine openings

Description and purpose

Oxidation wetlands are what most people think of as "wetlands". Metals, such as iron, manganese, and arsenic are precipitated through oxidation by aquatic plants and algae. The plant materials provide aeration and, when they die, provide adsorption surfaces for the metals and sites for algal growth. Algae help in the manganese removal process.

How to do it

An oxidation wetland looks like a marshy area with slow water flow around typical wetland vegetation, such as cattails and rushes. The base of the wetland should be unevenly graded to allow mine drainage to flow through both shallow (less than 10 inches) and deep (10 to 20 inches) areas and around vegetation islands. Care should be taken to prevent high velocity flow through the wetland. This would not allow sufficient time for oxidation to take place and could cause channels to form in the wetland, decreasing the amount of time the drainage spends in the wetland.

The size of the wetland depends on the amount of metals and pH of the drainage, volume of the drainage and the altitude of the site. A general rule of thumb is that treatment of one gallon per minute of drainage will require a 200 to 900 square foot wetland. The wetland can consist of one large cell or be broken into several smaller cells in order to achieve the necessary area to treat the drainage.

The wetland area should be filled with a mixture of gravel and organic material and planted with cattails, bulrushes, sedges and rushes. These can be taken from another wetland site and transplanted into the new wetland in clumps about a foot or so apart. Grass clippings and hay can be incorporated to provide algae.

Areas around the wetland disturbed during construction should be vegetated as soon as possible after construction to minimize erosion of the soil and sedimentation in the wetland.

When to do it

Construction of this BMP will be easiest during the driest time of the year.

Oxidation wetland containing peat moss

Considerations

This treatment method is applicable where the pH of the mine drainage is approximately 6.5 or higher and where the metals concentrations are primarily a problem during the summer months. Because this system depends mostly on plants to oxidize the metals, the efficiency of the system will decrease in the winter months.

Initial costs

Costs of this BMP depend primarily on the size of the wetland and the equipment used for construction.

Maintenance

A periodic inspection of the wetland system should be conducted to ensure that the flow is spread throughout the wetland and channelization has not occurred. Channelization problems should be fixed as soon as possible to achieve the maximum treatment this system can offer.

Metals will precipitate as the drainage is treated in the wetland. Properly designed wetlands generally have a life of 20 to 30 years, after which time the accumulated metals will begin to slow the flow and the treatment will not be as effective. At this time, the height of the berm can be increased, which will allow continued use of the wetland.

Best Management Practices

BMP #10 – BMPs TO TREAT ACID MINE DRAINAGE

There are BMPs that relate specifically to the treatment of contaminated drainage from mine openings. These include diversion of surface waters, dilution, land application, bulkhead seals, anoxic limestone drains, aqueous limestone injection and mechanical injection of neutralizing agents. In general, these BMPs must be designed and engineered to take into account the volume of water, water chemistry, and mine configuration, are expensive and require ongoing maintenance. Because of this, only a paragraph about each of these BMPs is included here. If you need further information about these types of BMPs, contact one of the agencies listed at the end of this report to obtain guidance.

Diversion of surface waters can sometimes work to reduce the amount of clean water infiltrating into the mine workings and being exposed to oxidizing pyrite. Obvious places where water is entering the mine can sometimes be identified during a site reconnaissance. That surface water flow should be channeled away from entering the mine.

Dilution involves mixing clean water with acidic mine drainage in a settling pond. The resultant increase in pH causes some of the metals in solution to precipitate.

Dilution can be a cost-effective method of treatment, because the neutralizing agent is simply uncontaminated water, however, the percentage of metals precipitated is significantly less using this method than using most other methods. This method is most effective in removing iron, aluminum, copper, cadmium and lead, but has only slight effectiveness for zinc and manganese.

Land Application is a method designed to use the natural processes in soils and subsoils, such as plant uptake, evaporation and transpiration and soil exchange capacity, to combine with and remove metals. This method can be used in places where mine discharge can be spread over a large area to infiltrate into relatively thick soils or unconsolidated deposits. Drainage should be neutral or near neutral in pH to avoid killing the plants where application occurs.

Bulkhead seals are used to control the formation of acid mine drainage inside a mine. A bulkhead seal is installed in an adit to prevent discharge from the nearby portal. The workings of the mine will flood behind the seal inhibiting the oxidation of pyrite and thereby decreasing the amount of acidic water produced. Bulkhead seals are expensive and require considerable geologic and engineering investigation and characterization and are therefore rarely used at inactive mines.

Anoxic limestone drains (ALDs) are used to treat acidic water discharging from an open or collapsed mine opening. Acidic mine discharge is channeled through a buried trench containing chunks of limestone, which are naturally high in alkalinity. The limestone dissolves in the acidic water, raising the pH of the water. A settling pond is generally placed below the ALD to catch the metals that drop out of solution.

Aqueous lime injection is a passive method to introduce neutralizing agents into mine drainage. Clean water is passed through a pond containing a high pH (alkaline) material (often lime). This high pH water is then mixed with the mine drainage before it enters a settling pond, where the metals will drop out. This system can be cost effective if alkaline waste such as kiln dusts or fly ash is readily available.

Mechanical injection of neutralizing agents is used to treat acidic drainage from mine openings. This system involves a wind, solar or hydro-powered mechanical feeder which continuously dispenses neutralizing agents (such as finely ground limestone) into the mine drainage. Introducing a high pH neutralizing material into the low pH mine drainage will raise the pH of the mine water, thus allowing the metals to drop out of solution. A settling pond is required below the feeder to capture the metals that precipitate out. This type of system requires frequent maintenance and may produce significant quantities of metal sludge.

Full-scale limestone injection system with limestone hopper, feeder system and control panels

Settling pond below a limestone injection system

Small-scale pilot lime injection system

Hazardous Openings

Safety hazards associated with inactive and abandoned mines account for several deaths and injuries throughout the country every year. Increased outdoor recreation, urban development, and general population growth into rural areas enlarges the potential exposure of the general public to hazardous inactive and abandoned mine features. With a litigious society, liability concerns are becoming important considerations to public and private landowners. The major safety problems associated with inactive and abandoned mines are open shafts, stopes, and adits.

Shafts are vertical openings in the ground giving access to the working area of a mine. They are often several hundred feet deep and an unwary person could easily stumble into the hole before seeing it. The openings are usually unmarked and unfenced, sometimes half-hidden among old boards and mining equipment. Areas around old shafts are often composed of unconsolidated soil or weathered rock which is apt to give way beneath the weight of a visitor. Some shafts have cribbing or timbers that appear sturdy but are, in fact, full of dry rot and extremely weak. Because old mining districts are interesting to tourists and visitors and access to many mining areas is relatively easy, these shafts pose a significant hazard.

Stopes, like open shafts, are hazardous because they are often deep and unstable around the edges. They are created as mining proceeds underground and the ore body is removed from above and dropped into ore cars. Sometimes, stopes extend upward so near the ground surface that it collapses into the underground workings. Stope complexes often radiate great distances away from the mine entry. They are somewhat more dangerous than shafts because there are often no structures or dumps to announce their presence.

Adits are horizontal openings allowing access to the mine workings. They pose a less immediate threat to visitors than shafts simply because one cannot accidentally fall into an adit. Some adits, however, have winzes (internal vertical shafts) just inside the entry. Adits are much more inviting to casual explorers than vertical shafts since shafts usually cannot be entered without special equipment. Some adits and

Stope showing stulls supporting hanging wall

Adit opening with timbered entry

shallow inclines still have supporting mine props in place; others are driven into solid rock; still others have no props or solid roofs and look as if they could collapse at any time. The fact that an adit has remained intact for many years gives a false sense of security to the visitor who, by some inadvertent action, may trigger a collapse and literally bring the roof down on his or her head. Another concern is that idle mines often have very poor ventilation, resulting in the accumulation of potentially fatal quantities of gases.

Safeguarding and Reclamation Alternatives

Safeguarding hazardous inactive and abandoned mine openings requires consideration of the fact that the site has not been maintained for many years. Because the mine and the area around the opening has been inactive for a long time, nature has often taken a toll on any improvements that helped ensure a safe condition when the mine was producing. This can make construction of an effective safeguard fairly complicated.

Reclamation alternatives should consider the size and stability of the opening, the type of material around it, its depth to competent rock, the effects of site drainage, mine ventilation, near surface mine workings, safety of construction, access, site disturbance during construction, requirements for protection of threatened/ endangered species and/or historic preservation, and any other factors that may affect the reclamation method or the construction effort.

Three general types of approaches are used for safeguarding shafts, stopes, and adits. **Barriers** are designed to keep visitors away from the hazard. **Seals** prevent entry to the mine. **Plugs** eliminate the hazard altogether.

Alternatives should be evaluated for a number of factors, such as:

Life span — will it be effective permanently, 50 years, 10 years?

Degree of hazard elimination — Completely eliminate it, provide a barrier or deterrent

Maintenance requirements — How prone is the closure to vandalism and environmental degradation?

Construction safety — Is it safe for workers, and does it require special skills or equipment? Is methane being produced by the mine? Is the mine atmosphere safe? Are there overhanging and /or loose rocks around the opening? Is this a uranium or vanadium mine requiring special health protection from radiation during construction?

Environmental concerns — Water quality and drainage. Is the site in a wetland area, near a steam? What will be disturbed to install the closure? Are there bats or other wildlife that may use opening for protection? Will there be loss of vegetation?

Design concerns — Is the closure method feasible to install? If competent rock is needed for anchoring grating or bedding concrete caps, is it close to the surface? Access for equipment—Is the site accessible by heavy equipment, or only by foot? Size of equipment needed — Depends on closure method and site access? Availability of materials— Are materials easily available and cost effective? Cultural resources — Is it in an historic area, is the building significant, in ruins?

Cost - Is the cost prohibitive? Reasonable?

Best Management Practices

BMP # 11 – BARRIERS

Description and purpose

Barriers can be appropriate when the opening is too large for other alternatives and when construction access is restricted. Barriers include fences of several types and grates made of steel bars. Chain link and iron fences can be effective at keeping casual visitors a safe distance from hazardous openings. Steel grates, using industrial grade material similar to that used for elevated walkways, can be installed over vertical openings or in the portal of horizontal openings. A locking door made out of the steel grating can be incorporated to allow continued access to the mine workings by the landowner or authorized people. Alternative methods involve placing a corrugated steel pipe in the adit and installing a grate on the outer end, or using a special grate of steel bars to allow for bat access.

Considerations

Barriers such as fences and grates should be recognized for exactly what they are – barriers. They are not intended to prevent entry by the determined visitor.

The advantages of fences are that they are safe to install with no exposure to the mine hazard, they disturb the site minimally, they are easy to install, and they are relatively inexpensive. The disadvantages of fences are that they are temporary, they don't eliminate the hazard but just discourage access, they are subject to vandalism, and they can be aesthetically intrusive in otherwise natural settings. When fences are used they must be located far enough away from the hazardous opening to survive erosion of the feature.

Steel grates, whether they are installed over a vertical shaft or at the portal of a horizontal mine opening, are more permanent and more of a deterrent than fencing. Advantages of grates are their somewhat long life (approximately 50 years), total elimination of access to the hazard, they involve little to no site disturbance, they can be installed in remote or difficult access situations, they allow continued ventilation of the mine workings, they can be designed to allow continued use of the mine by bats, and they are relatively low cost. Disadvantages include exposure to vandalism and corrosion over time, the necessity to protect workers from falling, unstable roofs, unsafe mine atmospheres during construction, and the need to have competent rock to anchor the grating in most situations.

Initial costs

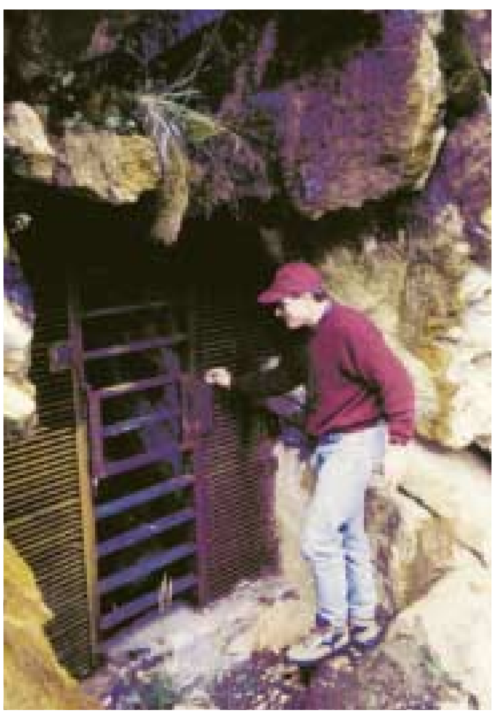
The cost of fences and barriers will vary depending on their length or size, the accessibility of necessary construction equipment, and the strength of the materials used. Fences are generally low cost with barbed wire being the cheapest, chain link being moderate in cost, and ornamental iron fences being most expensive. Grates are moderate in cost.

Maintenance

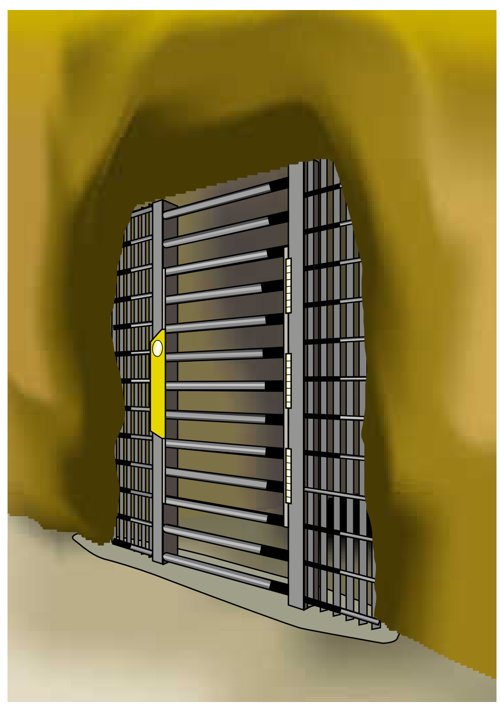
Periodic inspection and maintenance is required for continued effectiveness of this type of safeguard. They are especially susceptible to vandalism and the types of materials used defines their ultimate longevity.

Custom steel fence around an historic headframe and shaft

Fabricating a steel grate with a locking hatch



A steel grate barrier at an adit with bars allowing bat access and a locking door



An illustration of a steel grate barrier with bat access

Best Management Practices

BMP # 12 – PLUGS

Description and purpose

Plugs include backfills, monolithic plugs, and plugs utilizing polyurethane foam (PUF). They are designed to eliminate the hazard completely.

How to do it

Shafts, stopes, and subsidence features should be backfilled using graded materials, i.e., placing large rock riprap in the bottom of the feature, followed by successively smaller diameter materials with a plant growth media on the surface to allow for revegetation. Adits should be backfilled with a minimum depth of fifteen feet from the inner top of the fill to the outer top of the fill.

Monolithic plugs consist of pouring a four foot (4') thick concrete cap over mine shafts that have collapsed at the collar and have no apparent opening. The visible bottom of the usually shallow pit is most likely a false plug that will fail in the future. This work includes near surface excavation, furnishing and installing riprap, furnishing and installing concrete, backfilling, and revegetating disturbed areas.

A PUF closure uses a column of polyurethane foam placed several feet down into a vertical opening with mine waste or common fill material placed on top of it up to the level of the surrounding grade. The PUF plug is constructed in place using a lightweight form lowered into the opening and specialized equipment to mix two liquid components that immediately start expanding into a quick-curing, solid mass.

Considerations

Plugs provide a positive, permanent, and maintenance-free safeguard to hazardous mine openings. Plugs can be constructed with on-site mine waste, imported rock and material, concrete, and polyurethane foam (PUF).

Backfilled shafts and adits are permanent, completely eliminate the hazard, and are maintenance free. With proper equipment, construction workers' exposure to the mine hazard is low. If on-site material is used, waste piles may be eliminated. Although the techniques used are generally low-tech using commonly available equipment, care needs to be taken to ensure that the entire opening is filled with no void spaces remaining. Material placed in shafts must not be allowed to bridge and create temporary, unsupported plugs. Adits may need a bulkhead to support backfill. Hand-placed material in adits is difficult to compact and fill to the roof. Machines may need a special extension to get adequate closure. If any water is draining from an adit, a pipe or other method is required to prevent excessive water pressure on the plug. Material placed into shafts containing water must be benign. In situations involving water, on-site mine waste material is probably not acceptable and material will have to be imported.

Monolithic plugs are also permanent, completely eliminate the hazard, and are maintenance-free. Construction workers are not exposed to the hazard if no formwork is required. The technique disturbs only a small area around the shaft. The plug provides support of sidewalls of the shaft near the surface. The plug remains functional even if caved material below the plug fails. It is critical that the

POLYURETHANE FOAM BEING INSTALLED IN A CRIBBED SHAFT deepest part of the plug be placed in contact with competent bedrock to prevent piping of unconsolidated material around the concrete plug. Monolithic plugs are not appropriate for adits.

Polyurethane plug closures completely eliminate the hazard, and are maintenance-free. Although it is a fairly new technique with only about ten years of history, a properly installed PUF plug should be permanent. Workers can install the closure from ground-level and do not need to go down the shaft. Once mixed, PUF is inert. It can be installed in openings that are inside historic structures without damaging the structure. It can accommodate poor access situations. PUF can also be used as formwork for concrete closures. Disadvantages of PUF plugs are few: there is potential for vandalism if the PUF is exposed so a minimum of two feet of covering material is required. Additionally, the unmixed chemicals used in the PUF are toxic so exposure to them and their fumes must be prevented during construction. Exposed PUF will support combustion and will degrade in ultraviolet light so adequate covering materials again are important. Installation procedures are critical to success of this closure method. PUF plugs are not appropriate for most adit closures.

Installing concrete for a monolithic plug

Initial costs

The cost of plugs will vary depending on the type of material used and the accessibility for necessary construction equipment. Costs of backfill plugs can be inexpensive if on-site material is used. The cost may be high if imported material is required. The cost of a monolithic plug is generally low to moderate unless shoring is required to safely install it below the bedrock contact. PUF closures involve high material costs but relatively low installation costs.

Maintenance

An initial inspection of these closures should be conducted after one or two years to see if any settlement has occurred. If properly installed, the closures should not require any maintenance.

Backfilling a shaft using riprap

Best Management Practices

BMP # 13 – STRUCTURAL SEALS

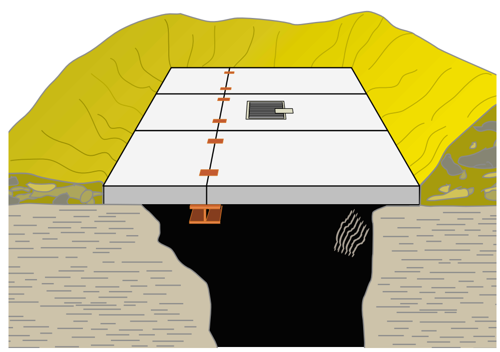
Description and purpose

Structural seals include precast concrete panels and poured in place concrete slabs installed over vertical or near-vertical mine openings. Bulkhead seals can be constructed in a horizontal opening or adit using poured concrete, concrete blocks, or native rock. Seals are designed to prevent access to all visitors. They can be removed only with heavy construction equipment.

Considerations

Seals using precast concrete panels or poured-in-place concrete slabs completely eliminate exposure to shaft and stope hazards and do not require maintenance. They are relatively permanent, having a lifespan of approximately 100 years. Construction involves working around the vertical openings but does not require entering the shaft. There is minimal disturbance to the site. These closures can incorporate a locking hatch if access is required. Panels can be prefabricated for standardized closures and both types of seal require minimal site-specific engineering. These caps need to be placed on competent rock to provide an adequate foundation for support. The caps must be large enough to overlap all sides of the shaft an appropriate distance. The caps will not prevent collapse of the shaft sidewalls. Access for bringing in precast panels or concrete trucks is needed.

Bulkhead seals in adits are permanent, they eliminate exposure to the hazard and require little or no maintenance. They require minimal site disturbance and can be constructed to blend in with their surroundings. Standard construction techniques are used. They are particularly good for poor access sites if native materials are used. They can also incorporate a locking hatch if access is required. If the adit is draining water, an adequately sized and properly installed drain pipe is required. During construction, workers must be protected against possible roof and rib falls and dangerous mine atmospheres. Bulkheads in adits must include keying into competent bedrock to prevent access around the sides.



Perspective cutaway drawing of a precast concrete panel

Placing precast concrete panels over a stope

Finishing construction of a native rock bulkhead at an adit

Initial costs

Shaft seals using precast concrete panels are relatively inexpensive due to the economies of scale of panel production and the lower cost of fabricating the panels in a central location. Cast-in-place concrete slabs are more costly due to the need and difficulty of constructing high strength formwork in a remote location and the usually difficult access for concrete trucks. Bulkhead seals at adits are fairly low cost because on-site materials can often be used and most elements of the closure can be transported by hand.

Maintenance

Periodic inspection is recommended for these types of safeguards. Although they are not particularly susceptible to vandalism, they are often very visible and attract attention. The most likely cause of failure of these closures is failure of the surrounding bedrock material due to natural weathering.

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