EPA-430/9-73-011

# PROCESSES, PROCEDURES, AND METHODS TO CONTROL POLLUTION FROM MINING ACTIVITIES

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

This report is issued under Section 304(e)(2)(B) of Public Law 92-500. This Section provides:

> "The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall issue to appropriate Federal agencies, the States, water pollution control agencies, and agencies designated under section 208 of this Act, within one year after the effective date of this subsection (and from time to time thereafter) information including ... (2) processes, procedures, and methods to control pollution resulting from --
>
> (B) mining activities, including runoff and siltation from new, currently operating, and abandoned surface and underground mines; ..."

This report, prepared under contract by the firm of Skelly and Loy, Engineers-Consultants, Harrisburg, Pennsylvania, and Penn Environmental Consultants, Inc., Pittsburgh, Pennsylvania, for the Environmental Protection Agency, provides general information on alternative control measures. It is intended to provide sufficient brief descriptive information on such measures to guide the reader in the tentative selection of alternative measures to be applied in specific cases. The details of application and methods of construction of each method must be ascertained on a case-by-case basis by qualified professionals in the mining and water pollution control fields.

Russell E. Train
Administrator

EPA-430/9-73-011

October 1973

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U. S. Environmental Protection Agency
Washington, D. C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $3.40

## ACKNOWLEDGMENTS

This report was prepared by Skelly and Loy, Engineers-Consultants, Harrisburg, Pennsylvania, and Penn Environmental Consultants, Inc., Pittsburgh, Pennsylvania (Contract No. 68-01-1830; report submitted to the Office of Air and Water Programs, Water Quality and Non-Point Source Control Division).

The Project Officer for EPA was Edgar A. Pash. The assistance and cooperation received from representatives of all Federal, State, and local agencies is gratefully acknowledged.

## PREFACE

This report provides information on processes, procedures, and methods to control pollution resulting from mining activities. The control methods included in this report are identified and described by way of brief text, generalized illustrations, and unit cost indications where possible. An extensive bibliography is appended with appropriate referencing in the description of each pollution control method.

This publication has been prepared to be a general overview of available pollution control techniques. Coverage of mining activities for this purpose is not all-inclusive; activities not covered include solution mining, milling operations, and coal washing operations. It does not provide the degree of detail that would be needed for this report to be used alone as a pollution control or abatement reference. It is intended that this report will point the direction for further detailed inquiry by State and local government agencies and other parties attempting to devise solutions to mining pollution situations.

The described techniques should be considered as potential alternatives for specific mining pollution problems. The applicability and effectiveness of identified alternatives for specific problems must be determined on an individual basis. The applicability of any method or combination of methods will depend upon many factors including climatic, geologic, engineering, economic, land use and aesthetic considerations. The usual case will be that a combination of techniques will be required to effect the elimination or reduction of the discharge of pollutants from mining sources.

The control measures described are conceivably applicable to mining sources of pollutants regardless of whether those sources are categorized as "point" or "non-point" sources. Point sources of pollution are usually defined as those utilizing any discernible, confined and discrete conveyance including any pipe, ditch, channel, conduit, etc. Non-point sources are defined, by inference, as those diffuse sources not confined or conveyed in these ways, such as runoff and seepage. Abandoned, natural, and certain other sources not amenable to discharge regulation may be defined as non-point. No distinction in applicability between point and non-point sources is made for the control measures included in this report.

The control measures and pertinent experience citations selected for inclusion result largely from studies and pollution control technology development that have occurred in association with coal mining pollution problems in the eastern U.S. The regional emphasis reflected herein is due to the greater availability and quantity of information from the East; and the short time available for preparation of this report. Care should be taken in attempts to extend the results of pollution control applications to regional situations that differ significantly from those described.

Cost data are shown where appropriate to indicate a broad range of costs for individual control measures. Any use of quoted costs should be limited to gross estimation for planning purposes.

CONTENTS

# I. INTRODUCTION

Mining of the various minerals which are natural resources of the United States has been occurring in ever increasing magnitude for the past 150 years. This mining has resulted in significant water quality deterioration within, and downstream from, the mining regions. Drainage from thousands of active and inactive mines has produced chemical and physical pollution of both ground and surface waters.

Lands adjacent to this water pollution have been reduced in economic value and potential use. This water quality and land degradation has severely restricted social-economic development of many mining regions.

Water pollution in drainage from mines occurs when dissolved, suspended, or other solid mineral wastes and debris enter receiving streams or encounter the ground water system. Mine drainage includes water flowing from surface or underground mines by gravity or by pumping, and runoff or seepage from mine lands or mine wastes. This pollution may be physical (sediments) or chemical (acid, etc.) and is frequently harmful to aquatic or other life.

Water pollution from mining activities detrimentally affects potential water uses in all forms: municipal, industrial, agricultural, recreational, navigational, private development, and governmental.

Mine drainage pollution is similar to industrial waste pollution, but is different in that mine wastes, or inactive mines that discharge pollution, are not the result of an industrial by-product. Mine drainage is an indefinitely continuing, on-going source of pollution that will continue to pollute long after completion of mining, unless control measures are effected.

There are two primary types of pollution control--at-source abatement (prevention of formation of the pollutants) and treatment of the mine drainage.

Pollution control technology applicable to mining activities (including new, currently operating, and abandoned surface and underground mines) has developed rapidly in recent years. Much additional research and demonstration should be pursued with respect to technology for mine drainage control. However, many control methods are presently available whose feasibility and practicability have been subjected to varying degrees of demonstration and subsequent evaluation.

This report was produced to provide information that identifies and evaluates available technology for control of water pollution from mining activities. Information is provided herein on techniques of at-source water pollution control applicable to the mining industry, whose practicability and feasibility have been demonstrated, or strongly indicated, by the results of research. Information is provided on chemical/physical mine water treatment methods, techniques of water control or hydrologic modification, mine refuse disposal, site rehabilitation involving surface stabilization and revegetation, and measures that may inhibit or prevent the formation of pollutants in mine water.

Information is included on special problems pertaining to mine drainage pollution control. The range of applicability of each method is described and evaluated, with available (appropriate) cost data provided wherever possible.

The project encompassed pollution control methods for mining in all the states. It included mining for organic materials (coal, lignite, peat), gems (precious stones), heavy metals and other metallic minerals (gold, silver, lead, zinc, iron, copper, and many others), and earth minerals (talc, gypsum, limestone, dolomite, sandstone, sand, nitrate, phosphate, and others). All mineable materials are referred to as "mineral" throughout this report.

This manual is not intended for use as a comprehensive handbook on how to control pollution from mining activities. Rather, it is intended to acquaint the reader with the many techniques now available for use, and to guide him to the appropriate reference or references for specific, detailed, comprehensive information on how to apply a particular technique.

The manual is divided into three major components: 1) Surface Mining; 2) Underground Mining; and 3) Treatment. The sections describing the various control methods are numbered sequentially through each major component to facilitate use of the manual.

Pollution control techniques are described, evaluated, limitations and/or usefulness described, cost data for each technique detailed, where appropriate or possible, and special problems defined.

Previous demonstrations of techniques are explained in some instances, and data relative to these demonstrations presented or referenced. Conditions and range of applicability are defined where possible (particular techniques that could be used for different sources and types of mining than originally intended).

Some pollution control problems for which abatement techniques have not yet been developed were uncovered by the study. Additional research has been recommended if appropriate, or suggestions are made for using abatement techniques for other forms of pollution control that may apply.

The depth of the investigation was limited to an extensive collection of data available on the subject (published and unpublished), interviews with experts on mining pollution control, and extrapolation of experience from as many agencies as possible within the time and resource framework available.

## II. MINING AND WATER POLLUTION

The relationship between mining and water pollution is well-known. Mining disturbs the earth and disequilibrates natural systems. The resulting physical and chemical environmental changes often result in water pollution. Most types of mining generate some form of water pollution. There are two major forms of water pollution -- physical and chemical. Physical pollution is the increased erosion caused by land disturbance, resulting in increased sediment load. Chemical pollution is caused by exposing minerals to oxidation or leaching, resulting in undesirable concentrations of dissolved materials.

Many miles of the nation's waterways are degraded by mine originated pollution. The combined impact of physical and chemical pollution from mining is large. Ground water systems have also been polluted by mining, but the full impact is as yet unknown. The magnitude of the problem is just recently being recognized by the general public, as the present and future projected demand for clean water is beginning to surpass the more readily available supplies.

There are two general types of mining -- surface and underground. Surface mining is performed without going underground, or more simply, to mine without having a roof of mineral. There are several forms of surface mining -- strip, open pit, dredging and hydraulic. Strip mining is accomplished when a large amount of overlying material is removed to expose an underlying deposit for extraction. Open pit mining is quite similar to strip mining; the distinction being that open pit has little overburden. Most of the material removed during open pit mining is mineral, whereas most of the material removed during strip mining is overburden or waste. The configuration of each type of mine is also different. Strip mining leaves an open cut and large amounts of spoil; open pit mining results in a large open hole with only minimal spoil.

Most strip mining is performed to obtain coal, which is classified as a mineral in this report. Open pit mining is performed for various minerals, and many open pit mines are quarries where stone for building products is mined. Nearly all minerals have at one time or another been removed by open pit methods, the most notable of which are the huge open pit copper mines.

Dredging recovers minerals from underwater. Dredging is confined to alluvial and sometimes colluvial deposits. Gravel accounts for the majority of dredging production. Dredging has had widespread use in the gold mining industry. The mineral is either removed from an existing body of water or stream, or an artificial impoundment is formed.

Hydraulic mining is performed by directing a jet of high velocity water at an unconsolidated deposit. It is used almost exclusively for gold recovery. The water-borne sediment is then passed through a sluice box or other recovery mechanism.

These forms of surface mining almost always result in siltation, unless there is an impoundment to settle out the solids. Any disturbance of the land surface usually increases erodability of the materials, and increased erosion occurs. Chemical pollution occurs where mining results in an increased rate of any pollution forming reaction.

*Surface mining is accounting for increased mineral production* each year. This trend is expected to continue until near-surface mineral reserves are depleted. Building products were always removed by surface mining methods. Other minerals were more commonly mined by underground methods. The advent of huge earth-moving equipment, and increased costs of underground mining, have caused the increased production by surface mining.

Underground mines result in little surface disturbance and subsequently cause only minor physical pollution. Surface rock dumps, mine waste piles, and tailings piles associated with underground mines do contribute significantly to siltation problems. These piles are particularly vulnerable to erosion because of siting (often in, or adjacent to waterways), their common inability to support vegetation, and their fine grained nature. Though not completely documented, it is reasonably safe to say that underground mines are responsible for far more chemical pollution than are surface mines. Undermined areas may eventually subside after mining has ceased due to deterioration and collapse of artificial or natural supports left in the mine workings. Should subsidence occur in developed areas, buildings, roads, and other man-made structures can be severely damaged. Subsidence in undeveloped areas can create fault-like scarps and sinkholes that can result in diversion of natural surface drainages and create hazardous conditions for wildlife and livestock.

The current status (active or abandoned) of a mine is important in water pollution control. The vast majority of polluting mines are abandoned. Most water pollution problems come from these abandoned mines. Active mines will not be significant sources of pollution after federal and state discharge requirements are fully implemented.

Chemical pollution occurs when a water leachable mineral is exposed so that increased water leaching occurs, or the mineral is exposed to increased oxidation, which in turn results in increased leaching of pollutants. The exposure of water leachable pollutants does occur, but the majority of chemical pollution is generated via increased oxidation.

Several unusual forms of pollution occur that do not fit the previous discussion. Uranium mill tailings are radioactive, and are washed or windblown into the water system where they continue to decay, releasing radioactivity. Chemical pollution can also result from physical pollution. This occurs where leachable materials are eroded and dissolve after entering the water system or where erosion exposes material to increased oxidation.

Most chemical pollution results from oxidation of sulfide minerals. The sulfides are relatively insoluble until oxidized. Oxidation results in acidity and the release of metals and sulfate to the water system. Acidity and metals are the primary pollutants that kill aquatic biota. Acidities are detrimental because they cause deterioration of water systems and water related facilities. Concentrations of metals found in mine drainage are often harmful or toxic to life.

These sulfide minerals are usually in a state of relatively slow oxidation prior to mining. The oxygen access to these minerals is very limited because of inundation by the water table or relatively slow oxygen diffusion rates into the earth. The sulfide minerals are slowly oxidizing at their outcrop or through the small amount of oxygen diffusing under ground. The ground water usually contains small concentrations (0 to 10 mg/l) of dissolved oxygen that allow a very slow oxidation of sulfides prior to mining. Mining suddenly exposes large quantities of sulfides to direct contact with oxygen and oxidation proceeds rapidly. Water pollution results. Unfortunately, sulfides occur with many of the minerals mined, and many of the metals are mined as sulfides.

Many mine slopes are unstable, causing failure (landslides), and consequent deposition of sediments in valleys and stream channels, erosion of newly exposed surfaces, and damage to buildings and timber.

## III. MINE WATER POLLUTION CONTROL

Mine water pollution control is a relatively new field. Mine water pollution abatement projects have been undertaken since the turn of the century, but these early attempts were generally unsuccessful. A concentrated research and demonstration effort began in earnest in the 1960's. Many new techniques were demonstrated with varying degrees of success. The technology is still crude and largely unavailable for large scope cleanup operations, particularly with respect to deep mine discharges. Many of the techniques in use today are still somewhat theoretical. Thorough documentation of their effectiveness and applicability is not available.

Mine water pollution control is generally achieved by changing the conditions responsible for pollution production or by treating the discharge. The following "Manual" portion of this report contains descriptions, evaluations, costs, and references for individual techniques that can be used to control water pollution from mining. Although the techniques are listed individually, very few are intended for use as a complete abatement plan. Combinations of several techniques are usually required to form a complete abatement plan. For instance, any type of regrading of a surface disturbance should be accompanied by revegetation and possibly water diversion.

Rarely is a single abatement technique a complete solution for a mine drainage problem. The set of conditions occurring at any particular mine can be considered as being unique to that specific mine site. Each technique used must be designed for each mine site, considering the particular conditions of the site. A thorough physical inventory and evaluation of each mine site should be undertaken before an abatement plan is formulated. The ultimate source and cause of the pollution should be known. An abatement plan should be formulated to specifically attack the cause of pollution for each mine site. Formulation of an abatement plan should only be done by individuals knowledgeable in mine drainage control. Many techniques are available for use in controlling pollution at many mines. Different techniques will have different levels of effectiveness and different costs. Detailed engineering is required for application of most of the techniques to a particular mine site. Effectiveness of the technique will be dependent on the manner in which the technique is designed and constructed.

Effective control techniques are not yet available for many mine drainage problems. Many of the deep mine discharges cannot be controlled with available at-source abatement techniques. Drainage treatment is then the only solution for many of these discharges.

The Manual is divided into three components: 1) Surface Mining; 2) Underground Mining; and 3) Treatment. The first two major components deal with at-source techniques. These are techniques that can be utilized at the mine site. They generally involve a single capital expense and low or zero operating and maintenance costs. Some of the at-source techniques are exceptions, and require continued maintenance and operation. The drainage treatment deals with methods of treating discharge water to remove undesirable constituents.

Each technique is evaluated to some degree. Many of the evaluations are subjective and are based on the opinion of the report authors. Evaluation of the effectiveness of a technique is extremely difficult because of the interplay of numerous variables. Some techniques have been field studied, but the published data is often insufficient for use as a basis for a sound evaluation. The reader will also have to make his own evaluation of the probable effectiveness of any technique to be used in a given situation.

The techniques are grouped into broad method categories according to general types of usage. These categories tend to overlap because the techniques do not all fit neatly into a category. Effective use of this manual requires that the reader be familiar with all of the techniques. This familiarity will allow the reader to evaluate all available techniques applicable to a particular mine pollution problem. More specific and detailed information can usually be obtained for each technique from the listed references.

After each technique is described and evaluated, the references that apply to that technique are listed by arabic numerals. The specific references are then listed numerically and described in the back of the manual. This was done to avoid the large amount of repetition that would have been necessary to describe each reference with each technique discussion.

Cost data is presented for the techniques when available. These costs are intended to be used as an indication of possible price ranges and to give the reader a rough idea of the cost differential between techniques. The costs of mine reclamation are extremely variable and are entirely dependent on prevailing site conditions and degree of adaption of the technique to the site. The project designer will be very influential in the project cost. Two designers can accomplish the same water pollution control goal for a particular situation at widely varying costs. Strip mine regrading has a relatively predictable cost, yet it can vary from $1,200 per hectare ($500 per acre) for an area strip mine in nearly flat terrain to $12,300 per hectare ($5,000 per acre) in the Pennsylvania anthracite coal region. Similar and sometimes greater cost variations occur with most of the techniques discussed. Reliable cost estimates can only be made after a detailed project evaluation.

Special legal considerations pertaining to the techniques are discussed in the technique or method sections. There are general legal considerations that apply to most of the techniques. The most important question is the assignment or assumption of legal liability for polluting discharges. Responsibility for water pollution control for active and future mines will be borne by the miner under new Federal-State discharge requirements for the period of mine activity. However, responsibility is unclear for presently active and future mines after abandonment. Responsibility for currently abandoned mines will have to be assigned or assumed by some party. It would be most difficult to assign responsibility to present landowners because of the high costs of reclamation and small land improvement benefits. The original mining was done in a legal manner (at the time) and past operators and owners would not be legally liable. It is possible that the responsibility for abandoned mine water pollution control would have to be assumed by the state or federal government.

Acquisition of access rights must be obtained for construction of abatement projects. Access can be obtained by outright purchase, gift, use of eminent domain, consent liens, lease, or simple access agreements. Mineral and water rights acquisition may also be required. Some abatement techniques such as strip mine regrading and underground mine flooding make future mineral extraction more difficult and sometimes unfeasible. Mineral rights owners may have to be compensated for their losses. The mineral remaining in waste piles may be considered as valuable property that may yield a profit in the future. The question of ownership is difficult to establish between the mine operator (or operators, as is often the case), the mineral rights owner, and the surface owner.

Multiple purpose abatement, particularly with respect to surface mine reclamation, can be an effective tool. Benefits other than water pollution control can help offset construction costs and increase project justification. Surface mined lands can be returned to a useful purpose for agriculture, silviculture, game food areas, parks, golf courses, airports, developments, industrial sites, and scenic areas.

# IV. THE MANUAL

# WATER

# POLLUTION

# CONTROL

# METHODS

# SURFACE

# MINING

# 1.0

# POLLUTION CONTROL PLANNING

# FOR

# FUTURE SURFACE MINING

## 1.1 METHOD DISCUSSION

Water pollution has been an integral part of most mining operations in the past. Most mine planners had designed their mining operations with little or no regard for prevention of water pollution. The main planning element was always the economics of mineral recovery. Quite often the cheapest means of mineral recovery resulted in the largest water pollution problems.

Recent water pollution laws have introduced a new economic element - water pollution control costs - to be considered in mine planning. Water pollution control costs can be extremely high. Foresighted planning can minimize these costs and provide better water pollution control.

Effective pollution control preplanning can eliminate pollution from active mines and minimize pollution that may occur after completion of mining. Presently available technology can practically eliminate water pollution by treatment of the mine water. Use of water treatment during mining has no effect on the levels of water pollution after treatment ceases and the mine is abandoned. Therefore, this section of the report deals with preplanning to reduce water pollution, both present and future, by using at-source control techniques.

Proper planning of mining and pollution control techniques should follow the concept of a complete, comprehensive reclamation plan. This plan should have control measures designed for all phases of mining from initiation through completion. Preplanning involves acquiring complete information concerning the future mine site, defining the reasons why mining could cause pollution from the site, and determination of available techniques to prevent or minimize formation or transportation of pollutants. Location of haulage and access roads and other mine related facilities should be included in preplanning for water pollution control.

Mine site planning is the primary step in establishing any new mining area and is the key to a successful, non-polluting and economical mining operation. Site characteristics should be carefully explored. Site hydrology is important because water is the major transport mechanism. If water influx to the mine area can be controlled, then pollution can be controlled. The future mine can be planned so that water inflow (both surface and ground water) is minimized. A surface mine should be sited to prevent interception of runoff from adjacent areas, either by avoidance of surface water flow channels or by construction of diversion systems.

Knowledge of availability and location of suitable material for revegetation should be gathered. The mining plan can be oriented toward segregation and stockpiling of this material for later reclamation efforts. The location and extent of pollution-forming materials should be known. This permits preparation of a mining plan that will handle these materials in a manner least conducive to formation of pollution. The chemical and physical nature of the overburden should be carefully explored so the various materials can be handled according to their pollution-forming potential. There should be sufficient non-polluting materials present to form the upper layer of the regraded surface upon completion of mining. The amount of pollution-forming materials in the overburden should be small enough to permit effective burial during reclamation. Mining in areas of toxic or pollution-forming overburden should be limited to operations where demonstrated, effective, and approved control measures will be implemented. Samples of the overburden materials can be gathered by the use of core borings, test pits, and soil sampling techniques. These materials should be laboratory tested to determine their revegetative and pollution-forming capacities prior to mining.

It is inevitable that some pollution-forming materials will be exposed to possible leaching during most surface mining operations. This exposure time can be minimized through the use of concurrent reclamation techniques. Erosion of exposed material is a problem that can be controlled by planning sediment ponds, diversionary measures, compaction, covering, or revegetation.

Local geology and ground water flow patterns should be analyzed prior to mining. Core borings, exploratory pits, and topographic mapping can reveal local geologic conditions that could increase water pollution problems. Mining in ground water discharge and recharge areas should be avoided or special water handling measures included in the mining plan. Ground water can be intercepted by various techniques to reduce the amount of water reaching pollution-forming materials. Knowledge of ground water levels can be useful in design of open pit mines. Some mines can be excavated below the water table so they will partially flood upon completion of mining. The open pit can be designed to serve as a water collection and settling facility during mining and after completion of mining.

Local soil and slope stability factors should be analyzed to determine if special precautionary measures should be taken. Some soils are highly erodible requiring rigorous erosion control measures. Some geologic formations weather rapidly upon exposure to air and water, become unstable, and are subject to sliding and flowing.

Physiographic considerations are also important. Special mining techniques, such as modified block cut, parallel fill, and slope reduction, should be utilized in steep terrains to prevent massive landslides of spoil material.

The methods to be used for overburden segregation and handling should be developed prior to initiation of mining. Soil material, pollution-forming material and non-pollution-forming material should be segregated during mining. Planned removal and replacement of these materials can eliminate costly excessive handling. The regrading plan should be integrated with the mining plan to reduce costs and increase effectiveness of the subsequent reclamation.

Past mining and drilling history should be investigated. Locations of underground mines and underground mine water pools should be known. Surface mine breakthrough into underground mines can cause the release of large quantities of impounded water, or provide a means of entry for water and air to the underground mines.

Local environmental conditions should be considered in surface mine siting. Some environments are extremely delicate and reclamation techniques are not very effective. It is difficult to revegetate surface mined lands in arid, semiarid , alpine and tundra areas. An area that is not revegetated after mining is subject to long term ravages of wind and water erosion. Specialized mining techniques should be used in areas of delicate environmental balance. Choice of plant species for revegetation should carefully consider adaptability to local environmental conditions.

Types of information to be used in surface mine planning may include:

1) United States Geological Survey topographic maps.
2) Aerial and spectral imagery photographs and photogrammetric mapping.
3) Soils maps.
4) Geologic, hydrologic, and structure maps.
5) Mine maps for adjacent underground mines.
6) Core borings with chemical and physical analyses.
7) Precipitation records.
8) Drainage areas tributary to a mine site.
9) Analyses of surface and ground water flow.
10) Well (oil, gas, water) logs.

Surface mine preplanning can greatly minimize the amount of water pollution which will come from a mine. However, in many cases pollution will still result from exposure of pollution-forming materials and inability of control mechanisms to completely prevent water from entering a mine area. Preplanning of collection and treatment systems can result in effective pollution control at reduced costs.

REFERENCES

9, 10, 28, 42, 43, 49, 50, 61, 62, 69, 70, 72, 121, 128, 142, 151, 153, 154, 177, 187

# 2.0

# CONTROLLED

# MINING

# PROCEDURES

## 2.1 METHOD DISCUSSION

Certain mining procedures provide better control of water pollution than other techniques. This section of the report is devoted to several of these techniques that are in use today. These are not merely regrading or reclamation techniques but are, in fact, mining techniques. These mining techniques are not complete reclamation plans, but rather methods of control that must be supplemented by additional techniques in order to arrive at a complete reclamation plan.

The technique discussions that follow are intended to show how each technique can be best utilized to accomplish an objective at any mine site. All of the techniques will not apply to any one mine site. The use of any technique will have to be adapted to the particular mine site.

## 2.2 OVERBURDEN SEGREGATION

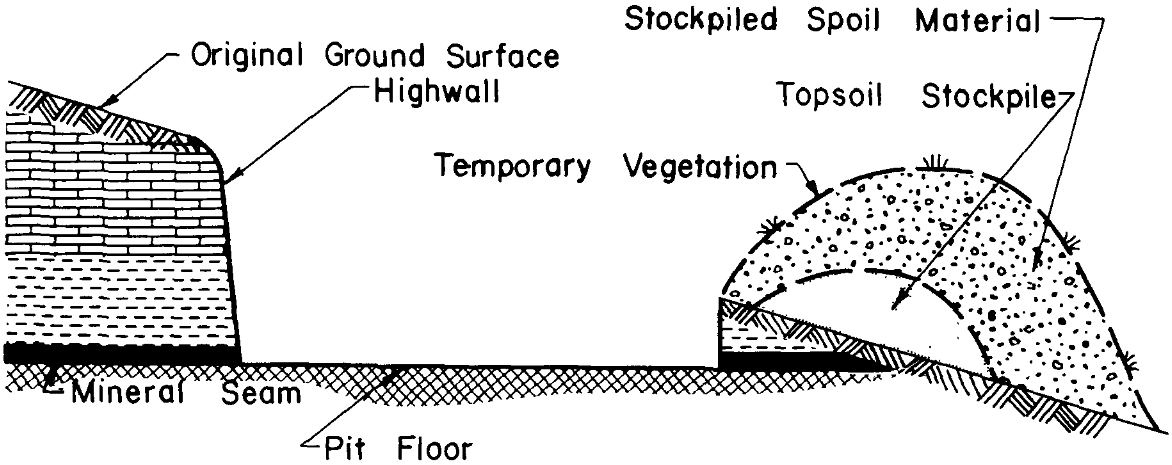
### DESCRIPTION

Overburden that must be removed to expose a mineral is seldom homogeneous. This overburden is usually a mixture of soil and rock that has varying physical and chemical properties. From a water pollution standpoint there are three classes of overburden material: 1) soil (material conducive to plant life); 2) clean fill; and 3) pollution-forming material. The purpose of segregating overburden is to keep these three classes of material separated during mining so they can be effectively utilized during later regrading.

Spoil segregation was rarely practiced by miners in the past because it was cheaper to pile all material together. Reclamation of these old abandoned mines is difficult, because good soil is lost and pollution-forming materials occur throughout the spoil.

Most of the water pollution from surface mines (other than erosion) occurs as a direct result of exposing pollution-forming materials to oxidation. These same materials are often covered by a ground water table and are isolated from free air oxygen prior to mining. As such, they do not have the opportunity to produce significant quantities of pollution. These materials are exposed during mining and begin to oxidize, forming water soluble salts. These materials will continue to produce pollution as long as they are exposed near the surface of the mine. These pollution-forming materials can be returned to conditions similar to pre-mining by means of deep burial in the regraded material. Burial helps to eliminate this free air contact and curtails oxidation. Burial also improves the chances that the material will be inundated by ground water, which will positively eliminate free air contact.

One of the primary purposes of overburden segregation is to stockpile soil for later establishment of vegetation. Soil from all surface mine sites should be removed, stockpiled and temporarily vegetated. This soil can then be spread over a mine surface on completion of grading. An effective vegetative cover is often difficult to establish in the absence of soil. Graded spoil material is often of coarse texture, usually stony, and will not function to retain water at the surface, as required for a good vegetative cover. Spoil is often a pollution-forming material which can further inhibit vegetative growth. Spoil material can be dark colored and absorb sufficient solar energy to prevent vegetative establishment due to high temperatures. Most of these problems can be eliminated by restoration of the original soil.




**OVERBURDEN SEGREGATION**

**Figure 2.2-1**

Although the illustration indicates downslope stockpiling of topsoil and spoil, this practice is not really desirable. The stockpiled topsoil can only remain buried for a limited time or it will lose its ability to enhance vegetative growth.

Segregation of pollution-forming materials prevents these materials from being mixed throughout the regraded surface. It also isolates these materials for later burial during reclamation. A layer of clean fill is first placed in a strip cut during regrading, followed by placement of pollution-forming material. The remainder of the clean fill is then compacted over the pollution-forming material. Stockpiled soil is spread evenly over the entire surface and immediately planted with seed to form a dense ground cover, such as grasses and legumes.

## EVALUATION

Overburden segregation has been successfully utilized many times in the coal fields of eastern United States.

Overburden segregation, when utilized with regrading and revegetation, is believed to be one of the most successful methods of controlling water pollution from surface mines. This technique is applicable only to active mining operations where it is still possible to perform segregation. It has only limited usefulness in old abandoned surface mines where the spoil material is a mixture of various types of overburden material.

There are three basic limitations to this technique. First, there may not be sufficient material conducive to growth to save. Alternate means of surface enhancement for vegetation should then be considered. The soil should be saved, even if there are only limited amounts available. Second, respreading topsoil may not be sufficient for establishment of vegetation. This is common in arid climates, and additional measures will be required. The third limitation is cost. Overburden segregation is an added mining expense. However, if material handling is well planned, the additional expense can be minimized. A miner operating in a competitive market may not have sufficient profit margins to allow for overburden segregation if other miners are not using this technique. Therefore, overburden segregation may have to be regulated by law to prevent inequities in the mining industry.

## COSTS

Costs of using this technique are borne by the mining industry and passed along by increased price of the mineral mined. The amount of increased mineral price is difficult to establish and will depend upon how overburden is handled at each mine. Good preplanning to eliminate excessive materials handling can reduce this cost to a minimal value. Costs will also vary in accordance with the amount of different overburden types present, terrain, geometry of the mine site, mining method, and equipment available. The cost of using this technique will have to be developed on an individual mine basis.

Costs cannot be determined from past applications of this technique because it is used in conjunction with other techniques. Costs of this technique have never been isolated from costs of the entire mining operation.

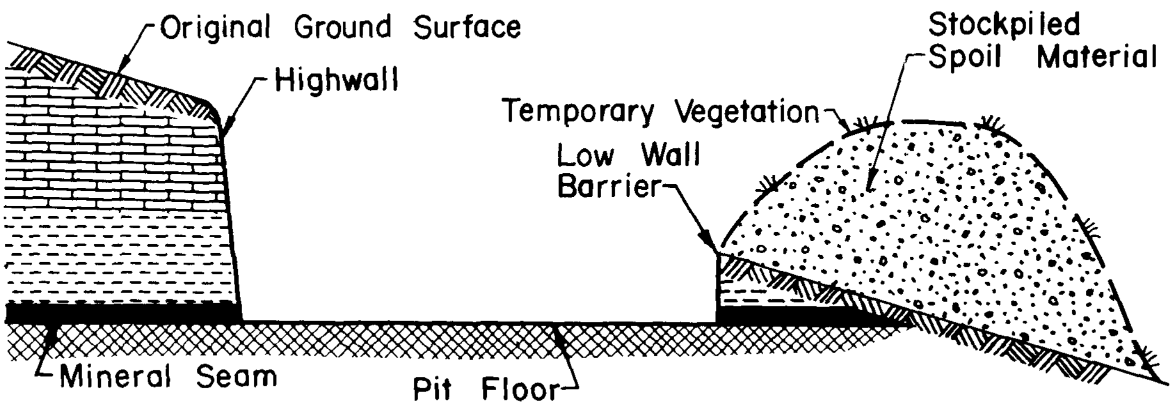
REFERENCES

33, 42, 43, 56, 61, 62, 69, 146, 151, 197, 198, 199

## 2.3 MINERAL BARRIERS OR LOW WALL BARRIERS

### DESCRIPTION

Mineral barriers are portions of the mineral and/or overburden that are left in place during mining. These barriers are common in the coal industry. Approximately a 9 meter (30 feet) width of coal outcrop is left in place during contour strip mining. The basic function of this "low wall" barrier is to provide a natural seal along the outcrop. This seal helps retain surface and mine water within the mine during the mining operation. After mining the barrier helps to confine ground water within regraded mine spoil.




CROSS SECTION OF
LOW WALL BARRIER
**Figure 2.3-1**

Mineral barriers are also left between surface mines and adjacent deep mines to prevent free passage of water between the mines.

Mineral barriers appear applicable to the dredge mining industry. A barrier could be left between the dredging operation and an adjacent stream or body of water in order to contain large amounts of sediment often generated from the mined area.

Mineral barriers are probably useful in any surface mining operation where there is a need to prevent the influx of water to a mine or to contain water within a mine.

## EVALUATION

Low wall barriers are applicable to most types of contour mining. However, they function best when mining has been performed to the rise of a mineral seam. Flow of ground water is toward the barrier in this instance.

Effectiveness of a barrier depends on integrity of the barrier and relationship between the barrier and local hydrologic conditions. For instance, barriers are not as effective on steeply inclined coal seams as on flat lying coals. A barrier often helps form a ground water dam that will inundate a portion of a reclaimed surface mine. The extent of flooding and water control can only be determined on an individual application basis. A degree of variability should be allowed in the application of the barriers. A hydraulic evaluation should be made at each mine to determine the type and extent of barrier to be utilized.

Mineral barriers can be effective in flooding selected portions of a mine site. Pollution-forming materials can be buried in these flooded zones.

Consideration should be given to preserving the integrity of a barrier during and after mining. One small breach in a low point of a barrier can render an entire barrier ineffective.

The barrier should be utilized in the context of a reclamation plan that includes other elements of control such as regrading, revegetation, and water diversion.

## COSTS

Cost of this technique is borne by the mining industry, mineral owner, and mineral consumer. Unfortunately, a low wall barrier utilized in contour coal mining contains the most easily extractable mineral in the mine. Leaving mineral in place costs the miner and mineral rights owner profit that would have been gained from removal of this mineral. It increases cost to the consumer because the mineral in the barrier would have been the cheapest to mine. The minerals remaining in low wall barriers are not likely to be mined in the future because of their geographic distribution over large areas.

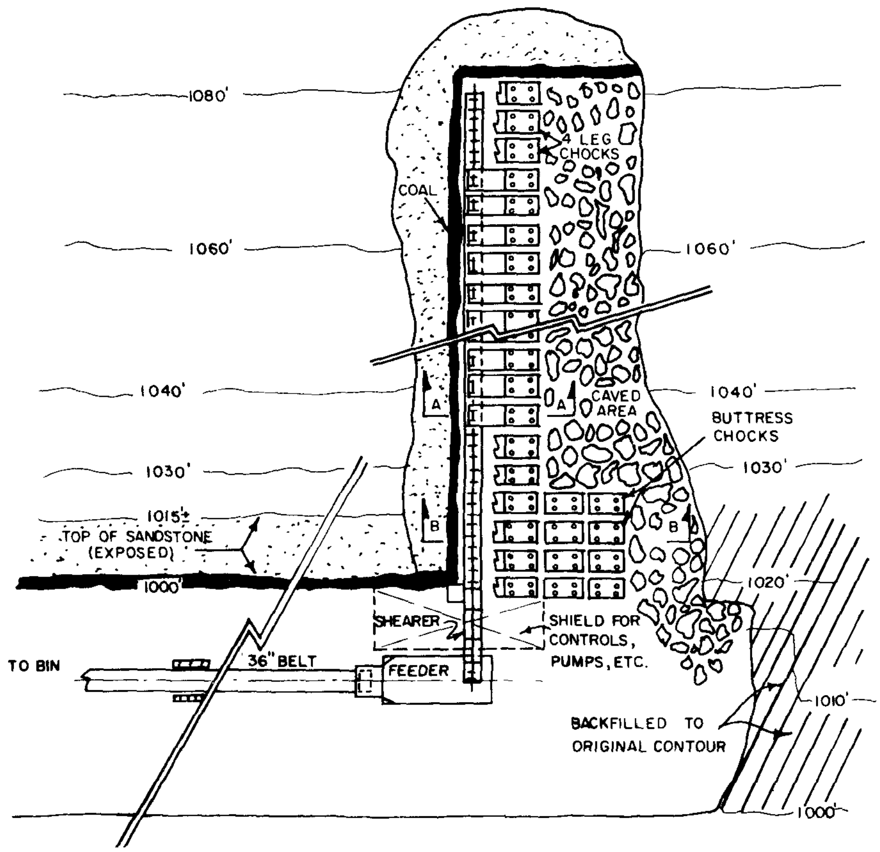
## REFERENCES

33, 61, 126

## 2.4 LONGWALL STRIP MINING

### DESCRIPTION

This concept is an adaptation of longwall underground mining. It is being investigated for mining of seam-type mineral deposits such as coal. This method is being researched as an alternative to strip mining. Longwall mining removes coal without removing overburden. A vertical trench is cut into a hill perpendicular to the coal outcrop, then automatic mining equipment is inserted in this trench and progresses through the coal seam in a direction parallel to the outcrop. Coal is cut by machine and transported to the outcrop with a conveyor belt.




PLAN
**LONGWALL STRIPPING SYSTEM**
Figure 2.4-1

The mine roof is held up by hydraulic jacks that progress forward with the cutting equipment, allowing the roof to collapse behind the miner. This type of mining does not leave void spaces as in an underground mine. It does not disturb the overlying material as in strip mining and could provide a high percentage of coal recovery. Equipment is controlled remotely keeping people out of the danger areas.

## EVALUATION

There is little surface disturbance required for the use of this technique, and most problems of strip mining are eliminated. Complete collapse of the mine roof after extraction may also eliminate many water pollution problems associated with oxygen in underground mines.

Relatively flat, or very gently rolling, coal beds are required for longwall strip mining. It is likely that this type of mining will disrupt local ground water conditions because of roof collapse.

While this technique is discussed as being possible, feasibility has not yet been established. The procedure is being evaluated economically and environmentally by the Environmental Protection Agency with an actual demonstration project. Longwall strip mining shows promise of being a feasible mining method that will have a smaller environmental impact than other common mining methods.

In view of limited application to date, its use must be considered experimental.

## COSTS

Costs are not yet available.

## REFERENCES

61, 128, 137

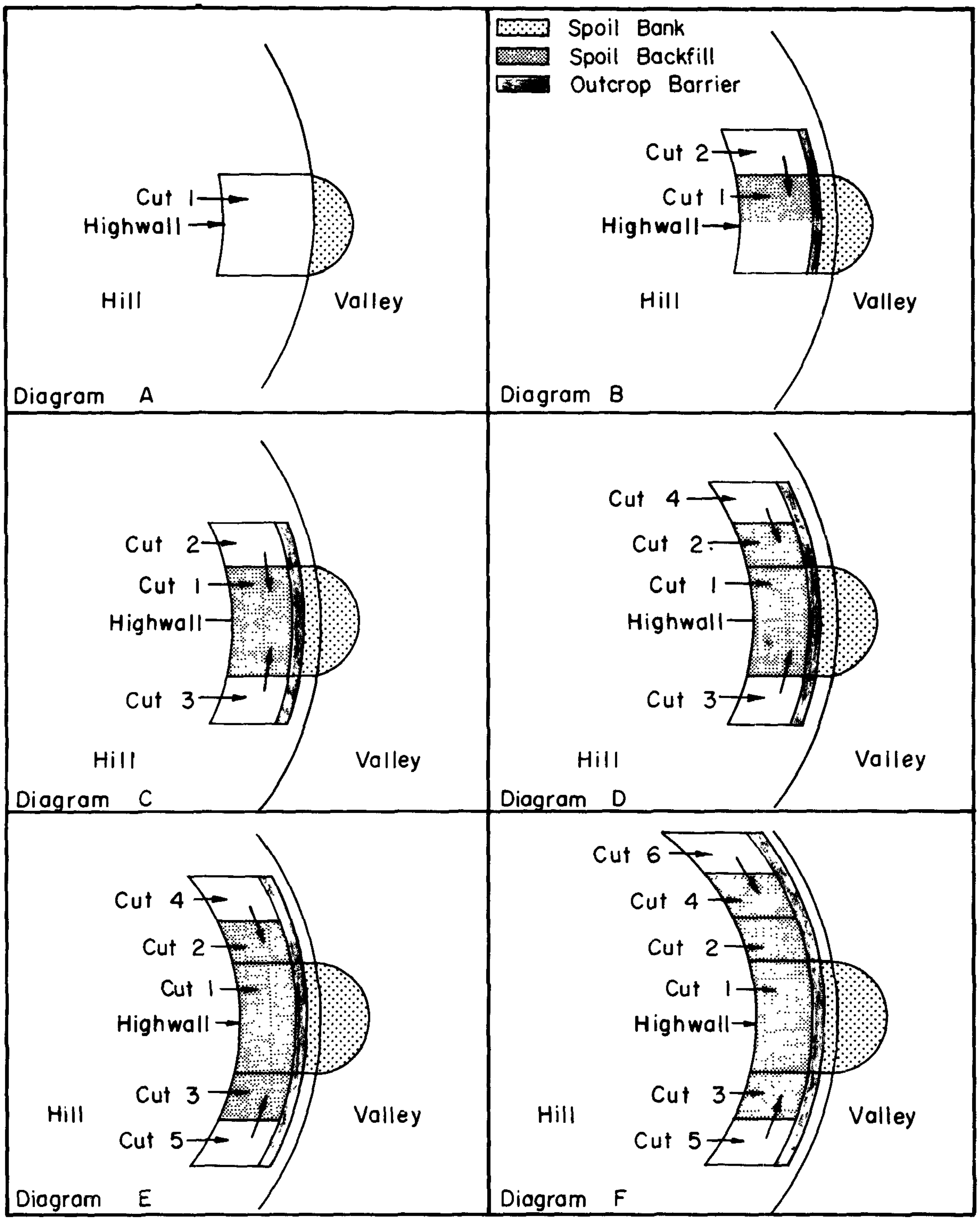
## 2.5 MODIFIED BLOCK CUT OR PIT STORAGE

### DESCRIPTION

This method was developed as an alternative to standard contour strip mining methods to facilitate contour regrading, minimize overburden handling, and contain spoil within the mined areas. Contour strip mining is usually accomplished by throwing spoil off the bench onto the area downslope from the mine. This downslope material is subject to landsliding and rapid erosion. The downslope material must be brought back up to the mine site if contour regrading is required upon cessation of mining. Disturbed land area and the areas requiring revegetation are much larger than the mined areas when the spoil is cast downslope.

In modified block cut mining only the material from the first box cut is deposited in adjacent low areas, such as a saddle in the ridge line, or at the head of a hollow. Remaining spoil is then placed in the mined portions of the bench. Mining is accomplished in the following manner.

An initial cut is made from a crop line into the hillside to the maximum highwall depth desired, and suitably cast in a low area, or placed in a suitable head of hollow fill area. This cut is usually three times wider than each succeeding cut in order to accommodate spoil material from succeeding operations. After removal of the mineral vein from the open block, spoil material from the succeeding cut is backfilled into the previous cut, proceeding in one or both directions from the initial cut. This step simultaneously opens resource recovery and provides the first step in strip mine reclamation. After completion of each cut, a void is left near the highwall where pollutant-forming materials encountered during mining can be placed. In this way, these materials can be directly buried using acceptable coverings prior to final regrading operations. When mining is completed, the entire mine is regraded to resemble original contour with a minimum amount of earth handling.




**MODIFIED BLOCK CUT**

**Figure 2.5-1**

Adapted from drawing in reference No. 69

## EVALUATION

This technique appears to be a good technique to reduce environmental damage of contour surface mining in mountainous terrains. Present experience with the method has been limited to terrain slopes of less than $20^{\circ}$ and average highwall heights of 18 meters (60 feet). It is expected this technique will prove feasible in even steeper terrain.

There are definite advantages to a mineral industry in that most of the overburden is handled only once, and grading and revegetation areas are reduced. The technique is environmentally sound because of concurrent reclamation, the small disturbed area, use of contour regrading, and confinement of most of the spoil to a mined area.

The basic limitation of the technique is the problem of where to place material from the first cut of overburden. The amount of open highwall needed for auger mining is limited, and could hinder auger recovery of highwall reserves.

## COSTS

It appears this mining method is no more expensive than any other method where contour regrading is required, and could prove to be less costly.

The Mears Coal Company, Pennsylvania has produced coal for $7.30/tonne ($6.60/ton) delivered at the coal preparation plant, in an area with a $20^{\circ}$ slope.

## REFERENCES

61, 69, 142

## 2.6 HEAD-OF-HOLLOW FILL

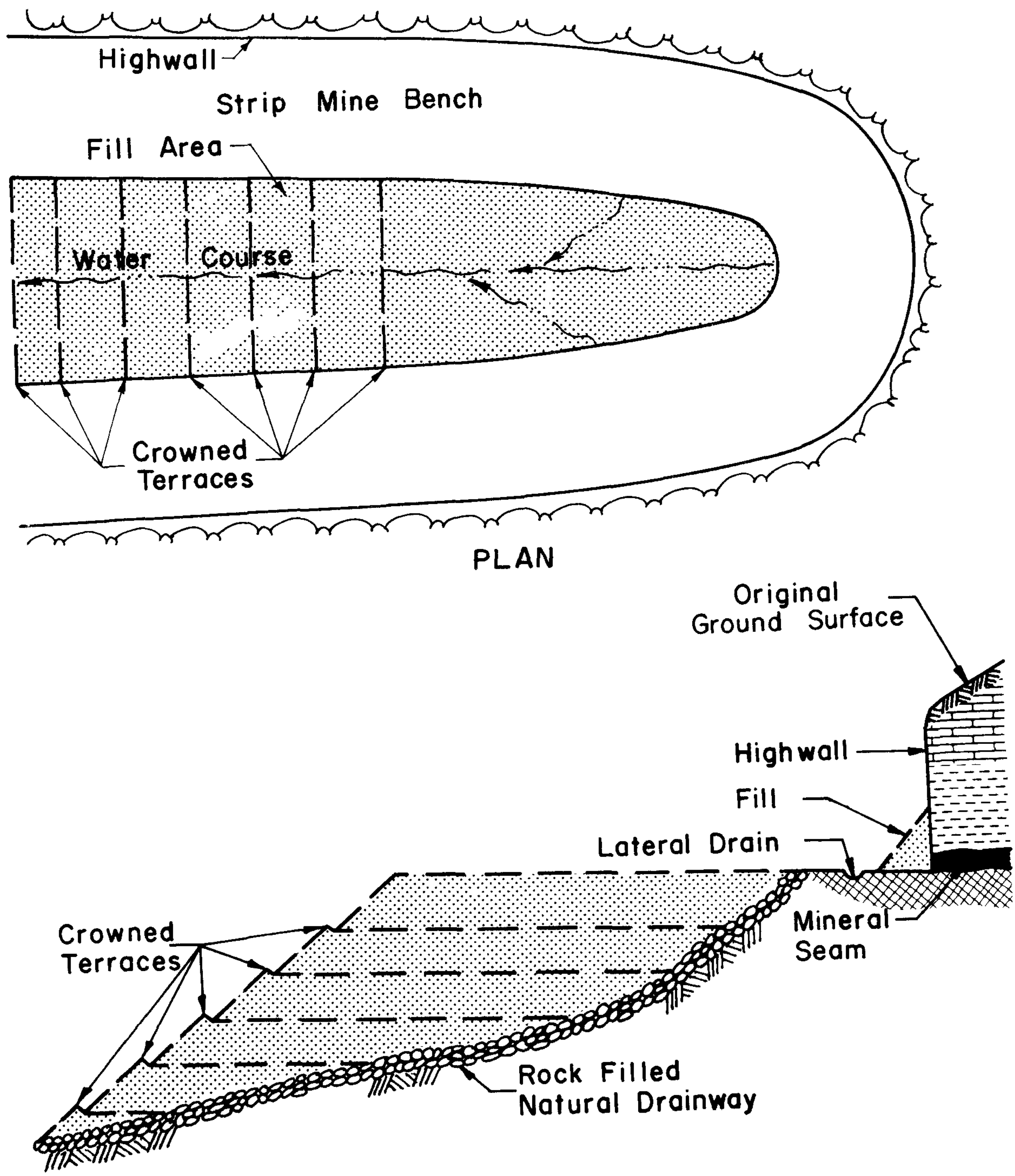
### DESCRIPTION

Head-of-hollow filling is often used with other methods of surface mine restoration. This is because this technique is essentially an overburden storage method. Basically, overburden material from adjacent contour or mountaintop mines is placed in narrow, steep-sided hollows. The material should be properly placed in compacted layers of 1.2 to 2.4 meters (4 to 8 feet) and graded so that surface drainage is possible. The natural ground should always be cleared of woody vegetation and drain (rock) should always be constructed where natural drains exist or may have existed except in areas where inundation occurred. This permits ground water and natural percolation to exit fill areas without saturating the fill. This reduces potential landslide and erosion problems. Normally the face of the fill is terrace graded to provide drainage to undisturbed lands.

### EVALUATION

This technique of fill, or spoil material deposition, should be limited to relatively narrow, steep-sided ravines that can be adequately filled and graded. Consideration must be given to the total number of acres in the watershed above the proposed head-of-hollow fill as well as the drainage, slope stability, and prospective land use. Revegetation should proceed as soon as the various steps are completed (along with the other erosion control techniques) to prevent erosion and siltation. If all overburden from a surface mining operation is used or placed in the fill, possible remaining exposure of the unreclaimed bench and highwall could cause pollutional problems from sedimentation or chemical reaction.

The technique can be utilized as a waste dump for overburden




CROSS SECTION OF
TYPICAL HEAD-OF-HOLLOW FILL
Figure 2.6-1

Adapted from drawing
in reference No. 61

from terrace benches resulting from contour mining, or for removal of entire mountaintops (daylighting), where mineral recovery is partially complete. It may provide a means of cleaning up islands of land left with no access, resulting from incomplete prior mining. It can reduce landslide potential and allow for full recovery of one or more mineral seams.

Effectiveness of the technique depends on good design and construction of drainage facilities. Special emphasis is required on water management during fill and grading operations. If the installation is to be permanent, or is on a steep slope, fill benching techniques and permanent tile drains should be utilized to prevent slope failure. These practices will help fill stability and reduce associated pollutional problem. Use of this method often results in creation of flat-lying land in mountainous areas that may help economic development.

A disadvantage of this method is that it leaves behind a large amount of disturbed land. Spoil is removed from a mined area and thus increases the total amount of disturbed area. Some spoil or soil should remain on the mine site for subsequent revegetation.

Under-drainage containing high concentrations of pollutants sometimes results and may require treatment to meet pollution control requirements.

## COSTS

Cost of head-of-hollow filling will depend on the method of mining it supplements. Such factors as haul distances, site preparation and equipment used, must be taken into account at each proposed site. Costs could be reduced in some applications where box cut or modified block cut mining methods are used, due to a consequent reduction in material to be discarded outside the mine bench. No specific costs are given since this technique is part of a mining procedure.

REFERENCES

61

## 2.7 BOX-CUT MINING

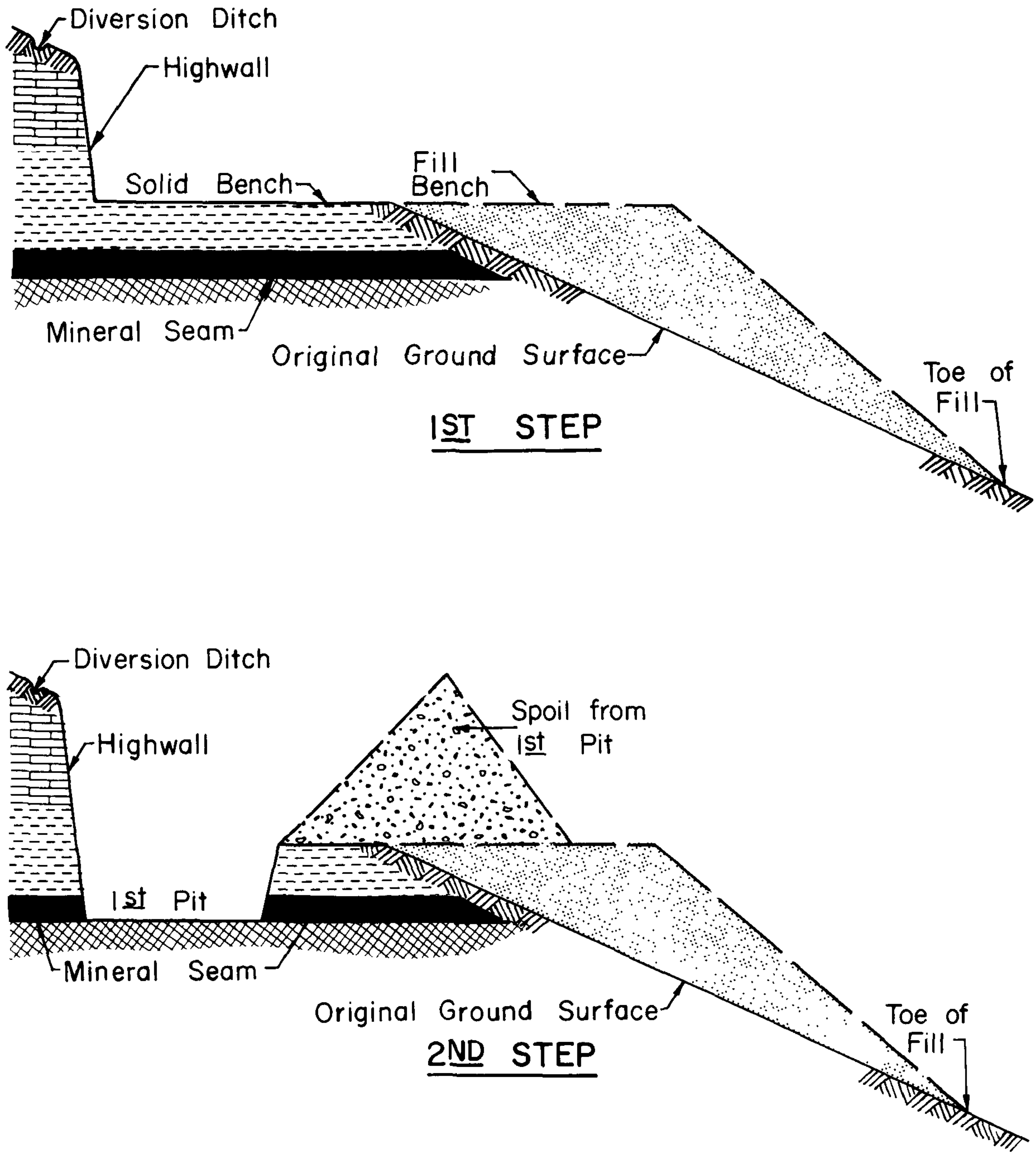
### DESCRIPTION

The box-cut method utilizing only one cut is essentially a normal form of contour strip mining which leaves an undisturbed bench over a low wall. Overburden is discarded downslope, using an acceptable slope control technique and eventually regraded, usually to a reverse terrace plan.

The box-cut using two (2) cuts is a refinement of the contour mining procedure. Initially, vegetation is removed and suitable topsoil overburden material stockpiled. Remaining overburden is removed to a pre-determined elevation and cast downslope. The box-cut operation then begins nearest the exposed highwall with this overburden cast on the bench over the low wall barrier. The mineral is extracted from the first cut opening. A second cut is then made toward the low wall barrier with the spoil material cast into the first cut trench. After completion of mining the remaining second cut overburden is regraded.

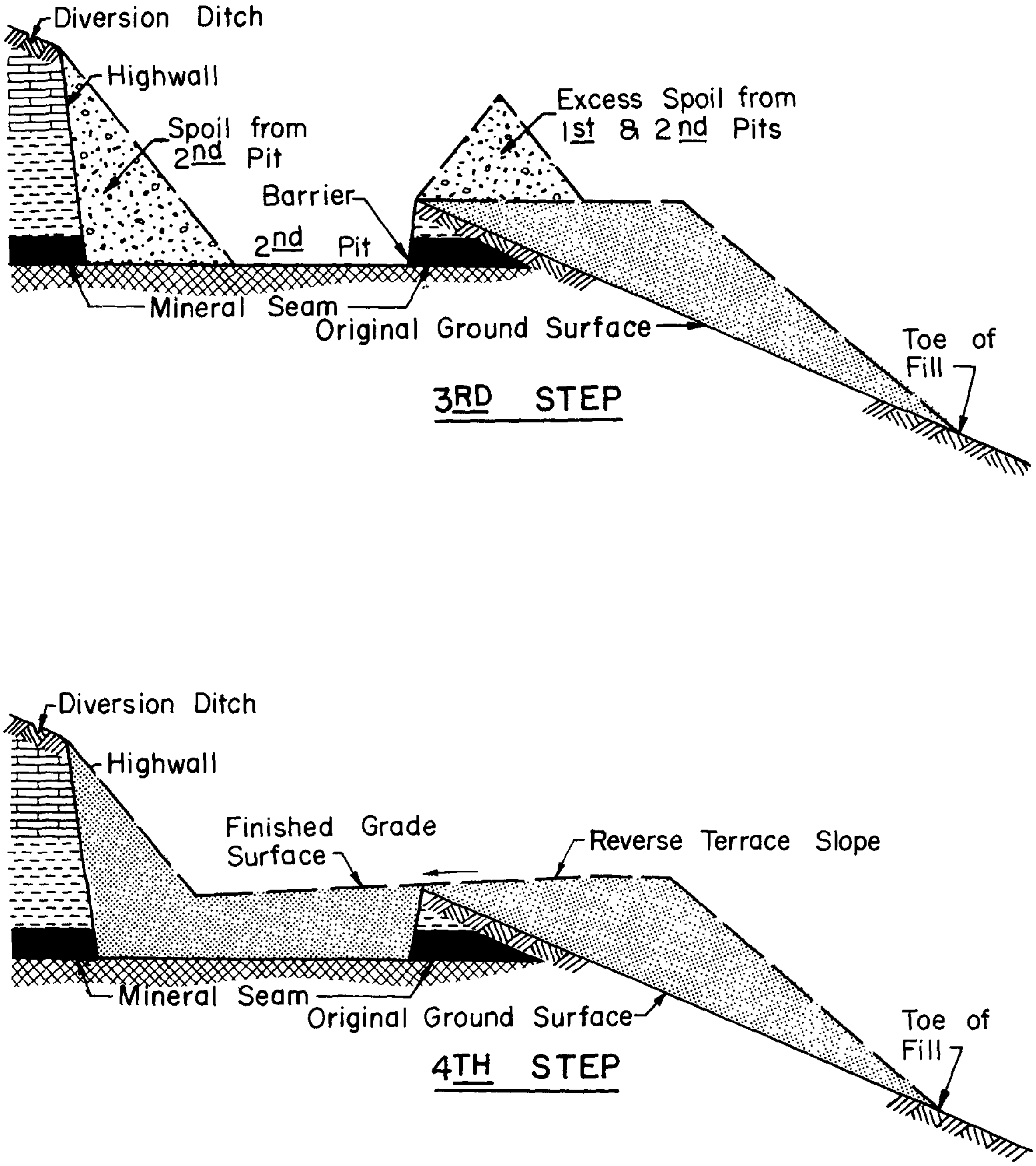
### EVALUATION

Use of this technique as a water pollution control procedure is questionable. Unless some very careful planning is done and operations carefully controlled, further problems may develop. The method is generally applicable to surface mining on rolling to moderately steep terrain, and may be applied to multiple-seam vein resource recovery. However, steep slope conditions could severely limit the application, especially when the spoil angle of repose is closely aligned with natural ground slope. If suitable head-of-hollow disposal were possible, indiscriminant downslope casting of overburden or spoil could be partially or completely eliminated.




**BOX-CUT MINING (2 CUTS)**
**Figure 2.7-1**

Reference No. 61




BOX-CUT MINING (2 CUTS)

**Figure 2.7-2**

The problem of preventing slide conditions, spoil erosion,and resultant stream sedimentation,is present in any downslope spoil disposal technique. The higher and often better grade portion of the spoil is cast downslope, leaving the materials with higher pollution potential on the bench. Reverse terrace grading induces infiltration to these toxic materials, causing a pollution problem. Because of this, the technique may have little use as a water pollutant abatement technique. However, the technique is conducive to auxiliary mining methods such as auger or longwall procedures.

Regrading is an essential part of reclamation. In this technique, backfilling, which often results in a reverse terrace, is done with poorer material. This limitation could be overcome somewhat, if soil segregation is practiced, topsoil put back as a final cover, and properly vegetated. Spoil segregation may be rather difficult to accomplish using this mining method. Other reclamation procedures will also be required, such as water and erosion control. Reverse terrace regrading is often used to reclaim box-cut mining, and is usually a poor abatement technique.

## COSTS

This is a relatively inexpensive mining technique. Costs are not given for mining techniques. Costs will vary according to the mining plan and local factors at each mine site.

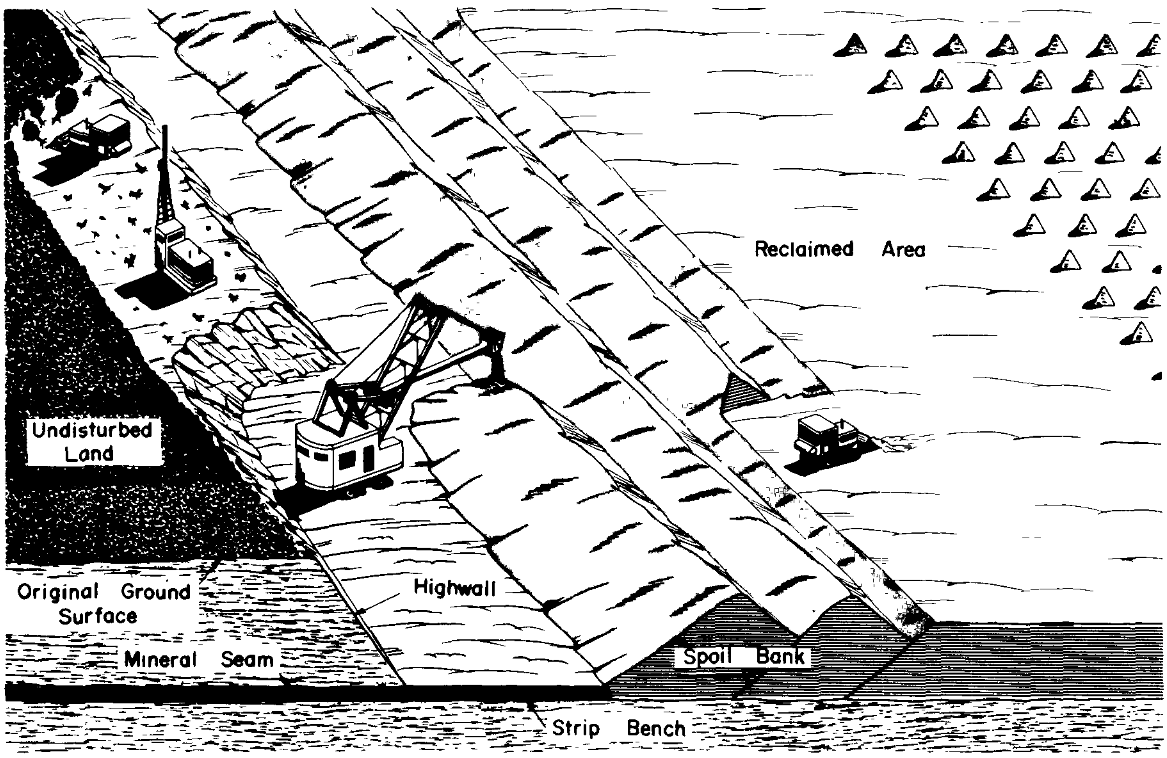
## REFERENCES

61

## 2.8 AREA MINING

### DESCRIPTION

Area mining is generally used in relatively flat terrain where mineral seams are roughly parallel to land surface. As its name implies, area mining involves removal of large blocks of minerals (whereas contour mining removes narrow bands of mineral). Area mining has been used almost exclusively for coal, but could be utilized for any mineral in seams whose geometry is similar to coal.




**AREA MINING**
**Figure 2.8-1**

Reference No. 166

An area mine is usually started with a box-cut, or trench, extending to the limits of the property or vein deposit, with a concomitant parallel spoil bank. Spoil material from each successive parallel cut or trench is placed in the preceding trench. The last cut or trench is bounded by overburden material on one side and an undisturbed highwall on the other.

## EVALUATION

Area mining is presented as a water pollution control technique because it has fewer associated problems than contour mining. Area mining is generally performed in gently rolling or flat-lying terrain. Surface water velocities are low around the mine because of gentle slopes. Many area mines, especially where there is no outcrop, have little or no surface water discharge. Erosion may be heavy on the mine site, but a large portion of the sedimentation occurs within the mine, and never reaches external surface flow channels. Spoil landslides are rare in area mining, because the spoil is usually contained within a relatively flat-lying mined area. Regrading area-mined lands is usually less expensive than regrading contour-mined lands.

Area mining has a greater potential for ground water pollution than does contour mining.

Overburden segregation, water diversion, regrading and revegetation are necessary in conjunction with area mining to eliminate water pollution, improve aesthetics, and return land to useful functions. Generally, regraded area-mined lands could be used for agriculture, silviculture, recreation and development purposes. If water quality is acceptable from an active area mine, the pond that may be allowed to form in the final cut could remain and possibly be used for recreational or other purposes.

Area mining will likely be used extensively in development of western coal fields. Revegetation has been extremely difficult to secure in these arid and semiarid regions, and this problem should be solved before large scale area mining is conducted in the west.

## COSTS

This is a mining technique and not a reclamation technique. Costs of reclamation are an integral portion of the total mining operation.

## REFERENCES

166

## 2.9 AUGER MINING

### DESCRIPTION

This mining method is used to recover coal behind a highwall of a surface mine. Large augers are driven horizontally about 60 meters (200 feet) into a coal seam. Coal is recovered in a manner similar to wood chips from a drill bit. Successive parallel holes are driven into the coal seam until the operation becomes unfeasible. The strip mine is then backfilled over the auger hole openings. Recovery is often less than 40%.

### EVALUATION

Auger mining is usually used to extract additional coal from a completed surface mine. Use of auger mining must be carefully controlled to prevent penetration into adjacent deep mines. Special compaction procedures should be employed when backfilling auger holes. Augering creates, in effect, many small deep mines. If the auger operation is carried out in acid producing seams of coal (where the seam rises from the outcrop) with a resulting acid water discharge, problems of adequate sealing will occur.

If auger mining is performed properly and extreme care exercised during and after augering, pollution can be minimized. Compacted and revegetated fill over the auger holes may help prevent influx of free air oxygen to the holes. Lack of free air oxygen will then prevent formation of pollutants after oxygen present in the holes has been consumed. Barometric fluctuations may still cause entry of free air oxygen to covered, deep auger holes, and proper design of auger plugs is necessary.

COSTS

This is a mining technique and not a reclamation technique. Therefore, costs are not presented.

REFERENCES

61, 135

## 2.10 CONTROLLED MINERAL EXTRACTION

### DESCRIPTION

This procedure is based on the fact that pollution-forming materials are not evenly distributed throughout a mineral seam. This phenomenon is particularly evident with coal. Of the many coal seams occurring in a given area, only a few are usually pollution forming. Lateral variabilities also occur in particular coal seams. A specific coal seam may be acid in one area and alkaline in adjacent areas.

Water quality and core boring sampling in polluted watersheds often indicates that pollution is not evenly distributed, but is concentrated in localized areas. A small portion of a watershed is generally responsible for a majority of the pollution.

This technique requires use of extensive water quality sampling to determine "hot" areas of the mineral seams. Location and mapping of areas or mineral seams with high pollution potential can be a valuable control tool. Stringent water pollution control measures can be utilized in areas of known high pollution potential.

Controlled mineral extraction is sometimes used for total mineral extraction, or "daylighting" an area by mining all salable minerals during one massive mining and reclamation operation.

### EVALUATION

Much future mine water pollution can be controlled or reduced by not mining or by strictly regulating mining in known high pollution potential areas. It may be possible to avoid mining minerals where high pollution potential exists. Conversely, there may be reserves of mineable minerals in low pollution potential areas where mining could be encouraged.

The first step toward utilization of this procedure is establishment of a water quality sampling program. This is followed by data analysis leading to identification and mapping of high pollution potential areas. These maps should not consider aerial extent alone, and should include data on a particular mineral seam. These maps could be developed for each individual mineral seam.

## COSTS

This is a regulatory technique. Consequently, costs are not given.

## REFERENCES

148, 198, 199, 200, 207, 208

# 3.0

# WATER

# INFILTRATION

# CONTROL

## 3.1 METHOD DISCUSSION

Most of the water pollution stemming from surface mine wastes is caused by surface water erosion and pollutant leaching due to water infiltration. Virtually all surface mine wastes consist of loose materials which are extremely permeable and easily eroded. Generally, erosion is easier to control than infiltration. A comprehensive discussion of erosion control is included in the Erosion Control section of this manual.

Unlike erosion, the source of infiltration is not always readily defined, and control is usually more complex. Infiltration can result from natural subsurface water movements, waters escaping from adjacent underground mines, or downward percolation of surface waters and direct rainfall.

Control of surface infiltration involves either isolation of waste material from the water supply or decreasing surface permeability. Methods of disposing of mine wastes are discussed in the "Handling Pollution-Forming Materials" section of this manual. Generally, it is not feasible to remove the large amounts of waste material generated by mining operations. Also, the waste material may be needed as backfill material for regrading. Under these conditions, if infiltrating water is causing formation of pollutants, abatement will require on-site control of infiltration.

Controlling water infiltration from rainfall and subsurface sources can be accomplished by placing impervious barriers on or around the waste material, establishing a vegetative cover, or constructing underdrains. Impervious barriers, constructed of clay, concrete, asphalt, latex, plastic, or formed by special processes such as carbonate bonding, can prevent water from reaching the waste material.

A dense vegetative cover may in some instances decrease infiltration. However, the reverse is more often the case. Vegetation tends to reduce the velocity of water, thereby inducing infiltration. A vegetative cover will build up a soil profile, which tends to increase the surface retention of water. This water is available for evaporation and can result in a net decrease in the amount of water entering underlying materials. Vegetation also utilizes large quantities of water in its life processes (again decreasing the amount of water that will reach the underlying material). The net effect of vegetation is probably an increase in infiltration, and is therefore not discussed in this section. Vegetation, however, is one of the most effective water pollution control techniques (for reasons other than reducing infiltration). Methods and techniques for establishing a vegetative cover are included in the "Establishing a Vegetative Cover" section of the manual.

When infiltration is caused by interception of surface flow, it will usually be beneficial to divert the flow. One or more of the techniques discussed in the Erosion Control section of this manual may be employed for this purpose.

Underdrains are often used to control water infiltration after it has entered the waste material. By offering a quick escape route, contact time between water and any pollution-forming material contained in the waste is reduced. Also, water flow paths through pollution-forming materials are shortened. The possibility of a fluctuating water table is eliminated. Underdrain discharges should be monitored to determine any pollutant pickup that may occur.

A number of techniques are described in the following section which can be used to control water infiltration in different situations. In some cases, the use of any infiltration control may prove to be ineffective or too costly. In these situations it may be more viable to use one or more of the techniques discussed in the Mine Waste Water Control section of the manual.

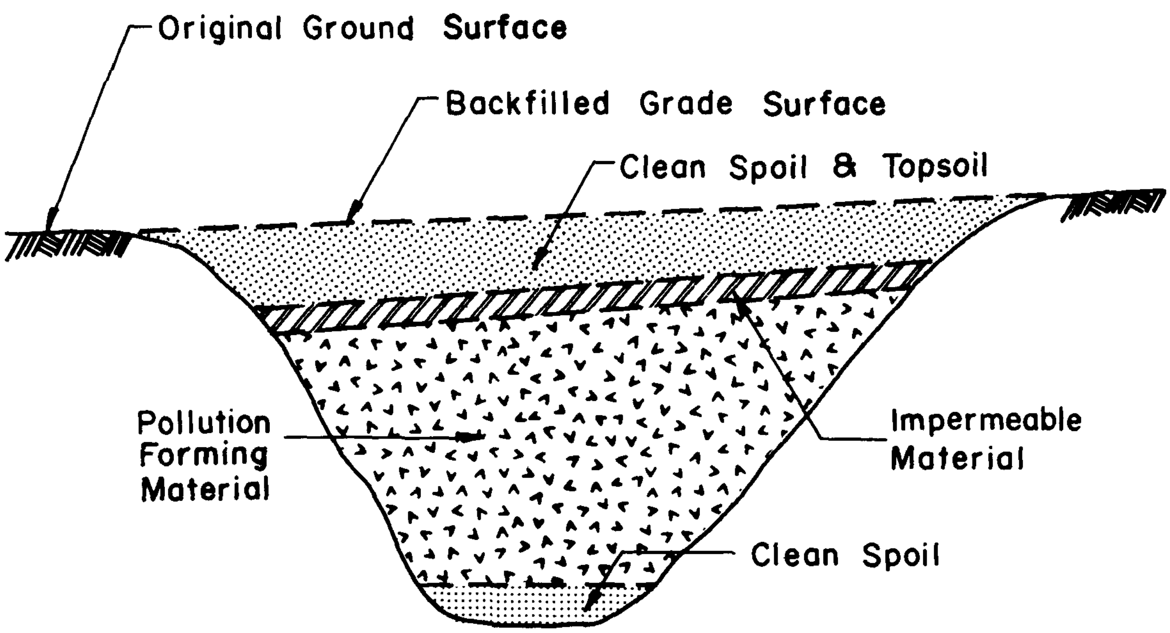
Devices installed to control water infiltration may require long term maintenance. This especially applies to diversion and drains.

## 3.2 REDUCING SURFACE WATER INFILTRATION

### DESCRIPTION

This technique involves reducing surface permeability of pollution-forming materials. This can be achieved by placement of impervious materials such as concrete, soil cement, asphalt, rubber, plastic, latex and clay. This effect can also be achieved by surface compaction and by chemical surface treatment (such as carbonate bonding).

Concrete and asphalt are applied in a layer on the pollution-forming material to form a water tight seal. The remaining materials may be left exposed, or may be covered with soil, depending upon the material and future land use.




REDUCING SURFACE WATER INFILTRATION TO BURIED POLLUTION - FORMING MATERIAL
Figure 3.2-1

Compaction of the existing surface materials will decrease infiltration to some degree. Degree of success will depend on the physical nature of the material and equipment utilized for compaction.

Latex soil sealant is applied as a dry compound at a predetermined depth in existing surface material. The latex compound reacts with infiltrating ground water to form a thin, impermeable film, or layer, at a desired depth.

Carbonate bonding is a physio-chemical application to an existing surface which produces a cement-like product. The procedure involves roto-tilling lime hydrate and water into the material, followed by installation of plastic perforated pipes. The pipes distribute pure carbon dioxide gas through the lime hydrate-waste material mixture, converting the lime hydrate into a hard carbonate material which acts as a surface sealant.

## EVALUATION

Asphalt and concrete are excellent sealants, but are expensive. The only presently economically feasible way to use these sealants is in multipurpose reclamation such as constructing parking lots, buildings, airport runways and roads over pollution-forming materials. They are too expensive for use as a single purpose water pollution control method. Use of pollution-forming materials in highway road base construction to eliminate surface water infiltration is a technique being researched.

Use of rubber and plastic as coverings has been accomplished experimentally. They are extremely prone to damage when exposed, and do not appear feasible without an extensive maintenance program. Attempts have been made to cover them with soil, but the equipment used to place the soil usually damages the covering. A soil cover on these materials is not very stable and tends to erode and slide. The soil coverings would also vegetate, which could result in root damage to the seals.

Compaction is one of the cheapest techniques, but unfortunately most mine wastes cannot be compacted sufficiently (without use of other techniques) to significantly control water pollution.

Carbonate bonding is essentially in the experimental stages. However, it shows promise of being a viable sealing technique. Further experimentation in practical situations should be performed before extensive use of the technique.

Use of latex as a soil sealant proved ineffective in a demonstration project in Clearfield County, Pennsylvania.

Clay appears to be the best practical sealant material. It is one of the least expensive and yet most maintenance free. Clay is compacted over the pollution-forming material, and should be covered with soil to prevent desiccation, failure, and subsequent erosion. Feasibility of clay as a sealer usually depends on local availability of clay.

Pollution-forming materials should be graded into the smallest practical area prior to sealing.

All of these sealants are subject to failure, either chemical or physical, and will require some maintenance.

## COSTS

Costs for this technique can vary widely due to the nature of the sealant materials. Individual costs are dependent on such factors as volume of material required, thickness and area of application, labor, material and equipment costs. Clay may cost $2.30 to $7.80 per cubic meter ($1.75 to $6.00 per cubic yard) including installation. Concrete costs $39 or more per cubic meter ($30 per cubic yard), and 5 to 7.5 centimeter thick (2" to 3") gunite applications cost from $19 to $22 per square meter ($1.75 to $2.00 per square foot). Asphalt installation may range in cost from $2.40 to $6.00 per square meter ($2.00 to $5.00 per square yard). Carbonate bonding costs range from $0.95 to $3.00 per square meter ($0.80 to $2.50 per square yard) depending on the desired application method. Latex, rubber and plastics are still largely experimental and, as such, have no definite established unit costs.(They are, however, rather expensive and are suitable for only small areas. For reference and estimating, a cost for rubber ranges from $5.40 to $10.75 per square meter ($0.50 to $1.00 per square foot) installed, and plastic may be about one-third the cost of rubber, depending on the selected thickness.

REFERENCES

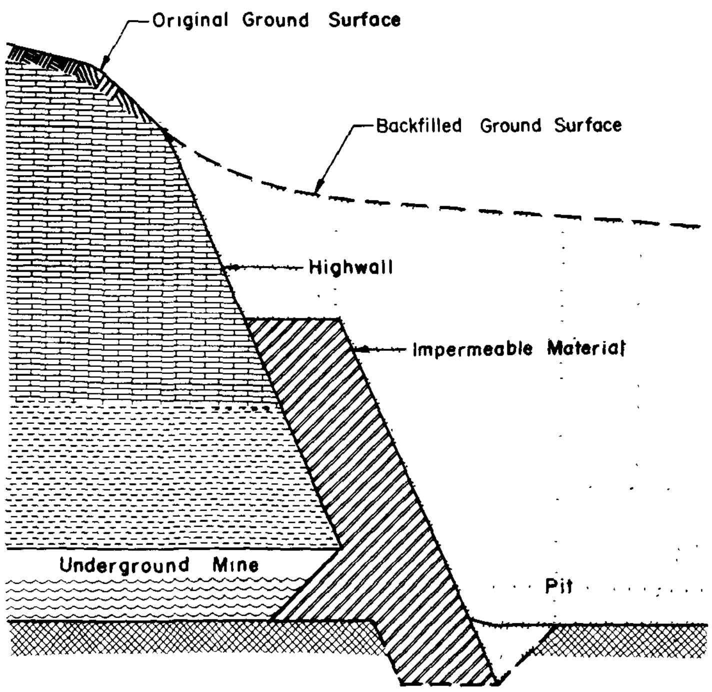
13, 19, 22, 44, 97, 111, 168

## 3.3 REDUCING GROUND OR MINE WATER INFLUX

### DESCRIPTION

Pollution caused by passage of ground or mine water through pollution-forming materials can be eliminated or reduced by impermeable barriers. Materials such as clay, concrete, or concrete block walls are placed between the water source and the pollution-forming material.

An impermeable liner can be placed against the highwall of a surface mine to prevent the influx of ground water. This application is seldom used except where there are auger holes that require sealing, or the surface mine has broken into an underground mine working. Underground mine openings encountered during stripping are often sealed with clay or concrete block walls.




CROSS SECTION OF A CLAY LINER
Figure 3.3-1

## EVALUATION

Use of impermeable barriers to stop flow of ground water has not had sufficient usage or documentation to judge its effectiveness. Theoretically it should be effective, but its use would be limited to specific problem areas because of cost.

Clay liners placed against the highwalls of strip mines appear to be effective in controlling pollution from auger holes. They also hold promise for sealing underground mines under low water pressure conditions.

## COSTS

Because of the high variability of technique application, only unit prices are shown. Clay ranges from $2.30 to $7.80 per cubic meter ($1.75 to $6.00 per cubic yard) including installation and depending on source and haul distance. Concrete, in place, costs approximately $39 per cubic meter ($30 per cubic yard) depending on area labor and materials cost.

Site preparation will involve additional costs, depending on present site conditions.

## REFERENCES

44, 47, 70, 111, 135

## 3.4 WATER DIVERSION

### DESCRIPTION

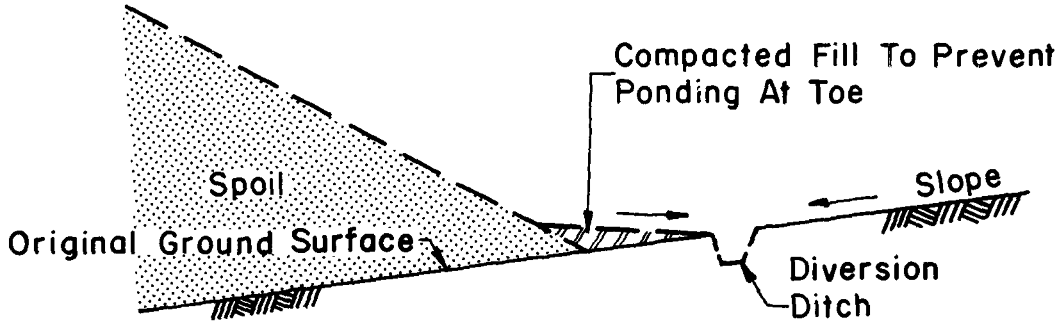
Water diversion involves collection of water before it enters the mine area, and then conveying it around a mine site. This procedure decreases erosion, reduces pollution and reduces water treatment costs by reducing the volume of water that needs to be treated.

Ditches, flumes, pipes, trench drains and dikes are all commonly used for water diversion. Ditches are usually excavated upslope of the surface mine to collect and convey the water. Flumes and pipes are used to carry water down steep slopes or across regraded areas. Riprap and dumped rock are sometimes used to reduce water velocity in the conveyance system.

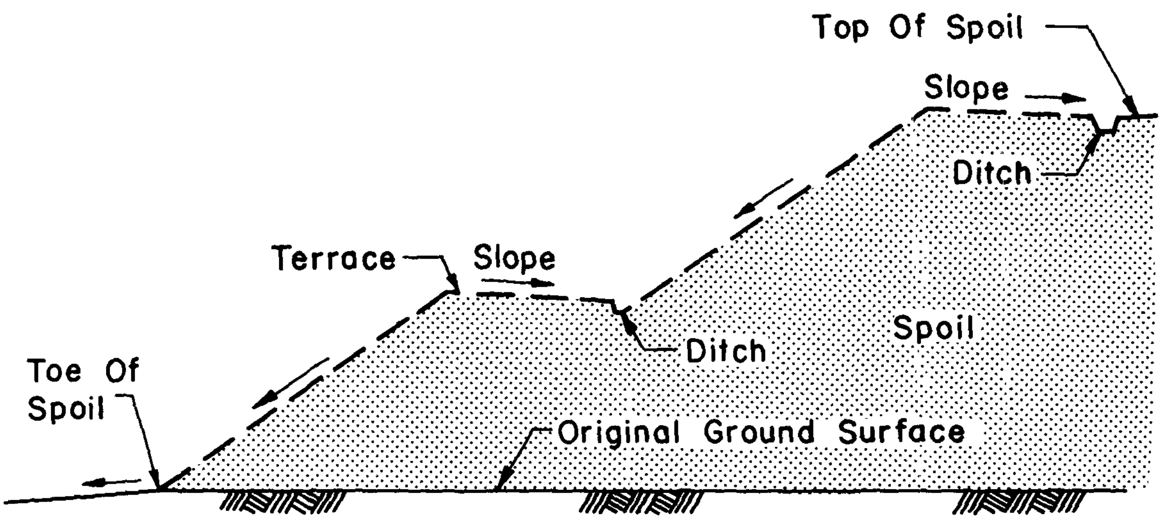
Water diversion can also occur within a surface mine. Drainways at the bottom of a highwall are helpful, in many cases, to convey entering ground water from the mine prior to its contact with pollution-forming materials.

Ground waters can be diverted by pumping water from the flow path area prior to entrance to the mine. In some instances, it may be cheaper to drill holes and pump ground water away than to treat the water after it passes through a mine.

Surface water diversion could be applied to many large valley fill bony piles in the east and tailings piles in the west. Many of these waste piles were built across valleys (natural watercourses) causing streams to pass through the pollution-forming materials. This water can be diverted around or conveyed through the waste material.

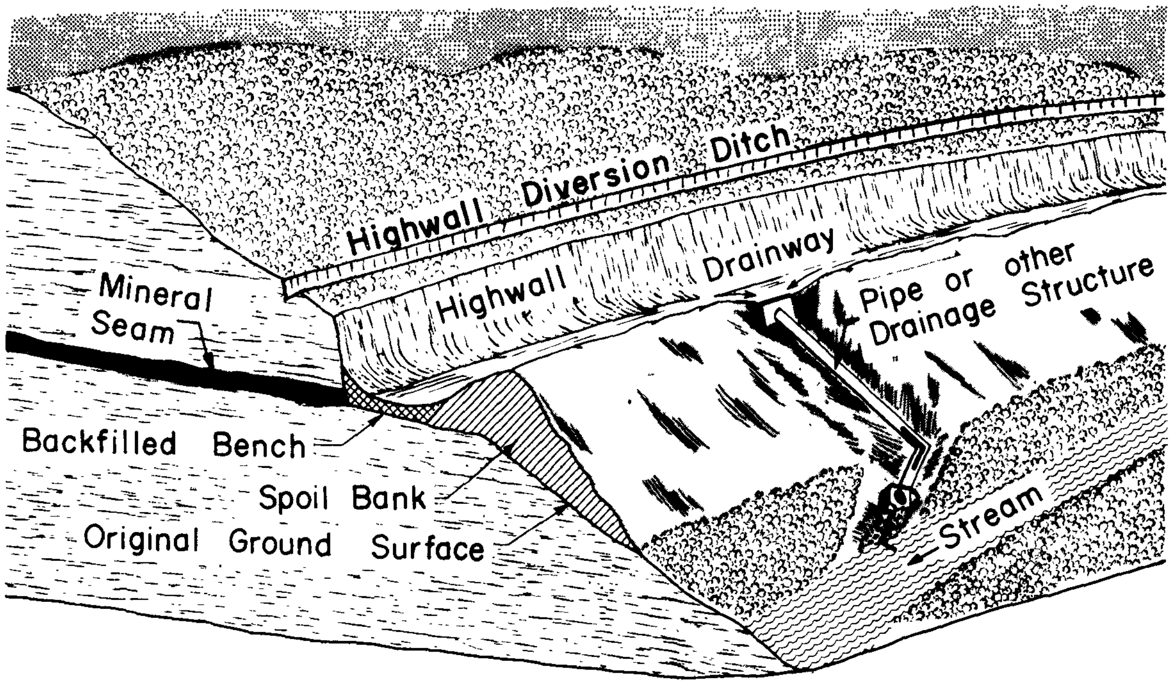


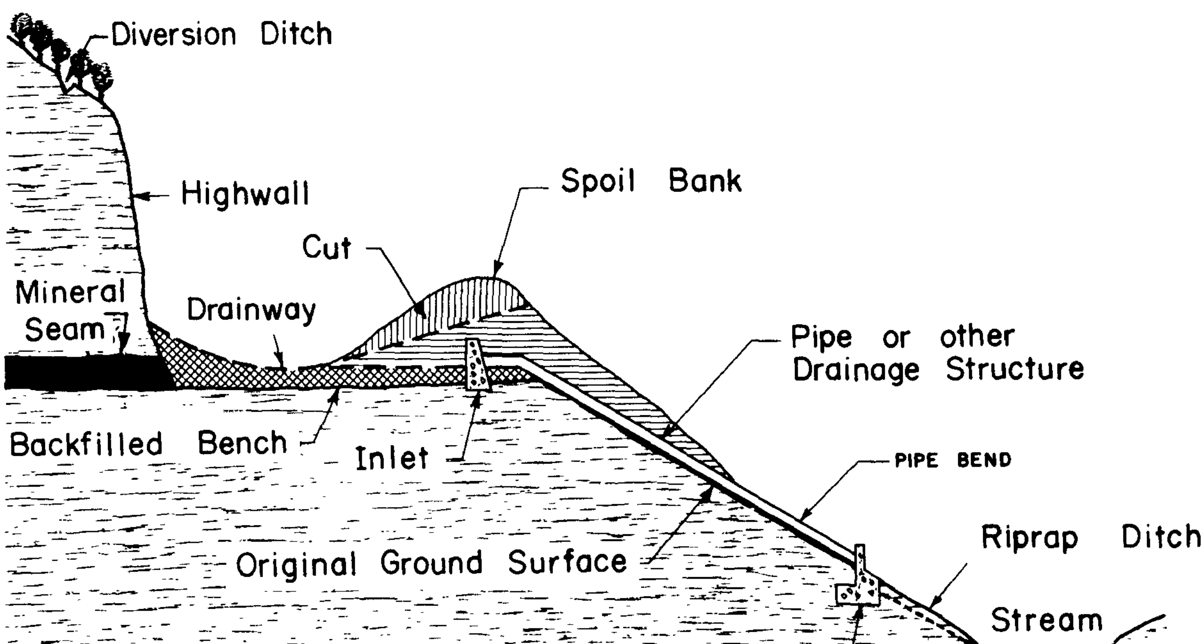

CROSS SECTION OF
DRAINAGE DITCH ON UPHILL SIDE OF A SPOIL PILE




CROSS SECTION OF
DIVERSION DITCH APPLICATIONS
Figure 3.4-1

Adapted from National
Coal Board, Great Britian




**WATER DIVERSION**
**Figure 3.4-2**

Adapted from drawing in reference No. 166

## EVALUATION

Surface water diversion is an effective technique for reducing water pollution. It can be applied to almost any surface mine or mine waste pile.

A water diversion system should be properly designed to accommodate expected volumes and water velocities. If the capacity of a ditch is exceeded,water can erode the sides and render the ditch useless for any amount of rainfall.

In many instances, diversion can be accomplished at a lesser cost than would be required to treat an equal volume of water.

## COSTS

Costs of various items to effectively handle water are outlined in Erosion Control, Diversion, Section 7.2.

## REFERENCES

34, 56, 115, 166

## 3.5 UNDERDRAINS

### DESCRIPTION

Underdrains of rock or perforated pipe can be placed below pollution-forming materials to quickly discharge infiltrating water. These devices shorten the flow path and residence time of water in the waste materials. Underdrains are designed to provide zones of high permeability to collect and transport water from the bottom of the piles. A common method of construction is to use trenches filled with rock.

Underdrains should prove effective for use with bony storage areas and large tailings accumulations. They are best suited for installation prior to creation of the pile. They can also be installed in existing piles, although the cost is higher.

### EVALUATION

These drains have been tried on western tailings piles, but their effectiveness has not been documented. They are recommended for use with the head-of-hollow mining technique. The concept is theoretically sound and will probably be demonstrated in the near future.

There are certain limitations to use of underdrains. They should not be used where inundation has occurred, because they will drain the pile and cause an adverse effect. They should only be used in piles where the water table is fluctuating, and flow is in direct response to rainfall. Care must be taken during design to preclude the possibility of fines clogging the completed underdrain installation.

Underdrains could be considered for use any time a new pile is to be created. All springs and seep areas that will be covered with pollution-forming materials should have this water conveyed from the area. The flow from underdrains should be monitored for quality determinations because such flows are generally of poorer quality than receiving waters.

## COSTS

Costs are extremely variable and should be developed for the particular usage. The price range for these drains should be approximately \$5.00 to \$33.00 per lineal meter (\$1.50 to \$10.00 per lineal foot) depending on the type and size used.

## REFERENCES

61

# 4.0

# HANDLING

# POLLUTION

# FORMING

# MATERIALS

## 4.1 METHOD DISCUSSION

The pollution-forming materials discussed here are particular wastes generated by mining operations and discarded on the land surface. These materials are exposed to oxidation, weathering, erosion and leaching. They are typically "sluggers", meaning they discharge large quantities of pollution for short durations during and after rainfall, unless there is continuous leaching by intercepted surface flow.

There are many techniques available to control pollution from these materials. Four of these techniques are discussed in this section but many of the other surface mining control techniques can also be utilized in conjunction with these four. Water infiltration control techniques are generally applicable. Special revegetation techniques should be employed (such as spreading soil) because these materials are often toxic to plant life. Certain ore milling processes introduce highly undesirable substances into the waste. Covering with soil and vegetation is one of the best techniques for controlling water pollution from mine wastes. This method is discussed in the revegetation section of this manual.

Most of the reclamation of pollution-forming materials to date has been either removal for burial or regrading, revegetation and water diversion in-situ. These have met with varying degrees of success. Effectiveness is difficult to document because of the highly variable nature of the discharge. Extensive before and after water sampling would have to be performed at several reclamation sites to document effectiveness.

Attempts at revegetating uranium tailings in the Utah-Colorado area have been successful to varying degrees. Uranium piles have to be stabilized to prevent erosion from carrying radioactive material to nearby streams. Uranium piles are often in arid to semiarid regions and require irrigation for vegetative growth. Irrigation of uranium piles, however, may cause leaching of radium into the regional water system. Riprap is used to stabilize one uranium pile in an area where rainfall is low and vegetation has not been established.

Many techniques have been attempted with coal waste piles in eastern coal fields. Water diversion, removal for burial, regrading, covering with soil and impermeable materials, and direct planting after roto-tilling limestone into the surface, have all been successfully demonstrated.

Waste slimes of the southern phosphate industry are a particular problem, because they cannot be dewatered economically. The volume of waste slime is often larger than the size of open pit mines, requiring use of holding ponds for disposal of the excess. The slime is incompetent and will not support weight. It is also toxic and will not support vegetation. Attempts have been made to utilize the slime for irrigation or for derivation of secondary products. These attempts have not been successful as yet. The only technique reported to show any promise is to mix the slime with sand overburden generated during mining. This reportedly increases competency of the slime to a point where it will support development.

These mine wastes create serious water pollution problems throughout the country. These wastes are reported to be the source of more water pollution than mines in western United States. The tailings are indiscriminately scattered about the land surface and often occur in low points where they intercept surface drainage.

There is an urgent need for demonstration of some of the techniques in this report and development of new techniques for control of water pollution from abandoned mine wastes.

There are special legal problems associated with mine wastes. Most of the wastes contain residues of the mineral mined, and small amounts of other valuable minerals. These wastes may become valuable when technology and mineral markets advance to where secondary recovery is feasible. As such, many of these piles have a certain, difficult-to-define value and may be treated as personal property. Ownership of the wastes is sometimes in question. The material was originally deposited as a discard, and ownership may or may not pass from the miner to the surface owner. This has not been established legally, and the miner may have a legitimate claim to ownership. Many mine waste piles were developed over long periods of time with contributions from different miners. This, of course, further confuses the ownership question. Ownership should be established or other legal provisions made before removal of a waste pile.

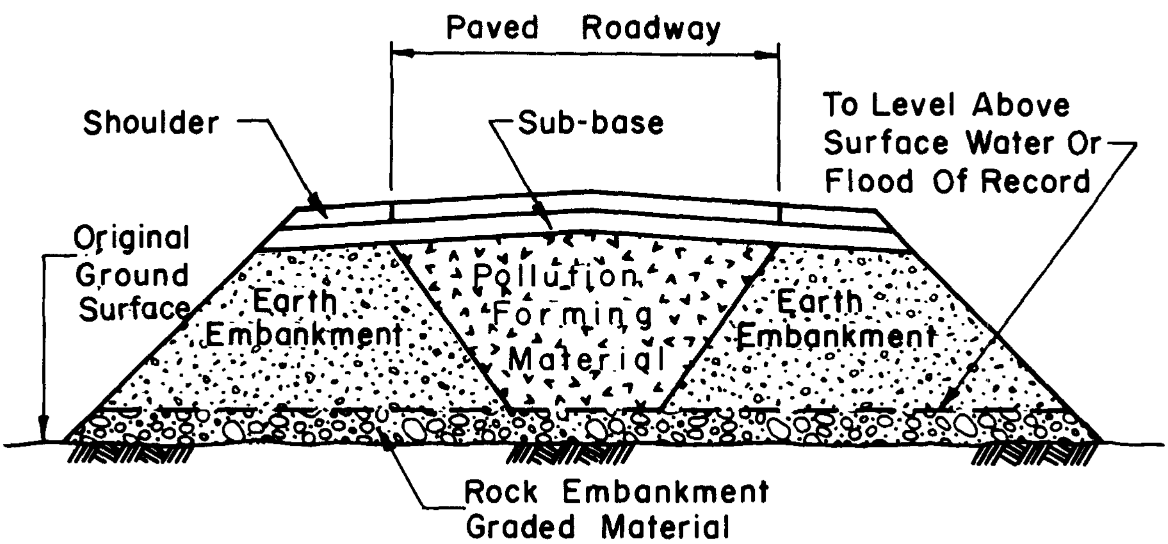
Waste piles should be examined for mineral content prior to implementation of water pollution control procedures. There may be sufficient recoverable mineral present to significantly offset the cost of control measures. Secondary recovery could turn a water pollution problem into an economic benefit.

## 4.2 USE AS CONSTRUCTION MATERIAL

### DESCRIPTION

This is a multiple purpose technique that eliminates a water pollution problem and results in a building product. Control of water pollution is extremely costly and can often be offset if waste material can be utilized as a salable product.

One promising technique is utilization of mine wastes for road-bed subgrades. Should this prove feasible, a large amount of existing mine wastes can probably be utilized in highway construction in the mining areas.




**CROSS SECTION OF A WASTE MATERIAL ROADBED**
**Figure 4.2-1**

Experiments have shown that copper mill tailings are useful in making brick.

The Appalachian Regional Commission is presently funding research within the Monongahela River Basin that may develop uses for coal mine wastes.

## EVALUATION

Use of mine wastes in construction materials is in the theoretical/experimental stage. Several uses may be developed in the near future. Research and demonstration is definitely required. Physical/chemical properties of various mine wastes will have to be explored to determine further uses.

Use of mine waste as fill in the center of a road base should hydraulically isolate pollution forming materials. A paved highway surface will prevent infiltration of water from above, and rock underdrains will keep a ground water level from rising into the waste. Physical properties of the mine wastes comprise a basic limitation. Wastes may require blending or mixing with other materials. Legal problems concerning ownership and acquisition of mine waste will have to be solved.

This technique has good potential to help solve the nation's mine waste problem. Possibilities of utilizing government subsidies to encourage private sector development to produce construction materials from mine waste piles should be explored.

## COSTS

Costs incurred by such variable factors as accessibility, haul distance, type of material, and local labor and equipment rates have to be considered to develop a representative cost for this technique.

For estimating purposes, a rate of $1.10 to $2.20 per tonne ($1.00 to $2.00 per ton) would be reasonable since construction material, such as crushed stone, is generally available for about $2.20 to $3.30 per tonne ($2.00 to $3.00 per ton).

REFERENCES

30, 86, 94, 110, 113, 123, 181, 183

## 4.3 SECONDARY EXTRACTION

### DESCRIPTION

This technique involves reprocessing mine wastes for secondary extraction of salable minerals. Most mine wastes contain residual amounts of the original mineral mined, and usually small amounts of other valuable minerals. Extraction of these minerals was either impossible or economically unfeasible during the original mining operation. Milling processes have advanced to a point where less pure ores can be processed. Mineral economics have also changed, and it may now be feasible to reprocess some of these mine wastes.

There are large quantities of coal in many coal refuse piles existing in eastern coal fields. Hard rock mine tailings in the west contain significant quantities of heavy metals. There are two general methods of secondary recovery. Wastes can be transported to active milling sites and refined using modern techniques, and hard-rock wastes can be leached in-situ. Acid is the most common leaching agent. It can be sprayed over the pile, then collected and conveyed to a treatment facility for recovery. Normal rainfall can leach large quantities of valuable mineral from wastes.

### EVALUATION

The value of this technique is purely a matter of technology and economics. If secondary recovery can be accomplished economically, then private industry will eliminate many waste piles. Secondary recovery will probably see widespread use in the future as minerals become scarce and mining becomes more difficult. Advancements in technology of low grade ore refinement will also boost future use of secondary recovery. Western hard rock mine tailings will probably be a significant area of extensive secondary recovery.

Wastes generated during secondary recovery will also be pollution forming, and will have to be disposed in a manner that will control pollution.

Secondary recovery from copper and uranium mill tailings is presently underway.

## COSTS

Costs cannot be presented. There would have to be a separate economic evaluation of each tailings pile to determine feasibility of secondary recovery.

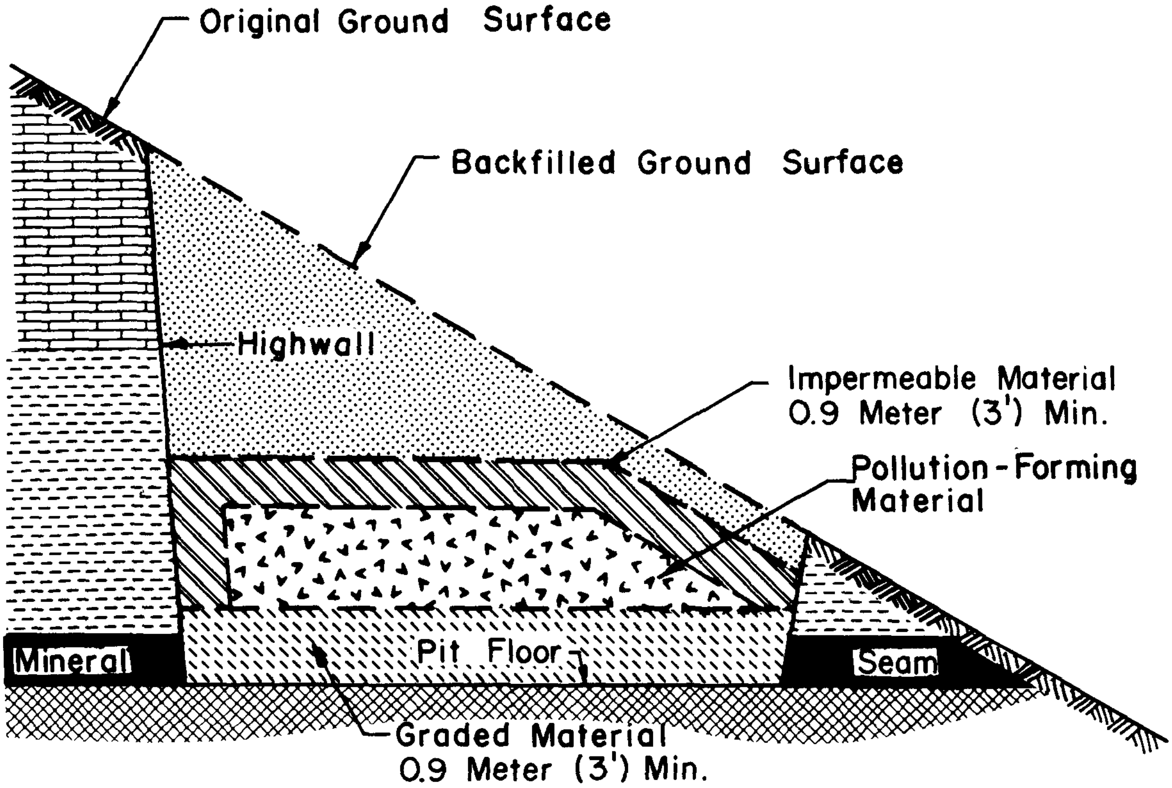
## REFERENCES

14, 39, 94, 110

## 4.4 RELOCATION

### DESCRIPTION

This technique comprises removal of mine wastes to a more suitable hydrologic location. First consideration should be given to handling the material in place using water infiltration control, regrading, erosion control, and revegetation techniques. If the water pollu-




CROSS SECTION OF
STRIP MINE SHOWING POLLUTION-
FORMING MATERIAL BURIAL
Figure 4.4-1

tion cannot be abated in place, the materials could be relocated, preferably to a burial location. The basic goal of this technique is to reduce contact with oxygen and leaching water, and to stabilize the material.

## EVALUATION

Direct burial in nearby surface mines is applicable to many mine waste piles, particularly in the east. Burial sites are not often available for hard-rock mine tailings in the west. Pollution from these tailings will have to be controlled in place or the tailings relocated to more suitable locations.

This technique is generally utilized in conjunction with strip mine grading where pollution-forming materials are buried and subsequently covered at the base of the cut. This technique has been used extensively in eastern mining areas to bury acid-producing coal refuse and acidic overburden.

Feasibility of this technique depends on the amount and type of material to be disposed, the nature of the material, whether it includes large rocks or debris that may require special handling, and haulage distance. The material must be placed in a favorable hydrologic setting, where contact with oxygen and leaching waters will be reduced. The technique should be accompanied by other reclamation procedures such as water infiltration control, erosion control, revegetation, and regrading. Pollutant materials that have been in place for any extended length of time may have undergone some degree of natural settling and consolidation, thus making that material much more difficult to remove from its present site. Need for burial site acquisition and preparation is also a factor that may limit use of the technique. The availability of suitable cover material could be a limitation.

A major problem could develop from unsuccessful relocation: the materials could continue to produce pollution in their new environment. In this case, the site of the water pollution problem has merely been moved to a new location, and control has not been accomplished.

There may be legal problems with landowners who do not want pollution-forming material transported over or placed on their land, even if it is adequately handled and buried. Ownership disputes concerning the pollution-forming material could arise, particularly if it has some re-extraction potential now or in the foreseeable future. This could become a complicated problem, as most mines have changed ownership many times, with each owner contributing refuse or material to the same pile. This specific situation has occurred in the eastern bituminous coal-mining regions, with regard to bony coal refuse piles.

## COSTS

Costs for this abatement technique are variable, and depend on the factors mentioned in the preceding discussion. A general cost figure for use of this technique is $1.30/cubic meter ($1.00/cubic yard) for haulage and burial and $0.65/cubic meter ($0.50/cubic yard) for covering the material. Additional burial site preparation such as clearing and grubbing, could cost as much as $742 to $1,235/hectare ($300 to $500/acre).

## REFERENCES

2, 9, 22, 44, 111, 112, 146, 149, 181

## 4.5 FLOODING

### DESCRIPTION

This technique eliminates oxidation of pollution-forming materials by inundation which prevents contact with free air oxygen. This is applicable to most mine wastes, except those that do not require oxidation for increased solubility. The principal chemical pollution resulting from mining is caused by oxidation of sulfides. Oxidation greatly increases solubility, allowing water to leach pollutants. Inundation of these types of materials eliminates free air oxygen contact, greatly reducing oxidation, causing these materials to remain in a relatively insoluble state.

Flooding can be accomplished by transporting the material to an impoundment or to a burial site that will be inundated. Dams could be constructed in areas of large amounts of waste after consolidating the waste in the area to be flooded.

### EVALUATION

This technique has not been adequately demonstrated to determine feasibility, but is theoretically sound and could have future use. Flooding would likely be most applicable for multipurpose use. Dams could be created to control water pollution from surface mines if there were other justifications such as flood control or recreation.

Initial flooding would release significant quantities of water pollution until the easily-soluble ions were leached. Pollution-forming materials should remain flooded. A fluctuating water level in pollution-forming materials would generate significant quantities of water pollution. The impoundment would have to be properly designed to insure success. Special legal problems, such as ownership of waste materials, and water rights infringement could arise. Use of this technique should be governed by a cost and effectiveness evaluation of this technique versus other available control techniques.

## COSTS

Costs would have to be developed on an individual application basis.

## REFERENCES

177

## 4.6 UNDERGROUND MINE BACKFILLING

### DESCRIPTION

Underground mine backfilling is a method of disposing of mine and mill wastes in an underground mine versus deposition on land surface. This will help to control surface subsidence, mine collapse, and reduce water pollution by reducing oxygen contact and stopping erosion. This practice could free large areas of land now utilized as surface storage areas for more useful purposes. Miners have used this method as an aid to recover pillars, control rock bursts and roof collapse, and stoping operations. Some mine waste is incompetent. Cyclone separators are then used to separate sand and heavies from slime. Slime is deposited on the surface and the heavy fraction is conveyed back into the mine.

### EVALUATION

The degree of water pollution control resulting from underground mine backfilling has not been demonstrated. Use of this technique will eliminate surface erosion problems occurring at tailings piles. Oxidation should be reduced, especially if wastes are placed in portions of a mine that will be flooded after completion of mining.

This technique should be particularly effective in semiarid and arid regions in underground mines that will not discharge. Underground mine backfilling could be an aid in controlling water pollution from underground mines. It should help raise water levels and reduce the amount of oxygen diffusion through underground mine voids.

Use of cyclone separators is questionable from a water pollution control standpoint. The slurry of fines discharged on land surfaces is likely to contain pollution-forming materials, and will probably be easily erodable. These fines could also be unstable due to lack of larger particulates and could result in landsliding.

This technique is not universally applicable, and its use will be limited by geometry of the underground mine, method of mining, and physical nature of the waste material.

## COSTS

It has been estimated that hydraulic placement using available refuse can be accomplished for about 5% of the cost of mining. Solid placement was estimated at 11% of the cost of mining. These costs would be significantly higher for mines utilizing low grade ores where most of the volume of material mined is waste.

The cost of underground mine placement of available refuse by hydraulic means has been estimated at $0.65 per tonne ($0.59 per ton). Normal surface disposal of preparation plant waste costs approximately $0.30 per tonne ($0.27 per ton). Therefore, underground mine disposal costs an additional $0.35 per tonne ($0.32 per ton) or about double the cost of conventional surface disposal techniques. These estimates are based on a hypothetical western Pennsylvania bituminous coal mine producing 1.1 million tonnes per year (1 million tons per year). Ref. 176.

## REFERENCES

94, 95, 138, 175, 176, 177, 178

# 5.0

# WASTE

# WATER

# CONTROL

## 5.1 METHOD DISCUSSION

This section discusses techniques used to handle polluted mine waters by using methods other than chemical treatment, which are discussed in other sections of the manual. Techniques described in this section are applicable to surface and underground mines. Source of the discharge is usually not pertinent to use of the technique.

These techniques are applicable when at-source control techniques are ineffective or economically unfeasible. Choice of any water pollution control technique should be based on the cheapest method that achieves desired results. At-source control techniques will reduce, but will seldom eliminate, pollution from active mines. Waste water control techniques or treatment processes are then required to control remaining pollution. At-source techniques such as diversion, infiltration control, erosion control and revegetation should be employed where applicable in conjunction with waste water control to reduce volumes of water and subsequent pollution.

These techniques are presented as alternatives to treatment, which can sometimes be prohibitively expensive. These techniques are generally more applicable to active mining operations than to abandoned mines because they require continuous operation. Evaporation ponds are appropriate to abandoned mines if they are periodically maintained.

## 5.2 REUSE OF DISCHARGE

### DESCRIPTION

This is an effective waste water pollution control technique. It is often called closed system mining, because water generated during mining and milling is not discharged. Water is used in the milling operation, passed through a settling pond or clarifier, then returned to the milling operation. Water pumped from the mine site is fed into the system.

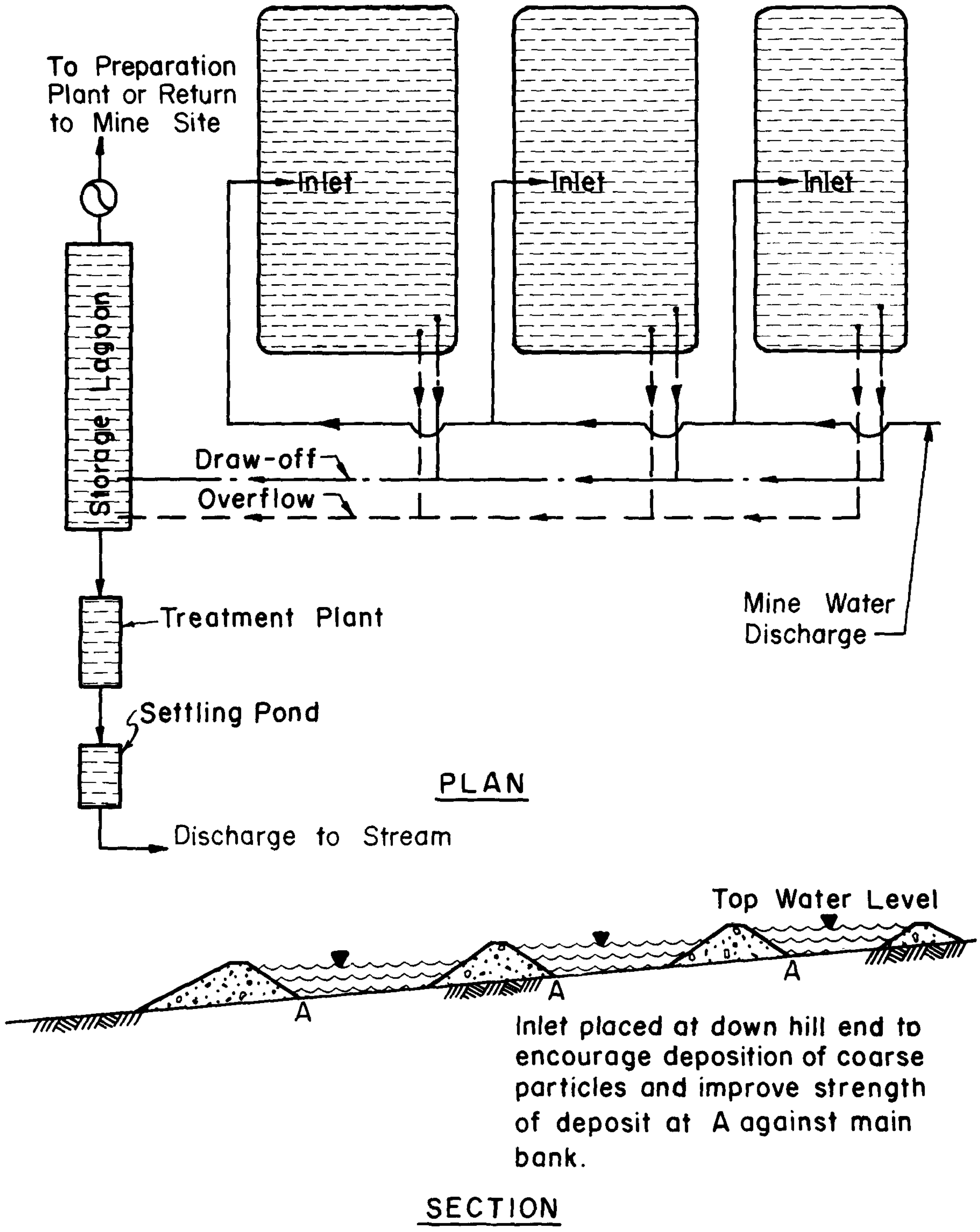
Large quantities of water are needed in milling and cleaning operations. The water is often polluted after passing through the mine or mill and should not be discharged. In many cases this water can be reused with a minimum amount of treatment.

Basic elements of closed circuit mine systems are: 1) a collection and conveyance system from the mine to the holding pond; 2) a pumping and conveyance system to deliver water from the holding pond to the mill; 3) a conveyance system from the mill to the tailings pond; 4) pumping and conveyance from the tailings pond to the holding pond (treatment may be required in this system). A sump area in an active deep mine can be utilized as a holding pond. Adjacent inactive deep mines could be utilized as a tailings pond.

### EVALUATION

Reuse of discharge is especially applicable in a low rainfall region where available water is at a premium. In high rainfall areas of the east, there is often more mine water than can be utilized.

Water quality is a severe limitation. Most suspended solids can be eliminated in settling ponds, but chemical constituents can render




## REUSE OF DISCHARGE

**Figure 5.2-1**

Adapted from National Coal Board, Great Britian water unfit for milling use. Chemically degraded water is not acceptable for use in some ore refinement processes. The water can be used as long as possible until its quality is such that it must be disposed or treated. This rejected water can be disposed by evaporation, spray irrigation or deep well injection.

A closed circuit mining/milling system must have capacity to store large quantities of water during peak flow periods. Underground mines are not as quickly affected by heavy periods of rainfall as are surface mines. Some of this effect can be reduced by using water diversion techniques around a mine area. A storage system of proper capacity can be designed using knowledge of local weather extremes and water needs of the operation.

One advantage of non-discharging, closed circuit, mining operations is that a discharge permit is not required.

This technique may be particularly useful in hydraulic mining. The sediment load could be settled out in large ponds and the water re-used for further mining. This would be expensive, but it might be a way to satisfy discharge limitations on settleable solids in water quality requirements.

## COSTS

Costs would have to be developed on an individual application basis.

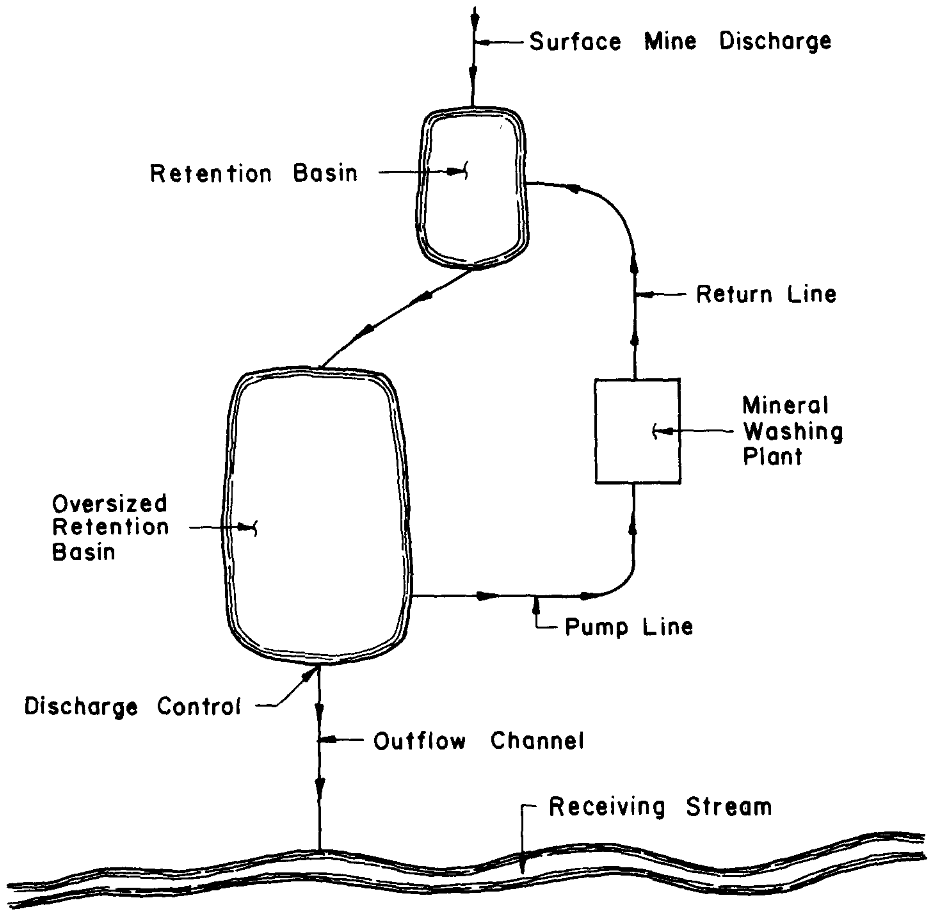
## REFERENCES

2, 7, 9, 16, 17, 28, 34, 38, 97, 116, 122, 138, 151, 155

## 5.3 EVAPORATION PONDS

### DESCRIPTION

Large holding ponds may be used to prevent discharge of polluted water by means of evaporation. Mine discharge can be collected and conveyed to a large holding pond or series of holding ponds. The system should be designed to provide that all mine water is lost to the atmosphere through evaporation, and no discharge occurs. The bottom of the pond should be lined where impoundment materials are permeable. Clay liners may be useful because of their ability to adsorb pollutant-forming chemicals, such as arsenic compounds.




EVAPORATION POND
Figure 5.3-1

The system must be designed for capacity flow during periods of high rainfall and low evaporation rates. Low evaporation rates in winter will have to be considered. The amount of water to be evaporated could be reduced by using diversionary measures. Settled solids will have to be removed from the pond periodically in order to maintain proper capacity.

## EVALUATION

Evaporation ponds could be a good water pollution control technique, but their use as a sole water pollution control device is restricted to arid or semiarid regions. Rainfall must be less than evaporation rates to facilitate operation. The system must also be capable of handling short term adverse conditions of high rainfall and low evaporation rates to be fully effective.

Oversize holding ponds could be used at a mine site to induce partial evaporation loss of water, which would decrease the volume requiring chemical treatment.

Design of an evaporation system would require detailed investigation of mine hydraulics and local weather conditions. Careful design would also be required to prevent leakage from the ponds that would pollute ground water. Any impoundment structure should be equipped with emergency, noneroding overflow spillways to prevent the devastation that would accompany a breach of the impoundment sides.

Requirement of periodic maintenance is a limitation of the use of evaporation ponds. Often a pit, whether lined or not, must be accompanied by monitoring wells to check seepage.

This technique appears viable theoretically, and warrants further research and demonstration.

## COSTS

The cost of grading and compacting pond dikes ranges from $0.45 to $0.85 per cubic meter ($0.35 to $0.65 per cubic yard). Lining costs depend on materials used, availability and area covered. Clay liners, for example, can be placed for approximately $2.30 to $7.80 per cubic meter ($1.75 to $6.00 per cubic yard) including material and installation.

## REFERENCES

2, 7, 9, 16, 17, 28, 34, 38, 116, 138, 151

## 5.4 SPRAY IRRIGATION

### DESCRIPTION

Spray irrigation can be used as an effective mine water disposal technique. Mine water is collected and distributed over a large land area. This technique will find most use in irrigating regraded surface mined lands in arid and semiarid regions. The water must not be toxic to vegetation and must not contain excessive concentrations of sodium or soluble salts that will result in long-term soil or spoil degradation. Treatment may be required to eliminate these elements.

### EVALUATION

Spray irrigation has been used for disposal of treated sewage water, but it has not had application in mine water pollution control. There are many problems involved in its use, but they will eventually be overcome. Use of the technique should be carefully regulated to prevent ground and surface water pollution.

The technique could likely be used with polluted water if application rates do not exceed vegetative and evaporation losses. Soil and ground water analysis should be routinely performed at spraying areas. Buildup of pollutant-forming elements would require periodic relocation to new spray sites. This technique could be used to establish vegetation in low rainfall areas. However, the amount of discharge from low rainfall areas will be small, and may not justify use of the technique.

The references listed with this technique should be consulted for further information on system design and function. These papers also detail precautionary measures to prevent pollution from spray irrigation.

## COSTS

Costs will have to be developed for each application of this technique.

## REFERENCES

122, 125, 150, 169, 181, 196

## 5.5 SUBSURFACE WASTE INJECTION

### DESCRIPTION

Subsurface waste injection is a means of disposing of liquid wastes in underground reservoirs. Vertical boreholes are drilled and cased to permeable zones. Liquids are introduced by gravity feed or by pumping.

Reservoir investigations are required prior to selection of a disposal site. An acceptable aquifer must be well below potable water zones. It must be confined by aquitards to prevent migration of the waste to potential water supply aquifers or to the surface. Feasibility test borings, water levels, and pumping tests are used to determine aquifer characteristics and suitability for disposal.

Subsurface waste injection has been widely practiced in the oil fields of Texas and Louisiana. Chemical processing, pharmaceutical and heavy metals industries have been using this method with increasing frequency. New discharge regulations may encourage future use of this technique,which may be cheaper than chemical treatment of waste.

Well casings should be cemented in place to prevent vertical migration of the waste. Casing material should be corrosion resistant.

### EVALUATION

The environmental impact of subsurface injection has not been fully explored. It can be a dangerous technique that merely transfers a surface water pollution problem to a potential ground water pollution problem. Very few aquifers are sufficiently contained to insure against migration. Many aquifers may have already been breached by exploratory boreholes. The possibility exists that a storage aquifer could be needed as a future water supply as water demands increase.

The potential disposal aquifer should be thoroughly evaluated to insure against ground water pollution. Boreholes and casings should be adequately designed to guard against failure, which could result in pollution of water supply aquifers.

The disposal system must be properly designed to insure that it functions effectively. A disposal aquifer must have sufficient permeability to accept the amount of flow required. Suspended solids must be removed to prevent clogging of the aquifer, thus decreasing its permeability. The chemical nature of an aquifer should be analyzed with respect to the waste. Chemical reactions involving precipitates could clog an aquifer. For example: slightly acidic, high iron solutions should not be disposed into a carbonate aquifer, because precipitated ferric hydroxide could clog the pores, unless the discharge is to a large solution opening.

Abatement of ground water pollution is much more difficult than abatement of surface water pollution. Severe ground water pollution is a problem future generations could inherit from subsurface waste injection. There may be little renovation of waste in a ground water reservoir.

There is very little legislation controlling subsurface waste injection. Adequate protective legislation should be proposed and enacted.

## COSTS

A rule of thumb for drilling costs would be about $1.30 per centimeter diameter per meter of well ($1 per inch of diameter per foot of depth). Deeper wells will cost much more. Cementing the casing will be an additional expense. If the waste is corrosive to the standard steel casings, then additional expenses will be incurred for noncorrosive casing. Costs of related facilities such as holding ponds, piping and pumps will have to be determined for each application.

REFERENCES

100, 209

## 5.6 REGULATED DISCHARGE

### DESCRIPTION

This technique is based on the variable nature of surface water quality and quantity. Water quality of streams is continually changing and their volume of flow is highly variable. Most streams have an assimilative capacity so that they can receive a certain amount of mine waste without adverse effects. The amount of material a stream is capable of assimilating is highly variable, depending on flow and water quality. In cases where the pollution would be discharged in any event, it would be beneficial to control the effects with this technique.

Mines, particularly deep mines, have less variation in their flow and discharge pollutants throughout the year. A receiving stream may not be capable of assimilating large quantities of pollution during low-flow periods, yet mines continue to discharge. Some streams are capable of assimilating the mine discharges for all but short periods during the year. However, it is these periods when fish kills can occur.

This technique requires releasing mine water only in amounts that the receiving stream is capable of assimilating at any given time.

The system is comprised of holding ponds capable of storing large quantities of mine water during periods of low assimilative capacity. The ponds are drained during periods when the stream is capable of accepting the waste water.

The technique could be effectively utilized with flood control dams on polluted streams. These dams could store flow when downstream reaches of the river are not capable of accepting water for release during more appropriate periods. Installation of a strategic dam on a polluted stream in an otherwise marginal water quality river system could be capable of controlling adverse pollution effects in an entire river system.

The discharge would have to be continuously regulated, based on continuous water quality measurements and flow monitoring of the receiving stream.

## EVALUATION

The concept of purposeful discharge of polluted water to a receiving stream seems to be a negative approach. However, the technique may be attractive in areas (particularly with respect to abandoned mines) where other abatement is ineffective or unfeasible.

A complete hydrologic evaluation of the area would be required for design of this system. Variabilities of water quality and flow in the receiving stream would have to be well documented. The storage facility would have to contain sufficient capacity to hold the largest quantity of water expected. A computer program could be developed to handle the mass of data and establish the design parameters.

It should be emphasized that dilution effect achieved through regulation of discharges is not a substitute for adequate treatment. Use of this concept should be regarded strictly as an interim measure.

## COSTS

Costs are not available.

## REFERENCES

2, 4, 7, 8, 37, 47, 66, 97, 112, 116, 138, 169

## 5.7 REROUTING

### DESCRIPTION

This technique involves collection of mine waste water and conveying it to more suitable discharge points. Mine water can be conveyed from one watershed to another, more suitable watershed, by use of drainage tunnels as explained in the Underground Mining - Waste Water Control section.

This technique can be applied where mine water is polluting upper reaches of a watershed but where lower reaches are largely unaffected. Mine water can be collected at a point of discharge for piping or channeling to a downstream point, where it can be assimilated without adverse affects.

This technique can be effective where a particularly desirable body of water is being polluted. Upstream discharges could be collected and conveyed past an impoundment or other desirable stretch of water and discharged back into a stream.

This technique was applied with notable success at Cold Stream Dam, Philipsburg, Pennsylvania. This impoundment was being polluted by several upstream deep mine discharges. The discharges are essentially uncontrollable and, at any rate, funds were not available for abatement. Fortunately, the discharges are all on the same side of the stream. Water quality upstream of the discharges is good. A diversion ditch was constructed along the side of the valley to collect and convey the discharges around the impoundment. This diversion ditch discharges to the stream directly below the dam. No pollution was abated, but the impoundment was returned to usefulness. It is presently used for swimming and it is on the Pennsylvania Fish Commission's approved trout stocking list. The stream itself is incurably polluted by abandoned mine discharges below the dam, and is tributary to Moshannon Creek, another grossly polluted stream.

This technique is designed for interim use where presently incurable water problems exist, particularly from abandoned mines. The water problems may be presently incurable either for reasons of lack of developed technology or lack of funds to effect the cure.

## EVALUATION

Though this technique does not abate pollution, it can significantly reduce adverse affects of pollution. In many cases, this technique can be effective and cost less than available at-source control techniques of questionable effectiveness.

This technique could be used successfully in many areas. Rerouting should be considered as a viable tool for use in water pollution control planning. Its use, however, should be intended as an interim measure pending funds availability or suitable at-source abatement technology.

## COSTS

Costs are not available and would have to be developed for each situation. It is expected that costs of rerouting can often be less than use of other techniques.

## 5.8 MINERAL RECOVERY

### DESCRIPTION

This technique involves the recovery of valuable minerals, particularly heavy metals, by chemical treatment of existing mine discharges. Heavy metals are precipitated by neutralization.

### EVALUATION

This technique is theoretical and there are no known applications. Many mine discharges have high concentrations of valuable minerals. Economic evaluations would have to be performed to determine if a recovery plant would be profitable. This technique could be utilized to offset the cost of treatment plants constructed by government agencies. Much research and demonstration would be required to develop this technique.

### REFERENCES

14, TREATMENT Section of this REPORT.

# 6.0

# REGRADING

## 6.1 METHOD DISCUSSION

Regrading, as applied to surface mining, is mass movement of earth to achieve a more desirable land configuration.

Surface mining usually involves removal of large amounts of overburden in order to expose a mineral. Historically, this overburden was commonly placed in the handiest location, at the angle of repose of the material, with little thought given to future regrading. The result has often been large open pits, large ugly, unstable spoil piles, heavy erosion, landsliding and water pollution.

New mining laws are requiring that this spoil be placed back in the mine pit and regraded to a desirable shape. There is waste material at all surface mining operations, and some sort of beneficial regrading can be performed after mining.

This section discusses various types of regrading available for use on surface mined lands. The techniques vary only according to the geometry of the final land surface. Regrading is the most essential part of surface mine reclamation. It cannot be considered a total reclamation technique. It must be used in conjunction with other techniques described in this manual.

The purpose of regrading is manifold:

1) aesthetic improvement of the land surface
2) returning the land to usefulness
3) providing a suitable base for revegetation
4) burial of pollution-forming materials
5) reduce erosion
6) eliminate landsliding
7) encourage natural drainage
8) eliminate ponding
9) eliminate hazards, such as high cliffs, deep pits and deep ponds
10) control water pollution

Regrading at an active mining operation is an entirely different matter than regrading abandoned mines. Regrading should be required of all active surface mines. A regrading plan can be developed during the preplanning stage, and mining can proceed in a manner conducive to regrading requirements. Spoil can be placed initially so that regrading is simplified, such as Modified Block Cut Mining.

Regrading is often more difficult in old abandoned surface mines because the spoil was placed without considering future regrading. Contour strip mines in steep terrain create special problems where spoil was thrown over the outslope and is difficult to regrade. It is difficult to achieve a suitable surface for revegetation on abandoned mines because spoil segregation was rarely practiced. The soil is generally lost, and pollution-producing materials are well mixed throughout the spoil.

Regrading should be performed in conjunction with:

1) spoil segregation
2) burial of pollution-forming materials
3) spreading soil if available
4) construction of water diversion facilities
5) sealing of underground mine openings or auger holes in the highwall
6) soil supplementation and revegetation

In some forms of mining such as open pit or quarrying, there is little overburden to regrade. However, the mine could be reshaped to reduce pollution and soil could be spread and revegetated.

Choice of a regrading technique will depend upon many variables, such as:

1) funds available
2) future land use
3) degree of water pollution control required
4) terrain
5) geometry of the spoil with relation to geometry of the mine

6) amount of spoil
7) highwall height and length
8) legislative requirements
9) leasing stipulations

Costs of regrading techniques are quite variable. The report Analysis of Pollution Control Costs written for the Appalachian Regional Commission by Michael Baker, Jr., Inc. is a good cost reference. Regrading costs are usually based on the amount of earth to be moved. The cost per cubic meter is also highly variable and depends on local conditions. Approximate cost ranges are given where appropriate. Costs are also dependent upon the agency performing the work. An active miner can place spoil piles so that regarding is simplified, and he has the necessary equipment immediately available at the site. Regrading in conjunction with active mining is much cheaper than regrading abandoned mines.

Effectiveness of regrading is dependent on the effectiveness of other techniques applied in conjunction with regrading. Each grading project should be designed using sound water pollution control principles. The mine should be evaluated with regard to basic causes of water pollution. A regrading plan should be designed to correct any deficiencies. Effectiveness of a regrading project is often indicated by vegetative cover and runoff characteristics. Actual effectiveness hinges on the amount of water pollution reduction.

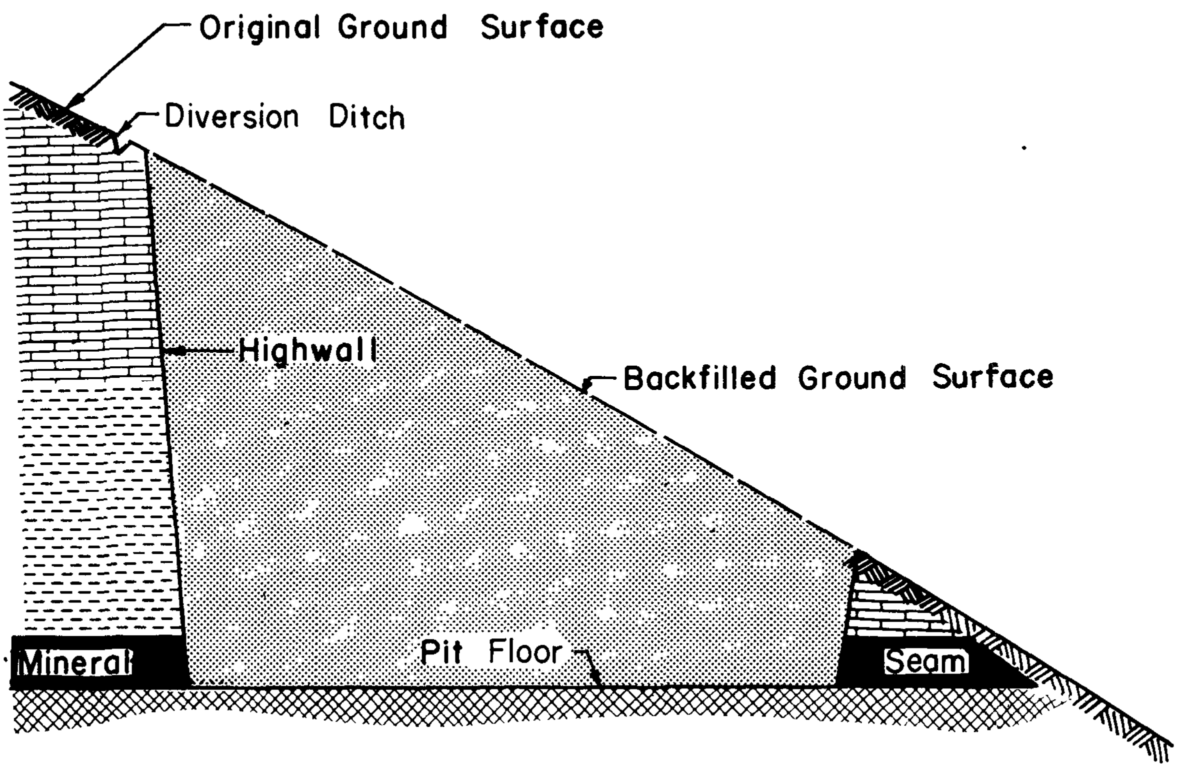
Legal problems often arise in regrading abandoned mines. There is often mineral remaining behind a highwall that was not economically extractable at the time of mining. This mineral may be economically mineable in the future. Regrading usually makes remaining mineral more difficult to extract. Mineral rights owners often balk at permitting regrading operations at abandoned mine sites for this reason.

Extensive documentation of relative effectiveness of various regrading methods does not exist. An adequate foundation of data to compare effectiveness of one technique with another is needed. Comparisons of regrading techniques effectiveness are primarily based on theory and some demonstration projects, but have not been proven.

## 6.2 CONTOUR

### DESCRIPTION

This technique involves regrading a mine to a shape that closely resembles original land contour. It is generally one of the most favored regrading techniques because it returns the land as closely as possible to its pre-mining state. This technique is also favored because all spoil is placed back into the mine resulting in less disturbed area, and usually less water pollution. Contour regrading facilitates deep burial of pollution-forming material. It reduces erosion due to reduction in size of disturbed areas.




CROSS SECTION OF
TYPICAL CONTOUR BACKFILL
**Figure 6.2-1**

Adapted from drawing
in reference No. 61

## EVALUATION

Contour regrading appears to be one of the best methods of water pollution control for surface-mined lands. It is also one of the most expensive, because of the large volume of spoil to be moved. It can be facilitated through use of mining techniques such as the modified block cut.

Contour regrading is difficult at abandoned strip mines in steep terrain. It is difficult and expensive to move downslope spoil back upslope onto the bench.

Contour regrading is limited to areas where sufficient spoil exists to achieve original contour. It is not applicable for mining reclamation where there is a large volume of mineral in relation to the volume of overburden, as in open pit or quarry mining.

Contour regrading is believed to be a most effective and aesthetically pleasing regrading technique.

## COSTS

Contour regrading will generally cost between $1240 and $6180 per hectare ($500 to $2500 per acre).

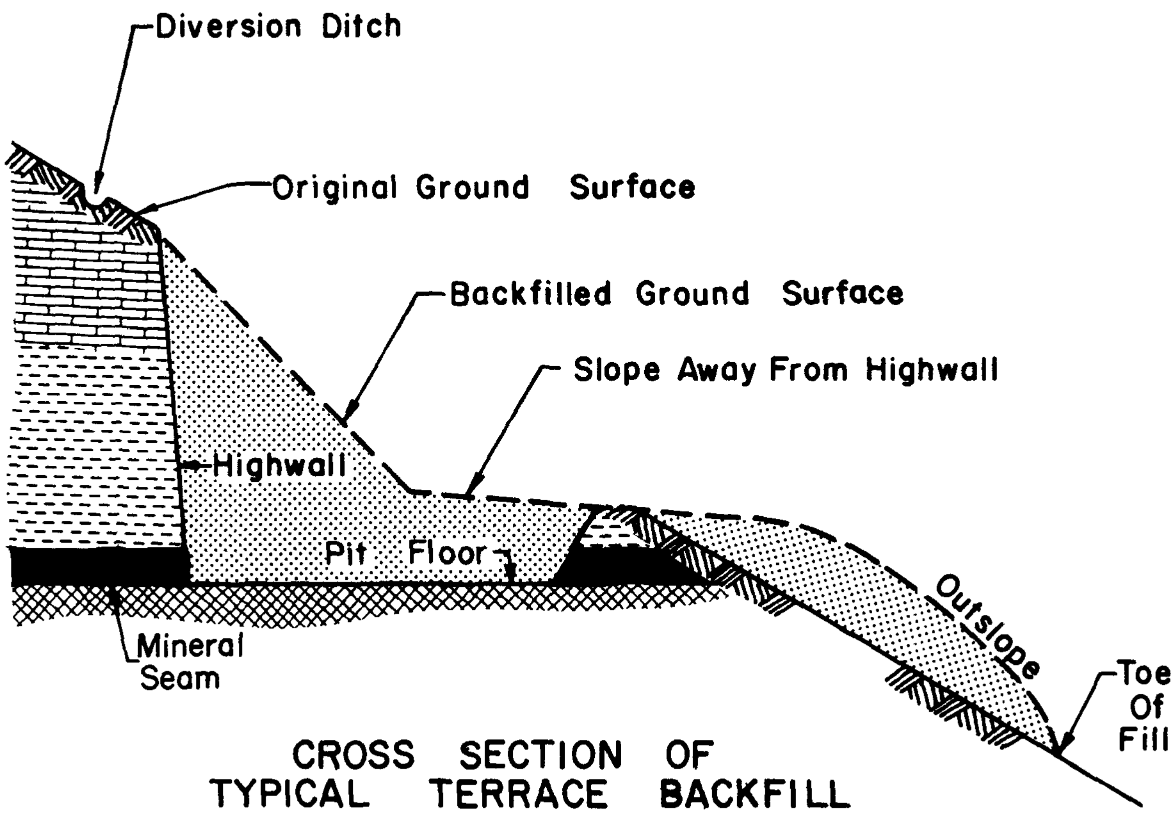
## REFERENCES

9, 33, 60, 61, 70, 145, 146, 148, 149, 166, 173

## 6.3 TERRACE

DESCRIPTION

Terrace and pasture regrading are similar in appearance and provide similar degrees of pollution control. They are discussed together in this section. Terrace regrading creates a gently sloping bench over a strip mine cut and results in a steep outslope beyond the mined area.




CROSS SECTION OF
TYPICAL TERRACE BACKFILL
Figure 6.3-1

Adapted from drawing in reference No. 61

## EVALUATION

Terrace regrading generally involves less earthmoving than contour grading, but more than swale regrading. It is useful in areas where the need for flat land is dictated by the potential future land use. It has been used principally in steep terrains where contour regrading is very difficult.

This technique has been used frequently. However, its water pollution control abilities are often less then desirable. Steep slopes at the highwall and at the outslope tend to encourage erosion. The steep outslopes of spoil material are often subject to landsliding. The gently sloping bench, on the other hand, does not encourage quick run-off and causes increased infiltration. Spoil is not confined to the mined area as in contour regrading, resulting in a larger disturbed area. The larger the disturbed area, the greater the erosion potential. Stockpiled topsoil must be spread thinner because of the larger disturbed area. Revegetation will be more costly because of the larger area, and is often difficult on the unstable steep slope areas.

Erosion and landsliding can be reduced by compaction and re-vegetation of the steep slopes.

## COSTS

Terrace regrading costs range from $500 to $4,940 per hectare ($200 to $2,000 per acre).

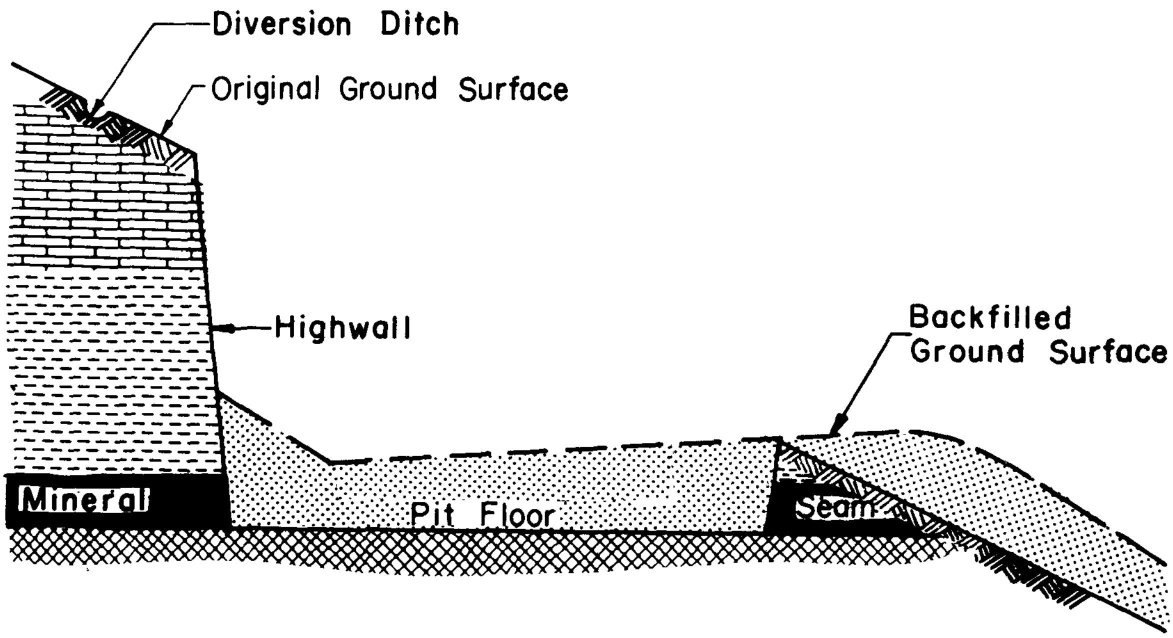
## REFERENCES

9, 33, 60, 61, 126, 135, 145, 146, 148, 149, 166, 173

## 6.4 SWALE

### DESCRIPTION

Swale regrading is used to describe various similar techniques that result in similar land configuration. Included with this discussion are: 1) Georgia V-Ditch; 2) Swallow Tail; 3) Reverse Terrace; and 4) rounding of spoil piles. Swale regrading is used to minimize earthwork in contour strip mine regrading. A smaller amount of spoil is moved from the low wall to the highwall (compared with contour and terrace regrading techniques). Much of the spoil is left in its present position. Grading is performed to create positively draining swales that collect and convey water from the mine. Grading is also performed to cover the mineral seam and pit floor, and to reduce steep spoil slopes.

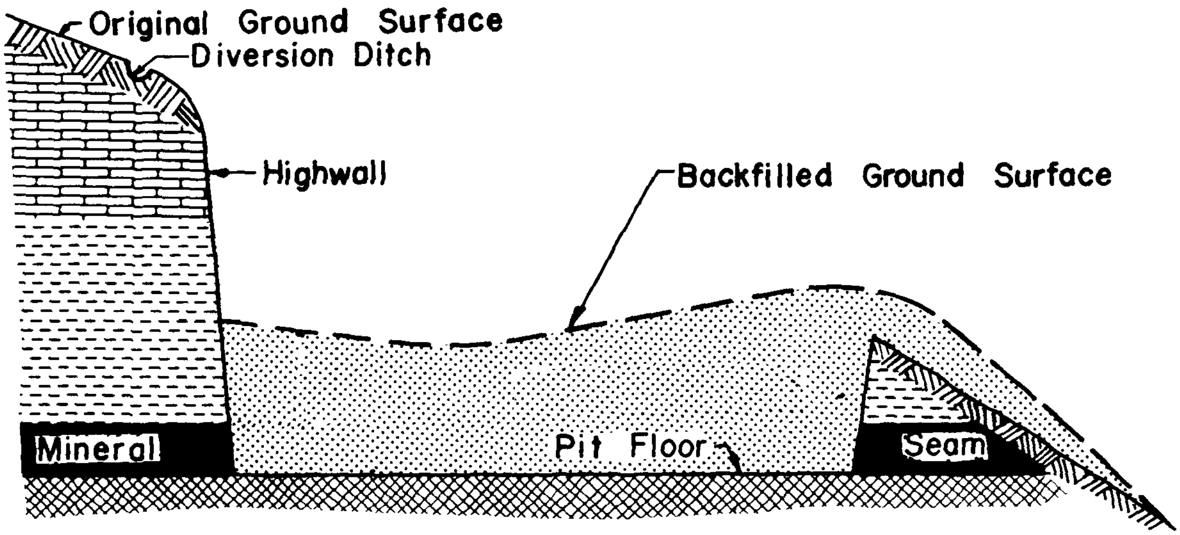



**CROSS SECTION OF TYPICAL SWALE BACKFILL**
**Figure 6.4-1**

Adapted from drawing in reference No. 61

Older applications of this technique such as "rounding of spoil piles and covering the coal seams" were mainly ineffective. Newer techniques utilizing more extensive grading, sound engineering design, and dependence on corrollary abatement techniques are much more effective.

The purpose of this technique is to minimize reclamation costs while providing water pollution control. Swale regrading is not as aesthetically pleasing as contour regrading. Upper portions of a highwall are left exposed, and a regraded surface is generally uneven.

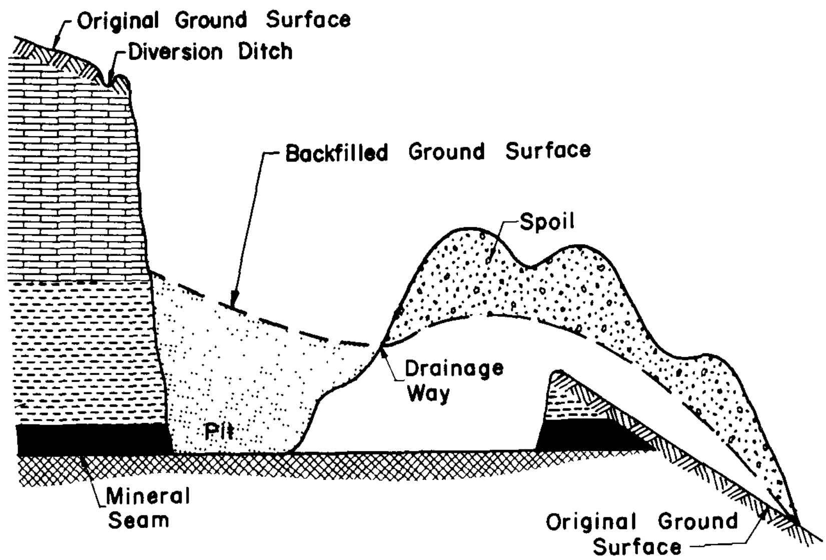



CROSS SECTION OF
TYPICAL GEORGIA V-DITCH BACKFILL
Figure 6.4-2

Adapted from drawing in reference No. 61

Swale regrading usually conveys runoff from a mined area faster than other techniques. Slopes are generally steeper, and the low points, or swales, if properly located, collect rainfall quickly and concentrate it in a flow channel where less infiltration will occur than if this water was distributed over a wider area.

Effectiveness of swale regrading is dependent on establishing a dense ground cover of grasses, legumes and shrubs. Its effectiveness is further controlled by 1) proper location of swales; 2) correctly designed swale gradients capable of conveying water; 3) water diversion ditches; 4) elimination of impoundments and; 5) burial of pollution-forming materials.




CROSS SECTION OF
TYPICAL SWALLOW-TAIL BACKFILL
Figure 6.4-3

Adapted from drawing in reference No. 9

## COSTS

Costs of swale grade average $500 to $3,700 per hectare ($200 to $1,500 per acre).

## REFERENCES

9, 60, 61, 72, 135, 145, 146, 148, 149, 166, 173, 179, 181

## 6.5 AREA

### DESCRIPTION

Area mining often results in large disturbed areas that resemble gigantic washboards. The mined area is composed of ridges and valleys of spoil material. The final cut is usually left open and often contains a pond bounded by a highwall.

Contour regrading of area mines is a relatively simple matter by comparison with reclamation of contour mines. Existing spoil ridges are pushed into adjacent low areas until the entire mine is smooth, and resembles the initial land shape. These slopes are often gentle, and erosion is controlled by establishment of a vegetation cover. The surface should be graded to provide for positive drainage, and pollution-forming materials should be buried during regrading. The disposal of spoils must be conducted with equal regard for vegetation and shallow aquifers.

Surface coal mining in western United States has been primarily accomplished by the area method. Regrading is less expensive in terms of cost per ton of coal produced in the west because of low overburden to coal ratios. Regrading to a suitable land form can be more difficult in the west due to large amounts of coal extracted and subsequent lack of fill material.

### EVALUATION

Area mine regrading and subsequent revegetation has proven effective in Illinois coal fields. It can return the land to a configuration useful for agriculture, silviculture, development and recreation.

Effectiveness is dependent on establishment of vegetation and runoff characteristics of the regraded surface.

## COSTS

Costs generally fall in the range of $1240 to $4940 per hectare ($500 to $2000 per acre).

## REFERENCES

56, 61, 72, 166, 179

## 6.6 OPEN PIT

### DESCRIPTION

Open pit mining is a major form of surface mining. It can be differentiated from strip mining by the relatively small amount of overburden removed in relation to the total amount of mineral deposit removed. Strip mining usually requires removal of large amounts of overburden to recover a relatively small amount of mineral.

Open pit mining is used extensively to recover minerals that occur in massive, usually near-surface deposits such as copper, hematite, taconite, and phosphate. Most open pit mining is done for the removal of building products such as stone, sand, gravel and clay. These open pit mines are generally termed quarries, and can be found near most population centers throughout the country.

Open pit mining begins by stripping off the soil and overburden to expose the deposit. The mineral is then removed and is transported to a processing area. In the case of building materials, there is little waste material after processing. Processing of ores, such as phosphate and copper, produces tremendous amounts of waste material.

Open pit mines generally present fewer water pollution problems than the other forms of surface mining. There is some chemical pollution associated with ore mining, such as the copper and iron industries. As a general rule, open pit mining results in physical pollution (sediment) rather than chemical. Open pit mining often results in a large enclosed hole in the earth. These pits will sometimes fill with water, however, seldom have a surface discharge. As such, most abandoned open pit mines are not sources of water pollution. Active open pit mines are more likely to be sources of pollution because of the necessity for pumping accumulated water from the pit. It is expected that these active mines will not be pollution sources after implementation of Federal and State discharge requirements.

Although most open pit mines do not have a surface discharge, it is likely that most of them act as ground water recharge basins. The pits collect some surface runoff and direct rainfall. If the pit does not have a discharge, then this water is being lost to the atmosphere via evaporation and/or to the ground water reservoir. Ground water pollution is likely to occur in cases of contaminated pit water. The nature and extent of ground water pollution from open pit mines is largely unknown.

There are some documented cases of reclamation of abandoned open pit mines. These cases were primarily where reclamation was performed to return the mine to a higher than original land-use category, which produced a profit to the landowner. The pits are usually left open and the removed overburden is abandoned wherever it was stockpiled. Revegetation has been primarily voluntary.

There are several reclamation and abatement techniques that can be used to control water pollution from open pit mines. Water diversion ditches can be used where surface runoff is entering the mine. The disturbed area around the mine can usually be graded and planted to reduce erosion. Milling wastes can often be placed back into the pit for regrading and revegetation. Soil can often be stockpiled at the beginning of mining and subsequently regraded around the disturbed area for establishment of vegetation and control of erosion. General regrading of the pit is sometimes applicable. Regrading can be utilized to stabilize steep slopes or to sculpt the area into a more usable form. The pit could also be developed so that it would fill with water after abandonment. This would be particularly useful for controlling chemical pollution resulting from oxidation. Impoundments in the pit are also useful as settling basins to reduce sediment discharge. Water passing over erodable material could be directed into the pit impoundment prior to discharge.

## EVALUATION

Some degree of reclamation can be performed at most open pit mines. Stockpiling of soil would be applicable in most instances. Water pollution problems from tailings piles associated with open pit mines can often be alleviated by grading the tailings into the pit. This would probably require that ore reduction be performed in close proximity to the pit. It would also require the use of a mine development plan that would allow placement of the waste concurrent with mining. This is not possible in all cases. The amount of earthwork involved in returning the tailings to the pit would be very expensive in many operations, such as the large open pit copper mines. Regrading is also limited when mining hematite and building products, where most of the material is removed from the mine site.

There is a wide variability among open pit mining operations and associated pollution problems. As such, there are no general rules of thumb that can be used to control pollution. The mines must be treated as individual cases. The water pollution impact should be determined for each site. Water pollution control techniques could then be prescribed for each mine site to correct or alleviate the problems of that particular site.

## COSTS

General costs are not available and depend on the requirements of the individual mine.

## REFERENCES

10, 15, 86, 112

## 6.7 HYDRAULIC

### DESCRIPTION

Hydraulic mining is performed by the application of a high velocity stream of water against an unconsolidated alluvial or colluvial deposit. The water is used to break up and wash away the unconsolidated deposit. The resulting mixture of water and sediment is then passed through a flume to recover gold. Hydraulic mining is used primarily for gold mining in Alaska, but its usage may spread if gold prices remain high.

The water quality impact of hydraulic mining is severe. It leaves a scarred landscape composed of unstable embankments of unconsolidated material. It also discharges a tremendous sediment load into the receiving stream.

The post-mining landscape could be regraded into a more stable and suitable shape for erosion control. Revegetation would also aid in reducing erosion. The types of materials mined by hydraulic methods are highly erodible and some type of stabilization is required.

Sediment catchment basins should be used for future hydraulic mining operations. These basins will fill quickly and should then be regraded and revegetated. Use of settling basins would likely require a continuous effort to regrade filled ponds and create new ponds.

### EVALUATION

Reclamation of hydraulic-mined areas has not been well documented, and it is doubtful if significant restoration has been attempted. Reclamation is required if the sediment loads from hydraulic-mined lands are to be reduced. Standard regrading and reclamation practices would apply. Species for revegetation would have to be selected for the climate of the mined area. Revegetation may be difficult in some of the primary hydraulic-mined areas in Alaska because of climatic extremes and a relatively fragile environment.

## COSTS

Costs are not available.

## REFERENCES

174

## 6.8 DREDGING

### DESCRIPTION

Dredge mining is a surface-mining method that involves the removal of ore or gravel from under water. Mining is usually performed from floating dredges using mechanical or suction recovery. Dredging is performed at an existing body of water, or performed on land from an artifically created pond by excavating below the water table.

Dredging operations for the removal of building products, such as sand and gravel, usually result in a water-filled pit. Regrading is only required for any disturbed land above the water table.

Dredging is also used for the recovery of precious metals, particularly gold. The small amounts of metal are removed and most of the material is then disposed near the mine site. These large amounts of material should be regraded and revegetated, unless they are disposed below water level.

Grading can be accomplished during the mining operation. Dikes can be constructed to isolate the operation from adjacent streams or lakes in order to contain the large sediment loads within the mined area.

### EVALUATION

Documentation of dredge mine reclamation could not be found, but specific instances of reclamation were reported. The mined area can be regraded around impoundments, thereby returning the area to recreational usage.

## COSTS

Costs are not available, and are dependent on the physical characteristics of the mined area.

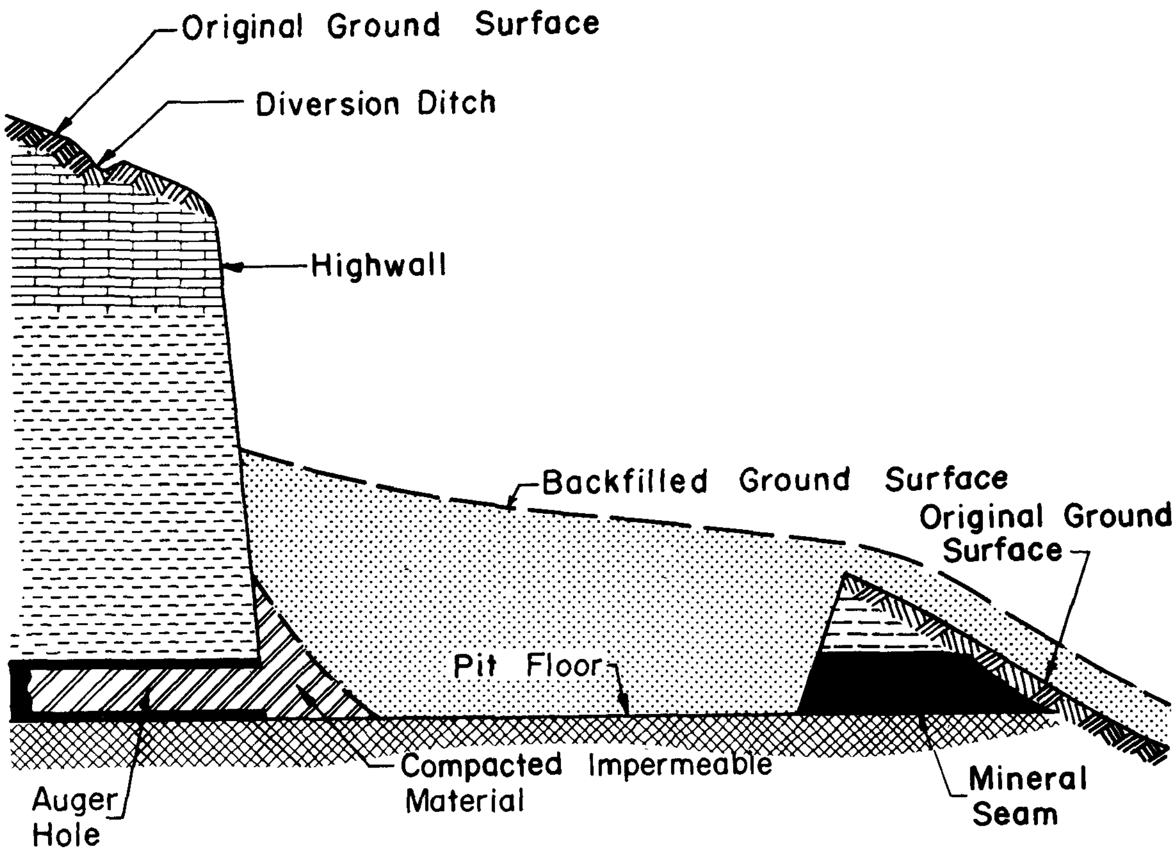
## REFERENCES

174, 202, 203

## 6.9 AUGER

### DESCRIPTION

Auger mining is performed by drilling large holes, up to 2.3 meters (7 feet) in diameter, into the face of a coal seam. It is usually performed from the bench of a contour strip mine to produce coal from behind the highwall where further strip mining is uneconomical.




CROSS SECTION OF TYPICAL AUGER MINE SEALING IN CONJUNCTION WITH PASTURE BACKFILLING

Figure 6.9-1

Reference No. 135

Auger holes must be sealed after mining to stop drainage or to reduce contact with free air oxygen. Many techniques have been utilized to control pollution from auger-mined areas. Sealing individual auger holes with various types of impermeable material has been attempted. These are described in the Underground Mining - Mine Sealing section of this report.

Auger mine sealing is also accomplished by grading earth against the exposed holes and the highwall. Construction of a clay liner against the highwall is an effective sealing technique. Less costly methods using compaction of a spoil barrier or simply regrading a strip mine over the auger holes have been employed.

Choice of method is partly dependent on the dip of the coal seam. This will determine the amount of water pressure that will ultimately be exerted at the seal. Complete inundation of the augered area is desirable. However, this is often impractical or economically unfeasible. Regrading techniques serve to partially (and sometimes completely) flood the holes, and decrease oxygen availability.

A clay liner can be constructed by compacting layers of clay against the face of the highwall, beginning from a slot excavated in the underclay. The layers should be relatively thin, 0.3 to 0.6 meters (1 to 2 feet), in order to be effective. The layer is placed and then compacted with rollers or by passage of heavy equipment. Compaction tends to force the clay into the auger holes and into cracks in the highwall, causing a tight seal. Acquisition of clay is often prohibitively expensive, and the least permeable material on-site is generally used to form the liner. This can be effective if on-site material contains a high percentage of clay and a low percentage of rock.

## EVALUATION

There has not been sufficient documentation to provide a basis for comparison of the various regrading sealing techniques. Clay liner should be the most effective, followed by compaction of on-site materials. The least effective technique would be standard strip mine backfilling.

Problems occur in areas where auger mines have broken into the downdip side of adjacent deep mines. Sealing of auger holes in this instance could cause extensive inundation, and produce large water pressures on the seals. If the water has no alternate route and continues to build up pressure, the seals will be breached and seepage will occur. Physical blowouts are minimized if the strip mine is backfilled over the sealed auger holes. Leakage caused by excessive heads of water does not signify lack of success: any inundation that occurs can result in at least partial control of pollution.

## COSTS

Costs of constructing clay liners may be \$2.30 to \$7.80 per cubic meter (\$1.75 to \$6.00 per cubic yard). Other abatement costs depend on the requirements of the specific mine.

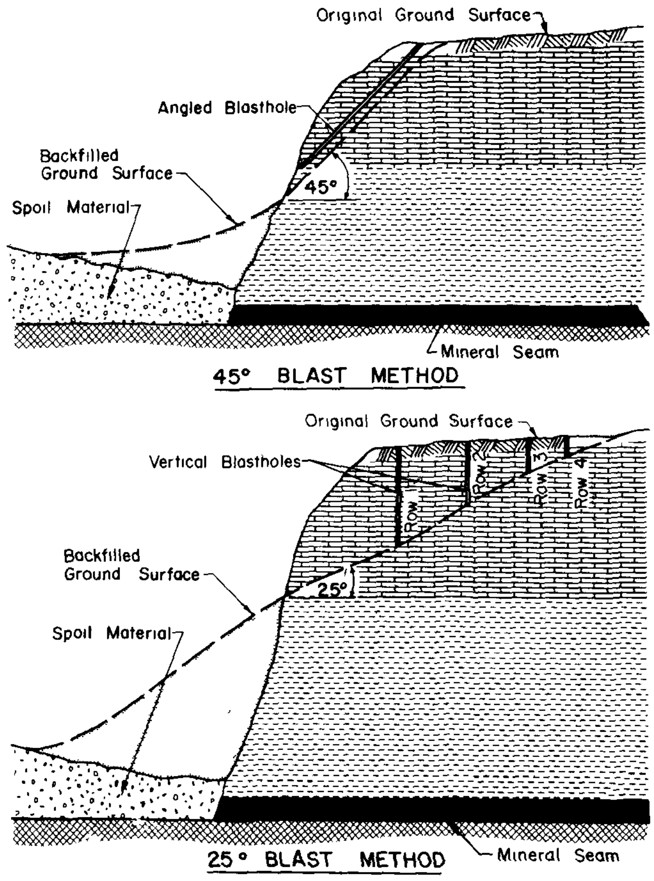
## REFERENCES

61, 67, 135

## 6.10 HIGHWALL REDUCTION

### DESCRIPTION

Highwall reduction is not a singular pollution control technique. It is often used in conjunction with regrading and total reclamation. The last cut of a strip mining operation usually leaves a vertical or near vertical face consisting of in-place overburden. The top edge or lip of the highwall can be removed by grading or blasting. This material can then serve as fill in the cut. The angled slope reduces the hazard of an exposed cliff and falling rock, and can improve aesthetics.




HIGHWALL REDUCTION
Figure 6.10-1

Adapted from drawings in reference No 60

This technique is only applicable for use with grading plans, such as swale or terrace, where the highwall is exposed.

Highwall reduction is also applicable to quarries and open pit mines. It can be used to help return the land to usefulness, eliminate cliffs, and provide fill for the pit.

## EVALUATION

The main function of highwall reduction is to increase safety and improve aesthetics. It has only limited use in water pollution control. Slope reduction will increase stability and decrease erosion from a highwall composed of unstable materials. It can also provide fill, but availability of fill material is not usually a problem.

Its erosion control values may also be limited. Most highwalls are composed of fractured rock which spalls off the face during periods of freeze and thaw. Exposed rock seldom produces sediment unless the rock is easily weathered. Sandstones with easily weathered matrices occasionally occur and can cause erosion problems. Highwall reduction and subsequent revegetation can control sediment production from erosion-prone highwalls.

## COSTS

Costs for this technique are variable due to the variation in desired final angle of the highwall, and the amount of additional regrading that may be needed. The cost will range from $27 to $44 per linear meter ($25 to $40 per yard) along the highwall.

## REFERENCES

60, 61

## 6.11 SLOPE REDUCTION

### DESCRIPTION

This technique is used to stabilize and reclaim downslope spoil material resulting from contour strip mining in steep terrain. Its purpose is to render the slope more resistant to erosion and sliding. There are two (2) generally accepted techniques of slope reduction; one called the "$7^{\circ}$ Storage Angle" and the other known as the "Parallel Fill".

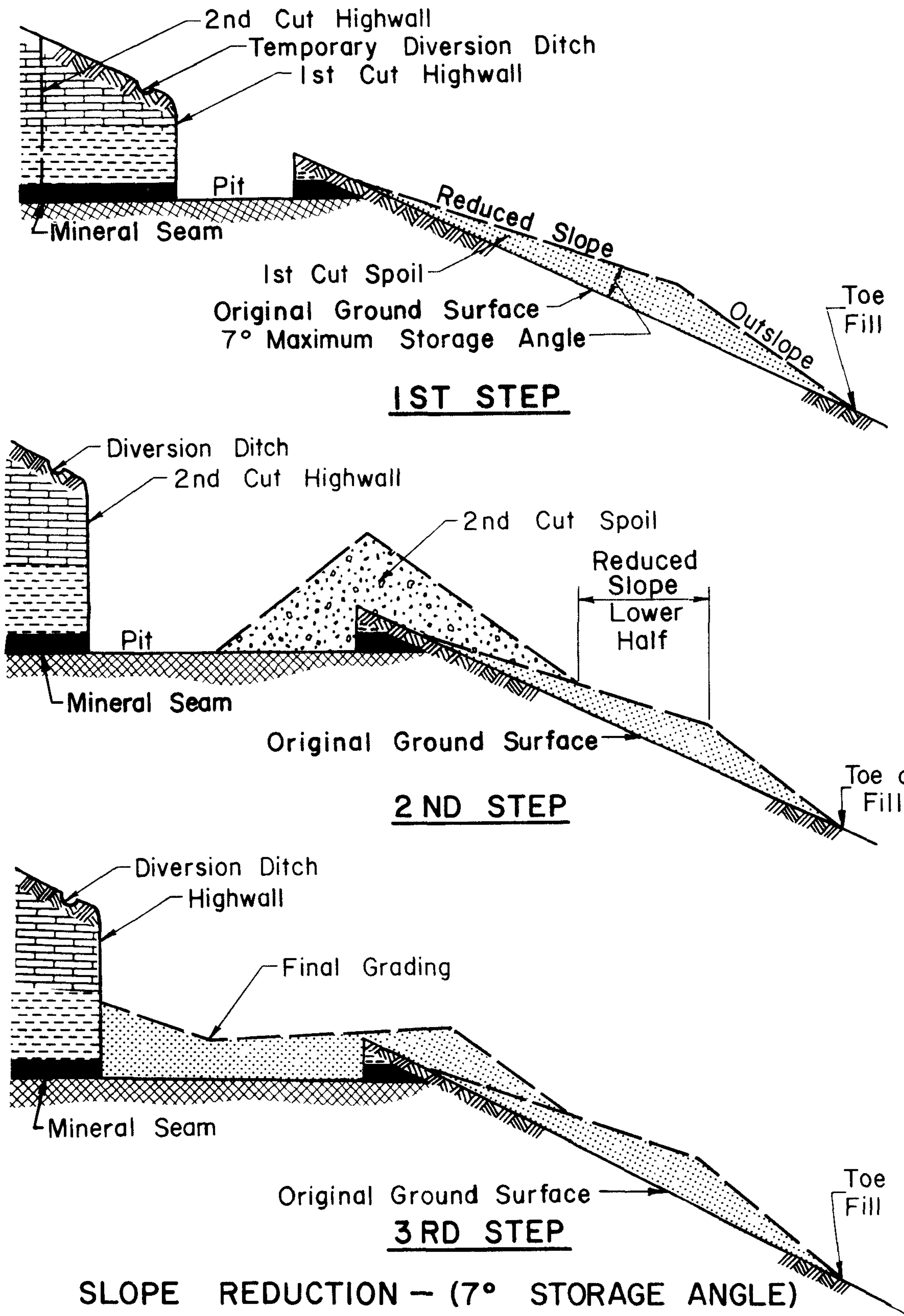
The $7^{\circ}$ storage angle essentially limits the lower half of the downslope to a maximum angle of $7^{\circ}$ greater than the angle of original ground slope. The parallel fill differs only slightly. It provides for the material to be stored parallel to the original ground line, and is built up in compacted layers, usually about 0.9 meter (3 feet) deep. The depth and angle of spoil material is determined by soil conditions of the existing slope and type of spoil material. Both techniques distribute the overburden over larger than normal areas.

Slope reduction is not limited to the outslopes of contour strip mines. It can be used to reduce the slope of any oversteepened spoil pile. It may be particularly effective for use on steep spoil and tailings slopes occurring at many western mines.

Slope reduction must be accompanied by revegetation to be effective in pollution and erosion control. Riprap or chemical (mainly petroleum derivitives) stabilization can be substituted for revegetation in arid climates where vegetation is difficult to establish and where land use considerations would allow.

### EVALUATION

Slope reduction has proven to be an effective tool in stabilizing

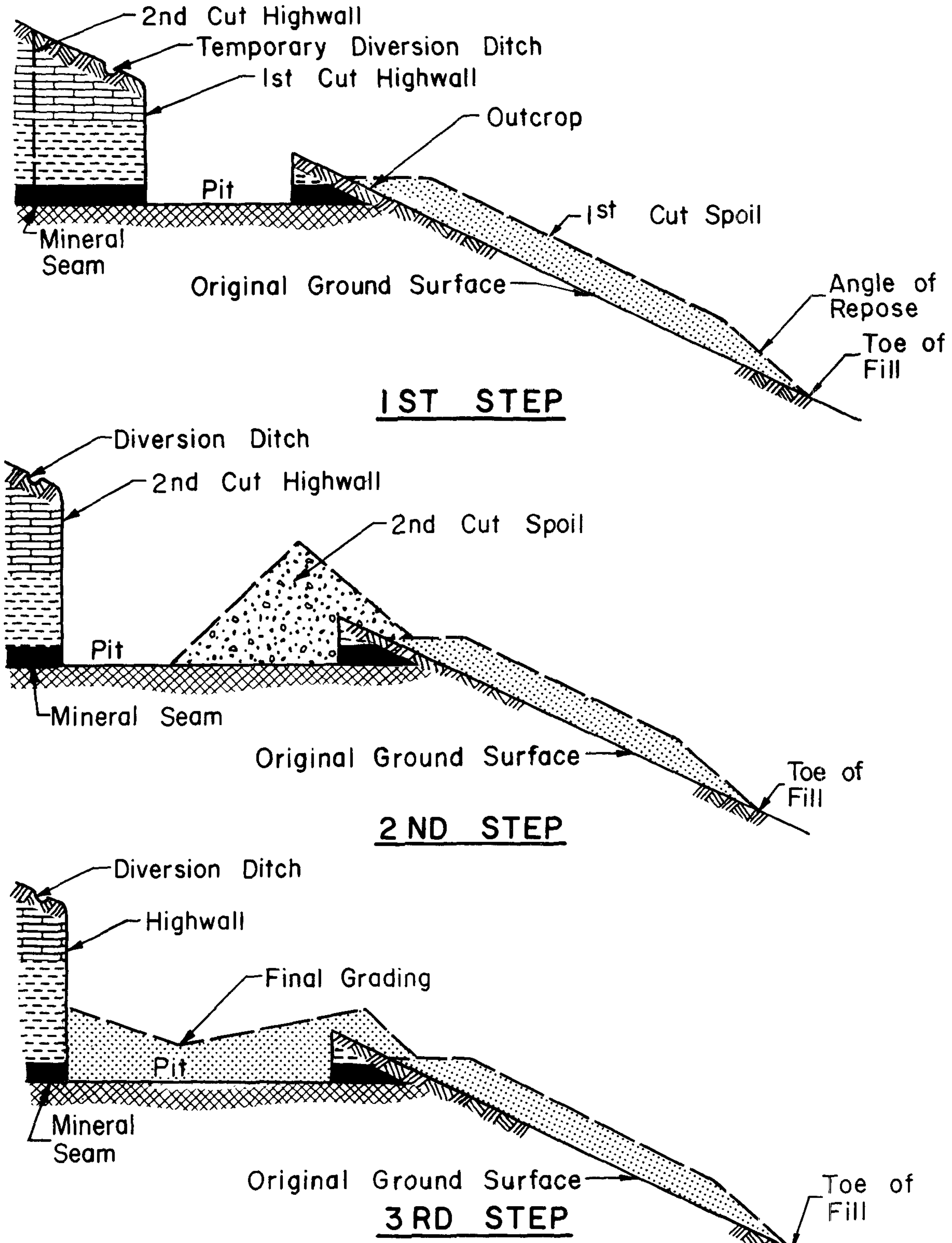



SLOPE REDUCTION — (7° STORAGE ANGLE)

**Figure 6.11-1**



Reference No. 61




SLOPE REDUCTION-(PARALLEL FILL)

**Figure 6.11-2**



Reference No. 61

steep spoil slopes and reducing erosion. It provides a stable base for revegetation.

Slope reduction results in a larger than usual disturbed area and increased revegetation costs. It is not as effective as contour regrading, but it is far less expensive and is often the only practical method of reclaiming abandoned contour strip mines in steep terrain.

Slope reduction may not eliminate landsliding in extreme cases of spoil instability and steep terrain. Rapid erosion will occur on the steep slopes unless vegetation is established concurrent with regrading. Establishing trees alone is not sufficient to control erosion. Planting should include grasses and legumes. Contour plowing and terraces would also be helpful in controlling erosion and establishing vegetation.

## COSTS

Costs are highly variable and are dependent on individual mine conditions. Cost will be less if slope reduction is accomplished during mining rather than after the mine is abandoned.

Costs can be expected to range from $500 to $4950 per hectare ($200 to $2000 per acre).

## REFERENCES

9, 61, 189

## 6.12 ALKALINE REGRADING

### DESCRIPTION

This is a very specialized form of regrading that has limited use. This technique will be demonstrated by the EPA in the Elk Creek Watershed, West Virginia. This technique will be discussed for its particular use in Elk Creek. The same type of situation where this technique would be applicable will undoubtedly occur in other localities.

This technique is not a true surface mine water control technique, but rather uses surface mine regrading to control underground mine discharges.

There has been extensive surface and underground mining on the Redstone and Pittsburgh coals in the Elk Creek Watershed. The Redstone coal is usually 10 to 15 meters (30 to 40 feet) above the Pittsburgh. Most of the interval between seams is composed of a low permeability soft claystone with a thin lens (maximum thickness about 1 meter) (3 feet) of limestone. The underground discharges are normally acidic because mine water does not have access to the limestone for neutralization. Surface mining breaks up the soft claystone and limestone, distributing limestone throughout the spoil, which makes it available for neutralization. The effect of the distribution of limestone was noticed during a field view of the watershed. Four-year old water quality data showed a large acid discharge from an underground mine. The outcrop of the underground mine had been subsequently strip-mined and terrace regraded. The underground mine discharge was passing through the regraded soil material and was found to be alkaline. Turbidity from precipitating ferric hydroxide indicated that neturalization had recently occurred. Several other strip mine discharges were found to have similar conditions.

Regrading of strip mine spoil caused the underground mine discharge to flow through spoil material resulting in neutralization from the disseminated limestone.

## EVALUATION

This technique is scheduled for demonstration by the EPA at several sites in the Elk Creek Watershed. Before and after water quality sampling will determine degree of effectiveness. This technique would appear to be applicable for similar conditions in other areas. A hydrogeologic study would be required to determine applicability.

Slurry trenching (the next technique description) is to be utilized in conjunction with an alkaline regrading demonstration to achieve wider distribution and longer retention time of acid water in the alkaline spoil.

## COSTS

The costs for alkaline regrading are the same as for terrace backfilling, which ranges between $500 and $4940 per hectare ($200 and $2000 per acre).

## REFERENCES

9, 40

## 6.13 SLURRY TRENCHING

### DESCRIPTION

Slurry trenching is primarily a waste water control technique. However, it is to be used with a regraded surface mine, and is to be demonstrated with alkaline regrading techniques.

A slurry trench is a narrow vertical trench excavated in unconsolidated materials. The vertical trench walls are maintained by filling the trench with a bentonite clay and water slurry. The excavation may be accomplished with a backhoe, clam shell, dragline or connecting drill holes. The slurry material is backfilled with the previously excavated material (if it is of the proper grain size distribution). The resultant backfill mixed with bentonite forms a relatively impermeable ground water dam.

The technique has not yet been used in mine drainage control. Its primary use has been for dewatering building foundations and for ground water cut-off trenches below dams placed on unconsolidated materials.

The slurry trench will be demonstrated by the EPA in conjunction with alkaline regrading in the Elk Creek Watershed, West Virginia. It will be placed in regraded spoil and keyed into the underclay to form a ground water dam. The placement and top level of the trench will be carefully controlled to cause acid underground mine water to rise in the alkaline spoil. The flow path through the spoil and the retention time will be increased, causing increased neutralization. Rise in water level at the discharge point will also cause the water level to rise in the underground mine, reducing acid production.

This technique should have further application. It could be used to flood underground mines where the down dip outcrop has been stripped away and the rise within the mine is small. The amount of inundation would be limited to the elevation of the top of the trench. This would be controlled by geometry of the strip mine spoil as related to the attitude of the underground mine.

Present indications are that the height of the trench should be limited to 10 meters (33 feet).

This technique may have application for raising ground water levels in pollution-forming materials, particularly valley fill tailings piles.

## EVALUATION

This technique will be evaluated in the Elk Creek Demonstration project. Its effectiveness as an impermeable barrier has been well documented by numerous construction projects (not related to mine water pollution control).

## COSTS

Costs of slurry trenching are expected to range from $16.00 to $43.00 per square meter ($1.50 to $4.00 per square foot).

## REFERENCES

40, 210

# 7.0

# EROSION

# CONTROL

## 7.1 METHOD DISCUSSION

Sedimentation is defined as the erosion, transport, and deposition of material by water and wind. Erosion occurs naturally as part of the weathering cycle, and is greatly accelerated by mining activities. Physical disturbance of soil and rock exposes materials to erosion mechanisms and increases erodibility. Moving water is responsible for most erosion from mined areas. However, wind erosion may be a significant transport mechanism, particularly in arid regions. Wind will transport fine-grained materials over wide areas, and occasionally directly to bodies of water. This widely scattered material will enter the surface flow network during periods of surface runoff.

The need for erosion control became apparent long ago. The science of erosion control has advanced significantly. Extensive research has been performed by the Departments of Agriculture and Interior of the Federal Government and by universities. The EPA publication "Guidelines for Erosion and Sediment Control Planning and Implementation" (EPA-R2-72-015) contains an excellent discussion of erosion and erosion control techniques.

This report is not intended to be a complete treatise on the subject of erosion control. It is only intended to present specific erosion control techniques that have had widespread use in the mining industry.

Erosion control procedures used in the mining industry are not as sophisticated nor as expensive as the techniques employed in urban and highway construction. The large amounts of disturbed land and limited budgets of reclamation agencies generally preclude use of all but the most elementary and low cost techniques. Revegetation, the simplest and most effective erosion control mechanism, has not even received widespread use. Unfortunately, erosion control for most surface mines in the past has been the planting of a few seedling trees on an improperly prepared and sometimes toxic surface.

Erosion and sediment control and mine water chemical pollution control sometimes are in conflict. Erosion control calls for decrease of water velocities. However, this factor can increase infiltration. If the underlying material contains water-leachable pollutants, infiltration should be discouraged. Mine water pollution control calls for rather rapid surface water runoff and reduced infiltration. Rapid runoff should only be encouraged to the extent that erosion does not occur. Where chemical pollution can occur, a good balance must be achieved between sediment and chemical pollution control. The principal pollutant from many mines is sediment. In this case water pollution control is entirely erosion and sediment control.

Erosion control is accomplished by several basic methods. One of these is isolation of erodible material from moving water. This is accomplished by diversionary channelization, and covering procedures.

Reduction of velocity of water flowing over erodible material is also effective. This is accomplished by various means, including slope control, revegetation and construction of flow impediments (mulches, scarification, dikes, contour plowing, and dumped rock).

Decreasing erodibility of the material is another method. This can be accomplished by compaction, chemical stabilizers, burial of erosion prone materials, and revegetation.

If erosion prevention methods do not achieve desired effectiveness, suspended material can be removed from the transport medium. This is usually accomplished by construction of a collection and conveyance system leading to an impoundment. The pond is constructed to provide water with sufficient detention time under quiescent (or reduced velocity) conditions to settle out suspended materials. Systems whereby water is spread out over a flat or rough textured area have proven effective in causing sediment deposition. Wind fences are capable of reducing wind velocities to at least partially cause wind-borne sediment to be deposited.

Preventive techniques are often insufficient to curtail erosion from active surface mines. Settling ponds are usually needed. The most efficient erosion control systems combine settling ponds with preventive measures such as diversion and/or revegetation.

The choice of erosion and sediment control techniques should be made during mine preplanning, and should consider local conditions, including erodibility of disturbed material, topography, rainfall, relationship of surface flow channels, drainage area tributary to the mine, site hydraulics, and settleability of transported material.

Erosion and sediment control should be an essential part of surface mining and reclamation planning. It is not intended as a complete abatement plan. It should be used in conjunction with other abatement techniques such as regrading, controlled mining, water infiltration control, handling of pollution-forming materials, and waste water control.

Legal considerations influence erosion control planning. Local, state, and federal laws often regulate the infringement on stream channels, allowable water velocities, impoundment construction, and discharge limits of settleable solids. Increasing sediment amounts and water velocities in downstream flow paths can cause downstream problems. Failure of water impoundments can result in loss of life and massive damages as evidenced in the pond failure in Buffalo Creek, West Virginia in February 1972.

Costs of erosion and sediment control are extremely variable and will need to be developed for individual installations. Local physiographic, weather and soil conditions will cause extreme variations in control costs.

## 7.2 DIVERSION

### DESCRIPTION

Diversion is the process of collecting and channeling water before it reaches erodible materials. This is usually accomplished by excavation of ditches along the high end of a mine or wherever significant amounts of water will drain to the mine. Water is collected before it reaches a disturbed area and conveyed around or through the area to a receiving stream. Topographic maps are useful in locating diversion and conveyance ditches. Size and gradients of the ditches are designed to carry expected flows estimated by knowledge of historic storm intensities and drainage areas. Storm intensity data can be obtained from the National Weather Service, local weather services, State Highway Departments, and the Soil Conservation Service. Flow computation procedures can be obtained from these same agencies. Flumes, culverts, riprap, and various forms of matting can be used in channels conveying water down steep slopes to prevent erosion. Dikes can be used in the same manner as ditches. They are often used together when material excavated from a ditch is used to form a downslope dike.

Diversion can be employed within the mine to collect and convey incoming ground water prior to contact with erodible material.

### EVALUATION

In most cases, diversion is an economical form of erosion control. It is not meant to function as a complete erosion control, but as an integral part of an erosion control plan. It is less expensive than constructing settling ponds and repair of erosional damage. Surface flow can be effectively gathered and conveyed from the site before contacting erodible material.

## COSTS

Diversion ditches cost from $1.30 to $3.90 per cubic meter ($1.00 to $3.00 per cubic yard). Dikes range from $0.45 to $0.85 per cubic meter ($0.35 to $0.65 per cubic yard). A 91.5 centimeter (36 inch) ½ section of bitumized fibre pipe averages $32.80 per linear meter ($10.00 per linear foot) in place. A 45.7 centimeter (18 inch) corrugated metal pipe is $26.00 per linear meter ($8.00 per linear foot) in place. Concrete costs approximately $39 per cubic meter ($30 per cubic yard) in place. Asphalt paving ranges from $2.40 to $6.00 per square meter ($2.00 to $5.00 per square yard) in place. Dumped rock costs from $2.60 to $7.80 per cubic meter ($2.00 to $6.00 per cubic yard) and riprap ranges from $13.00 to $34.00 per cubic meter ($10.00 to $25.00 per cubic yard). Jute matting costs $0.70 to $2.40 per square meter ($0.60 to $2.00 per square yard).

## REFERENCES

22, 34, 61, 115, 119, 166, 179

## 7.3 RUNOFF CONTROL

### DESCRIPTION

The section on Diversion was primarily concerned with techniques directed toward preventing water from entering a mined area. Runoff control is the use of various techniques to handle water after it reaches the mine site. Runoff control, as used in this context, is meant to imply control of erosion caused by water flowing over a mined area. Unfortunately, runoff control and pollution control are sometimes conflicting. Pollution control of chemical contaminants from mine spoils and wastes often involves reducing the amount of infiltrating water. Runoff control usually results in increased infiltration. The basic causes and degree of pollution should be examined at each mine to determine if use of runoff control measures will result in increased chemical pollution. Water pollution in some mines is caused by sediment and not by chemical changes. In these instances, runoff control measures can be utilized without causing the adverse effects of chemical pollution.

Runoff control can also reduce chemical pollution: the mine surface is stabilized, preventing erosion from exposing new material to oxidation. Runoff control is instrumental in helping to establish vegetation, decrease erosion, and increase infiltration to root systems. In this fashion, runoff control helps to decrease chemical pollution.

There are many runoff control techniques available for use on surface mined lands. Choice of technique will likely be a question of economics. Some of the techniques may be prohibitively expensive because of the large amount of disturbed area involved and limited fund availability. The many techniques of runoff control are not discussed in detail in this report. Erosion control is a science of itself and numerous agencies and institutions are conducting research, demonstrating techniques, and producing literature on the subject.

Establishment of vegetation is probably the most effective, cheapest, most universally applicable of all the runoff control techniques. Revegetation of surface mined lands is discussed in Section 8 of this report.

Mulching can be used for runoff control. However, it is often a temporary measure. It is commonly used to facilitate germination and early growth of vegetation. The mulch decreases erosion of a seeded area, tends to hold water near the surface of a mine and, in the case of organic mulches, adds nutrients to the soil. Mulches are also used to temporarily reduce erosion in areas where other erosion control measures will be utilized at a later date. The function of a mulch is to protect the surface from the impact of raindrops and reduce the velocity of water on the land surface. The most common mulch is straw, which is used quite extensively for revegetation. Straw is the cheapest and most readily available mulch. Wood fiber mulches made from shredded trees are being used more extensively as a replacement for straw. Both of these mulches can be applied by hand spreading, by large shredders and blowers, or hydraulically. In areas with high winds and low moisture, the mulch can be held in place with hemp or wire nets. This is quite expensive and will have only limited use. Artificially produced mulches are also available, as described in reference 115. Mulches must be selected to fit the climatic conditions where they will be used.

Slope reduction is effective in helping to achieve runoff control. Steep slope areas are graded to gentler angles to reduce water velocity.

Riprap has been used in western areas to reduce erosion where vegetation cannot be established. Riprap is expensive and would only be practical for extreme slopes, and arid areas, where revegetation is very difficult.

Terracing of embankments such as described in the Head-of-Hollow Fill section of this report is effective. This is especially applicable in areas containing tailings piles where steep and unstable slopes cannot be avoided. A series of terraces can be cut in an embankment to intermittently reduce water velocities on steep slopes. A series of parallel diversion ditches excavated in a configuration nearly parallel to surface contours is an adaptation of this technique. The diversion ditches collect moving water at regular intervals along a slope, and the water is subsequently conveyed out of the disturbed area and discharged where erosion cannot occur.

Surface scarification is an effective runoff control technique. It is accomplished by creating a series of closely spaced ridges roughly parallel to the contour lines. The ridges reduce water velocity and cause part of the sediment load to settle out in the adjacent lows. Scarification is performed by contour plowing, furrow grading, contour discing, or any other means of abrading the surface parallel to contour. This can be performed in the most rudimentary fashion by having machinery travel the area parallel to contour. The wheel or tract scars then act as the ridges and valleys. Scarification is temporary, and should be used in conjunction with revegetation. The beneficial effects of scarification are short lived, because the ridges tend to erode and the valleys fill with sediment. Scarification serves to help establish vegetation and control erosion until the vegetation is established. Scarification further serves to concentrate water in the low spots. This is helpful for establishing vegetation in arid areas.

Runoff control can be achieved by the use of surface stabilizers. There are many of these products marketed. They are usually applied by spraying a liquid over the surface. This stabilizer reduces erodibility of the surface. They are often expensive and temporary, and are subject to weathering and physical damage.

## COSTS

Costs for the various items necessary for vegetation are outlined in more detail in Section 8.0, Revegetation. Mulching (hay) approximate average cost is $100 per hectare ($ 40 per acre).

Contour plowing should range from $0.80 to $1.60 per meter ($0.75 to $1.50 per yard), depending on terrain. Costs for slope reduction and terracing of embankments are highly variable and dependent on individual mine conditions. Costs can be expected to range from $500 to $4940 per hectare ($200 to $2000 per acre).

Chemical stabilization varies from $120 to $1,000 per hectare ($50 to $400 per acre). Diversion ditches and riprap costs are given in Section 7.2, Diversion.

REFERENCES

34, 37, 42, 47, 53, 56, 92, 108, 115, 119, 134, 171

## 7.4 CHANNEL PROTECTION

### DESCRIPTION

Various techniques can be used to control erosion in channels. Most of these involve placement of a protective liner such as riprap, concrete, jute matting, or dumped rock in the channel to reduce water velocities and/or protect the underlying material. Cross channel dikes or energy dissipators are also used for channel protection by reducing water velocities. Flumes are often used to prevent erosion of channels.

Dumped rock, riprap and jute matting are the cheapest and most widely used channel protectors.

These techniques are used for channels through a mined area and to protect the waste piles from nearby streams. Riprap and dikes have been employed to protect mine tailings piles from adjacent streams.

### EVALUATION

All of the above-mentioned techniques have been proven effective. Choice of technique is governed by water velocity and installation cost. It must be recognized that indiscriminate use of erosion control techniques for channels can be harmful to existing aquatic biota. This factor should be given careful consideration during design.

### COSTS

Costs for energy dissipators are quite variable and depend on type and size of dissipator desired. Other channel protection costs are defined in Section 7.2, Diversion.

## REFERENCES

34, 53, 56, 115, 119, 162

## 7.5 SETTLING

### DESCRIPTION

Settling is used to trap sediments being transported in runoff. Techniques described in other sections of this report discuss erosion prevention. It is extremely difficult to control erosion from active surface mines because of the large amount of disturbed earth involved and the continuing mining activity. Erosion and sediment control measures such as diversion and revegetation should be employed to reduce erosion and sediment transport. Solids settling systems should be incorporated to remove sediments from most surface mining operations. Water collection and conveyance systems are usually installed to carry water to settling ponds. Settling occurs because of the decrease in water velocity. This lowers the competency of water to carry suspended material. Size of a settling pond must be determined from the amount of flow anticipated and the time required for the suspended material to settle. Proper residence time must be provided to ensure effectiveness.

Snow fences have also been used to settle windblown material. Snow fences were used on old uranium piles, but success was questionable.

Settling can also be achieved without use of impoundments. Distribution systems will reduce water velocity and depth, allowing suspended material to settle. A distributary is formed by distributing a discharge over a large area. The area should have a gentle slope and a rough textured surface. Effectiveness of a distributary system was documented in "Effects of Placer Mining on Water in Alaska." (Ref. No. 174).

## EVALUATION

Properly designed settling systems are often adequate to reduce settleable solids to acceptable levels. Flocculation systems are required where settling alone will not achieve proper results. Use of settling ponds and flocculation is described in "Preventing the Sedimentation of Streams in a Pacific Northwest Coal Surface Mine" (Ref. No. 109.)

Effectiveness of settling systems is based on settling velocities of the material in suspension. A settling system must be designed so there is sufficient residence time to allow a desired amount of solids to settle. Residence time is controlled by amount of flow and capacity of the impoundment.

High flow conditions should be considered in impoundment design.

## COSTS

Costs of settling ponds vary with type, size, and location. Snow fence costs average approximately $3.30 per linear meter ($1.00 per linear foot).

## REFERENCES

2, 7, 9, 16, 17, 28, 32, 34, 38, 115, 116, 119, 138, 151, 174

# 8.0

# REVEGETATION

## 8.1 METHOD DISCUSSION

The revegetation techniques described in this section are used to encourage establishment of a vegetative cover on disturbed lands. Surface-mined lands are often hostile to vegetation. Voluntary revegetation does not generally occur to a satisfactory degree for many years, if at all.

Revegetation is one of the most effective pollution control methods for surface mined lands. If properly established it will provide effective erosion control, and contribute significantly to chemical pollution control. Revegetation results in aesthetic improvement, and often returns land to agricultural, recreational, or silvicultural usefulness.

A dense ground cover stabilizes the surface with its root system and reduces velocity of surface runoff. A dense ground cover deposits yearly crops of organic matter on the surface and can virtually eliminate erosion. A soil profile begins to form, followed by a complete soil ecosystem. This soil profile acts as an oxygen barrier in that the oxygen is utilized by soil bacteria. The amount of oxgyen reaching underlying pollution-forming materials is reduced. This in turn reduces oxidation, which is responsible for most of the pollution.

A soil profile tends to act as a sponge that retains water near the surface. The mine spoil materials are often permeable and allow water to infiltrate quickly. Little water remains near the surface. Water held near the surface by a soil profile is important. It acts as a surface coolant because it will evaporate from the surface. This decreases surface temperatures and enhances vegetative growth. Water evaporated from the surface is water that will not pass through underlying potential pollution-forming materials.

Vegetation also utilizes large quantities of water in its life processes and transpires it back to the atmosphere, again reducing the amount of water reaching underlying materials. However, vegetation does not necessarily reduce the amount of water reaching underlying materials, since certain types of vegetation increase infiltration.

Difficulties encountered in reestablishing vegetation on surface-mined land result from disturbance of the area and inability to restore the area to its pre-mining condition. Loss of the soil zone is a major hindrance to revegetation and, therefore, topsoil stockpiling is encouraged. The natural hydrology of the area is grossly disturbed, and this accounts for most of the revegetation problems in arid and semi-arid regions. Mining often results in steep, unstable slopes, which are extremely hard to vegetate. The surface condition of a mine is often a limiting factor for vegetation. The surface is often toxic with high concentrations of salts, metals and acid. Chemical conditions may inhibit or completely prohibit growth. The surface is often rough-textured and has little soil or fine material to act as a medium for root development. Many of the stony mine surfaces are often highly permeable, and retain little water near the surface (which is needed for plant growth). Dark-colored materials on the surface absorb large amounts of solar energy, resulting in elevated surface temperatures that discourage growth. Nutrient levels are usually low and sometimes are insufficient to support plant life.

Too often, a number of these adverse conditions will occur at one site. Revegetation techniques are designed to reduce the effects of these conditions or develop species tolerant to these conditions.

Revegetation can be an entire pollution control plan in some instances, but generally it must be an integral part of more comprehensive plans that incorporate regrading, diversion and overburden segregation.

Past revegetation efforts were primarily concerned with planting trees. This is now believed to be inadequate, and any tree planting should be accompanied by establishment of dense ground covers of grasses and legumes. Trees are not effective in erosion control for many years after planting. They are slow to form soil profiles and do not provide effective chemical pollution control until long after planting. Wildlife grazing (over-grazing) on revegetated lands can also be a problem.

The following sections present the various techniques that can be used in revegetation.

## 8.2 TOPSOIL REPLACEMENT

### DESCRIPTION

The best medium for plant growth at almost all surface mine sites is the topsoil that originally covered the area. Past mining practices have largely ignored the presence of the soil, and mining started without regard to stockpiling and saving the soil. The soil was subsequently mixed with the spoil or placed in the bottom of spoil piles where it was not available during regrading. Revegetation is usually successful when the original topsoil is spread over the surface of the mine after regrading the spoil.

### EVALUATION

Topsoil stockpiling historically was not performed because of the additional cost of scraping it from the site, stockpiling it, and protecting it from erosion. Multiple handling can be reduced by pre-mine planning of spoil placement location and sequence of final grading activities.

Soil stockpiling is relatively simple when the reclamation plan calls for contour regrading. The soil is merely scraped downhill to the low wall and covered with the spoil piles. The spoil is regraded upward during reclamation and the last material encountered in the bottom of the pile is the soil, which can then be spread over the surface.

The soil can also be scraped upward initially, and deposited as a dike on the highwall. This will serve as a diversion ditch. Any soil left exposed should be temporarily revegetated to protect it from erosion during the life of the active mine.

The soil should be considered as a valuable natural resource and should not be wasted during mining.

Topsoil can also be imported to the mine site for revegetation. This is expensive and is not practical in most instances. The topsoil borrow area could also be an environmental scar.

## COSTS

Costs of soil stockpiling could only be developed through a comparative analysis of mining, using this technique versus mining without stockpiling soil.

Costs of soil stockpiling could be developed from standard cost manuals. However, this would not reflect the true cost to the miner, because he would have to remove the soil during mining. The true cost, therefore, would be the difference between the optional methods of handling the soil. The cost would also vary according to distance moved, thickness of layer to be stockpiled, and terrain.

## REFERENCES

211, 212

## 8.3 SURFACE PREPARATION

### DESCRIPTION

The regraded surface of most spoils is not adequate to support a good vegetative cover. This section describes techniques that can be utilized to enhance a regraded surface for vegetative growth.

The surface texture is important, especially when grasses and legumes are to be planted. The mine surface should be raked, if practicable, to remove as much rock as possible and to decrease the average grain size of the remaining material.

Materials toxic to plant life should be buried during regrading, and should not appear on or near the final surface.

Dark-colored shaly materials should also be buried and not appear on the final surface. Dark-colored materials have also been successfully mixed with light materals and supported vegetation. These materials are responsible for high surface temperatures caused by solar heating.

Compacted surfaces are not conducive to plant growth; they should be scarified by discing, plowing or roto-tilling prior to seeding.

### EVALUATION

The adverse effects of non-prepared surfaces are well documented throughout agricultural literature. Unfortunately, sound agricultural practices were too often ignored during surface mine revegetation accomplished in the past.

## COSTS

Costs are not meaningful except on an individual application basis. Costs will be entirely dependent upon the conditions of the mine surface.

## REFERENCES

56, 80, 145, 146, 149, 151, 170

## 8.4 SOIL SUPPLEMENTS

### DESCRIPTION

Soil supplements are often required for establishment of a good vegetative cover on surface-mined lands and refuse piles. These surfaces are generally deficient in nutrients and should be supplemented with applications of fertilizer. Mine spoils are often acidic, and occasionally basic. Lime or acid must be added to adjust the pH into the tolerance range for the species to be planted. Fertilization is usually required in semiarid and arid climates. It may be necessary to apply additional limestone to revegetated areas for some time to offset continued acid generation and coating of previously applied calcareous material.

The amount and type of fertilizers and pH adjusters needed can be determined by soil analysis of the regraded surface. Soil tests should be accompanied by pot and field trials.

Other soil supplements are undergoing research and experimentation. Fly ash is a waste product of coal-fired boilers and resembles soil in certain physical and chemical properties. It is often alkaline, contains some plant nutrients, and possesses moisture retaining and soil conditioning capabilities. Its main function is that of an alkalinity source and a soil conditioner. Fly ash disposal has always been a problem. Use of fly ash on mine surfaces is promising because most fly ash is generated in or near the coal fields. The varying quality, particularly with respect to pH, is a problem. Fly ash is not a complete revegetation soil supplement by itself. Fertilizer and lime are also required. Doubts have been expressed relative to the pollution potentials of fly ash. It may contain leachable pollutants. Future research, demonstration and monitoring of fly ash supplements will probably develop its potential use.

Use of large quantities of limestone screenings applied to a regraded surface mine is to be demonstrated as a source of long term alkalinity for acidic spoils. Acidic spoils generally continue to produce acidity as oxidation continues. Use of lime for direct planting upon these spoils is effective, but may provide only short term alkalinity. The lime is usually used up after several years and the spoil may return to its acidic condition. Limestone screenings are of larger particle size and should continue to produce alkalinity on a decreasing basis for many years, after which a vegetative cover should be well established. Use of large quantities of limestone should also add alkalinity to the receiving streams as well as neutralizing the spoil. Limestone screenings are much cheaper than lime, providing larger quantities of alkalinity for the same cost. Application rates varying between 99 and 494 tonnes per hectare (40 and 200 tons per acre) are to be demonstrated in the near future in Pennsylvania and Maryland.

Use of digested sewage sludge has good possibilities as a soil supplement to replace fertilizer and to alleviate the problem of disposal of the sludge. Digested sewage sludge application requires incorporation of liquid or dry sewage sludges into mine spoils or refuse. Liquid sludge applications require large holding ponds or tank trucks, from which the sludge is pumped and sprayed over the ground, allowed to dry and disced into the underlying material. Dry sludge requires use of various dry-spreading machinery before the material is disced. Besides supplying various nutrients, sewage sludge can reduce acidity and/or alkalinity, and effectively increase soil absorption and moisture retention capability.

Rates of application would be a function of vegetation species and climate.

## EVALUATION

Use of any soil supplement is governed by a number of variables. Before using a supplement an analysis of its characteristics and the spoil characteristics must be made.

Standard commercial fertilizers are available almost everywhere.

Limestone, digested sewage sludge, and fly ash are all limited by their availability and chemical composition. Unlike commercial fertilizers, the chemical composition of these materials may vary greatly, depending on how and where they are produced. Therefore, a nearby supply of these supplements may be useless if it does not contain the nutrients or pH adjusters that are deficient in the area of intended application. Fly ash, digested sewage sludge, and limestone screenings are all waste products of other processes. They are usually inexpensive and may even be free in some cases. The major expense related to any of these wastes is the cost of transporting and applying the material to the mine area. Application of liquid digested sewage sludge can be quite costly, due to the need for special spray and holding devices.

Uniform application is required to effect complete and even revegetation. Also, incorporation of other procedures such as regrading, erosion control, soil stabilization, planting techniques, and proper species selection must be considered for each situation to insure a successful vegetative cover.

When large amounts of certain chemical nutrients are utilized, it may be necessary to institute nutrient controls to prevent chemical pollution of adjacent waterways. Nutrient controls may consist of proper selection of vegetation to absorb certain chemicals, or the construction of berms and retention basins where runoff can be collected and sampled, then either discharged or pumped back to the spoil.

One or more supplements can be utilized to create a soil condition conducive to vegetation on most mine spoil or refuse. However, an analysis of some spoils may indicate the need for such extensive supplementation and related controls that it would be economically unfeasible. In this case, topsoil application to support vegetation may be a viable alternative.

Use of soil supplements should be determined by the requirements of the species to be planted, analysis of present soil conditions, requirements to adjust present soil conditions to desirable levels for the species, and analysis of the particular supplement.

## COSTS

Costs are affected by requirements of the species to be planted and the nature of the soil. Costs can be reduced by selecting species that require less adjustment of present soil conditions. If the spoil is acidic it is best to use a species that is acid-tolerant.

The average cost for fertilizer application is $120 per hectare ($50 per acre).

The general range for limestone screenings is $1.10 to $4.50 per tonne ($1.00 to $4.00 per ton) depending on transportation costs.

Lime application averages $150 per hectare ($60 per acre) depending on spoil acidities.

Cost data is not available for digested sewage sludge; but, because it is a waste product, it is reasonable to assume the acquisition costs will be nominal or zero. Costs will vary according to haulage distance and handling characteristics of a particular sludge.

Fly ash is generally available free from the site or at a nominal cost of $0.30 to $1.70 per tonne ($0.25 to $1.50 per ton). Application costs are again dependent upon haulage distance.

Haulage rates can be estimated using a figure of $0.07 per tonne per kilometer ($0.10 per ton per mile). Costs should include acquisition, haulage, spreading, and mixing (discing) if required.

## REFERENCES

1, 3, 27, 36, 62, 124, 145, 147, 149, 154

## 8.5 SPECIES SELECTION

### DESCRIPTION

Careful consideration should be given to selection of the species to be planted on surface-mined lands. Species should be selected on the basis of a land use plan which is based upon the degree of pollution control to be achieved, and the site environment. As previously described, a dense ground cover of grasses and legumes is preferable to tree seedlings from a pollution control standpoint. There are many species and varieties of grasses and legumes to choose from. Trees and shrubs can be planted along with the grass cover. Trees are often needed in areas of poor slope stability to help control landsliding.

The intended future use of the land is an important consideration with respect to species selection. It may be preferable to return surface-mined lands to high use categories, such as agriculture, if the land has the potential for growing these crops. In many cases, the spoil potential is so low that the choice is limited to finding any species that will grow.

Many strip mines are in rural and mountainous areas. Terrain, climate and soil conditions often limit future agricultural usages. These lands can be planted as game food areas by addition of game food species. Desirable and adaptable tree species can be planted for later harvesting of wood products. Surface-mined lands may have potential as pasture area if the land management conditions are feasible.

Environmental conditions, particularly climate, are important considerations in selecting species. It is best to choose species that are native to the area, and particularly species that have been successfully established on nearby mines with similar climate and spoil conditions. Importation of alien species should be carefully considered, based on their demonstrated ability to withstand climates similar to the mined areas.

Choice of vegetation should be based on all of the preceding considerations. It may be best to first consider the species for which the least surface preparation and supplementation will be required. A list of desirable species can be made and cost and effectiveness values can be determined. Land values before and after vegetation should be considered in the selection. In most instances, except where specific agricultural crops are desired, it would be best to plant several compatible species to insure success in case of failure of any one species. A plot of land left unattended will succumb to plant succession where species dominance and typical associations of species will change as the vegetation evolves through each successive stage.

Introduced plant species may have to be metal-tolerant. Introduced plants may have to be maintained for several years by fertilization and irrigation until native vegetation invades and reestablish itself.

## EVALUATION

Success of the vegetation will depend on the ability of the species to provide a dense ground cover. The best matching of species to the site conditions and climate is usually preferable. Major use of soil supplements to suit a particularly desirable species is not recommended unless a maintenance program is established to maintain these conditions. For instance, to attempt to grow a species that is intolerant of acidic conditions on acid spoils would require regular applications of neutralizers.

It is beyond the scope of this report to present the various species, their range of adaptability, their pollution control attributes, and their soil requirements. Some of this work has already been performed and can be found in the vast storehouse of agricultural literature. Consultation with an agronomist would be helpful in species selection.

## COSTS

Costs are highly variable and depend on the individual cost of the following items:

1) necessary surface preparation
2) soil supplements
3) seed or seedlings acquisition
4) planting
5) maintenance; such as additional soil supplements or irrigation

Costs should be justified from pollution control considerations and future land use potential.

## REFERENCES

56, 213, 214, 215

## 8.6 PLANTING TECHNIQUES

### DESCRIPTION

Seeds and/or transplants are the two methods used to initiate a vegetative cover. Transplants are seeds which have already germinated and are mature enough to be moved from one area and planted in another. In either case proper distribution is necessary to effect a good growth, and can be accomplished by a number of available planting techniques. Seeding can generally be performed by either broadcasting or drilling.

Broadcasting is scattering seed directly on the surface without subsequent soil coverage. Both manual and mechanical means can be employed to distribute seed. However, manual applications are rare and only feasible for small areas. Mechanical application can be performed by dropping the seed from aircraft, blowing it over an area by a fan-created airstream, metering it from ground roving spreaders, and by mixing it with a liquid for hydraulic dispersal.

Drilling is classified as any process which deposits seed into an artifically-formed surface depression and subsequently covers the seed with soil material. A variety of machines are available to perform this operation, however, they are all generally alike. Each machine provides a cutting or compaction device to create a depression. Immediately following this is a device which drops the seed. Finally an attached rake or drag pulls soil material into the depression.

Planting seedlings requires that their root systems be buried. Machines such as augers and seed drills may be used to create holes, and some machine adaptations will even place and cover the plant. However, usually seedlings are placed and covered manually. Under certain conditions special planting procedures may have to be used. Experiments with tubelings and supplemental root transplants to establish dryland vegetation are being conducted by the Montana Agriculture Experiment Station.

Tubelings are plant seedlings nursery-developed in two-ply paper cores 0.6 meters (two feet) in length, 6.35 centimeters (2½ inches) in diameter, and reinforced with a 1.25 centimeter (½ inch) square mesh plastic sleeve. When the root system develops and extends from the tube, the tubeling is placed in an augered hole in the field, sealed around the top, and abandoned.

Supplemental root transplanting requires removal of a pair of interconnected seedlings. The top of one seedling is pruned off, leaving two root systems connected to the unpruned seedling. The horizontally-connected root systems are then planted in a vertical attitude with one down in deep soil moisture and the other in the upper, drier, surface soil.

## EVALUATION

Broadcast seeding is the least expensive procedure for establishing a vegetative cover, and is particularly useful for large areas. Use of either broadcasting or drilling for seed application will depend on type of terrain, seed species and weather conditions.

Dry broadcasting is not effective in high winds or during intense rainfalls. These conditions curtail effective dissemination of seed particles and erode seeds lying on the surface, creating an uneven distribution. A hard or compacted surface material will amplify the erosion problem. This technique effects a wide dispersion. Therefore, it cannot be used to apply species in rows or other selective patterns. This is an excellent seeding technique under favorable conditions. Broadcasting effects a rapid and relatively inexpensive seed distribution especially applicable to large areas.

Drilling requires use of land roving machines and is greatly restricted by steep slopes and rough terrain. This technique is slower, more expensive and does not provide the extensive coverage that is obtained from broadcasting. Essentially this technique is best suited for relatively even terrain over a small surface area. The confined seed distribution renders it especially useful for planting agricultural seeds.

Transplanting is best for initiating a rapid vegetation. Both seedlings and seed provide established root systems to stabilize the soil and create a surface cover which dissipates the energy of wind and rain. This is the most expensive planting technique due to plant costs and because manual labor is often necessary for planting. The expense of transplanting makes it more feasible for small areas or for surfaces which will not promote seed germination.

Hydraulic or hydroseeding accompanied by hydro-mulching is receiving widespread use. This method will help keep the seeds in place, reducing the effects of wind and water erosion. This technique can be used in almost any terrain as long as all points are accessible within range of the sprayer. Hydroseeding is advantageous in that it can plant large areas quickly, combining fertilizer, lime, seed, mulch and moisture in one application.

Choice of planting technique will be dependent on species selection. Some seeds must be buried to germinate. Some plants will not germinate and will have to be planted as seedlings. Grasses and legumes are generally acceptable for hydroseeding.

## COSTS

Broadcast seeding generally averages $500 to $1200 per hectare ($200 to $500 per acre), including materials, equipment and labor. Planting tree seedlings costs about $0.06 per tree, depending on size and type.

Hydroseeding varies from $500 to $2000 per hectare ($200 to $800 per acre), including materials, equipment, and labor.

## REFERENCES

56, 80

## 8.7 ARID AREAS

### DESCRIPTION

Revegetation of arid and semiarid areas deserves special consideration because of the extreme difficulty in establishing vegetation. Lack of rainfall, coupled with effects of surface disturbance creates a condition hostile to growth. Experimentation and demonstration projects are presently being conducted to solve the problem. Three general techniques have been explored: moisture retention; irrigation; and use of tubelings.

These techniques are being developed for use on abandoned mined lands. It is expected that revegetation would be easier on newly mined lands if better mining and planned reclamation techniques were employed during mining. Regrading and overburden segregation should prove helpful.

Moisture retention utilizes entrapment, concentration and preservation of water within a soil structure to support vegetation. This may be obtained by utilizing pits, snow fences, mulches, deep chiseling, gouging, offset listering, dozer basins, and condensation traps.

Pits are depressions created to collect and maintain storm water runoff. They are designed to collect and concentrate water, providing pockets of moisture for plant growth.

Snow fences can be utilized to collect wind-blown snow in or adjacent to revegetation areas. When the drifted snow melts, moisture is released to infiltrate the soil. Snow fences reduce the sublimation losses of the snowfall.

Mulching is application of various soil covers, such as wood chips, straw, hay or other suitable material, to promote collection and retention of moisture. A mulch blanket creates a resistance to surface water runoff which facilitates infiltration and, because it is a cover, moisture loss through evaporation is reduced. Mulching also creates a resistance to wind and water erosion.

Deep chiseling is cutting of parallel slots, 15 to 20 centimeters (6 to 7 inches) deep, in compacted soils. Generally, large agricultural chisels, or other cutting instruments, are towed behind a suitable vehicle in a direction perpendicular to that of surface runoff. The resultant slots and loose soil impede runoff and increase infiltration.

Terracing is the channeling or embanking of constructions across the sloping lands on or approximately on contour lines at specific intervals.

Gouging is the creation of many small surface depressions approximately 25 centimeters (10 inches) deep, 46 centimeters (18 inches) wide and 64 centimeters (25 inches) long, usually with a backhoe to enhance collection, retention, and concentration of runoff.

Offset listering is excavation of a series of shallow trenches. This technique is generally accomplished with a bulldozer or other suitable earth mover, and functions similarly to gouging and deep chiseling.

Dozer basins are large depressions in the soil designed to accomplish the same effect as the above three techniques. The basins are normally created by the tilted blade of a bulldozer about 0.9 meter (3 feet) deep, 7.6 meter (25 feet) long and at intervals of 9 meters (30 feet).

Condensation traps are plastic coverings designed to collect and distribute moisture to plant seedlings. A deep planting basin is excavated and a stock seedling implanted in the center. The basin is covered with a plastic sheet which is heeled in around the basin's outer edges to contain air. After cutting an opening through which the seedling may protrude, the sheet is weighted in the center with rocks, creating a taut funnel configuration. Thus, condensate collecting on the underside of the plastic can trickle down to the seedling root system.

Irrigation is artifical addition of water to areas with inadequate natural water supplies for the purpose of establishing vegetation.

Pipes and/or ditches are used to transfer water from a supply such as a pond, stream, river, well, lake, or holding tank to dry areas. Movement from the supply to the dry area can be created by gravitational flow and/or pumping, depending on their differences in elevation. In any case, the final total area distribution is executed by networks of ditches or spray pipes.

The primary prerequisite for any irrigation system is a sufficient supply of water of acceptable quality and an effective distribution network. Ideally, the supply will be close to and at a higher elevation than the distribution area. These conditions will promote use of shorter and less expensive ditch or pipe transfer systems, and provide a gravitational flow. This eliminates pumps, which require continouous power and maintenance. However, no matter how favorable the supply, other factors must be considered. Ditches in permeable materials will require an impervious lining to prevent water loss. The amount of water introduced onto the vegetation will have to be constantly controlled to satisfy the vegetative requirements. Irrigation of mine wastes which contain water-reactive pollutants must cease immediately after the vegetation is established to preclude continuous pollutant leaching.

Obtaining water rights may be especially difficult in the arid and semiarid regions of the country where this technique is used.

## EVALUATION

Use of moisture retention techniques is experimental, and further development will be necessary. Evaluations of the various techniques are contained in the articles referenced at the end of this section.

Water availability is generally low in areas that could use irrigation. Irrigation could cause pollution problems if used on materials that contain water-leachable pollutants. Irrigation would, seemingly, only be practical where it could be used intermittantly during peak plant demand and low rainfall periods for the initial establishment of vegetation. If it could be used for initial establishment, then be discontinued after vegetation has taken root, it may be feasible. Continuous irrigation would be practical only if a marketable crop could be produced to offset the cost.

Techniques of large scale revegetation of disturbed lands in arid and semiarid regions have not been documented.

## COSTS

Costs are not presented because of the developmental nature and variability of local conditions for these techniques.

## REFERENCES

39, 80, 108, 115, 122, 134, 150

## 8.8 ALPINE AREAS

### DESCRIPTION

Revegetation of alpine areas is given special consideration because of the difficulties involved, and lack of knowledge for making these sensitive ecosystems suitable for revegetation. A study of mine reclamation in alpine terrains is to be accomplished by EPA Region VIII, headquarters in Denver, Colorado.

Knowledge of alpine revegetation may be gained during construction of the Trans-Alaska Oil Pipeline.

### EVALUATION

There are no demonstrated techniques for revegetating alpine mine areas. Any future mining in these areas will probably remain unvegetated for long periods of time.

# UNDERGROUND

# MINING

# 9.0

# CONTROLLED

# MINING

# PROCEDURES

## 9.1 METHOD DISCUSSION

Many water pollution problems can be avoided by use of water control preplanning for future mining operations. Water producing zones such as faults, fracture zones and aquifers should be identified by photo-interpretation, field geology, and core borings. Special provisions can be included in the initial mining plan to avoid these zones. A mine opening can be sited so that there is a good area for deposit of tailings piles, and for location of treatment facilities. Progression of mining can be planned to allow for backfilling of waste materials. Mine openings can be situated so that there will either be complete inundation or zero discharge on completion of mining. Planned flooding of the mine will indicate the location of the points of highest hydrostatic pressure that will occur. Mineral barriers of sufficient size to withstand this head of water can be allowed to remain in place to permit flooding.

The techniques described in this section are all control methods that can be incorporated with active underground mines. Most of the techniques are aimed at preventing water pollution after mining is completed. The water pollution generated during mining can be treated to present effluent standards, but under existing requirements, treatment is unlikely to occur after completion of mining. All of these techniques increase the cost of mining.

Daylighting of underground mines is also presented in this section. It is not a controlled mining method, but it is a means of controlling water pollution from underground mines, and as such is included in this section.

## 9.2 PREPLANNED FLOODING

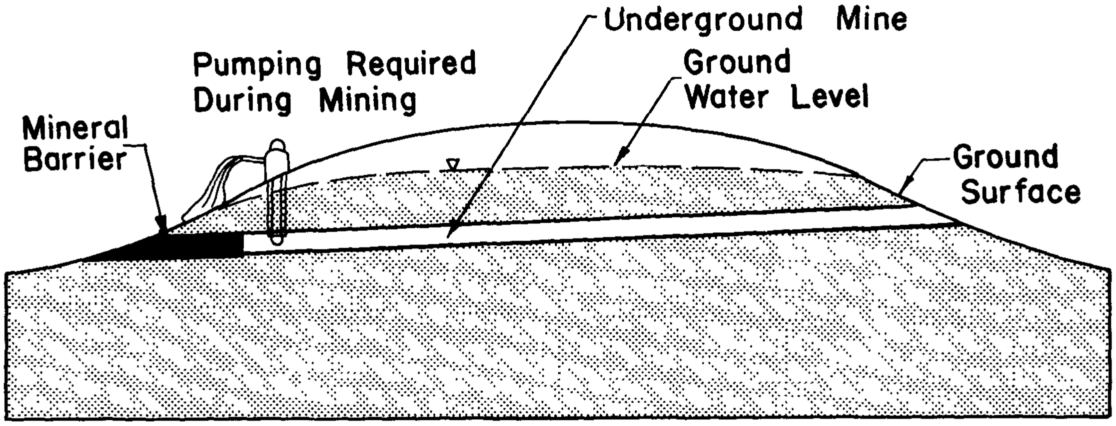
### DESCRIPTION

Most pollution forming materials require oxidation for increased solubility. The sulfides which are responsible for most pollution are relatively insoluble and inert until oxidized. Underground mining provides a source of oxygen to these minerals, which have only limited oxygen contact prior to mining. If a mine contains air after abandonment, then the minerals will continue to oxidize. Flooding of a mined zone is the only practical method of eliminating the oxygen source under present technology. Elimination of free air atmosphere greatly reduces oxidation. Ground water entering a mine will have a small amount of dissolved oxygen: on the order of 0 to 10 mg/l. This supply is insufficient to sustain any significant amount of pollution formation. Flooding is not always the best solution, because some minerals will be dissolved under acidic conditions, which are likely to occur during flooding.

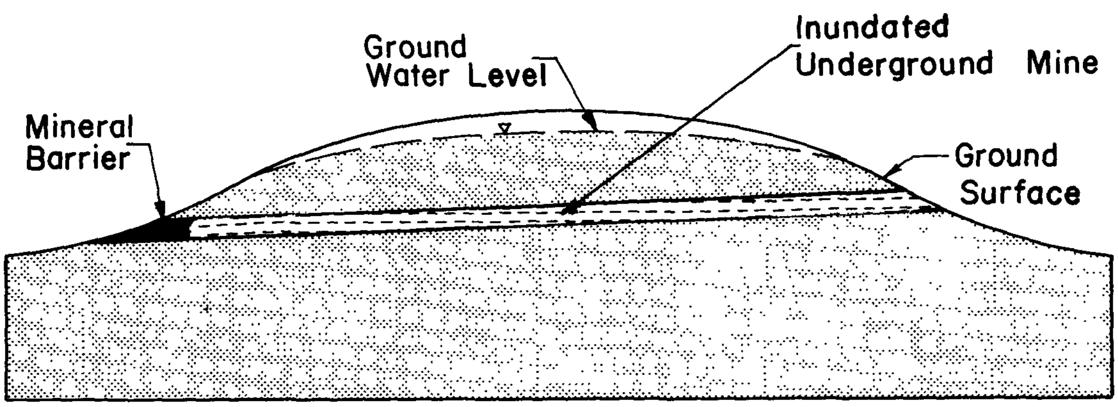
Free air oxygen is not always required for oxidation. For example, pyrite can be oxidized by ferric ions. The extent of this type of reaction is unknown. Most literature sources seem to indicate the elimination of free air oxygen will eliminate a large portion of pollution production. This means that oxidation is insignificant without the presence of free air oxygen.

Underground mines can be developed so that either flooding or zero discharge will occur after completion of mining. This merely requires positioning the openings at the highest elevation and developing the mine in a downward direction. The openings do not always have to be in the highest position if sealing is planned. The elevation difference between the openings and the highest elevation of a mine should be held to a minimum to insure effective operation of the seal. The seal and the rock in the seal area should be capable of withstanding the maximum attainable water pressure.

Study of local hydrogeological conditions may reveal that the




DOWNDIP MINE - DURING MINING




DOWNDIP MINE - AFTER MINING

PREPLANNED FLOODING
Figure 9.2-1

Adapted from drawing in reference No. 121

mine could never be fully flooded. In these cases, discharge can be minimized by locating the mine opening above the highest attainable post mining water level.

Flooding cannot occur unless an entire mine area is capable of withstanding imposed water pressure. Consideration must be given to the fact that the seal area may not be the weak point. The down dip outcrop area, and points where mining approached the land surface, are potential weak spots. These areas could physically fail under high water pressures.

Failure is not the only problem. The rock units may have enough permeability that a significant discharge will occur under the increased head. Sufficient mineral barriers should remain along the perimeter of a mine to insure flooding. Consideration should always be given relative to closeness of approach to the land surface at any given area. Mineral barriers should also remain between adjacent underground mines to prevent interflow from compounding problems.

This system basically utilizes down dip mining with appropriate mineral barriers in place.

## EVALUATION

Most underground mines were developed to the rise of the mineral wherever there was a choice of going to the rise or to the dip. This was done to facilitate gravity drainage from the mine. It also allowed full mine cars to exit the mine under gravity influence, and the empty cars were then hauled uphill. The majority of abandoned underground coal mines in the eastern United States were developed to the rise. These mines are large sources of pollution and they are extremely difficult to seal. If downdip mining had been practiced, along with judicious use of mineral barriers, a large portion of the acid mine drainage problem we now face would never have occurred.

Use of this technique will entail additional costs for underground mining. Water will collect in low spots and will have to be pumped from the mine. Pumping costs will vary greatly. They can be prohibitive at times, as evidenced by the decline of underground mining in the Pennsylvania Anthracite Field. Leaving mineral barriers in place will cause additional costs because the barriers consist of non-recoverable mineral.

## COSTS

Costs are not presented because of the highly variable nature of individual mines. Many mines are presently operating under these type conditions and would not experience cost increases.

## REFERENCES

19, 53, 65, 117, 121, 140, 145, 146, 149, 167, 186

## 9.3 ROOF FRACTURE CONTROL

### DESCRIPTION

Most of the water entering many underground mines passes vertically through the mine roof from overlying strata. The original source of this water is infiltrating rainfall. Collapse of a mine roof is sometimes responsible for increased vertical flow, particularly in coal mines. Horizontal permeability is characteristically much greater than vertical permeability in the rock units overlying coal mines. These rock units generally have well developed joint systems. These joint systems tend to cause vertical flow, except for intercalated beds of shale and clay that tend to inhibit vertical flow. Roof collapse causes widespread fracturing in the strata around a mine roof, and subsequent joint separation far above the roof. These opened joints can tap overlying perched aquifers and provide flow paths to the mine. Roof collapse in shallow mines will often cause surface subsidence. Subsidence fissures collect and then funnel surface runoff directly to the mine.

Roof collapse is directly responsible for a large portion of the drainage from many underground mines. This source of water can be substantially reduced by using mining procedures that ameliorate the severity of roof collapse.

Fracturing of overlying strata can be reduced by employing one or a combination of the following:

1) pillars
2) roof support
3) limiting the width of openings in which caving will occur
4) backfilling of voids with materials.

Pillar mining is accomplished by partial extraction of the mineral resource, leaving the remaining mineral to support the overburden. Also, the geometry or shape of an opening can increase stability of a mine roof. Circular voids reduce stress concentrations that occur at corners of rectangular voids where shear failures usually develop. Timbers and roof bolts add additional support. By limiting the width of openings, the vertical extent of roof rock fracturing can be controlled. This should reduce the vertical extent of joint opening, and therefore reduce the vertical extent of aquifer interception.

Backfilling consists of filling mine voids with waste rock and other materials to aid in supporting overlying strata. It is a common procedure in countries with more limited coal resources. Mine voids can be filled by solid stowing or by hydraulic stowing. Hydraulic backfilling is conducted in some underground metal mines in the western states, and has also been used in areas with inadequate pillar support in the anthracite region of eastern Pennsylvania.

## EVALUATION

Mining without caving is not feasible for those types of mining operations, such as block caving, which require caving of roof rock. However, when mining without caving is applicable, major sources of water can be excluded from the mine environment. However, careful consideration must be given before limiting the extraction of scarce mineral resources.

Controlling fracturing by limiting void width is best applicable to linear sedimentary mineral deposits such as coal. Methods used to extract massive tabular mineral deposits do not readily lend themselves to small void opening workings. The geologic setting may provide another restriction to application of this technique. If there is little vertical separation between the mine and overlying aquifers or the surface, it is usually difficult to prevent fracturing into these water sources.

Backfilling used in conjunction with controlled void width could be an effective method for preventing interception of overlying water sources. Backfilling is limited by availability of suitable backfill material, and the costs and handling problems of transporting the wastes back into the mines. Some waste materials are structurally incompetent and will provide little support. Cyclone separaters have been used in several hard rock mines in the western states to increase competency. The cyclone separates sand and heavy fractions from the slime. The sand and heavys are used for backfilling, and the slime is then placed in tailings ponds.

## COSTS

A mining company would incur profit losses as a result of partial extraction. The amount of loss will depend on the type and amount of mineral left as support. Savings in treatment and pumping costs can partially alleviate profit losses.

Under some circumstances, backfill material costs may be prohibitive, but it is possible that industrial or municipal solid wastes may be available at no cost. Backfilling by solid stowing may cost as much as 11 percent of the cost of production, while hydraulic stowing costs could be about 5 percent of the cost of production. In both cases it is less costly to backfill during active mining than after completion of mining.

## REFERENCES

94, 95, 138, 175, 176, 177

## 9.4 CONTROLLED MINERAL EXTRACTION

### DESCRIPTION

Use of this technique is the same as discussed in detail in Controlled Mineral Extraction, Section 2.10, in the Surface Mining division of this report.

The central theme of this method is to shift emphasis from mining in areas which have a high probability for causing pollution, to areas where pollution is unlikely to occur. Again, it should be understood that pollution potential usually varies greatly, even within small areas. Use of this method assumes that advances in technology will provide for future removal of minerals from high pollution potential areas, with less environmental harm than would occur today.

### EVALUATION

Effective use of this method would require water quality surveys, core boring analyses, and/or review of existing data to define the high pollution potential areas. The state of Ohio is presently engaged in such a program.

### REFERENCES

148, 198, 207, 208

## 9.5 CONTROLLED ATMOSPHERE MINING

### DESCRIPTION

This technique is similar to mine inundation in that free air oxygen is eliminated from an underground mine. Pollution production is reduced through the reduction of oxygen, as explained in Section 9.2 of this manual.

A feasibility study was made for the Federal Water Pollution Control Administration by Cyrus Wm. Rice Division, NUS Corporation in 1970. This is a very complex mining method that involves replacement of normal mine atmosphere with an oxygen free, non-combustible gas. The mine workers must wear complex life support and communications systems.

### EVALUATION

This system is reported to be feasible. A pilot scale demonstration will develop better feasibility data. The feasibility report indicates this system will increase mine safety and health factors. This report should be consulted if additional information is desired.

Water pollution control continues only as long as the oxygen free atmosphere is maintained. The mine will revert to normal pollution production conditions when mining is completed, unless the oxygen free atmosphere is maintained. This is unlikely. More conventional means, such as sealing, will probably be utilized to control pollution after abandonment. The beneficial affects occur only during mining activities. Therefore, the criterion for use of this technique for purposes of water pollution control is economic, based on the cost differential between using this technique or creating the mine water discharge.

## COSTS

The feasibility study report estimates that capital costs would increase 12% and that operating costs would remain the same. An increase in production cost could occur through the use of this technique.

## REFERENCES

87

## 9.6 DAYLIGHTING

### DESCRIPTION

Daylighting is performed by completely stripping out underground mines. This method is presently in the research and demonstration stage. A feasibility study conducted for the EPA indicates that it is feasible, and a demonstration project is scheduled.

Daylighting is carried out similar to strip mining, and all surface mining pollution control techniques apply. This technique substitutes a regraded strip mine for an underground mine. Care must be exercised to ensure that the strip mine does not create more pollution than the old underground mine.

### EVALUATION

There are two general prerequisites necessary to make this technique feasible. There should be sufficient marketable mineral to offset some of the cost of overburden removal, and the underground mine should be a documented pollution source.

To satisfy the first requirement, a complete resource evaluation should be performed to determine the amount and quality of remaining mineral. The total value of recoverable mineral should be determined for the mine site. Costs should then be developed for the daylighting operation, including mineral and surface rights acquisition. The mineral removal costs may exceed the marketing returns. This cost differential may then have to be justified from a water pollution control standpoint in order for the daylighting to be feasible. Daylighting for many of the deeper mines will not be feasible.

Use of mine maps to determine recoverable reserves should require the maps to be authenticated. Secondary and tertiary mining operations often were conducted to recover much of the resource left from the first stage of mining. These later operations were not always mapped.

## COSTS

The feasibility of this technique is closely related to production cost, and since production cost is similar to that for active surface mines, it is recommended that active surface mine operators be consulted during economic evaluation.

## REFERENCES

153

# 10.0

# WATER

# INFILTRATION

# CONTROL

## 10.1 METHOD DISCUSSION

These techniques are designed to reduce the amount of water entering underground mines, and subsequently reducing the amount of drainage exiting the mine. These techniques can often be advantageously employed by active miners to decrease the volume of water that needs to be handled and treated.

Use of these techniques for abandoned mine water pollution control is based on the premise that a decrease in the amount of flow exiting the mine will result in a decrease in the total pollution load. The pollution load is the actual weight of specific pollutants passing a point within a specified time period. The load is calculated by multiplying pollution concentration in the water by the amount of flow, using appropriate conversion factors. Loads are commonly expressed in the unit kilograms per day (pounds per day).

In order for this technique to be useful in pollution control, the resultant decrease in flow must not be accompanied by a proportionate increase in pollution concentration. If such a trade-off should occur, the pollution load could remain essentially the same. This trade-off is not an entirely unlikely possibility.

Coal mine drainage will be used as an example of how this could occur. Coal mine drainage pollutants result from the oxidation of pyrite. Oxygen and water are required for this oxidation reaction in a non-flooded mine. The relative humidity in an underground coal mine is usually at or near saturation (100% relative humidity). Mine walls are normally damp. Water required for the pollution forming reaction is almost always available. Flushing of the oxidation sites is not even required. Salts resulting from oxidation are hygroscopic, meaning that they will draw water from the atmospheric humidity. The salts will weep downward from the accumulated humidity, exposing the reaction sites to further oxidation. The point of this discussion is that the availability of oxygen is the oxidation rate controlling factor, and the amount of water flowing through the mine does not control the oxidation rate. Pollution production may be constant within the mine regardless of the flow of water through the mine. Decreasing flow may result in increased pollution concentrations.

Therefore it is possible that decreasing mine drainage could have little or no effect in controlling pollution. Decreased flow may result in decreased water pollution if the amount of drainage is reduced sufficiently to prevent pollution transportation from the mine. In this case, decreases in water pollution coming out to the surface could also result in increases in ground water pollution.

The techniques discussed in the following sections can be used to decrease the amount of water flowing through underground mines. Choice of technique and extent of its use will depend on hydrologic conditions in the area and cost effectiveness of the technique. These techniques are not universally applicable. Some mines are already receiving minimal infiltration, and further decreases may be difficult to obtain.

Infiltration generally occurs as a result of rainfall recharge to the ground water reservoir. Water can enter from below, or laterally through the mineral or adjacent rock units. Rock fracture zones and faults have strong influence on ground water flow patterns. They often collect and convey large quantities of water. Infiltration can usually be reduced by avoiding these zones during mining.

## 10.2 INCREASING SURFACE RUNOFF

### DESCRIPTION

Water infiltration can be decreased by increasing surface water runoff. This technique involves elimination of depressions and grading the surface to increase water velocities. Subsidence depressions often collect and convey large quantities of surface water to underground mines. The amount of water collected depends on size of drainage area tributary to the depression, and annual rainfall and runoff rate. Subsidence holes in stream channels can cause entire streams to enter underlying underground mines. Uneven surfaces caused by agricultural, logging or other surface activities can cause increased infiltration.

Surface runoff can be increased by grading an overlying area to a smoother, better draining configuration. Surface depressions can be filled in and even lined with clay. Stream channels can be flumed, reconstructed with impermeable liners, or diverted around water loss areas. Channel stability under increased flows must be assured.

Use of latex as a soil sealant was demonstrated as a means of decreasing infiltration. It was found to be generally ineffective as well as expensive.

### EVALUATION

Surface water runoff can be increased. Effectiveness of any particular application will depend on site hydrology. Site evaluations are necessary to determine the amount of infiltration caused by correctable situations. Flow measurements can be made to determine the amount of excess infiltration by comparison with similar adjacent non-mined or undisturbed areas.

This technique is effective where water is lost in a stream channel. Large volumes of water can often be prevented from entering underground mines at relatively low cost. The capacity of a flume or reconstructed channel will have to be large enough to handle heavy rainfalls. Local hydrologic data detailing maximum runoff volumes for any storm over the normal frequency ranges is usually available.

## COSTS

Costs are variable, and can only be determined for each separate area. Stream rechannelling and fluming costs are detailed in Section 7.2, Diversion.

## REFERENCES

145, 168

## 10.3 REGRADING SURFACE MINES

### DESCRIPTION

Surface mines are often responsible for collecting and conveying large quantities of surface water to adjacent or underlying underground mines. Non-regraded surface mines often collect water in an open pit where no surface exit point is available. Many abandoned underground mine outcrop areas have been contour stripped. These surface mines often intercepted underground mine workings, providing a direct hydrologic connection. The surface mine does not have to intercept underground mine workings in order to increase infiltration. Surface mines on the updip side of underground mines collect water and allow it to enter a permeable coal seam. It then flows along the coal seam to underground mines. Overlying surface mines that collect and entrap water can also be significant sources of infiltration. These surface mines facilitate entry of surface runoff to the ground water system, which eventually works its way into an underground mine.

Hydrogeologic studies can be performed to determine the nature and extent of infiltration caused by surface mines. Drainage areas above surface mines can be determined and flows calculated.

A regrading operation is then designed to conduct flow around a surface mine by diversion (and by flumes if necessary), and to increase surface runoff. The regrading operation is the same as discussed in the Surface Mining division of this manual. Contour regrading may be preferred in this instance, because of its good drainage characteristics.

### EVALUATION

Surface mine regrading to prevent infiltration of surface water to underground mines is presently underway in the Dents Run Watershed, West Virginia. Reduction in underground mine flow has already been reported. The EPA feasibility report for the Dents Run Watershed is a good source for further information concerning use of this technique.

Effectiveness of this technique will depend on the amount of water being entrapped by the surface mine and the effectiveness of the reclamation work.

## COSTS

Costs are the same as strip mine contour regrading, plus diversion and revegetation.

## REFERENCES

135

## 10.4 SEALING BOREHOLES AND FRACTURE ZONES

### DESCRIPTION

Boreholes and fracture zones act as water conduits to underground mines. They are usually vertical, or near vertical, and tap overlying aquifers. They collect and transport ground water.

Boreholes are commonly present around underground mines and usually remain from earlier mineral exploration efforts. These boreholes can be located and plugged to prevent passage of water. Concrete can be inserted hydraulically to form a seal. Boreholes can be easily sealed from below in an active underground mine. Difficulty can be encountered if sealing has to be performed from the surface. Abandoned holes are often difficult to locate on the surface, and many times they will be blocked by debris.

Fracture zones are often major conduits of water. They increase vertical movement of water and can cause large lateral movements. Fracture zones are usually vertically oriented planar type features. Their location can be plotted by experienced personnel using aerial photography. Permeability of these zones can be reduced by drilling and grouting. Holes are drilled into the zone and grout is inserted hydraulically. Care must be taken to ensure that the boreholes are located in the fracture zone at the point of grouting. There are various types of grout available, however, concrete is commonly used.

### EVALUATION

Boreholes can be successfully sealed. The seal should be located well above the roof of a mine to guard against roof collapse from additional water pressure.

Fracture zone sealing in underground mines is theoretically possible, but documentation of successful applications was not found.

## COSTS

The cost for sealing a borehole should range from $100 to $1200 per hole perhaps averaging $600 per hole depending on the size, depth and condition of the hole. Grouting generally ranges from $80 to $260 per linear meter ($25 to $80 per linear foot) of grout curtain, depending on depth of holes, difficulty of drilling, and amount of grout required.

## REFERENCES

9, 54

## 10.5 INTERCEPTION OF AQUIFERS

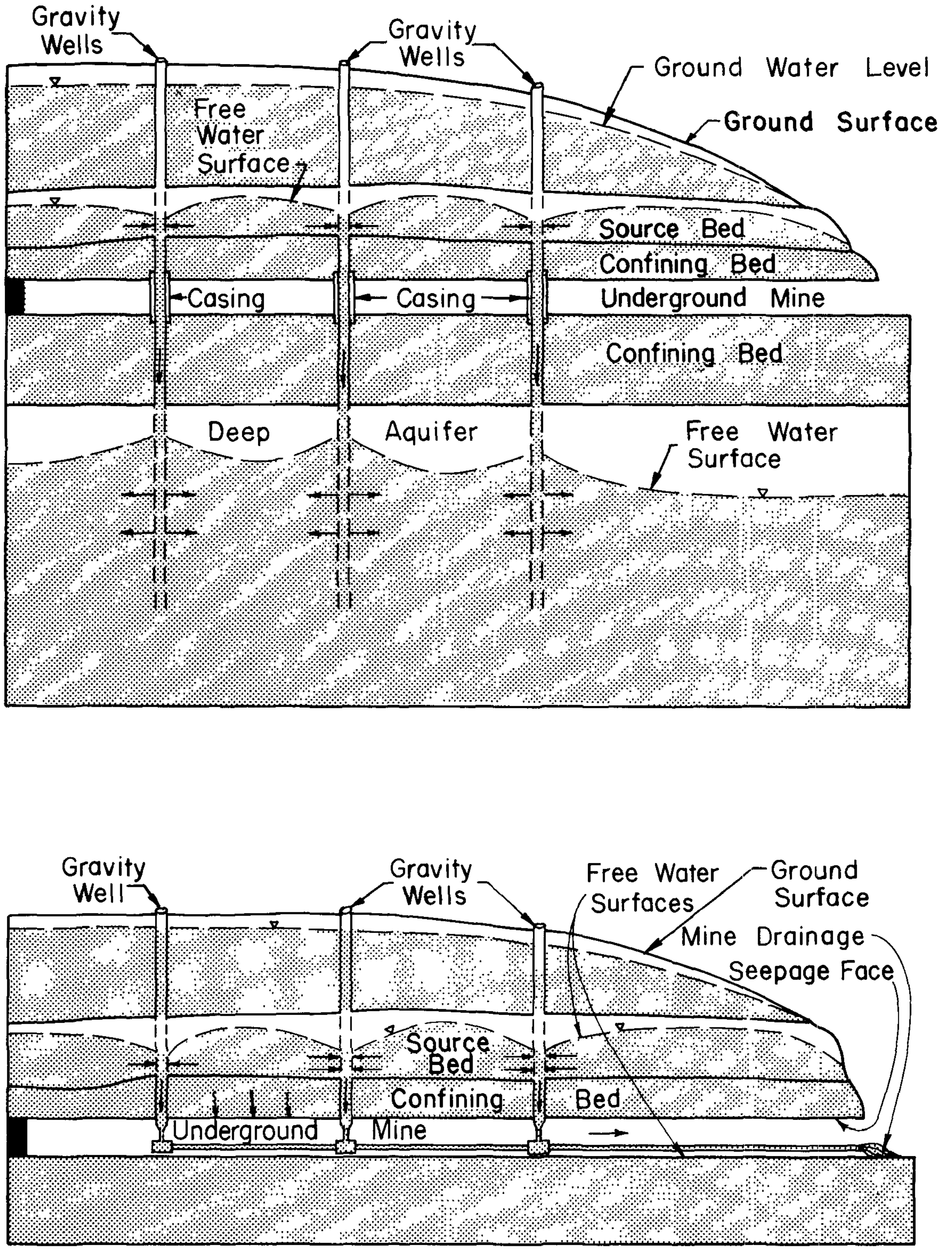
### DESCRIPTION

This technique takes advantage of the natural geologic and hydrologic systems surrounding a mined area. It involves use of boreholes, casing, and pumps to transfer water from one point to another in order to reduce water flow into an underground mine. The techniques are theoretical and will require development and demonstration to establish feasibility.

A complete hydrogeologic site evaluation of a mined area to determine aquifer characteristics and water flow systems is required prior to implementation. Most underground mines receive water from overlying aquifers. Several techniques can be employed to tap these aquifers and reduce the amount of water entering a mine. Overlying aquifers can be drilled and the water pumped to the surface. Boreholes can also be drilled through aquifers, passing through an underground mine and into underlying aquifers. The borehole must be cased through the mined zone (it collects water from the overlying aquifer, passes it through the mine zone for discharge to an underlying aquifer). The underlying aquifer must be capable of accepting the anticipated flow.

A variation on this technique is to drill holes to the underground mine, case the last zone from the deep mine opening up into the roof. The boreholes are then connected by pipes and the water carried outside the mine. The uncased portion of the borehole collects water from overlying aquifers and passes it into the piping system for conveyance out of the mine, never contacting pollution forming materials.

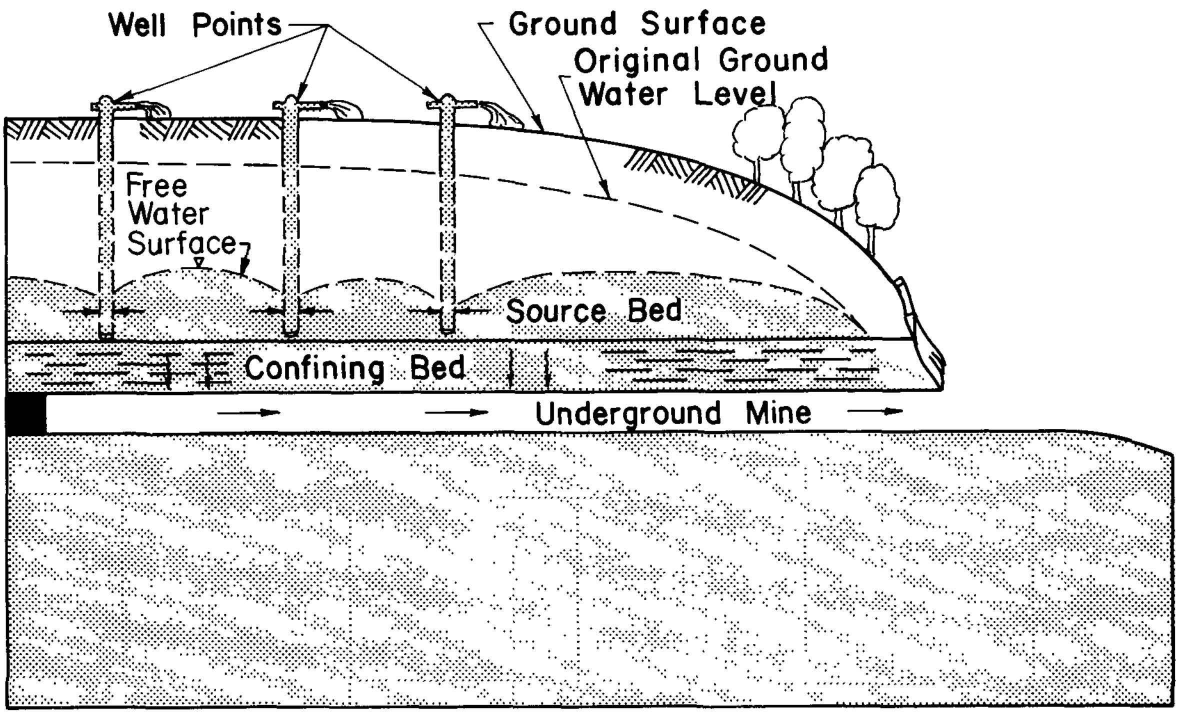
Boreholes, pumps and piping systems can also be used to convey acid mine drainage to a nearby alkaline aquifer, or alkaline underground mine, to encourage mixing, neutralization and settling of precipitates.



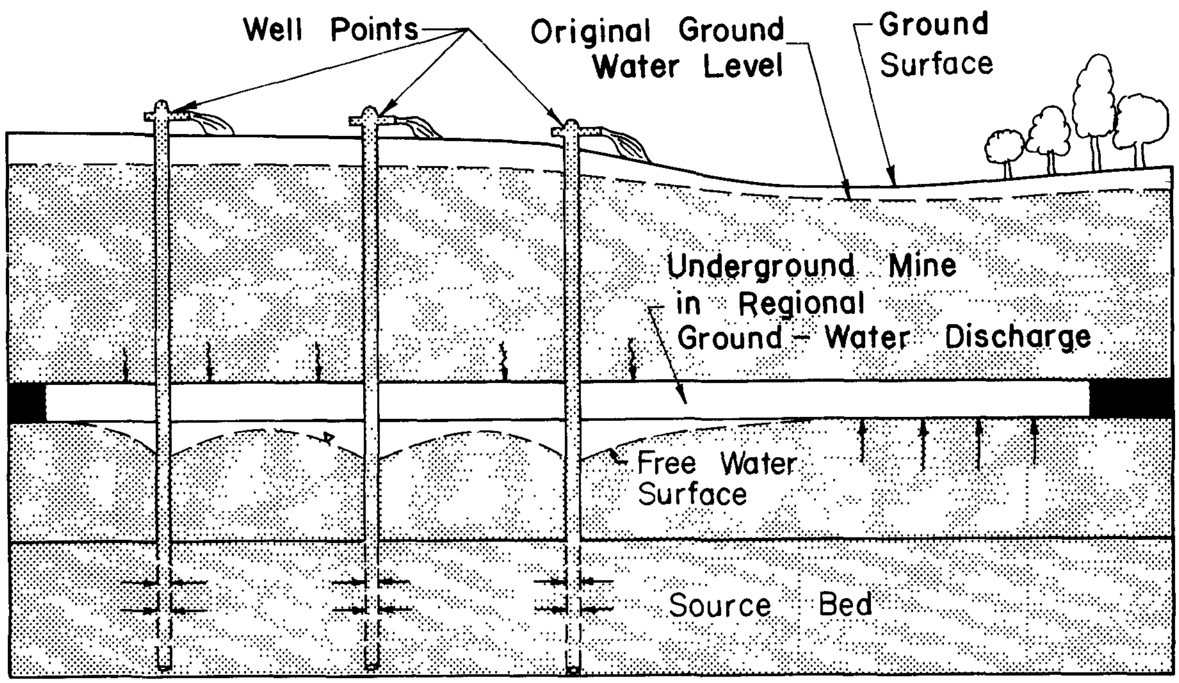

INTERCEPTION OF AQUIFERS

**Figure 10.5-1**

Adapted from drawing in reference No. 121




PUMPING OVERLYING AQUIFERS




PUMPING UNDERLYING AQUIFERS

INTERCEPTION OF AQUIFERS

Figure 10.5-2

Adapted from drawing
in reference No. 121

## EVALUATION

Use of these systems is highly technical. Therefore, a ground water geologist should be consulted to perform site evaluation, determine feasibility, and design the system.

These techniques are not universally applicable, and will work only under favorable circumstances. System design will be variable, depending on local hydrogeologic factors.

## COSTS

Costs can only be developed on an individual application basis.

## REFERENCES

121

# 11.0

# WASTE WATER

# CONTROL

## 11.1 METHOD DISCUSSION

The techniques available for waste water control are identical with the techniques discussed under this same heading (Section 5.0) in the Surface Mining division of this report.

One different technique--construction of drainage tunnels--is discussed in this section.

## 11.2 DRAINAGE TUNNELS

### DESCRIPTION

Drainage tunnels have been constructed in western hard rock mines and eastern anthracite and bituminous coal mines. They are purposely driven to dewater mining complexes by means of gravity flow. Existing drainage tunnels sometimes originate in a watershed adjacent to the mined watershed. Tunnels are driven from a low point upwards at a slight angle to intercept the lowermost mine workings. They are usually constructed when mining is impeded by water problems. Drainage tunnels are often connected to many mines, and serve as a common gravity drain, permitting mining to continue to lower elevations.

The drainage tunnels are normally a pollution source, because they interconnect many workings over a large elevation differential. They are difficult, if not impossible, to seal and they make it difficult or impossible to seal individual mines.

Drainage tunnels can be used in water pollution control in special instances, where it would be necessary to collect and treat discharges from many mines within a mining complex.

### EVALUATION

A drainage tunnel could be driven to collect the combined discharges of many mines in order to consolidate the flow for treatment at one point.

A study would be necessary to be sure installation of a tunnel would do more good than harm. Use of a tunnel would be based on economics. A tunnel could be employed where it would be cheaper than using conventional surface collection devices.

A variation of the tunnel concept would be to break into a deep mine to cause the discharge to exit at a point more advantageous for treatment plant installation.

## COSTS

Costs are variable and must be developed on an individual application basis.

# 12.0

# MINE

# SEALING

## 12.1 METHOD DISCUSSION

Mine sealing is usually employed to promote inundation of underground mine workings to reduce oxidation of pyritic materials. Seals have also been used to prevent the entrance of air or water to the underground mine.

Mine sealing for purposes of inundation involves construction of a physical barrier in a mine opening to prevent passage of water. A barrier must be designed to withstand the maximum expected pressure (head) of water that will be exerted against it. Sealing underground mines is somewhat analogous to creating a surface water impoundment: a major portion of the dam structure would already be in place and the seal merely closes the opening. Engineering considerations are also similar to these for surface impoundment design. The entire dam structure must be capable of withstanding exerted pressure, and leakage rates must be determined. Underground mine seals have seldom been successful due to lack of consideration of leakage rates and weak points. Seals can be designed to withstand a large amount of pressure, but the seal is only a small part of the impoundment structure. The perimeter of the mine forms most of the impoundment, and often it is not capable of withstanding any significant amount of pressure.

The first step in mine sealing is to obtain and analyze all pertinent available site data including:

1) Geology
2) Mine Maps
3) Locations of Sink Holes
4) Hydrologic Data
5) Rock Hydraulic Characteristics
6) Borehole Logs
7) Location of Strip Mines
8) Outcrop Lines
9) Mineral Structure Contours
10) Aerial Photogrammetric Mapping

Sealing feasibility and practical limits of inundation are then determined. Limits of the expected mine pool are plotted on a mine map. Areas where water pressure will be exerted are then delineated, including the expected pressure to be exerted for each area. Hydraulic evaluation of all pressure areas is required to determine if existing barriers are capable of withstanding the applied pressure. Areas deemed incapable of withstanding the anticipated applied pressure must be evaluated further. This evaluation is to determine whether additional measures, such as grouting, would be successful in rendering the areas capable of withstanding expected water pressure. If the required work is technologically or economically not practical, the desired mine pool level will have to be lowered, or the sealing program abandoned.

As previously stated, mine seals can be designed to hold reasonable heads of water. Mine sealing problems generally occur from natural weak spots such as the outcrop, fractures and subsidence. The mineral and natural rock systems around underground mined areas usually become more permeable due to the nature of the rock and the disturbance caused by mining.

The outcrop area normally is the weakest link in an underground impoundment. The mineral outcrop is generally of non-uniform thickness. Mining approached very close to the outcrop in some areas, resulting in very little material remaining to withstand any water pressure. Surface mined crop areas are seldom capable of withstanding significant water pressure. Mine roof collapse in a flooded zone will provide highly permeable zones, allowing water to escape, thus preventing extensive flooding. Physical failure of outcrop areas will sometimes occur, but more often the increased pressure results in seepage through the permeable zones, preventing significant amounts of water level increase. Water can also be lost through the mine floor.

The second step in mine sealing is to determine the ability of the natural system to withstand water pressure. The ability of a natural barrier to withstand pressure can be increased by use of grouting and sealing subsidence holes. The practicality of implementing these procedures will have to be evaluated.

Unfortunately, precise data is seldom available for evaluation of mine conditions. The engineer designing the system may have inadequate knowledge of how the natural system will react. The hydrologic characteristics of mined areas are highly complex and variable from mine to mine. The natural response of the area to changes in hydrostatic pressure is even more complex, and is difficult to approximate without voluminous amounts of data and computer analysis. Mine sealing decisions and design are therefore judgmental projects that should involve personnel that are expert in mine and ground water hydraulics.

A mine seal can be constructed in many ways, using many different types of material. Any material capable of withstanding water pressure has theoretical application. A mine seal must have internal strength capable of withstanding the water pressure, and it must be tied into the floor, roof, and sides of a mine opening. Sufficient internal strength is easily obtained. Physically anchoring the seals to the mine opening is much more difficult. Many mine seals leak around their edges due to poor anchoring.

The natural rock and mineral surrounding the seal area is usually fractured, fissured, uneven and unstable. Leakage occurs through this permeable zone because of the inability of most seals to penetrate surrounding materials. Most mine seals are incapable of providing effective sealing between the top of the seal and the roof rock. Extensive grouting directly around the seal area can help to tie the seal into the surrounding rock and reduce perimeter leakage. Grouting should occur very close (within 1 meter) to the sides of the seal and directly into the overlying roof to insure effective grout penetration. Curtain grouting extending outward along the outcrop from the seal is usually employed with most mine seals where appreciable heads are expected. This serves to decrease permeability and reduce the amount of leakage that is bypassing the seal.

Seal failure has also occurred due to its being constructed in moving water. Water flow should be stopped prior to placement of a seal, especially when using liquid or alkaline sealants such as grout, concrete or gel.

Flow can be stopped by pumping an existing mine pool (if one is present) or by construction of an impounding dike and piping system behind the seal area.

Mine sealing can be a very dangerous operation. The ultimate water level behind the seal is seldom controlled, and excessive water pressures can build up, resulting in a mine seal or outcrop failure. Sudden release of large quantities of water can have devastating downstream effects. Subsequent flooding can and has caused loss of life and massive property damages. Release of large quantities of polluted water can also result in far-reaching downstream fish kills.

Excessive increase in water pressure can be prevented through use of boreholes drilled into a mine pool area from above. Boreholes are drilled from a surface elevation equal to the maximum permissible mine pool elevation. Boreholes should be cased and protected to insure that they remain open. When the mine pool reaches the maximum elevation, the boreholes begin to flow and thus prevent further water level increase. Boreholes must be of sufficient size and distribution to be capable of transmitting the greatest expected inflow to the mine pool without allowing further water level rises. This is a natural, gravity operating system that does not require supervision.

A mine pool drawdown system should also be installed during mine sealing. This usually consists of a pipe constructed through the mine seal which has a manually operated valve. When the valve is opened, water can flow through the seal, lowering the pool elevation to its original pre-sealing level. This is mainly a safety device, but it could be used to drain a mine pool if future mineral extraction should be desired in a flooded area without destroying the seal.

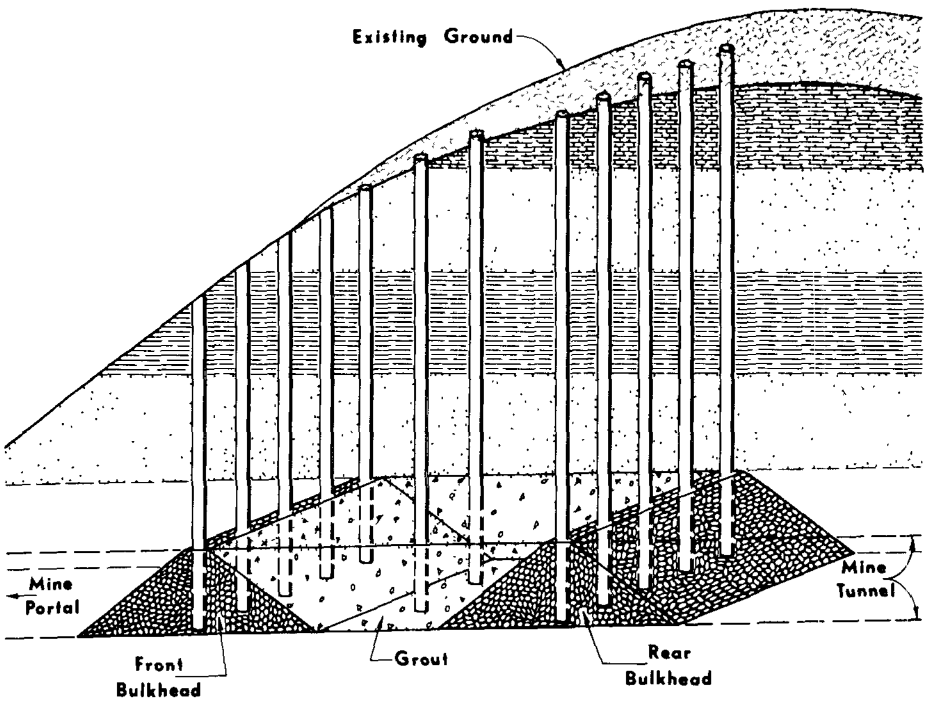
Special legal considerations are involved in mine sealing. Adjacent mineral extraction is often difficult or impossible after sealing. Mineral rights owners may have valid damage claims. The extent of damage is often difficult to establish and could lead to prolonged legal disputes. Mine sealing in arid and semi-arid regions could infringe on the water rights of downstream users. Mine water, even though of marginal quality, is a valuable resource in some areas.

Many of the sealing techniques described in the sections following have not had notable success in mine water control. In most cases the lack of success is not due to failure of the seal itself. The lack of success is more often attributable to the manner of placement and lack of proper consideration for the natural system.

## 12.2 DOUBLE BULKHEAD SEALS

### DESCRIPTION

The technique involves placement of two retaining bulkheads in a mine opening followed by placement of a seal in the space between the bulkheads. Bulkheads can be placed from a mine portal, if it is open and accessible, or through vertical boreholes from above. Grout or concrete is then placed between the bulkheads via pipes through the front bulkhead, if accessible, or from vertical boreholes.




CROSS SECTION OF DOUBLE BULKHEAD SEAL

Figure 12.2-1

Adapted from Drawing in reference No. 54

Two types of double bulkhead mine seals have recently been successfully demonstrated. In inaccessible mine entryways a grouted seal has been used, and for accessible mines quick setting concrete seals have proven effective.

Grouted double bulkhead seals have been recently constructed at Moraine State Park, Pennsylvania, under the state's "Operation Scarlift" reclamation program. This method utilized dry, coarse aggregate for front and rear bulkheads placed through drill holes. The bulkheads were then grouted to form solid front and rear seals. Water was pumped out of the center cavity between the two bulkheads by newly placed drill holes. Concrete was poured into the space between the two bulkheads. These same mine seals have also been successfully installed without grouting the retaining bulkheads.

Use of double bulkhead seals for accessible mine entries has been attempted only a few times, primarily by the Halliburton Company under contract to the EPA. A quick-setting slurry consisting of water, cement, bentonite and sodium silicate was used to construct the two bulkheads. The void between the bulkheads was filled with a special light concrete composed of portland cement, fly ash, bentonite and water, pumped through a grout pipe. In another case, this void was filled with pneumatically pumped limestone aggregate, which was then grouted with light concrete.

## EVALUATION

These seals have been successfully demonstrated and appear capable of withstanding relatively large amounts of water pressure. The maximum pressure exerted has been limited to 10.7 meters (35 feet) of head. However, these seals should be capable of greater pressures as installation procedures improve.

Grout curtains are required for total effectiveness. Seal leakages generally occur through the bottom and around the sides of a seal. It is difficult to get a good seal at the mine roof because of slumping. The perimeter of a seal should be well grouted. Special grouting procedures are explained in Section 12.5.

## COSTS

Double bulkhead seals without curtain grouting range in cost from $7,500 to $15,000 per seal. These seals have cost as much as $50,000 in certain instances.

Quick-setting double bulkhead seals in accessible entry mines average $9,500 per seal without curtain grouting.

## REFERENCES

9, 31, 54, 140

## 12.3 GUNITE SEALS

### DESCRIPTION

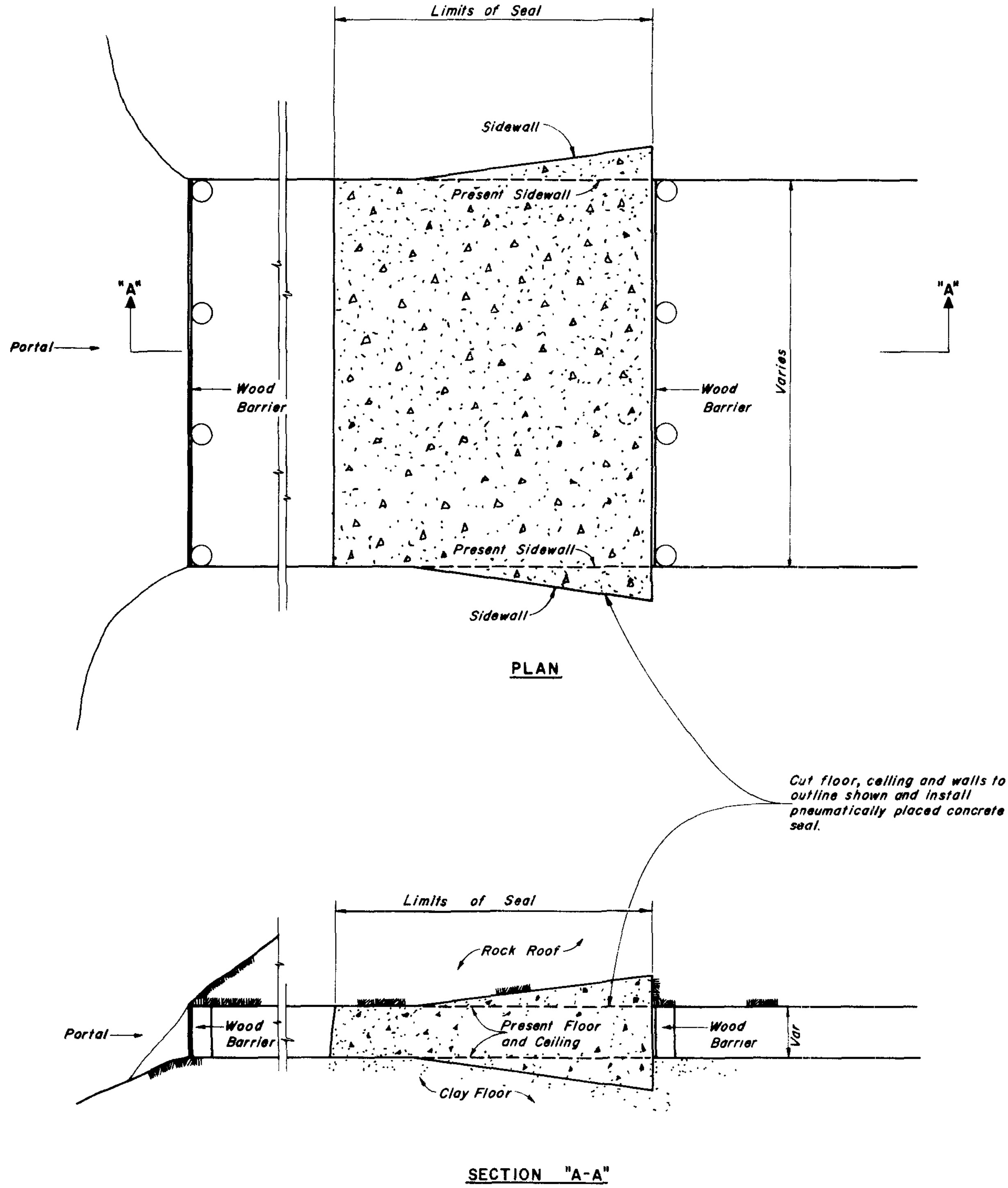
This technique involves use of gunite, a pneumatically-placed low slump concrete, to rapidly and effectively seal mine openings. Gunite is projected by an air jet directly into place and, by proper adjustment of the mix and nozzle, will stand vertically eliminating the need for forms. An area is selected for the seal within sound or reasonably sound zones and the roof, sides and floor are shaped so that the space will be a form for a tapered gunite "plug" and to provide clean surfaces against which to construct the seal. A wood bulkhead is constructed of the inner limit of the seal to support the initial placement of gunite. The seal is then constructed by placing successive thin layers of gunite. Care must be taken to remove "rebound" from the floor as construction progresses to avoid a permeable zone in that area.

A seal constructed by this process completely fills the opening in which it is placed and should provide an effective seal, particularly if an expansive type cement is used. Since the seal is pneumatically placed against the perimeter of the opening (which has been first shaped and cleaned) and since the shape of the seal is such that it becomes tighter as the pressure against it increases without relying on flexural characteristics, it should be particularly effective in sealing against higher hydraulic heads.

A gunite underground mine seal will be demonstrated in the Cherry Creek Watershed by the State of Maryland and the Appalachian Regional Commission in the near future.

### EVALUATION

This technique shows promise of being an excellent underground mine seal. The seal forms a good bond with the mine opening. However, grout curtains are still deemed necessary.




TYPICAL GUNITE SEAL
Figure 12.3-1

## COSTS

Costs will generally average $260 per cubic meter ($200 per cubic yard) of gunite installation. Excavation, cleaning, and shoring in the mine opening will entail additional expense. A complete gunite seal in a standard mine opening is estimated to cost $13,000.

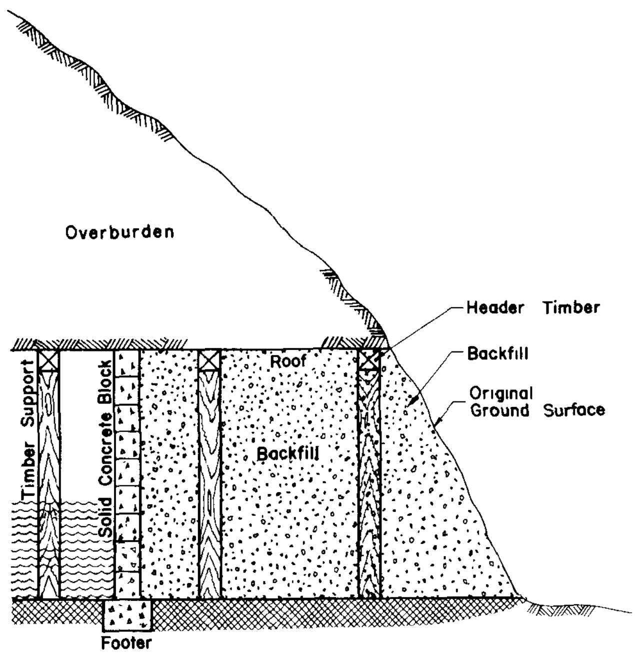
## REFERENCES

147

## 12.4 SINGLE BULKHEAD SEALS

### DESCRIPTION

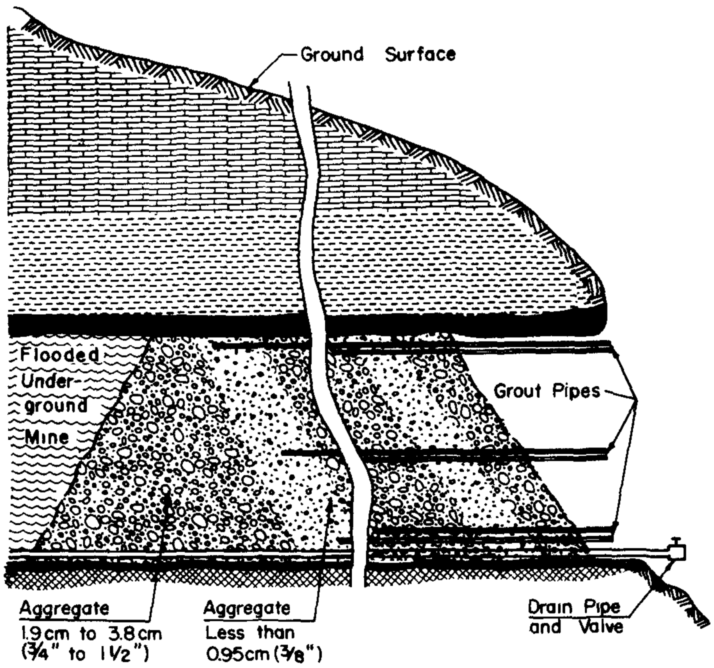
Single bulkhead mine seals are generally composed of a grouted aggregate bulkhead. They can be constructed of other materials, such as masonry block. The seals are placed remotely by using boreholes from above, or constructed directly in the opening, if accessible. Exploratory and observation boreholes are used for remote installation to determine the size and condition of the opening, and to locate the best sealing location.




CROSS SECTION OF SINGLE BULKHEAD SEAL
Figure 12.4-1

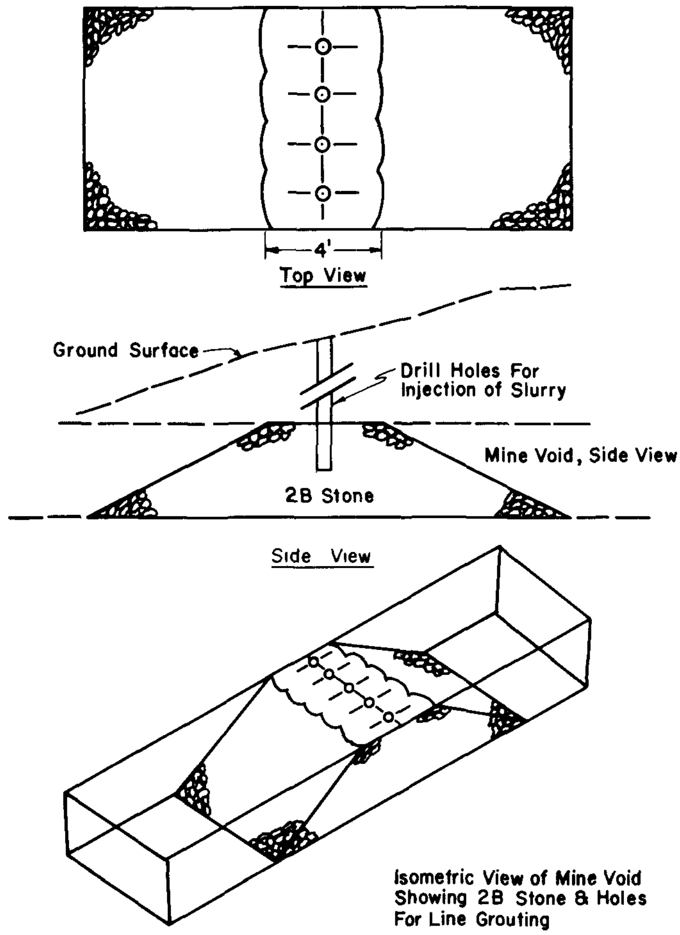
Adapted from drawing in reference No 135

An aggregate bulkhead is placed either through vertical boreholes or directly from the mine opening. The aggregate is then grouted, using a quick-setting slurry composed of water, cement, bentonite and sodium silicate. The slurry is introduced either through pipes inserted into the mine opening or vertically through boreholes from above. The aggregate usually slumps away from the mine roof during grouting, and additional grout must be added. Curtain grouting is usually needed to tie the seal to the surrounding rock and mineral.




CROSS SECTION OF
ACCESSIBLE ENTRY SINGLE BULKHEAD SEAL
Figure 12.4-2

Reference No. 65




INACCESSIBLE ENTRY SINGLE BULKHEAD SEAL

Figure 12.4-3 Adapted from drawing in Penn. Dept of Environmental Resources Contract No. SL 151-1A

Single bulkhead seals utilizing a concrete block wall have also been used. These walls are highly susceptible to damage and could not be used where high water pressures are expected.

## EVALUATION

The grouted aggregate single bulkhead seal has been successfully demonstrated. Some of these seals were unsuccessful, but this was possibly due to poor anchoring with the existing rock and mineral or incomplete grouting of the aggregate. These seals should be used where the expected water pressure will be low. The double bulkhead seal is better for high pressure.

The concrete block seal has only limited usefulness, under low head conditions. Long term effectiveness of a concrete block wall is questionable. A concrete block wall seal can be strengthened and protected from weathering if earth is backfilled against it.

## COSTS

Accessible entry aggregate seals cost approximately $3,500 each.

Remotely placed aggregate seals cost about $2,100 each.

Concrete block wall seals cost in the range of $1400 to $6000 each.

## REFERENCES

54, 65, 135, 140

## 12.5 GROUT CURTAINS

### DESCRIPTION

Grout curtains are used in conjunction with other types of mine sealing to reduce permeability around a mine seal and other seepage areas. Grouting is only applicable where void areas are small.

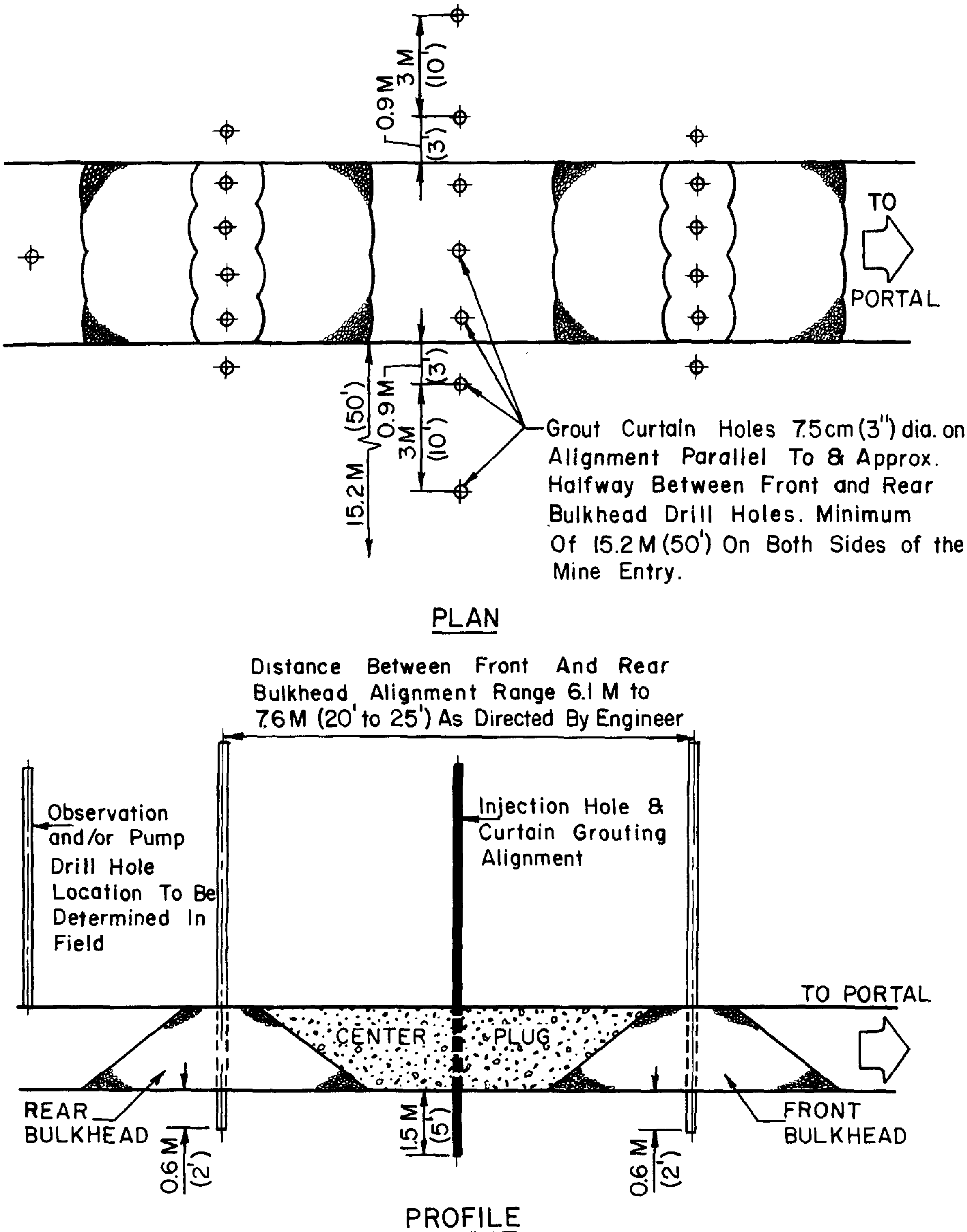
Grout is commonly used around, and extending away from, mine seals. It tends to fill voids between a mine seal and the mine entryway, and to decrease permeability in adjacent rock. This will reduce seepage bypassing a seal area. The grout is generally pressure injected from boreholes placed on 3 meter (10 foot) centers. Pressure forces the liquid grout from the borehole into permeable zones of the rock units. The grout sets or solidifies in small voids and greatly decreases permeability. Effectiveness of grouting is difficult to determine during the operation. There is no way of knowing where it is going and where it is collecting. The three meter center spacing is somewhat arbitrary: the spacing should be sufficient to ensure the entire space between holes receives grout.

Grout curtains can also be placed in areas of permeable or weak outcrops during mine sealing. This serves to decrease leakage rates and strengthens the outcrop to decrease failure possibilities.

### EVALUATION

Grout curtains have been successfully utilized many times. The success of grout curtains in leak areas has not been documented by before and after flow recording, but it is said to be effective.

Efficiency of grout curtains is dependent on the manner of injection. Effectiveness may be increased by use of packers to grout




**GROUT CURTAIN WITH DOUBLE BULKHEAD SEAL**

Figure 12.5-1 Adapted from drawing in reference No. 54

individual zones, instead of attempting to grout the entire hole at one time.

Grout effectiveness can be further enhanced by varying the viscosity at the mixer. The viscosity is increased in permeable zones and areas with larger voids. The machine operator can tell when viscosity changes are required by observing flow rates.

Grouting is more effective if aggregate is placed in large voids encountered during drilling.

Grouting will also be more effective if the first grout holes are placed within 1 meter (3 feet) of the seal. Grout holes should be drilled into the seal from above. Contact of a mine seal with the roof and sides of a mine opening is a weak spot where leakage commonly occurs. Extensive grouting in these areas will improve effectiveness of a seal.

If there is a possibility of a leak in the bottom of a mine seal, the holes drilled into the top of the seal should continue on through for grouting the bottom of the seal. The bottom of a concrete seal is likely to leak if it is placed in moving acid water. Flowing acid water can dissolve cement, leaving behind porous sand and aggregate. Remotely placed double bulkhead seals may leak at the bottom. Slumping of the front and rear retaining piles of aggregate may introduce aggregate into the bottom of the center void. The concrete center plug material may be unable to flow into this aggregate, leaving a permeable zone.

## COSTS

Grouting curtains generally cost in the range of $80 to $260 per meter ($25 to $80 per linear foot) of curtain.

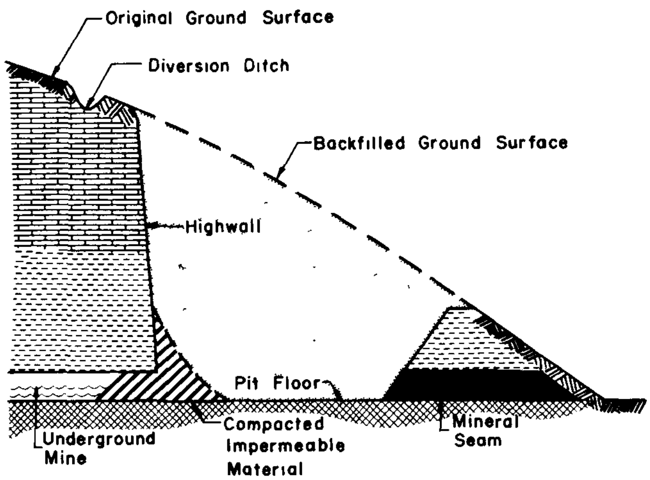
## REFERENCES

9, 54

## 12.6 CLAY SEALS

### DESCRIPTION

Clay can be used to form a hydraulic underground mine seal where low water pressure is expected. The mine opening is first cleaned of debris and loose rock. Clay is then compacted into the opening to form a seal. A good quality plastic clay should be used to ensure impermeability, and to enable the clay to flow into cracks and voids along the walls and roof of the seal area. Hand placement and compaction would probably yield a better anchor between the plug and the seal area. Earth should be backfilled and compacted around the mine opening and over the seal to hold it in place and prevent the clay from flowing under pressure.




CROSS SECTION OF
TYPICAL UNDERGROUND MINE SEALING
IN CONJUNCTION WITH SURFACE MINE BACKFILLING
Figure 12.6-1

Adapted from drawing in
reference No. 135

## EVALUATION

This should prove to be an effective and inexpensive mine sealing technique for low water pressure installations. The mine opening has to be accessible in order to use a clay plug. Effectiveness of the seal will depend on quality of the clay, manner of placement, and physical condition of the seal area. Clay seals may be capable of withstanding 10 meters (approximately 30 feet) of head of water under ideal conditions.

## COSTS

Costs will depend on availability of suitable clay, its acquisition, and transportation costs. Costs will also vary in response to difficulty in preparing the seal area, and the installation. Costs will generally range from $1,200 to $4,000 per seal.

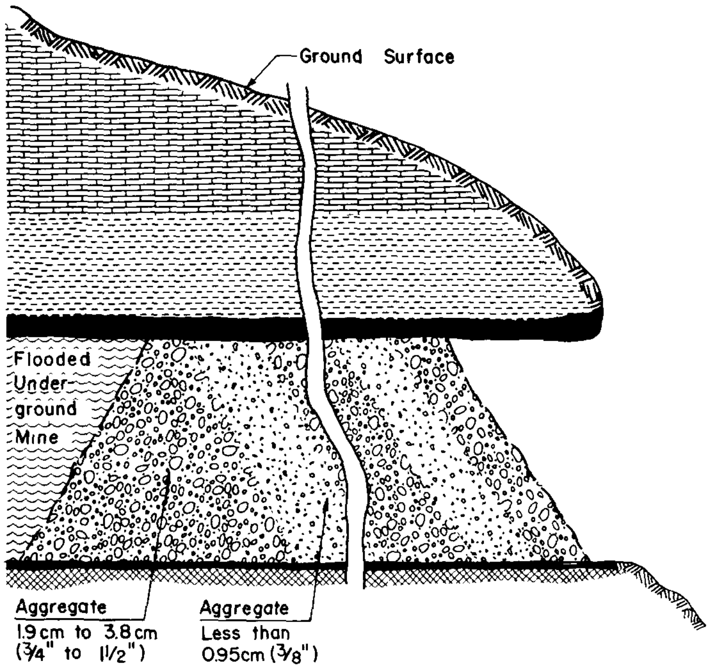
## REFERENCES

9, 54, 135, 147

## 12.7 PERMEABLE AGGREGATE SEAL

### DESCRIPTION

Permeable aggregate underground mine sealing involves use of ungrouted alkaline aggregate material that will neutralize acid water passing through it. This causes formation of precipitates, which progressively clog the pores in the aggregate. Theoretically, the precipitate continues to form and clog all of the pores in the aggregate, until the permeable aggregate seal actually becomes a solid, single bulkhead seal of aggregate and precipitate material.




CROSS SECTION OF
PERMEABLE LIMESTONE AGGREGATE SEAL
Figure 12.7-1

Adapted from drawing in reference No 65

An example of this technique is use of limestone aggregate to seal underground coal mines that discharge acid mine drainage. Here the acid water is neutralized during its flow through a limestone aggregate plug, causing iron hydroxide and calcium sulfate to precipitate, filling the pores of the aggregate and producing a solid bulkhead type seal.

Limestone aggregate seals were demonstrated by the EPA in West Virginia.

## EVALUATION

The seals helped attain various degrees of mine inundation. A 1.8 meter (6 feet) head of water was reported behind one seal. The seals continued to leak, meaning that precipitates have not completely clogged the pores, or the precipitates are unable to withstand the water pressure. Increases in pH and alkalinity, and decreases in acidity of the discharge, showed the neutralizing ability of the seal. The neutralization is only temporary and is expected to decrease as the limestone aggregate becomes coated with precipitate. The long term value of this type of seal would be due to its capabilities to withstand water pressure and cause inundation. Its long term capabilities in this respect have not yet been demonstrated.

Slumping of the aggregate, causing an opening at the mine roof, has been a problem. Grouting of the opening may help solve this problem.

## COSTS

Costs incurred by the Halliburton Company in two acid mine drainage related experimental applications were $3,048 and $8,463 per seal. Michael Baker's report suggests use of an average cost estimate of \$7,500 per seal. Costs of other mineral industry applications of the technique would be determined largely by the aggregate materials used.

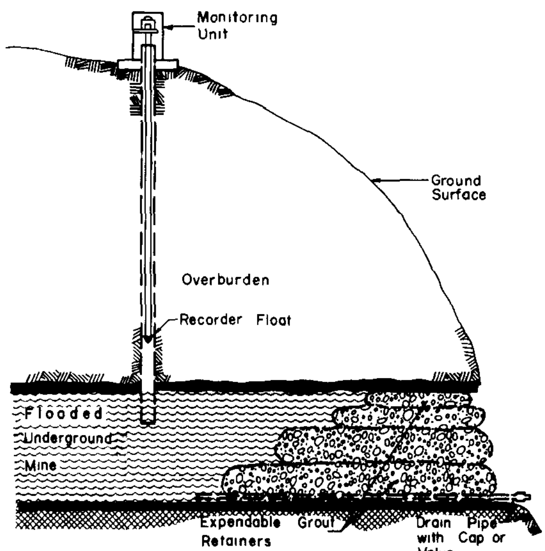
REFERENCES

9, 65, 140

## 12.8 GROUT BAG SEALS

### DESCRIPTION

This method of underground mine sealing involves placement of expendable grout containers to seal accessible mine openings. Seals are constructed by a vertical series of cement grout slurry filled nylon or cotton bags, which decrease in length from bottom to top of the entryway. The container placed on the floor of the entryway is 6.1 meters (20 feet) long, with other dimensions matching those of the mine itself. The container is positioned in the mine and filled with slurry, which causes it to conform to the shape of the mine opening. As each container hardens, a new, shorter one is placed above it and filled with slurry. This process is repeated until the top container, measuring about 3.1 meters (10 feet) in length, has been positioned and filled.




CROSS SECTION OF EXPENDABLE GROUT RETAINER UNDERGROUND MINE SEAL
Figure 12.8-1

Adapted from drawing in reference No. 65

## EVALUATION

A grout bag seal was unsuccessfully demonstrated near Coalton, West Virginia. Leakage occurred around the contact between the bags and the mine entryway. Leakage increased as erosion widened the gaps. The grout bags will not conform well to an uneven surface and will not penetrate the many cracks and fissures. Efficiency may be increased by means of concrete grouting around the seal.

Other mine sealing techniques such as gunite or double bulkhead seals appear to be more efficient.

## COSTS

Costs for one experimental installation were $3,300 per seal.

## REFERENCES

9, 65, 140

## 12.9 REGULATED FLOW SEALS

### DESCRIPTION

This technique is designed for use with treatment plants in order to maintain flow at a constant level from underground mines. The seal is used to back up excess flow within a mine during peak flow periods where complete mine inundation is impractical and treatment is required. This technique is theoretical; its use has not been documented.

Underground mine flow rates are variable and depend on the response characteristics of individual mines to seasonal rainfall variations. Near surface mines usually have sporadic (flashy) flow volumes, indicating short response times. Treatment plants are normally designed to handle the largest expected flows when complete treatment is needed. The treatment plant's capacity is then usually much larger than the average flow from the mine. Extra costs are involved in constructing a treatment plant to handle large flows. These extra costs may be eliminated by constructing a mine seal which includes a pipe network to the plant. The mine pool will rise and fall with seasonal variations in rainfall, but the treatment plant will continue to accept average flow. This technique would also allow the treatment plant to cease operations during repairs without allowing discharges of polluted water.

### EVALUATION

Feasibility of this technique depends on the economic differential between savings in treatment plant installation and operation, and costs of mine seal installation. The mine must be capable of being sealed, and the pool capacity should be sufficient to impound water during periods of maximum rainfall.

## COSTS

Costs must be developed on an individual application basis.

## 12.10 SUBSIDENCE SEALING

### DESCRIPTION

Mine subsidence holes can be active leak areas after a mine sealing program. Sink holes that are lower in surface elevation than the mine pool elevation are possible leak zones. These areas can be sealed using clay, concrete, or by grouting.

Documented cases of subsidence sealing to prevent leakage from below are unknown. However, subsidence holes have been sealed to prevent surface waters from entering deep mines.

The subsidence holes should be cleaned of soil and surface debris with a backhoe or similar device. The underlying fractured rock can be grouted if necessary. Clay can then be compacted into the depression. Concrete would probably be more applicable than clay if high water pressures are expected.

### EVALUATION

Documented cases are unknown. These seals would be capable of withstanding various amounts of water pressure, depending on the manner of installation and the soil and rock condition.

## 12.11 DRY SEALS

### DESCRIPTION

A dry seal is an underground mine seal constructed by grading earth over a mine opening, or constructing bulkheads consisting of clay or block walls.

Dry seals are not meant to be used in mine openings discharging water. Their function is to prevent entrance of water and air into a mine. They have been used extensively in conjunction with air sealing programs. They should not be used where any significant amount of water pressure is likely.

### EVALUATION

These seals have only limited usefulness in water pollution control. Air sealing does not appear to be effective, therefore use of dry seals in conjunction with an air sealing program is not effective.

They do have application in instances where surface water is entering an underground mine opening. A dry seal can be used to keep the surface water out of the mine.

### COSTS

Dry seal costs range from $100 to $500 for regrading, $1,200 to $1,500 for clay bulkheads, and $2,200 to $5,100 for masonry bulkheads.

REFERENCES

9

## 12.12 ROOF COLLAPSE

### DESCRIPTION

This technique is to be demonstrated by the EPA in the Elk Creek Watershed, West Virginia. It is not meant to be used as a primary mine sealing technique. It has limited use under special situations. The purpose of roof collapse in Elk Creek is to partially inundate underground mine workings, and to partially neutralize acidic underground mine waters. It will be used on a Pittsburgh coal seam underground mine that has a non-acidic clay stone (soap stone) roof containing stringers of limestone. The limestone is locked into the roof material and is not presently available for neutralization. Explosive collapse of the roof will bring some of the limestone into contact with acidic underground mine waters. The physical characteristics of the clay stone are such that it will also restrict the flow of underground mine water, causing impoundment, and some acid forming strata inundation. Mine roof collapse is only a partial control technique, and it will be used in conjunction with alkaline strip mine regrading (Section 6.12) and slurry trenching (Section 6.13).

Accurate mine maps, or a test boring program, are necessary to determine the best placement of explosives. Boreholes are drilled to a pre-determined height above the mine roof. Explosives are set in the boreholes. The holes are then plugged to direct energy in a downward direction.

### EVALUATION

This technique is only capable of a minimum amount of flooding, and should be accompanied by other water pollution control benefits such as the above-mentioned neutralization. Its use is limited to areas where mine roof materials are capable of obstructing flow.

Use with a blocky sandstone or shale roof would not be helpful in restricting mine flow because of the permeable nature of these materials. Roof collapse should never be used where roof materials are pollution forming, as commonly occurs in coal mines. Normal care in use of explosives is necessary to prevent damage to structures. There should not be any structures overlying or adjacent to the work areas.

## COSTS

Costs are as yet unknown and will depend on the number and size of boreholes required, cost of explosives, setting charges and sealing boreholes.

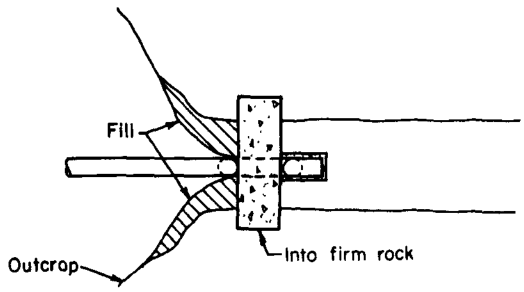
## REFERENCES

40

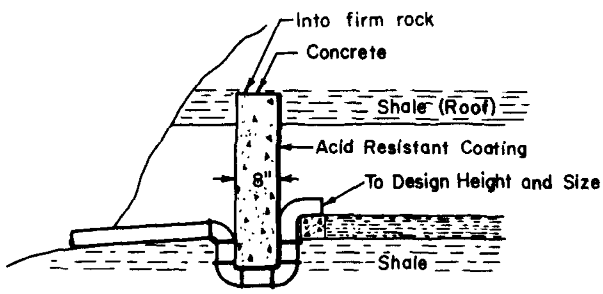
## 12.13 AIR SEALS

### DESCRIPTION

Air seals are structures placed in discharging underground mine openings that permit water to exit from a mine without allowing air to enter. The non-discharging openings in the mine are also sealed by other conventional dry sealing techniques to prevent entry of air. Drill holes in the mined area are also plugged.




PLAN




SECTION

**AIR SEAL**
**Figure 12.13-1**

Handbook of Pollution Control Costs in Mine Drainage Management, U.S. Dept. of Interior, Federal Water Pollution Control Administration, 1966.

An air sealing program is designed to prevent influx of free air oxygen into an underground mine. Free air oxygen is responsible for most of the pyrite oxidation, which is responsible for acid mine drainage. Elimination of free air oxygen is, therefore, the most desirable method of underground mine water pollution abatement.

Many air seals were placed in eastern coal mines in the 1930's. Several air seals have been placed more recently.

The seals are constructed of various materials, but their operation is based on the same principle employed by using traps in plumbing systems.

## EVALUATION

There has not been much documentation of the effectiveness of older air seals. Many of these seals have been destroyed, and many of the remaining seals are discharging large quantities of pollution. There is no documentation showing the newer seals to be effective.

It is reasonable to conclude that air seals are not effective for two reasons. The underground mines have numerous air passages such as surface mines, boreholes, joints, fissures and mine subsidence cracks that allow passage of air into and out of underground mines. Changes in atmospheric pressure outside the mine causes a pressure gradient, resulting in air flow into and out of the underground mine.

## COSTS

Costs generally range from $3,100 to $5,000 per seal.

## REFERENCES

9

## 12.14 GEL MATERIAL SEALS

### DESCRIPTION

The technique involves use of commercially available grouts with a cheap filler material to remotely seal mine voids through boreholes without benefit of retaining bulkheads. The only attempt to use a gel material as a mine sealing agent was made in a high flow mine entryway, and failed. This mine sealing attempt did indicate that use of gel for sealing low flow and dry mine entrys may be possible.

### EVALUATION

The cost of the gel materials proved to be greater than originally estimated. The cost of this seal is not competitive with other sealing techniques. This technique has not proved feasible for use.

### COSTS

The costs of the gel material alone is estimated at $9,000 per seal. The sealing operation would add considerably to the total cost.

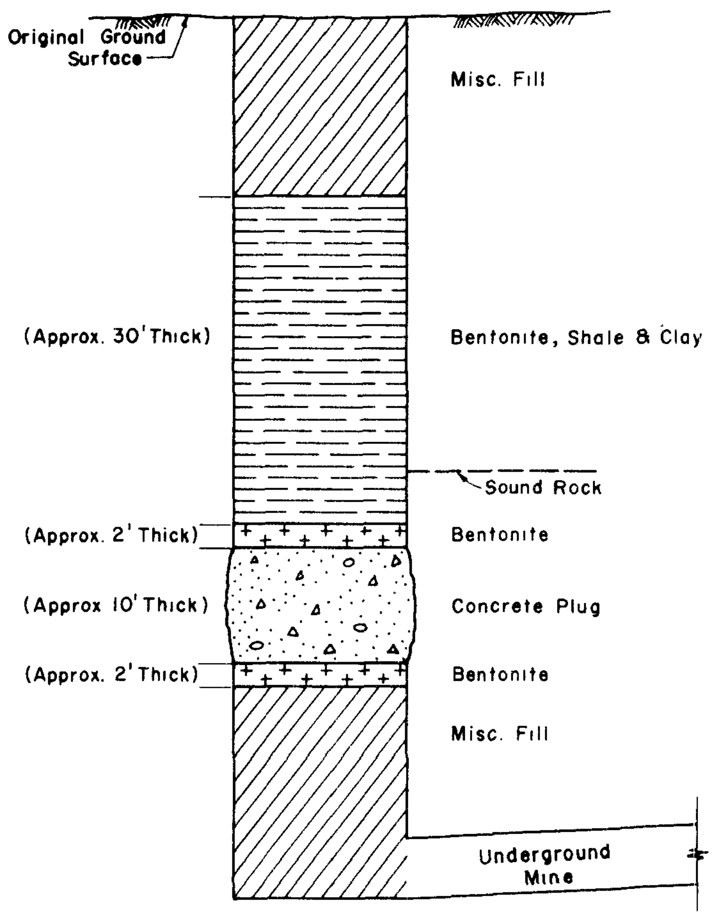
### REFERENCES

31

## 12.15 COAL MINE SHAFT SEALS

### DESCRIPTION

A shaft is a vertical or near vertical entryway to an underground coal mine. The presence of a shaft implies that there is no coal outcrop in the vicinity. Lack of an outcrop usually increases the probability of success of a sealing program.




CROSS SECTION OF SHAFT SEAL
Figure 12.15-1

Discharging mine shafts are common in eastern coal fields. Coal mine shaft sealing is generally more successful than drift or slope sealing. Rock around the seal is less likely to leak because of low vertical permeability in the undisturbed coal strata. Shaft seals are theoretically able to withstand much more pressure than outcrop seals, and large amounts of mine inundation can be accomplished. The degree of success of a shaft seal is partially dependent on depth of the mineral below the surface. Very deep underground mines can be successfully sealed. Leakage is more likely from shallow underground mines. A complete hydrogeologic evaluation is required to determine the feasibility of shaft sealing.

The shaft is first opened and cleared of debris. A suitable sealing zone within the shaft, such as a sandstone bed, is selected for sealing. Any flow from the shaft is stopped by pumping the mine pool. Miscellaneous fill is placed in the shaft up to the sealing level. The seal of clay and/or concrete is then placed. The shaft should be backfilled to the surface.

## EVALUATION

Shaft seals have been placed, but documentation of their effectiveness could not be found. This technique should be highly effective in underground mine inundation when used under favorable mine conditions.

## COSTS

The cost will be highly variable, depending on site conditions, condition of the shaft, size of the shaft and any auxillary work required.

Shaft seals will generally range in price from $7,000 to $25,000 per seal based on estimated shaft seal costs in the Muddy Run Watershed, Clearfield County, Pennsylvania.

REFERENCES

149

# TREATMENT

FOREWARD

Many minerals and ores are obtained by mining. Usually, these minerals are associated with inorganic (metallic) sulfides, which are broadly classified as pyrites. Some ores that are mined for the recovery of metals such as lead, zinc, silver, and molybdenum are sulfides themselves. In other instances, the pyrites may be intermixed in the ore or mineral, or located adjacent to the deposit.

In general, exposure of pyrites and other inorganic sulfides to the atmosphere results in their oxidation to a sulfate salt. The dissolution of these salts into ground or surface waters results in a varying degradation of water quality. These sulfate compounds usually impart acidity to the water, and as the drainage becomes more acid, most of the associated elements and compounds become more soluble. The most common ions associated with mine drainage are iron (ferrous and ferric forms), aluminum, calcium, magnesium, manganese, copper, zinc, lead, cadmium, nickel, arsenic, silver, chloride, fluoride, sulfate, phosphate, radioactive materials and others. The presence and concentrations of any ion in mine drainage will vary with the mineral or ore being mined, the geographical location, the hydrological season, etc. This variation can even be significant within different areas of the same mine.

Mine drainage can be treated by combinations of various chemical and physical processes to produce a water of almost any desired quality. Most often, mine drainage is treated to remove those chemical compounds considered to be pollutants to the aquatic life or other uses of the receiving stream. In some locations, mine drainage is being treated for use as public and industrial water supplies where it is the only source of water available.

# 13.0

# NEUTRALIZATION

# PROCESSES

## 13.1 METHOD DISCUSSION

When mine drainage is acid, the acidity can be neutralized by addition of an alkaline material. By properly selecting the alkaline agent, many metals (cations) can be removed during neutralization as insoluble hydroxides. Anions such as phosphates, fluorides and sulfates can also be removed by calcium alkalis using this insolubility principle.

### Alkali Selection

Several alkaline materials are available for neutralizing acid mine drainage. These include lime, hydrated lime, limestone, caustic soda, soda ash and others. The choice of alkali may depend on its cost, reactivity, availability, volume of sludge produced, ease of handling and desired effluent quality.

Recent studies have optimized analytical, bench-scale, and pilot plant methods for evaluation of alkalis and treatment processes. A cost comparison of several alkalis is presented in Table 13.1-1.

TABLE 13.1-1
COST COMPARISON OF VARIOUS ALKALINE AGENTS AVAILABLE FOR NEUTRALIZING MINE DRAINAGE

| | Basicity[a] Factor | Cost[b] $/Tonne | Cost $/Tonne of Basicity |
|---|---|---|---|
| Quick Lime (Calcium Oxide) | 1.786 | $25.35 | $14.19 |
| Hydrated Lime (Calcium Hydroxide) | 1.351 | 27.56 | 20.40 |
| Limestone, Rock (Calcium Carbonate) | 1.000 | 8.82 | 8.82 |

| | Basicity[a] Factor | Cost[b] $/Tonne | Cost $/Tonne of Basicity |
|---|---|---|---|
| Limestone, Dust (Calcium Carbonate) | 1.000 | $11.02 | $11.02 |
| Dolomite (Calcium-Magnesium Carbonate) | 0.543 | 25.90[c] | 47.70[c] |
| Magnesite (Magnesium Carbonate) | 1.186 | 27.56 | 23.24 |
| Caustic Soda (Sodium Hydroxide, 50%) | 1.250 | 83.77 | 67.02 |
| Soda Ash (Sodium Carbonate, 50%) | 0.943 | 39.68 | 42.08 |
| Ammonium Hydroxide | 1.429 | 71.65 | 50.14 |

a. Grams of calcium carbonate ($CaCO_3$) equivalent per gram of alkaline agent.

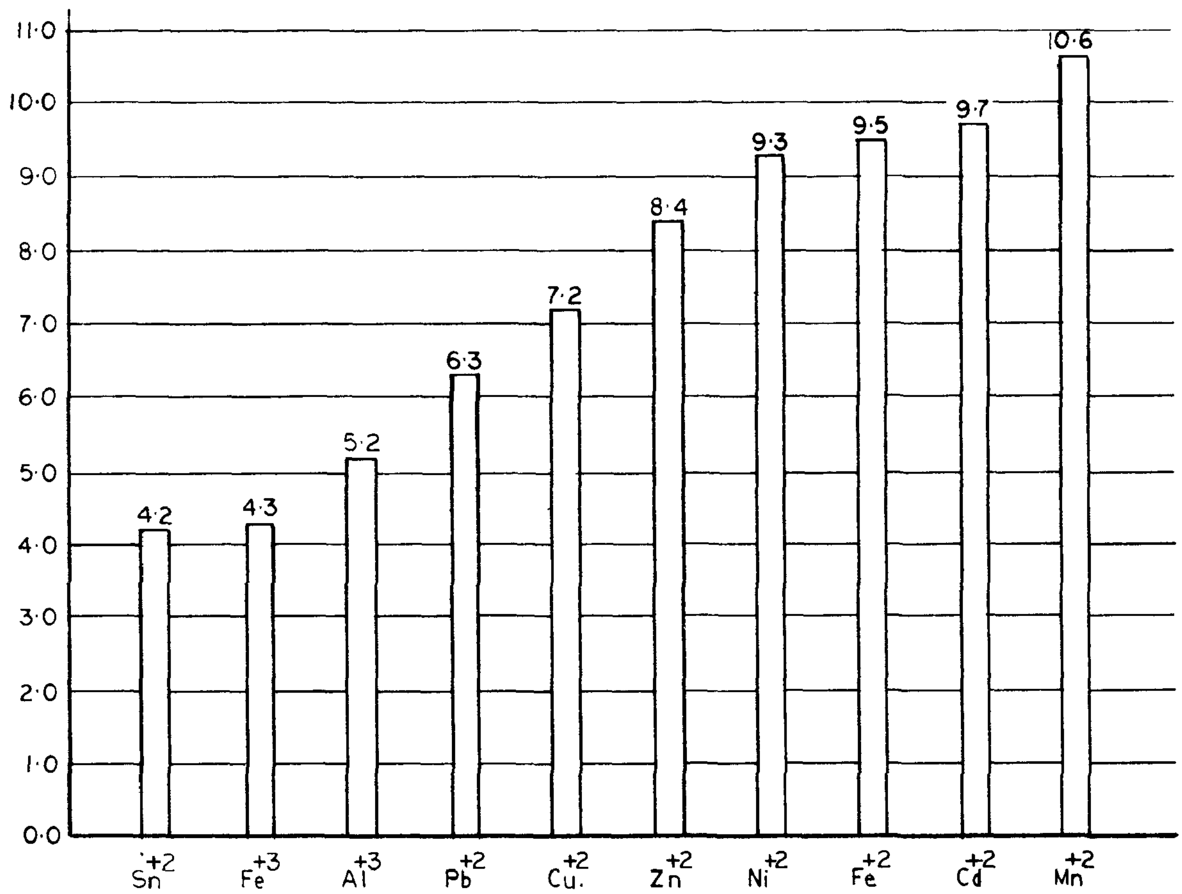
b. F.O.B. costs to Pittsburgh, Pennsylvania, June, 1973.

c. Estimated costs, material as such is not generally available.

The available alkalinity in each material is defined by its calcium carbonate equivalent. This can be used with the material's cost to calculate an equivalent cost per tonne of calcium carbonate content. If a material is not 100% efficient; i.e., if it must be added in excess, then its cost will be proportionately higher.

Practically any alkaline material can be used to remove or neutralize acidity. Since most mine drainage treatment facilities must treat large volumes of water, cost and effluent quality are usually the most important factors. As a result, lime, hydrated lime and limestone are the more commonly used alkalis.

The concentrations of heavy metals in aqueous solution can usually be reduced by precipitation as insoluble hydroxides. The pH at which this precipitation occurs is different for each metal. Typical pH values from one study are presented in Figure 13.1-1. Precipitation as the insoluble hydroxides will generally remove these metals to concentrations of one mg/l or less. In the case of amphoteric metals, such as zinc and aluminum, the metal will resolubilize if the solution becomes too alkaline. This may present a problem if more than one metal is to be removed from solution.




MINIMUM pH VALUE FOR COMPLETE PRECIPITATION OF METAL IONS AS HYDROXIDES
Figure 13.1-1

## Iron Removal

The choice of neutralizing agent becomes important if ferrous iron is present in the drainage. Ferrous iron does not reach minimum insolubility as the hydroxide, unless the pH is above 9.5. Ferric iron, however, can be essentially removed as a hydroxide at a pH of about 5.0. Ferrous iron can be oxidized to the ferric form, but this too is pH dependent, and the solution pH should be 7.0 or higher for the reaction to proceed quickly. Aeration is required to provide an excess of oxygen in the system for this oxidation reaction.

Alkaline materials such as lime, soda ash and caustic soda can easily neutralize the acidity and raise the pH to a level where ferrous iron oxidation can be accomplished. When using limestone, carbonic acid is formed in the neutralization reaction, and this suppresses the solution pH to a point where the ferrous iron oxidation is slow. Vigorous aeration can be used to drive off the carbon dioxide, but this does not greatly improve the process. Overall, limestone is impractical for use in neutralizing mine drainage containing substantial concentrations of ferrous iron.

When ferrous iron is present in mine drainage that is alkaline, the oxidation and removal as ferric hydroxide will occur naturally. Large settling ponds with detentions of several days have been used for this purpose.

The processes and methods available for the oxidation and removal of iron from mine drainage are discussed in Section 22.0 of this manual.

REFERENCES

11, 12, 75, 93, 131, 144, 190

# 14.0

# NEUTRALIZATION

# WITH

# LIMESTONE

## 14.1 METHOD DISCUSSION

Limestone is a general term applied to a family of rocks composed primarily of calcium carbonate or combinations of calcium and magnesium carbonates. Since limestone is an inexpensive material, it is often considered for use in neutralizing acidic wastewaters. Early investigations employing limestone for neutralization of acid mine drainage, found that the limestone surface quickly coated with iron, rendering it unreactive. Recent studies into the problems associated with mine drainage treatment have developed techniques for optimum utilization of limestone.

For neutralizing acidic wastes, limestones can be rated by their calcium carbonate or calcium oxide equivalent content. It has been found that limestones containing appreciable amounts of dolomite (magnesium carbonate) react very slowly. The neutralizing efficiency of limestone increases with higher calcium oxide and lower magnesium oxide content. Calcites, therefore, are more effective than either colomites or magnesites. Size of the limestone particle also has an effect on neutralization, with the smaller sized particles reacting at a faster rate.

Overall efficiency of any system using limestone to neutralize acid mine drainage depends primarily on the concentration and ionic form of any iron present. As mine drainage is formed, iron is in the ferrous form and cannot be completely removed as a hydroxide precipitate unless the pH is greater than 9.5. Ferrous iron can be oxidized to the ferric form, which is more insoluble, and will precipitate as the hydroxide in a 5.5 to 7.0 pH range. Oxidation of ferrous iron is greatly dependent on the pH of the solution. The oxidation is slow at pH's between 4.0 and 6.0, moderate in the 6.0 to 8.0 range, and proceeds rapidly at the higher pH's.

If the drainage contains iron in the ferrous form, it will be difficult to treat with limestone. Limestone will effectively neutralize mineral acidity, but forms carbonic acid in the process. This limits the solution's pH to about 6.5. At this point, ferrous iron is soluble and does not rapidly oxidize, so little is removed. Aeration of the drainage will expel carbon dioxide and increase oxidation. As the oxidation reaction occurs, additional acid is formed and the pH of the drainage will decrease. As a result, additional amounts of limestone must be added to accomplish complete neutralization and iron removal. Therefore, limestone treatment of mine drainage containing high concentrations of ferrous iron is impractical.

Limestone can be used effectively to treat mine drainage that contains mostly ferric iron. One problem is that the limestone will coat with a film of calcium and iron sulfate which will slow, and eventually stop, the reaction. If the iron and acidity concentrations are low, stationary limestone beds or pulverized limestone can be used. For acid drainages containing significant amounts of iron, a means to keep the limestone free of this coating is necessary. Processes using agitation for pulverized limestone and rotating tumblers for crushed limestone rock are discussed in the next two sections of this manual.

Limestone has several advantages over other alkaline agents. The sludge produced in the treatment process has been found to be more dense in that it settles more rapidly and occupies a smaller volume. The limestone feed rate is not as sensitive as with other alkalis; i.e., an overfeed of limestone will not drastically affect the pH of the treated water. Also, limestone is easier to handle than other alkaline materials.

Disadvantages in using limestone center around its slow reactivity. Since the reaction rates are slower, longer detention times are required in the treatment units. As a result, excessive limestone is used and the cost for neutralization is usually more than when using lime. Limestone gives poor results when treating acid mine drainage containing ferrous iron in concentrations above 100 mg/l.

Very few actual operating systems have been installed that use limestone for the treatment of acid mine drainage. As a result, the only construction and operating costs that are available, are estimates from studies to be discussed. The estimated construction costs from one study are in line with those presented for lime neutralization.

Actual and projected operating costs have been found to vary greatly. The quality of the drainage, presence of ferrous iron, efficiency of the mixing and aeration systems, and delivered cost of limestone all influence the chemical operating costs. On an equalized limestone price of $6.60 per tonne ($6.00 per ton), limestone costs have been reported to vary from 1.0 to 2.6 cents per thousand cubic meters treated per mg/l of acidity (4-10 cents per million gallons treated per mg/l of acidity) for drainages containing mostly ferric iron, and from 1.32 to 2.11 cents (5-8 cents) for drainages containing mostly ferrous iron. Generally, ferric iron waters are more easily treated than those containing ferrous iron and the chemical costs will be lower.

REFERENCES

11, 12, 18, 25, 74, 75, 77, 81, 89, 114, 144

## 14.2 TREATMENT WITH PULVERIZED LIMESTONE

### DESCRIPTION

Two studies have been completed on the use of pulverized limestone for treating acid mine drainage. In both cases, the work was performed in pilot sized units and full scale plants have never been constructed. The purpose of these studies was to determine if limestone would effectively treat acid mine drainage, containing ferrous iron in one study and ferric in the other, while producing an acceptable effluent. Costs were then determined for comparison with other processes. Both processes are essentially the same and each is discussed briefly.

#### FWQA Norton Field Site Study

The Federal Water Quality Administration studied the treatment of acid mine drainage at their Norton, West Virginia Mine Drainage Field Site which had an average quality of:

| | | |
|---|---|---|
| pH | = | 3.0 |
| Acidity (hot) | = | 1200 mg/l |
| Iron, total | = | 100 mg/l |
| Iron, Ferrous | ≤ | 25 mg/l |

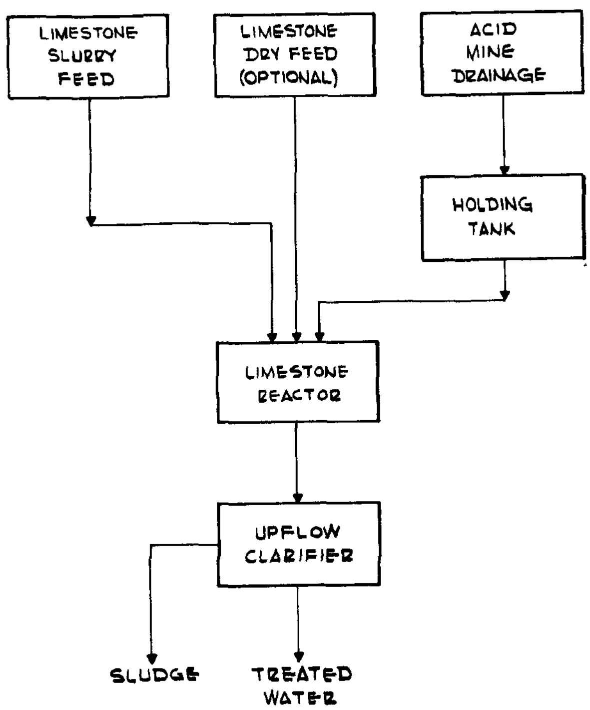
The mine drainage was introduced into a reactor vessel equipped with a flash mixer. Limestone was used both in a dry form (rock dust < 50 mesh), and as a slurry. The treated drainage was then settled for about four hours. Figure 14.2-1 is a flow sheet of this pilot facility.

### EVALUATION

There was essentially no difference in overall results by using limestone in a slurry rather than as dry rock dust. Aeration of the solution following limestone addition had no overall effect. However, using a slurry and aerating the neutralized drainage both have a significant effect on the reaction or detention times required. This should be taken into consideration in the design of any treatment facility. Without aeration, the pH of the mine drainage treated with limestone had not stabilized after 4 days.

Limestone treatment produces a dense, rapidly settling, sludge. The sludge was found to contain a considerable amount of unused limestone, which is a waste of the alkalinity purchased. It was recommended that recirculation of the sludge to the reactor be provided in a full size facility in order to reduce the amount of limestone needed for treatment.

From this study it was concluded that limestone can effectively produce an effluent with a pH of 6.5 and an iron concentration of about 2.0 mg/l. Sulfates were reduced to the calcium sulfate solubility, which is about 1000 mg/l as $SO_4$.




SCHEMATIC FLOW DIAGRAM
FWQA PILOT PLANT SYSTEM
NORTON FIELD SITE

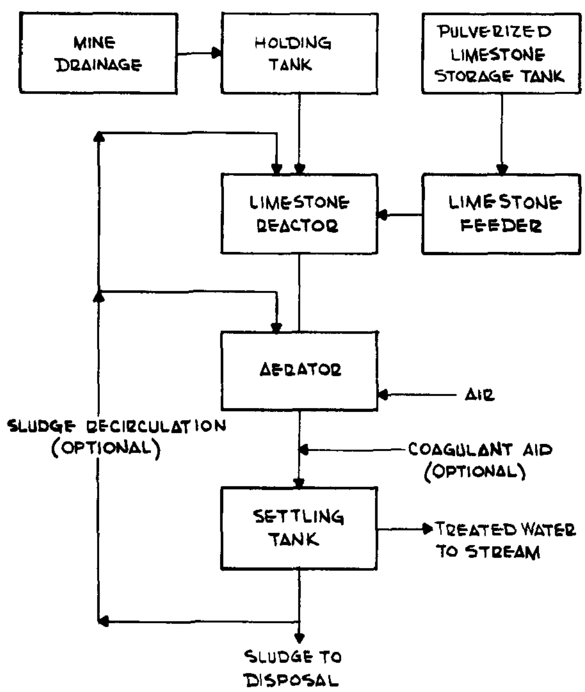
Figure 14.2-1

## BCR Limestone Treatment Process

Bituminous Coal Research, Inc. conducted an extensive pilot scale study on the treatment of acid mine drainage containing mostly ferrous iron with pulverized limestone. Their studies were performed on acid mine drainage having an average quality of:

| | |
|---|---|
| pH | 4.6 - 5.6 |
| Acidity, mg/l ($CaCO_3$) | 190 |
| Ferrous iron, mg/l | 90 |
| Ferric iron, mg/l | 0 |
| Sulfate, mg/l | 1200 |

Experimental work was conducted in a pilot facility consisting of the units shown on the flowsheet, Figure 14.2-2. From this, it was recommended that the individual units be designed to provide minimum detentions of 12 hours in the Equalization and Settling basins, and one hour each in the Reactor and Aeration units.




FLOW DIAGRAM
BCR LIMESTONE
TREATMENT PROCESS
Figure 14.2-2

## EVALUATION

The study concluded that acid mine drainage containing ferrous iron in concentrations up to 100 mg/l could be treated with pulverized limestone to produce an acceptable effluent. Limestone having a high calcium content and pulverized to a size of 200 mesh and smaller is most ideal and should be pre-mixed for slurry feed. Sludge recirculation produced a more dense sludge and nearly complete use of the available alkalinity. Vigorous aeration was required to drive off the carbon dioxide formed in the neutralization reaction and to oxidize the ferrous iron. Detention times in the aeration unit are excessively large when compared to treatment with other alkalis.

## COSTS

This study presented construction cost estimates for facilities to treat flows of 378.5, 3785, 15140, and 26,495 cu.m./d (0.1, 1.0, 4.0 and 7.0 mgd). These cost estimates assumed that land was available with level topography so a gravity flow system could be developed. The aeration and settling basins would be of earthen construction and clay is on site for lining these units. A separate dewatering basin would be provided for the sludge removed from the settling basins. Duplicate units are not provided, but the system is well equipped and is automated as much as practical.

The construction and operational cost estimates are summarized in Tables 14.2-1 and 14.2-2. The construction costs are in line with those presented for the conventional lime neutralization process discussed in Section 15.2. These costs estimates were made in June 1971, when the ENR construction cost Index was about 1575.

## REFERENCES

12, 55, 75

TABLE 14.2-1
SUMMARY OF ESTIMATED CAPITAL COSTS
BCR LIMESTONE TREATMENT PROCESS

| ITEM | DESIGN PLANT CAPACITY | |
|---|---|---|
| | 378.5 $m^3$/day* (0.1 MGD) | 3785 $m^3$/day* (1.0 MGD) |
| 1. Structures | $ 29,610 | $151,650 |
| 2. Control Building | 30,000 | 48,000 |
| 3. Equipment | 20,275 | 44,050 |
| 4. Piping | 12,000 | 25,000 |
| 5. Electrical | 10,000 | 15,000 |
| 6. Control Equipment | 5,000 | 12,000 |
| 7. Other | 4,800 | 7,250 |
| 8. Contingencies | 11,090 | 29,790 |
| 9. Engineering | 7,500 | 19,260 |
| Total Capital Costs | $130,275 | $352,000 |
| Cost/Unit Capacity, $/$m^3$ | $ 344.19 | $ 93.00 |
| | 15,140 $m^3$/day** (4.0 MGD) | 26,495 $m^3$/day* (7.0 MGD) |
| 1. Structures | $327,900 | $771,800 |
| 2. Control Building | 48,000 | 64,000 |
| 3. Equipment | 86,950 | 191,900 |
| 4. Piping | 40,000 | 58,000 |
| 5. Electrical | 30,000 | 36,000 |
| 6. Control Equipment | 24,000 | 35,000 |
| 7. Other | 9,000 | 12,950 |
| 8. Contingencies | 56,150 | 115,350 |
| 9. Engineering | 36,960 | 76,200 |
| Total Capital Costs | $658,960 | $1,361,200 |
| Cost/Unit Capacity, $/$m^3$ | $ 43.52 | $ 51.38 |

* Theoretical design quality of coal mine drainage:
Acidity as $CaCO_3$ = 1000 mg/l, Ferrous Iron = 500 mg/l, and Ferric Iron = 0 mg/l

** Actual Coal Mine Drainage Tested with Average Quality of:
Acidity as $CaCO_3$ = 190 mg/l, Ferrous Iron = 90 mg/l, Ferric Iron = 0 mg/l

TABLE 14.2-2
SUMMARY OF ESTIMATED OPERATING COSTS
BCR LIMESTONE TREATMENT PROCESS

| ITEM | DESIGN PLANT CAPACITY - CU.M/DAY COSTS REPORTED IN CENTS PER CUBIC METER | |
|---|---|---|
| | 378.5* (0.1 mgd) | 3785* (1.0 mgd) |
| Labor | 7.61 | 1.00 |
| Limestone | 1.53 | 1.53 |
| Coagulant Aid | 0.45 | 0.45 |
| Power | 1.82 | 0.50 |
| Maintenance | 2.11 | 0.37 |
| Sludge Disposal | 3.01 | 2.99 |
| Direct Operating Cost | 16.53 | 6.84 |
| Capital Cost Amortized*** | 8.22 | 2.22 |
| Contingencies | 0.95 | 0.26 |
| Total Operating Cost | 25.70 | 9.32 |
| | 15,140** (4.0 mgd) | 26,495* (7.0 mgd) |
| Labor | 0.32 | 0.26 |
| Limestone | 0.29 | 1.32 |
| Coagulant Aid | 0.45 | 0.45 |
| Power | 0.61 | 0.53 |
| Maintenance | 0.13 | 0.08 |
| Sludge Disposal | 0.66 | 3.01 |
| Direct Operating Cost | 2.46 | 5.65 |
| Capital Cost Amortized*** | 1.03 | 1.22 |
| Contingencies | 0.11 | 0.13 |
| Total Operating Cost | 3.60 | 7.00 |

* Theoretical design quality of coal mine drainage:
Acidity as $CaCO_3$ = 1000 mg/l, Ferrous Iron = 500 mg/l, and Ferric Iron = 0 mg/l

** Actual Coal Mine Drainage Tested with Average Quality of:
Acidity as $CaCO_3$ = 190 mg/l, Ferrous Iron = 90 mg/l, Ferric Iron = 0 mg/l

*** Capital costs are amortized for 20 years at 6% interest. Contingencies are 1% of the estimated construction costs.

## 14.3 TREATMENT WITH CRUSHED LIMESTONE ROCK

### DESCRIPTION

Crushed limestone rock has been successfully used to treat acid mine drainage discharged from two Pennsylvania coal mines. Rotating drums partially filled with the rock are used to prevent the coating of calcium and iron sulfates on the limestone surfaces. In both cases, the iron present was mostly in the ferric form.

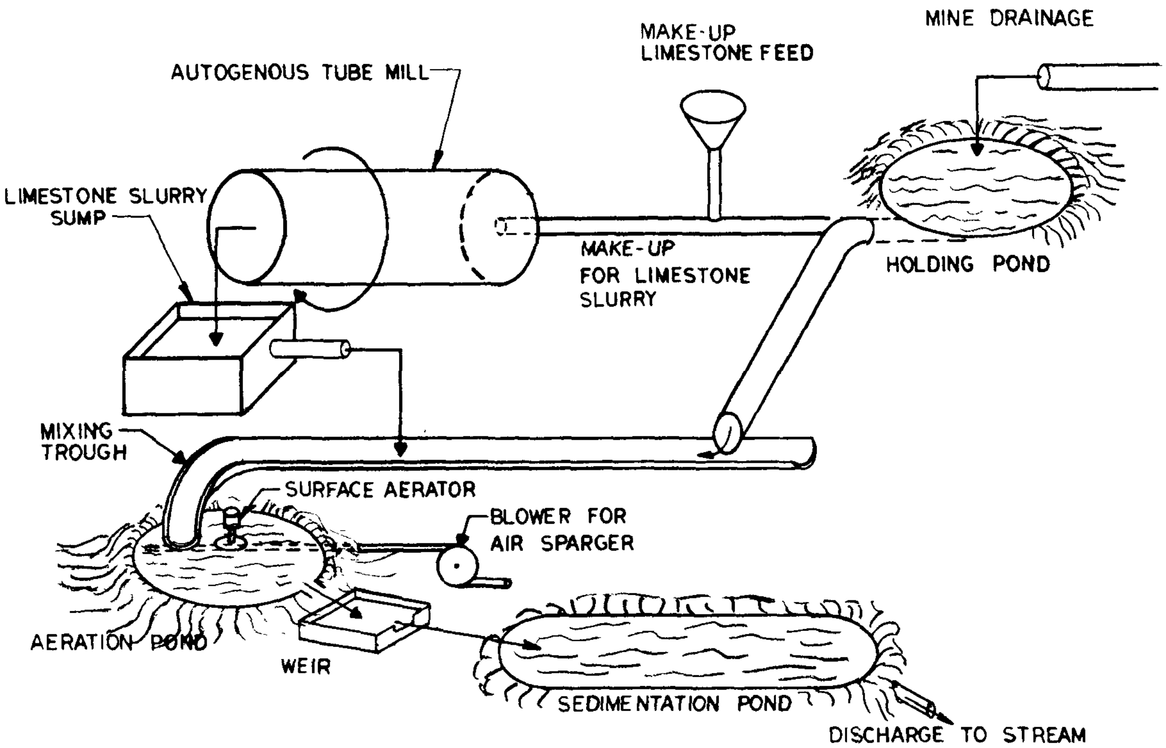
### EVALUATION

The U. S. Bureau of Mines began to study the neutralization of acid mine drainage in 1966. From this, a process was developed and an operating facility installed in 1967-68 that treats a flow of about 18.93 l/s (300 gpm) having a quality of:

| | |
|---|---|
| pH | 2.8 |
| Acidity, mg/l ($CaCO_3$) | 1700 |
| Ferrous iron, mg/l | 36 |
| Total iron, mg/l | 360 |
| Sulfate, mg/l | 3900 |

The treatment facilities consist of an 11,355 cubic meter (3.0 million gallon) holding basin; a 0.914 meter (3'-0") diameter by 7.32 meter (24'-0") long tube mill driven by an 11.2 kW (15 Hp) variable-speed motor; 227 cubic meter (60,000 gallon) earthen aeration basin equipped with a surface aerator and air sparging system, and a 132.5 cubic meter (35,000 gallon) settling basin. A flowsheet for this process is shown on Figure 14.3-1.

The tube mill was used to produce a limestone slurry. Tests were conducted to optimize the limestone size, rotation speed and water flow through the tube mill. It was concluded that 0.39 cm x 1.18 cm (1" x 3") limestone rocks, and a small flow of water at a high rotation speed of 2.62 rad/s (25 rpm) produced high dissolution rates of limestone into the slurry. The slurry was then mixed with the mine drainage in a long trough before entering an aeration basin for oxidation of the ferrous iron. This was followed by a settling basin for removal of the precipitated solids. The facility produced a treated water with a pH of about 7.0, and a total iron content of less than 7 mg/l.




FLOW DIAGRAM
LIMESTONE BALL-MILL NEUTRALIZATION PROCESS
AFTER U.S. BUREAU OF MINES (114)
Figure 14.3-1

## COSTS

The limestone cost in treating water by this facility was $0.03 per thousand cubic meters ($0.115 per million gallons) treated per mg/l of acidity, based on a delivered cost of $6.60 per tonne ($6.00 per ton). Construction cost estimates for treating a wide range of flows and quality were presented by the Bureau in a subsequent study; however, these estimates seem out of line when compared to costs reported elsewhere. For this reason, they are not presented here.

## REFERENCES

25, 114

# 15.0

# NEUTRALIZATION

# WITH

# LIME

## 15.1 METHOD DISCUSSION

Lime has been used for many years by industry to neutralize acid waste waters and remove heavy metals as insoluble hydroxides. Lime is available in a variety of forms, but two are the most useful. Quicklime is produced by calcining (burning) limestone at high temperature. It is composed almost entirely of calcium oxide (88%) and has to be slaked into a slurry of hydrated lime for use. The slaking process produces considerable heat and must be carefully controlled to obtain maximum reactivity.

Hydrated lime is a dry powder obtained by treating quicklime with water. It costs about the same as quicklime and is ready to use; i.e., it can be easily mixed with water to form a solution or slurry. This form of lime is most often used for the neutralization of acidic wastes, including acid mine drainage.

Lime is readily available, relatively simple to use, and consistently neutralizes the acidity and removes the iron and other metals present in mine drainage at a reasonable, if not the least cost. For these reasons, lime is used in most of the estimated 300 plants now in existency that treat mine drainage. There are disadvantages associated with using lime; these include, an increase in the hardness of the treated water, problems with scale (gypsum) formation on plant equipment, the possibility of over-treatment resulting in high discharge pH's, and the difficulties in dewatering or disposal of the large volumes of sludge that are produced.

### REFERENCES

9, 68

## 15.2 CONVENTIONAL LIME NEUTRALIZATION PROCESS

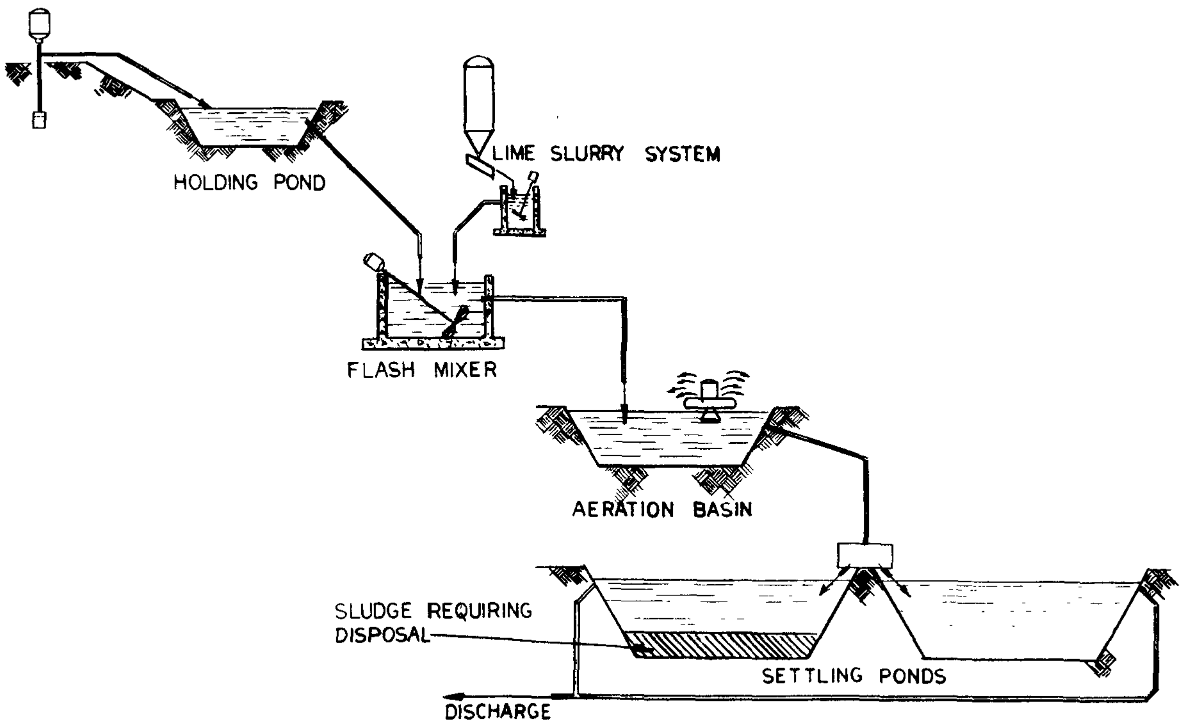
### DESCRIPTION

In the lime neutralization process, there are four basic steps that are commonly employed to effectively treat mine drainage. First the drainage is neutralized with lime, usually in a slurry form, by vigorous mixing for one to two minutes. Neutralization is immediate, and the drainage is then aerated for a 15 to 30 minute period to oxidize ferrous iron to the ferric form. Following this, the drainage is settled in either mechanical clarifiers, or large earthen settling basins for removal of the solids formed by the process. The treated water is discharged and the final step involves disposal of the sludge produced in the clarification operation. General methods available for sludge disposal are discussed in Section 16.0.

### EVALUATION

In the conventional lime neutralization process, each of these four operations follows in normal sequence, i.e., neutralization (mixing), aeration, settling, and sludge disposal. Flow is once-through and gravity systems are usually employed. A flowsheet for the typical system is shown on Figure 15.2-1.

To simplify the controls needed in the system and to minimize operator attendance, a constant flow with only small variations in quality is desirable. To accomplish this, the mine drainage is collected in large holding or equalization basins. From these, it either flows by gravity or is pumped to the treatment facilities. Since most mines are in rural areas, both the holding and settling basins are usually surface impoundments of earthen construction.




CONVENTIONAL LIME NEUTRALIZATION PROCESS
Figure 15.2-1

COSTS

Many factors affect the costs associated with the treatment of mine drainage. Construction costs are affected by the capacity of the plant, the availability of land with acceptable topography, site accessibility, availability of electricity, and method selected for sludge disposal. While many plants use this conventional process, actual cost data is not readily available. Construction costs from documented case histories have been used to develop the curve presented in Figure 15.2-2.

CAPITAL COST VS. CAPACITY
CONVENTIONAL NEUTRALIZATION PROCESSES

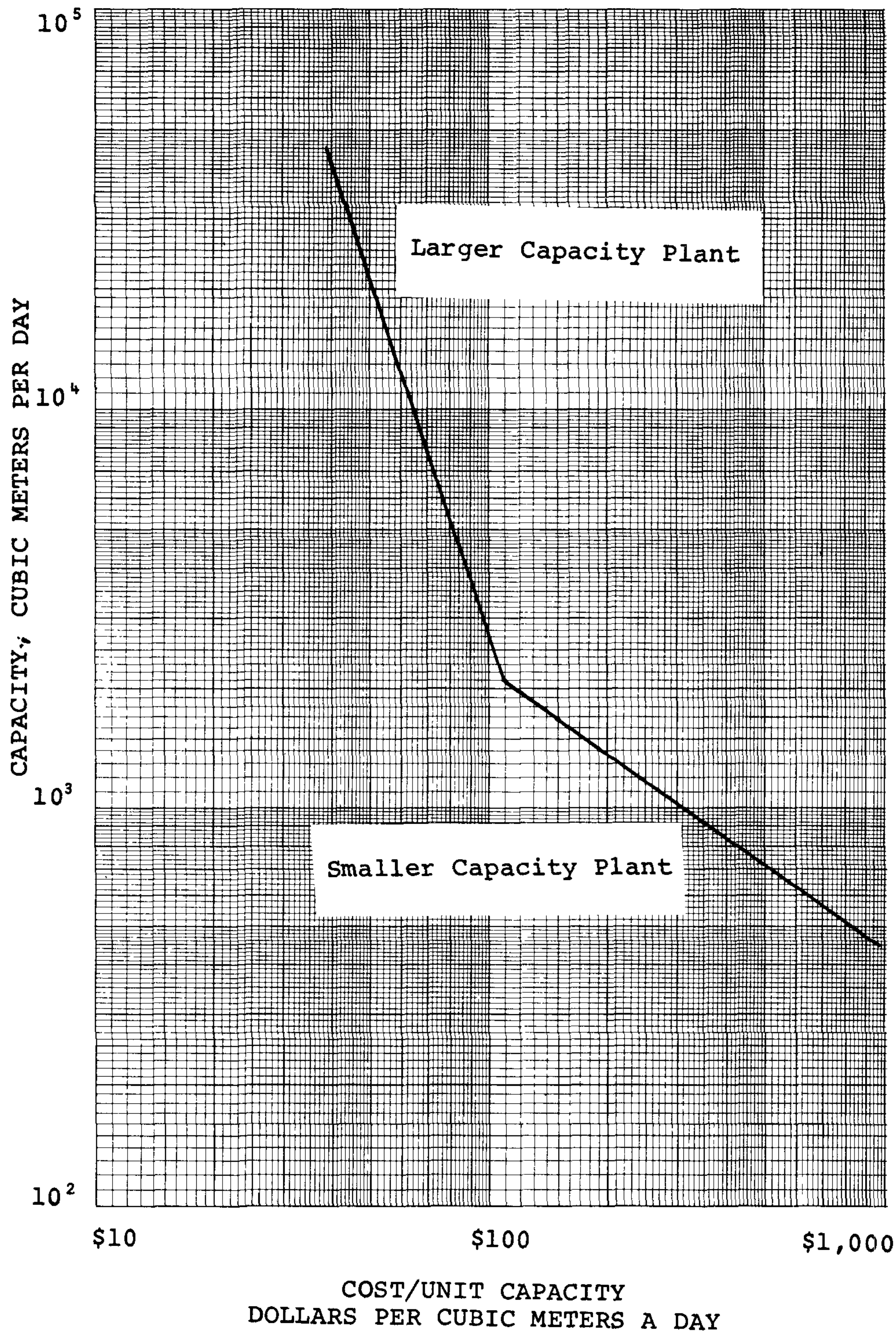



Figure 15.2-2

Operating costs vary significantly, and are affected by the drainage quality (chemical requirements), pumping needs, chemical and power costs, labor needs, and sludge disposal. The costs for sludge disposal can be as much as 50% of the total operating cost, and the methods available for this are discussed in Section 16.0. Actual and estimated operating costs for several plants are tabulated in Tables 15.2-1 and 15.2-2. Operating costs vary from 3 to 12 cents per thousand cubic meters (11 to 45 cents per million gallons) treated per mg/l of acidity, but are generally in the range of 4 to 7 (15 to 27) cents.

REFERENCES

9, 45, 46, 64, 68, 82, 98, 101, 163

TABLE 15.2-1
SUMMARY OF CAPITAL COSTS
CONVENTIONAL LIME NEUTRALIZATION PROCESS

| | | Design Flow Rate $M^3$/Day | Total Acidity mg/l | CAPITAL COSTS Total Cost | $/$M^3$ |
|---|---|---|---|---|---|
| 1. | Bethlehem Mines Co. No. 58-A | 908 | 4,080 | $ 347,200 | $382.38 |
| 2. | Bethlehem Mines Co. No. 58-B | 1,136 | 8,150 | 423,200 | 372.53 |
| 3. | Young & Son | 681 | 770 | 229,900 | 337.59 |
| 4. | Morea Strip | 15,140 | 190 | 657,400 | 43.42 |
| 5. | Blue Coal Corp. Loomis No. 4 | 21,802 | 560 | 1,094,000 | 50.18 |
| 6. | Duquesne Light Co. Warwick No. 3 | 2,271 | 1,250 | 229,700 | 101.14 |
| 7. | West Virginia University School of Mines Mine No. 1 | 1,136 | 3,500 | --- | --- |
| | | 1,136 | 1,400 | --- | --- |
| | | 1,136 | 650 | --- | --- |
| | | 3,407 | 3,500 | --- | --- |
| | | 3,407 | 1,400 | --- | --- |
| | | 3,407 | 650 | --- | --- |
| | | 10,220 | 3,500 | --- | --- |
| | | 10,220 | 1,400 | --- | --- |
| | | 10,220 | 650 | --- | --- |
| 8. | Duquesne Light Co. Warwick No. 2 | 11,446 | 1,560 | 582,000 | 50.85 |
| 9. | Commonwealth of Pa. Slippery Rock Creek Treatment Plant | 11,446 | 240 | 750,000 | 65.53 |
| | Rausch Creek Mine Drainage Plant | 37,850 | --- | 1,747,380 | 46.17 |
| 10. | Mountaineer Coal Co. | 2,725 | 250 | 120,000 | 44.04 |

TABLE 15.2-2
SUMMARY OF OPERATING COSTS
CONVENTIONAL LIME NEUTRALIZATION PROCESS

| | | Design Flow Rate $M^3$/Day | Total Acidity mg/l | OPERATING COST Annual Cost | OPERATING COST Cents/1000 $m^3$ per mg/l acidity |
|---|---|---|---|---|---|
| 1. | Bethlehem Mines Co. No. 58-A | 908 | 4,080 | $ 95,250 | 7.0 |
| 2. | Bethlehem Mines Co. No. 58-B | 1,136 | 8,150 | 140,000 | 4.1 |
| 3. | Young & Son | 681 | 770 | 47,400 | 24.8 |
| 4. | Morea Strip | 15,140 | 190 | 126,571 | 12.1 |
| 5. | Blue Coal Corp. Loomis No. 4 | 21,802 | 560 | 475,000 | 10.7 |
| 6. | Duquesne Light Co. Warwick No. 3 | 2,271 | 1,250 | 117,500 | 11.3 |
| 7. | West Virginia University School of Mines Mine No. 1 | 1,136 | 3,500 | 68,448 | 4.7 |
| | | 1,136 | 1,400 | 44,236 | 7.6 |
| | | 1,136 | 650 | 30,223 | 11.2 |
| | | 3,407 | 3,500 | 172,463 | 4.0 |
| | | 3,407 | 1,400 | 108,405 | 6.2 |
| | | 3,407 | 650 | 73,913 | 9.1 |
| | | 10,220 | 3,500 | 477,968 | 3.7 |
| | | 10,220 | 1,400 | 290,723 | 5.6 |
| | | 10,220 | 650 | 196,607 | 8.1 |
| 8. | Duquesne Light Co. Warwick No. 2 | 11,446 | 1,560 | 209,715 | 3.2 |
| 9. | Commonwealth of Pa. | | | | |
| | Slippery Rock Creek Treatment Plant | 11,446 | 240 | 51,000 | 5.1 |
| | Rausch Creek Mine Drainage Plant | 37,850 | -- | --- | -- |
| 10. | Mountaineer Coal Co. | 2,725 | 250 | --- | -- |

## 15.3 HIGH DENSITY SLUDGE PROCESS

### DESCRIPTION

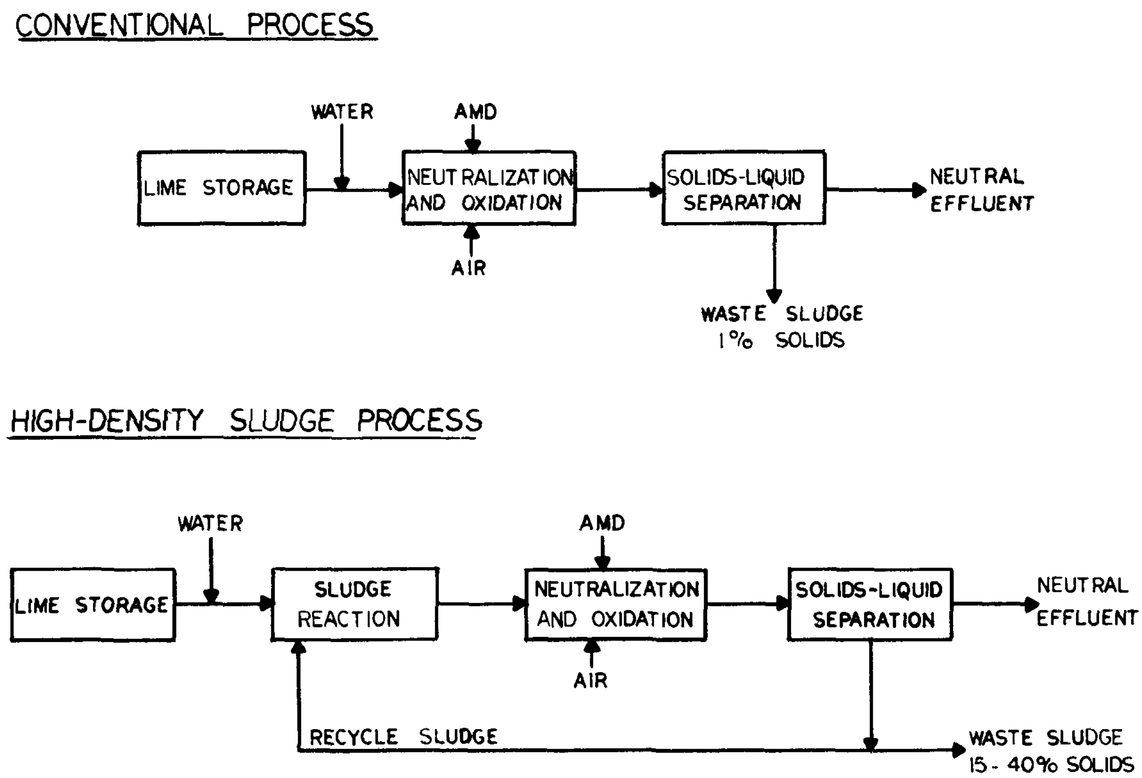
The Bethlehem Steel Corporation reported development of the High-Density Sludge Process in 1970. This process uses lime for neutralization and produces a very dense sludge of much less volume than the conventional lime neutralization process (Section 15.2). The process is based on a high sludge recirculation rate within the system with a 20 to 30:1 ratio of solids recirculated to solids removed considered optimum. The sludge is returned to a reactor vessel where the lime slurry is added. This point of alkali introduction to the system is important. The slurry is then mixed with the acid mine drainage in a neutralization reactor where aeration is provided for oxidation of ferrous iron. Removal of the systems' solids is accomplished in a mechanical thickener. The process flow sheet is shown in Figure 15.3-1.

### EVALUATION

The higher sludge solids was found to vary with the ferrous to ferric iron ratio in the raw acid mine drainage. Sludge densities of up to 50% solids were obtained as the ferrous iron content approached 100%. On a high ferric iron drainage, a sludge density approaching 20% solids was obtained. These can be compared to sludge densities of 2 to 6% that are normally produced in the conventional lime neutralization process.

### COSTS

Cost information for the High-Density Sludge Process is not available. Capital costs can be expected to be about the same, or slightly higher than for treatment by conventional means. A demonstration plant constructed in 1967 treated a maximum flow of 50.5 1/sec (800 GPM). The total cost of the plant including modifications and changes was $350,000. A substantial cost savings for sludge disposal will be realized by using this system.




HIGH DENSITY SLUDGE PROCESS
Figure 15.3-1

REFERENCES

See Section 15.2 on Lime Neutralization.

## 15.4 COMBINATION LIMESTONE - LIME TREATMENT PROCESS

### DESCRIPTION

The Environmental Protection Agency has investigated a two-stage neutralization process using limestone and lime at their Mine Drainage Field Site at Norton, West Virginia. It had been found that limestone is highly reactive in neutralization tests at low pH's, but becomes relatively inefficient at pH's above 6.0 due to inherent problems with the formation of carbonic acid and oxidation of ferrous iron.

### EVALUATION

Limestone has advantages over lime in raw material cost and it produces a more dense sludge of lesser volume.

The study was conducted on acid mine drainage containing iron in the ferric form. Tests on the combination process were conducted in a pilot-scale plant and compared to treatment by lime and limestone separately. This study concluded that the best results are obtained by using limestone to neutralize the drainage to a pH of 4.0, and then using lime to achieve any desired final pH. Reaction times of 20 to 30 minutes are required for efficient utilization of limestone and 10 to 15 minutes for lime. This combination process produced a sludge volume one-half that produced when using lime alone, with a solids content five times more dense. This volume of sludge, however, was slightly more than that produced by using limestone alone. All three materials produced a treated water of similar quality.

## COSTS

The investigators of this combination process feel that it has a "tremendous economic potential for cost reductions in acid mine drainage treatment." Additional equipment for the combination process consists of bulk storage, feeding, slurry mixing and reactor (large mixing vessel) facilities. These should not increase the capital cost of the treatment plant by more than 25%.

Operating costs of the combination process are based on limestone and hydrated lime costs of $6.61 and $19.84 per tonne ($6.00 and $18.00 per ton) respectively. Estimated chemical costs for neutralization of acid mine drainage are compared to neutralization with either lime or limestone alone in Table 15.4-1.

TABLE 15.4-1
ESTIMATED CHEMICAL OPERATING COSTS
COMBINATION LIMESTONE - LIME TREATMENT PROCESS

Typical Chemical Costs
Cents/3.785 $M^3$ (Cents/1000 gallons)

| Final pH | Lime Only | Limestone Only | Limestone - Lime Cost | Limestone - Lime % Savings |
|---|---|---|---|---|
| 6.5 | 2.61 | -- | 1.94 | 25.7% |
| 6.5 | -- | 3.44 | 2.37 | 31.1% |
| 9.0 (ferric) | 3.13 | -- | 2.46 | 21.3% |
| 9.0 (ferrous) | 4.43 | -- | 3.77 | 14.9% |

The acid mine drainage used had an average quality of:

| | |
|---|---|
| pH | 2.8 |
| Acidity, as $CaCo_3$ | 430 mg/l |
| Iron, total | 92 |

This process also reflects cost savings for the treatment of drainages containing more acidity or ferrous iron. When ferrous iron is present, limestone is not practical to use, but a cost comparison for lime and the combination limestone - lime process is presented in the preceding Table.

## REFERENCES

190

## 15.5 STREAM NEUTRALIZATION

### DESCRIPTION

The Pennsylvania Department of Environmental Resources has constructed an automatically operated hydrated lime neutralization system for treatment of streams affected by acid mine drainage. The system is applied to streams which are mildly acid but contain very little iron, aluminum, manganese or other compounds that will precipitate as insoluble compounds.

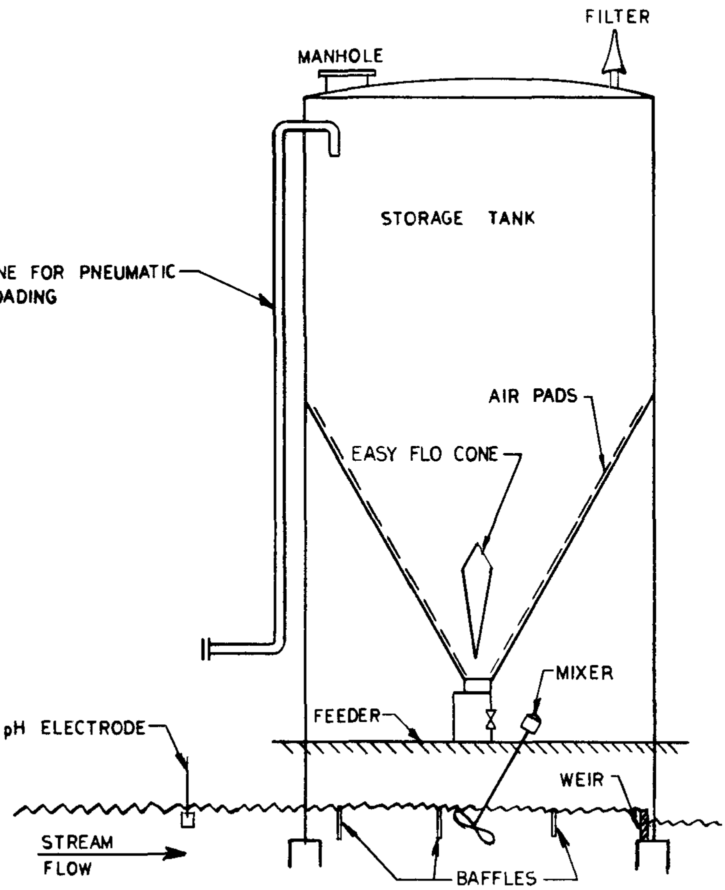
The system as shown in Figure 15.5-1, consists of a lime storage bin with a variable speed feeder. Stream flows are measured by a float behind a weir, and flow and upstream pH both control the lime feed rate. Lime is introduced dry behind the weir and an electric mixer and baffles insure rapid dissolving.

### EVALUATION

These plants have operated with little problem and have returned several streams to a quality that supports aquatic life.

### COSTS

The several plants installed by Pennsylvania have capital costs ranging from $40,000 to $54,000 and have treated flows ranging from 568 to 21,764 cubic meters a day (0.15 to 5.75 mgd). Operating costs have ranged from $300 to $741 a month, or 1.5 cents a cubic meter ($0.0573/1000 gallons) in periods of low flow to 0.18 cents a cubic meter ($0.0068/1000 gallons) in periods of high flow.




TYPICAL INSTALLATION OF IN-STREAM NEUTRALIZING SYSTEM BY PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL RESOURCES

Figure 15.5-1

REFERENCES

104

# 16.0

# SLUDGE

# DISPOSAL

## 16.1 METHOD DISCUSSION

Neutralization of acid mine drainage with any of a variety of alkalis, results in production of substantial quantities of sludge containing insoluble precipitates and unreacted solids. The sludge is usually very voluminous, containing from one to five percent dry solids by weight, which presents a considerable volume for disposal. Those methods that are currently used or proposed for use in sludge disposal are discussed herein.

A significant portion of the operation costs of any treatment system will be for sludge disposal. Cost data for disposal of these sludges is not available. As a guide, one study presented costs for the disposal of sewage sludges. These costs do not provide for sludge conditioning or ultimate disposal, nor are they directly comparable to mine drainage sludges. These are presented in Table 16.1-1 and should be used only to compare one method to another.

TABLE 16.1-1
COSTS OF SEWAGE SLUDGE DEWATERING METHODS

| System | Capital & Operating Costs $/Dry Tonne | |
|---|---|---|
| | Average | Range |
| Lagooning | $ 2 | $ 1 - 5 |
| Sand Bed Drying | -- | 3 - 20 |
| Vacuum Filtration | 15 | 8 - 50 |
| Heat Drying | 35 | 25 - 40 |

### REFERENCES

12, 23, 74, 82

## 16.2 LARGE SETTLING IMPOUNDMENTS

Lagooning of wet sludge is the most commonly used method of disposal. At times, land conditions permit construction of enormous settling ponds. These may have the capacity to store settled sludge for several years or, perhaps, for the life of the mine drainage treatment facility. Usually the damming of entire valleys or use of open cuts in strip mines are required to develop these large settling ponds. Construction and land costs must be considered in using this method of sludge disposal.

REFERENCES

93, 107

## 16.3 AIR DRYING

Another method of sludge disposal involves use of two or more settling basins for removal of the precipitated solids. When a basin's sludge storage capacity becomes filled, it is taken out of service and the clear water above the sludge level is drained. The sludge is then air dried for several weeks, depending upon weather conditions. This drying method reduces the sludge volume considerably and it can then be removed for final disposal.

A variation of this sludge disposal method is use of sludge drying lagoons separate from the settling basins. Sludge is pumped from a settling basin on a frequent basis into a separate air drying lagoon for dewatering as discussed above.

REFERENCES

32, 102, 120

## 16.4 DEEP MINE DISPOSAL

Wet or dry sludge has been effectively disposed of in abandoned sections of deep mines. This method is applicable if the iron in the sludge is all in the ferric form. Since ferric iron is soluble at a pH of less than 4.0, any drainage from the proposed section of mine to be used must have a pH above 4.0, or it will be affected by re-dissolving iron from the sludge. Solids such as calcium sulfate will also dissolve in mine water, thus raising the total dissolved solids.

REFERENCES

58, 68, 93, 126

## 16.5 POROUS DRYING BEDS

Drying beds for dewatering the sludge produced by neutralization are usually constructed of a 0.3 to 0.6 meter (12-24 inches) thickness of a porous media such as slag, limestone, sand and gravel or other available material. Underdrains of perforated pipe are used to remove water percolating through the sludge layer. Wet sludge is pumped onto the bed and dries by evaporation. Covered beds can provide rapid drying within several days. Accumulations of sludge of 0.45 meters (18 inches) have been reported. Porous drying beds may provide a feasible sludge dewatering means in systems where the volume produced is not excessively large.

### REFERENCES

23, 32, 91, 102, 194

## 16.6 VACUUM FILTRATION

Revolving-drum vacuum filters are commonly used to dewater various types of waste water sludges. It has been found that sludge produced from neutralization of mine drainage cannot be dewatered on a cloth covered filter due to its high compressibility. Use of a precoat rotary filter provided better results with a diatomite precoat media.

Actual operating experience on dewatering by vacuum filtration is very limited and additional demonstration worked is needed. Sludge cakes of 30% to 45% solids have been projected.

REFERENCES

32, 90, 91, 194

## 16.7 LAND DISPOSAL

The ultimate disposal of dewatered sludge from mine drainage treatment poses a considerable problem. This material has poor stability and above grade disposal should not be considered. Many of the constituents in the sludge are soluble in water. A site should be selected where contamination of either surface or subsurface waters can be prevented. Disposal within abandoned deep mines seems the most satisfactory where conditions permit. Burying the sludge in a landfill type operation has been proposed but there are no records of such practice.

REFERENCES

32

# 17.0

# EVAPORATION

# PROCESSES

## 17.1 METHOD DISCUSSION

### DESCRIPTION

Evaporation processes are commercial methods of distilling saline or brackish waters, including mine drainage, to produce a high quality water suitable for potable or industrial uses. There are three different processes in use for producing potable water by evaporation. These include: (1) multi-stage flash evaporation (MSF); (2) multi-effect long tube evaporation (ME-LTV); and (3) vapor compression (VC).

A study by the Westinghouse Electric Corporation concluded that the multi-stage flash evaporation (MSF) process could be applied to a mine drainage source to produce potable water at an economical cost. The MSF process is based on the fact that water boils at lower temperatures as it is subjected to progressively lower pressures. The feed water is heated (93$^{o}$C) and introduced into a chamber where the pressure is reduced and causes a "flash" of some water into vapor. The vapor rises in the chamber, condenses on tubes, and is collected in a separator as product water. Dissolved solids remain in the feed water which is termed "brine." The brine flows into a second chamber where the pressure is lower than the first, and additional vapor flashes. This process is repeated several times. As the brine leaves the final chamber, it is used to heat the incoming feed water.

### EVALUATION

Expensive alloys must be used for construction of any process equipment that will contact acid mine drainage to prevent corrosion problems. As the drainage concentrates in the process, the calcium sulfate (gypsum) concentration increases and a potential scaling problem exists. The brine requires a disposal method that will prevent water pollution problems. The product water produced by this process will contain less than 50 mg/l of total dissolved solids. This quality is much better than is generally needed.

Following their studies, Westinghouse was awarded a contract by the Commonwealth of Pennsylvania to design an MSF system to produce 18,925 cu.m./day (5.0 mgd) of potable water for the Wilkes-Barre area. The plant was to have been constructed in conjunction with a public utility steam producer. Steam was to be obtained from that source at a cost much less than could be produced independently.

Plans to construct the MSF plant were abandoned when it was found that it would be necessary to produce steam, with temporary oil-fired boilers for the first two years, at excessive operating costs. Also, the Pennsylvania Department of Environmental Resources rejected the Westinghouse plan for disposal of the brine by storage in plastic-lined pits.

## COSTS

Capital and operating costs from the Westinghouse design for the 18,925 cu.m./day (5 mgd) Wilkes-Barre plant are presented in Tables 17.1-1 and 17.1-2. The operating costs in Table 17.1-2 do not include capital cost amortization or disposal of the brine and solid residues. It is believed that these capital cost estimates are low, which was another reason why the plans for construction of this plant were abandoned.

## REFERENCES

37, 105, 106, 185, 186

TABLE 17.1-1
SUMMARY OF ESTIMATED CAPITAL COSTS
MSF EVAPORATION PLANT DESIGNED TO PROCESS
18,925 $M^3$/DAY (5.0 MGD) OF MINE DRAINAGE*

| ITEM | ESTIMATED COST |
|---|---|
| 1. Plant Construction | |
| Major Equipment | $6,509,124 |
| Site Development | 567,000 |
| Equipment Erection | 914,760 |
| Piping | 655,200 |
| Electrical & Instruments | 654,827 |
| Buildings, Painting, etc. | 441,000 |
| Sub-total | $9,741,911 |
| 2. Other Facilities | |
| AMD Pumping System | $ 597,996 |
| Cooling Tower | 432,180 |
| Temporary Boilers | 1,007,760 |
| Product Water Post-Treatment | 63,000 |
| Engineering | 1,023,041 |
| Start-up Expenses | 214,200 |
| Sub-total | $3,338,177 |
| Estimated Total Plant Cost | $13,080,088 |

*Westinghouse Electric Corporation, 1971

TABLE 17.1-2
SUMMARY OF ESTIMATED OPERATING COSTS
MSF EVAPORATION PLANT DESIGNED TO PROCESS
18,925 $M^3$/DAY (5.0 MGD) OF MINE DRAINAGE *

| | ESTIMATED OPERATING COST WITH PURCHASED STEAM | |
|---|---|---|
| | ANNUAL | CENTS/3.785 $M^3$** |
| Steam | $ 505,050 | 27.7 |
| Electricity | 344,064 | 18.9 |
| Maintenance | 69,600 | 3.8 |
| Labor, direct | 93,600 | 5.1 |
| Labor, indirect | 40,580 | 2.2 |
| Total Estimated Operating Cost | $1,052,894 | 57.7 |

| | ESTIMATED OPERATING COST WITH ON-SITE STEAM PRODUCTION | |
|---|---|---|
| | ANNUAL | CENTS/3.785 $M^3$** |
| Steam | $3,968,800 | 217.5 |
| Electricity | 602,760 | 33.0 |
| Maintenance | 75,000 | 4.1 |
| Labor, direct | 126,880 | 7.0 |
| Labor, indirect | 142,472 | 7.8 |
| Total Estimated Operating Cost | $4,915,912 | 269.4 |

* Westinghouse Electric Corporation, 1971
** Equal to Cents/1000 gal.

# 18.0

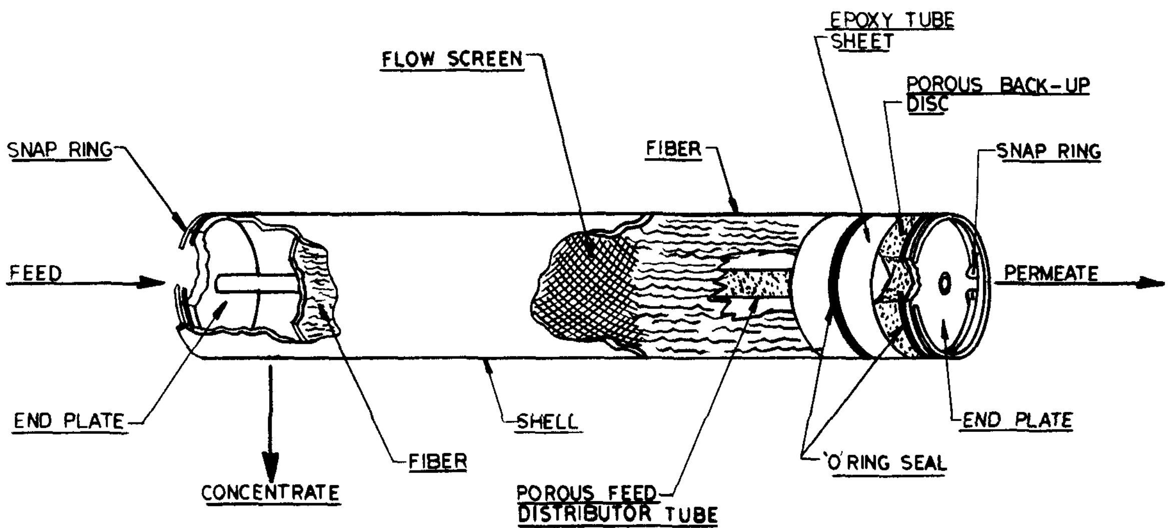
# REVERSE

# OSMOSIS

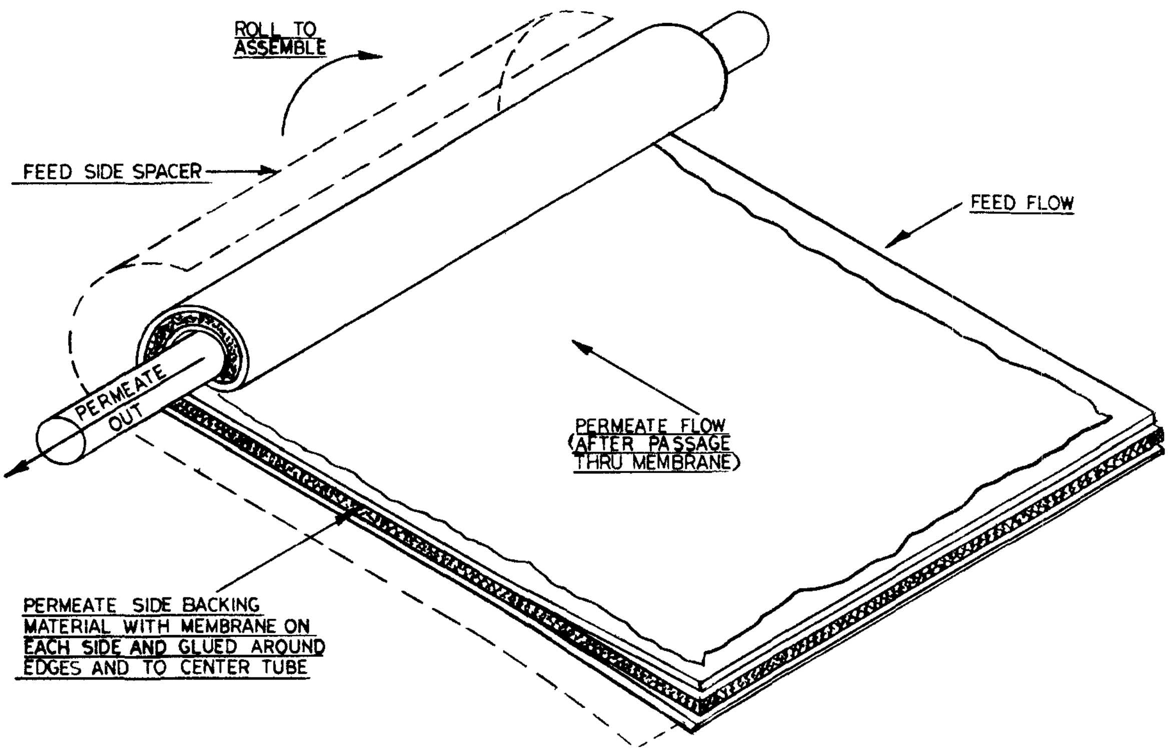
## 18.1 METHOD DISCUSSION

Natural osmosis occurs when two solutions of different concentration but in a common solvent are separated by a permeable membrane. If the membrane is permeable by the solvent and not the solute, then the solvent will flow from the dilute solution into the more concentrated solution until an equilibrium of equal concentration is established. In the reverse osmosis process, the direction of solvent flow is reversed by the application of pressure to the more concentrated solution. As a result, the concentrated solution's strength increases and this is termed the solute or brine. The solvent or permeate is the product from the process.

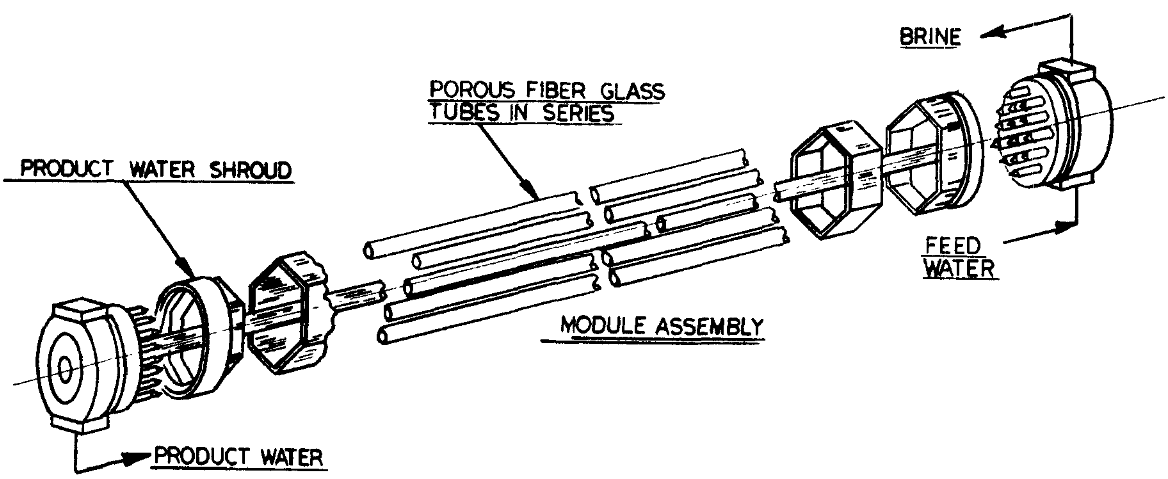
The development of reverse osmosis membranes has been significant during the last decade. There are three types of reverse osmosis systems commercially available; they are the hollow fiber, spiral-wound, tubular and membranes (Figures 18.1-1, 18.1-2, 18.1-3). Membrane construction centers around the use of cellulose acetate.




HOLLOW FIBER MODULE
Figure 18.1-1




SPIRAL WOUND MEMBRANE
Figure 18.1-2

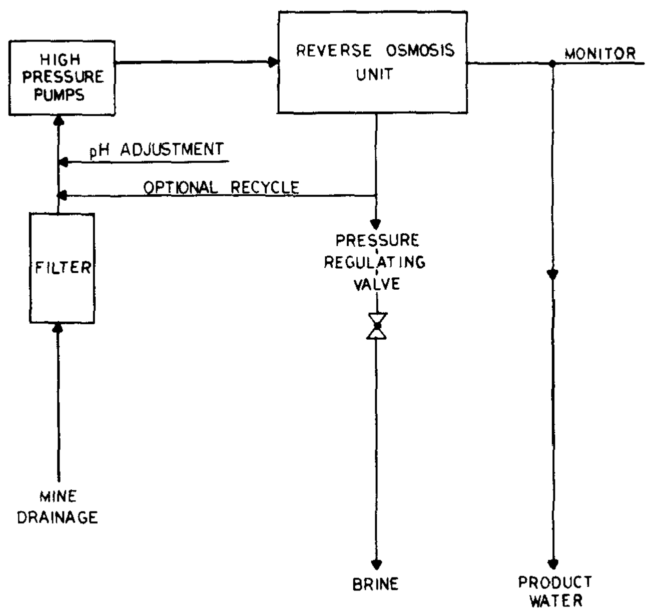



TUBULAR RO MODULE CONFIGURATION
Figure 18.1-3

## 18.2 REVERSE OSMOSIS PROCESS

### DESCRIPTION

The reverse osmosis process has been studied for use in treating acid mine drainage by the Federal Government. Studies were conducted using the spiral wound, tubular, and hollow fiber membranes in 37.85 cubic meter per day (10,000 gpd) test units. Mine drainage was first filtered to remove suspended solids and then processed through the test units at 600 psi operating pressures. Brine from the units was partially recycled to increase the feed water dissolved solids concentration and increase the product water output. The flowsheet for this system is shown in Figure 18.2-1.




FLOW DIAGRAM OF THE REVERSE OSMOSIS SYSTEM USED IN TREATING ACID MINE DRAINAGE (59,132,191)

Figure 18.2-1

## EVALUATION

These studies demonstrated that the reverse osmosis process is highly effective in removing nearly all of the dissolved solids in acid mine drainage. Recoveries of 80% to 90% of the feed water volumes were obtained.

Problems with membrane module fouling occurred from calcium sulfate formation but this could be flushed from the units by operating at lower pressures for a short period. Iron fouling occurred in one test but was prevented in later studies by lowering the pH of the feed water to less than 3.0. Acid mine drainages containing both ferric and ferrous iron forms were successfully processed. Mine drainage containing high concentrations of dissolved solids including sulfates, caused operating problems with excess calcium sulfate formation and could not be processed. Biological oxidation of ferrous iron was prevented by ultraviolet disinfection. There was no advantage to first treating the raw water to remove the iron, acidity, and other parameters.

Product water from the unit usually contained less than 70 mg/l of dissolved solids. Typical quality of the product water is given in Table 18.2-1.

Water of this quality; however, is not acceptable for potable uses due to its pH, acidity, iron and manganese content. Further treatment by chemical neutralization, coagulation, filtration and disinfection would produce a potable quality water.

The brine or reject water produced when processing acid mine drainage presents a disposal problem. In the tests conducted, brine volume was usually about 10% to 15% of the raw water feed. This results in an increase of 8 to 12 times in the concentrations of the various ions that were present in the raw water. Methods for disposal of the brine would include the Neutralization Processes discussed in Section 13.0, Evaporation Ponds - Section 5.3, Deep Well Injection - Section 5.5, and the Neutrolosis Process - Section 18.3.

TABLE 18.2-1
TYPICAL PRODUCT WATER QUALITY
BY REVERSE OSMOSIS SYSTEMS*
TREATING ACID MINE DRAINAGE

| Parameter** | Raw Water Quality | Product Water Quality |
|---|---|---|
| pH | 3.1 - 3.4 | 4.2 - 4.4 |
| Specific Conductance | 1000 - 2000 | 17 - 46 |
| Acidity | 210 - 460 | 32 - 46 |
| Calcium | 125 - 260 | 0.4 - 2.2 |
| Magnesium | 92 - 170 | 0.3 - 1.4 |
| Iron, total | 77 - 110 | 0.4 - 1.2 |
| Iron, ferrous | 61 - 71 | 0.3 - 1.0 |
| Aluminum | 12 - 15 | 0.2 - 1.0 |
| Manganese | 14 - 43 | 0.1 - 0.5 |
| Sulfate | 660 - 1340 | 0.9 - 4.6 |

* Synopsis of tests conducted on spiral wound, tubular, and hollow fiber membrane systems.

** All units are in mg/l, except specific conductance ($\mu$ mhos), and pH.

## COSTS

Actual costs for treatment of acid mine drainage are not available. Numerous studies and demonstration plants have been completed by the Office of Saline Water on the desalting of brackish and saline waters. Cost information available from these sources can be applied to estimating capital and operating costs for treating acid mine drainage. In the tests conducted on mine drainage, product water output was about one-third less than the output in processing sea water. Consequently, the capital cost estimating figures presented here have been increased 50% to compensate for this. Capital costs will vary from 18 to 28 cents per liter per day ($0.68 to $1.05/gpd) for a plant capacity of 3785 cubic meters per day (1.0 mgd). Operating costs for plants of this size will range from 13.2 to 18.5 cents per cubic meter treated (50 to 70 cents/1000 gals.). When processing mine drainage, the cost for brine disposal and final treatment of the product water must also be included.

REFERENCES

37, 59, 76, 99, 103, 132, 133, 191, 192, 193

## 18.3 NEUTROLOSIS PROCESS

### DESCRIPTION

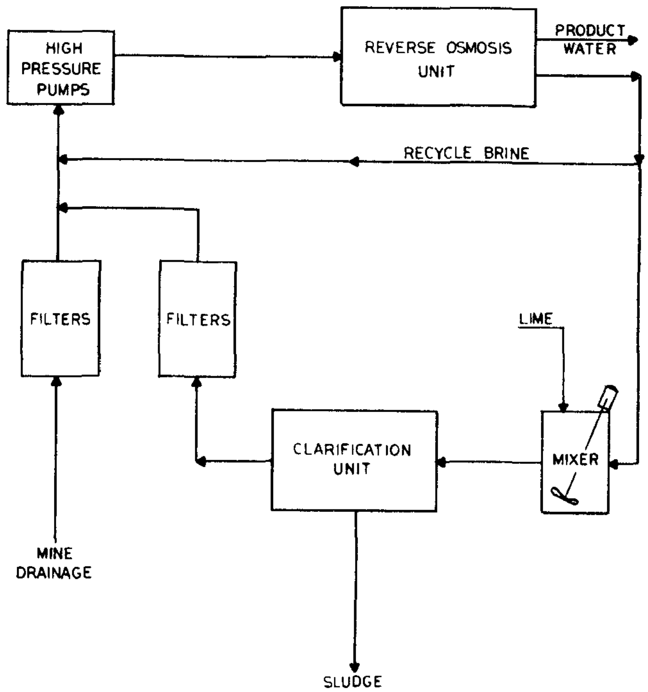
During evaluation of the reverse osmosis process in treating acid mine drainage, methods were investigated for the economical treatment of the reject water or brine. This would amount to 10% to 15% of the volume of raw water processed, and would contain an 8 to 12 times increase in the concentration of the raw water's dissolved solids. The treatment methods considered centered around the neutralization processes. As a result the Neutrolosis Process was developed.

The Neutrolosis Process consists simply of treating the brine from the reverse osmosis unit by a conventional neutralization process (Section 15.2), and returning the clarified treated water to the reverse osmosis unit's feed stream. As a result the Neutrolosis Process produces product water, and sludge. A flow sheet for this process is shown on Figure 18.3-1.

The mine drainage treated by this neutrolosis pilot plant contained iron mostly in the ferric form. In neutralizing the resulting brine, the pH was raised to 4.5, at which point most of the iron and aluminum was removed. To control solids formation in the reverse osmosis unit, the pH is adjusted to less than 4.0. Therefore, it is an advantage to have the treated brine water at a pH as low as possible. When ferrous iron is dominant in the raw mine water and the brine, it will be necessary to raise the pH much higher for treatment. Consequently, additional acid will have to be added to this treated water to maintain the pH below 4.0 in the raw water feed stream. Continued recycle of the treated brine may cause the dissolved solids to increase to a point where a periodic blowdown may be required. Dissolved solids at these levels are not expected to have an affect on the operation of the reverse osmosis unit.

The sludge produced by the Neutrolosis Process consists mostly of ferric hydroxide and calcium sulfate. The sludge volume was about

1% of the raw water feed volume.




FLOW DIAGRAM OF THE NEUTROLOSIS PROCESS (76)
Figure 18.3-1

## COSTS

There is no cost information available for the construction or operation of a system using the Neutrolosis Process. Estimates can be made using the data presented in Sections 15.2 and 18.1.

## REFERENCES

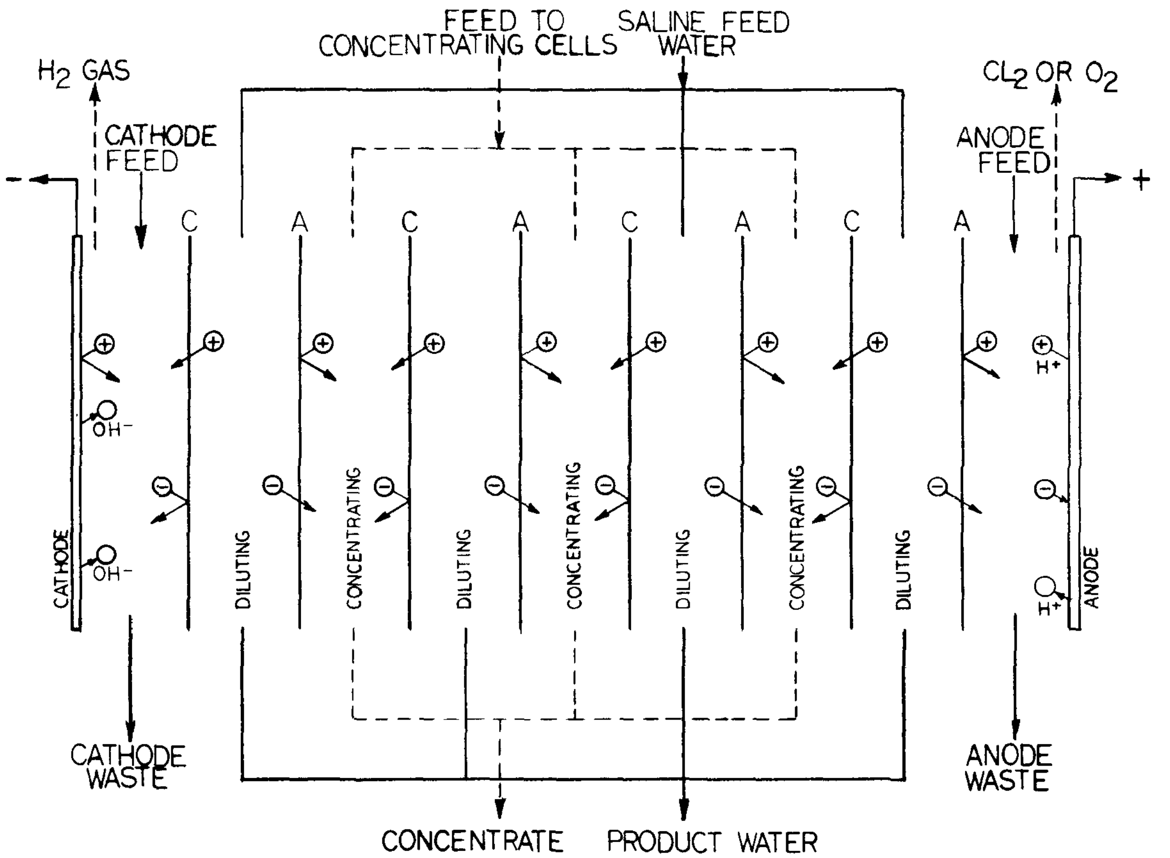
37, 59, 76, 132, 133, 192

# 19.0

# ELECTRODIALYSIS

## 19.1 METHOD DISCUSSION

Electrodialysis is a modern process that can be used to substantially reduce the dissolved solids in brackish water. An electrodialysis unit consists of a number of narrow compartments separated by closely spaced membranes. Each compartment is bound by both cation and anion membranes as illustrated in Figure 19.1-1. Positive and negative electrodes are located at opposite ends of the unit. The solution being processed fills the channels between the membranes and when the electrodes are energized, the ions in the solution migrate through the channels. Cations pass through the cation membranes and anions through the anion membranes. As a result, channels of low dissolved solids water and brine water are developed.




ELECTRODIALYSIS STACK

Figure 19.1-1

Bench scale studies have been performed on acid mine drainage by the Environmental Protection Agency at Norton, West Virginia. It was found that the cation membranes quickly fouled with ferric iron. Further tests on mine drainage that had first been treated by coagulation and filtration to remove the iron were successful.

At this time, insufficient information is available to judge the reliability or costs of acid mine drainage treatment by electrodialysis. Essentially no testing has been performed within the past four years while progress has been made in the development and operation of the process for producing water of low dissolved solids.

REFERENCES

37, 129, 139

# 20.0

# ION EXCHANGE

# PROCESSES

## 20.1 METHOD DISCUSSION

Ion exchange in water treatment can be defined as the reversible interchange of ions between a solid medium and the aqueous solution. To be effective, the solid ion exchange medium must contain ions of its own, be insoluble in water, and have a porous structure for the free passage of the water molecules. Within the solution and the ion-exchange medium, a charge balance or electroneutrality must be maintained; i.e., the number of charges, not the number of ions, must stay constant. Ion exchange materials usually have a preference for multivalent ions, therefore, they tend to exchange their monovalent ions. This reaction can be reversed by increasing the concentration of monovalent ions. Thus, a means exists to regenerate the ion exchange material once its capacity to exchange ions has been depleted.

The most common ion exchange use is the softening of "hard" or mineral-bearing water for domestic or commercial purposes. The hardness in water is attributed to its calcium and magnesium content. Initially, the ion exchange material is charged with monovalent cations, usually sodium. The hard water is passed through a bed of ion exchange material and the divalent calcium and magnesium cations are exchanged for sodium ions. Ion exchange materials tend to form stable compounds through this exchange principle. When more than one type of cation is available, the material will have an affinity for certain ones more than others.

The earliest ion exchange materials were either natural or synthetic zeolites - mineral produced from mixtures of aluminum salts and silicates. In the 1930's plastic materials called resins were developed which expanded the applications of ion (cation) exchange. In 1949, an anion exchange resin was developed which enabled the process to be used for total demineralization of water. In the present day technology of ion exchange, the resins available can be classified as strong-acid cation, weak-acid cation, strong-base anion, and weak-base anion types. The affinity or selectivity for the various ions each type of resin will remove is given in Table 20.1-1.

TABLE 20.1-1
TYPICAL ION SELECTIVITY
MODERN ION EXCHANGE RESINS

| ION EXCHANGE RESIN | RESIN ION SELECTIVITY DECREASING ORDER OF PREFERENCE |
|---|---|
| Strong-Acid Cation (Sulfonic Acid Type) | $Ba^{++} > Ag^{+} > Pb^{++} > Hg^{++} > Sr^{++} > Ca^{++} > Cu^{+} > Ni^{++} > Cd^{++} > Zn^{++} > Fe^{++} > Mg^{++} > Mn^{++} > K^{+} > Na^{+} > H^{+}$ |
| Weak-Acid Cation (Carboxylic Acid Type) | $H^{+} > Cu^{++} > Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ |
| Strong-Base Anion (Quaternary Ammonium - Type I) | $I^{-} > HSO_4^{-} > NO_3^{-} > Br^{-} > CN^{-} > HSO_3^{-} > NO_2^{-} > Cl^{-} > HCO_3^{-} > OH^{-} > F^{-}$ |
| Weak-Base Anion | $OH^{-} > SO_4^{--} > CrO_4^{--} > NO_3^{-} > PO_4^{---} > I^{-} > Br^{-} > Cl^{-} > F^{-}$ |

In water treatment applications, whether for softening, demineralization or for specific ion removal, the different ion exchange resins are generally used as follows:

Strong-Acid Cation Resins:

Sodium Form - for removal of hardness cations, namely calcium and magnesium.
Hydrogen (acid) Form - for removal of all cations.

Weak-Acid Cation Resins:

Hydrogen (acid) Form - for removal of cations associated with alkaline anions. Hardness cations associated with bicarbonate alkalinity are removed, whereas cations associates with chloride or sulfate anions are not.

Strong-Base Anion Resins:

Strong Base Form - for removal of all anions, although carbonic acid is formed in total demineralization. This can be removed physically be decarbonation.

Weak-Base Cation Resions:

Weak Base Form - efficiently removes entire strong acid molecules, e.g., hydrochloric acid ($HCl$) or sulfuric acid ($H_2SO_4$).

Combinations of the available resins have been used in systems for treatment of different waters for specific purposes. The applications of these systems to the treatment of (acid) mine drainage has been studied mainly to produce potable water where a reduction in the total dissolved solids is required. These systems include: (1) the Desal process; (2) the Sul-biSul process; (3) the Modified Desal process; and (4) the Two Resin system. Each of these systems has been studied in pilot sized laboratory units, and three have been evaluated in the field in larger capacity systems. From these investigations it has been concluded that ion exchange processes can be used to demineralize mine drainage and produce water with a quality acceptable for potable use.

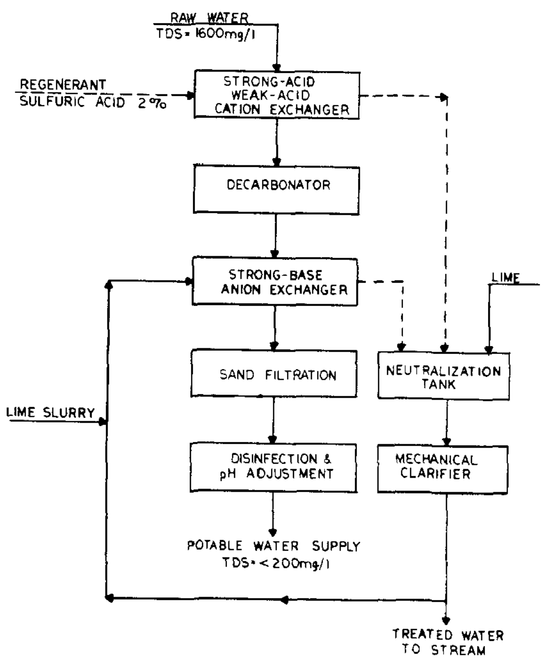
REFERENCES

26, 52, 103, 156, 158, 159, 160

## 20.2 SUL-BISUL PROCESS

### DESCRIPTION

The Sul-biSul Process was developed by the Nalco Chemical Company but is now assigned to the Dow Chemical Company. The process employs a two or three bed system. Cations are removed by a strong-acid resin in the hydrogen form, or by a combination of weak-acid and strong-acid resins. A strong-base anion resin operates in the sulfate to bisulfate cycle and removes both sulfate and hydrogen (acid) ions during the exchange reaction. Following this, the effluent water is decarbonated to remove carbon dioxide formed in the process. A flow diagram for the Sul-biSul Process when used in a potable water process is shown in Figure 20.2-1. Filtration of the Sul-biSul Process effluent is provided because of State Health Regulations.




SUL-BISUL CONTINUOUS ION EXCHANGE FLOWSHEET
POTABLE WATER TREATMENT SYSTEM
SMITH TOWNSHIP, PENNSYLVANIA (195)
Figure 20.2-1

Regeneration of the cation exchange bed is accomplished with either hydrocholoric or sulfuric acid. The anion bed regeneration process is novel; the bisulfate anions are converted back to the sulfate form by the feed water. The addition of lime slurry to the regenerant will speed this part of the process.

## EVALUATION

The Sul-biSul Process can be used to demineralize brackish water containing predominantly sulfate anions. This process will be used to treat mine drainage to produce potable water. The process can be applied to waters with a dissolved solids content of up to 3000 mg/l. The raw water should have an alkalinity content of about 10 per cent of the total anion content with a sulfate to chloride ion ratio of at least ten to one. The process is especially suited to alkaline waters containing calcium sulfate such as those contaminated by mine drainage.

Limitations to the process center around the anion exchange resin's low exchange capacity and its inefficient method of regeneration. The exhausted anion resin can be regenerated by the raw water itself; however, this requires a considerable volume of water and takes a significant length of time if the sulfate content is low. The addition of a cheap alkali such as lime is reported to improve the regeneration; however, a recent study showed poor results. One problem is the requirement for disposal of this large volume of regenerants.

The Sul-biSul Process has been demonstrated as a process that will demineralize brackish waters containing high sulfate concentrations. The process is to be used at Smith Township, Pennsylvania, to produce a potable water from a stream contaminated by mine drainage. The typical raw and finished water quality projected for this plant is given in Table 20.2-1.

TABLE 20.2-1
TYPICAL RAW AND FINISHED WATER QUALITY
SUL-BISUL PROCESS AT SMITH TOWNSHIP, PENNSYLVANIA

| Parameter | AVERAGE QUALITY * Raw Water | Finished Water |
|---|---|---|
| pH | 6.5 - 8.4 | 8.0 |
| Alkalinity, mg/l | 76 | 10 - 30 |
| Dissolved Solids, mg/l | 1500 - 2000 | 300 |
| Sulfates, mg/l | 400 - 1300 | 50 - 100 |
| Hardness, mg/l | 1600 | < 150 |
| Chlorides, mg/l | 16 | 2 |

COSTS

Cost data for the Sul-biSul Process is limited to the few studies and one plant that has been constructed. The Smith Township, Pennsylvania plant was recently constructed with a capacity to treat 1893 cubic meters a day (0.5 mgd) at a capital cost of $828,000. Operating costs are not available as there are start-up problems with the continuous ion exchange units. Projected operating costs were estimated to be in the range of 10 to 13 cents per cubic meter (40 to 50 cents per 1000 gallons).

REFERENCES

20, 26, 83, 103, 180, 195

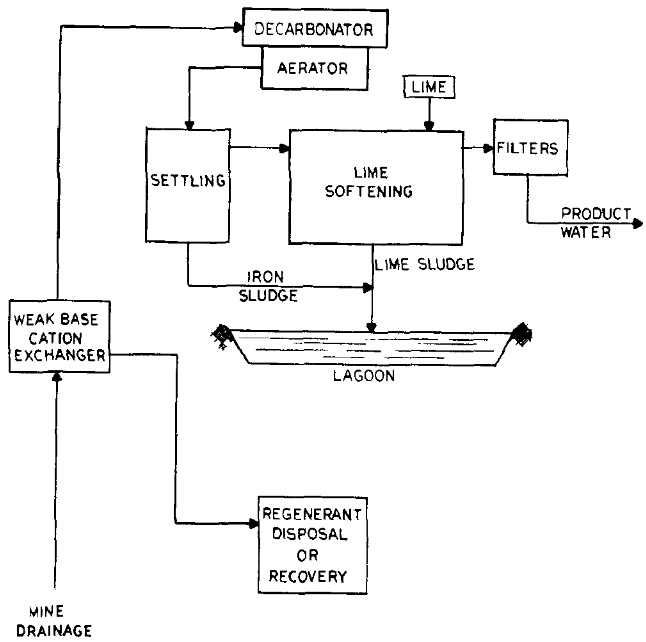
## 20.3 DESAL AND MODIFIED DESAL PROCESSES

### DESCRIPTION

The Desal Process employs a three-bed system consisting of a weak-base cation resin in the bicarbonate form, a weak-acid cation resin in the hydrogen form, and another weak-base anion resin, but in the free base form. In the first bed, anions are removed and replaced with bicarbonate ions. Cations are removed in the second unit and replaced by hydrogen ions. In the third bed, carbonic acid is removed by hydroxide ions which converts the resin to the bicarbonate form. In practice, when the system is regenerated, the flow is reversed and the third bed becomes the first.

The Desal Process is ideally suited to saline waters which are alkaline and contain little iron. Most metallic salts are converted into soluble bicarbonates and do not precipitate in the resin beds; however, ferric iron cannot be tolerated. These salts must then be removed by coagulation and sedimentation techniques following this ion exchange process. Regeneration of the beds is very efficient.

The Modified Desal Process is an adaption of the Desal Process for use in treating acid mine drainage. In the Modified Desal Process only the first step of the Desal Process is employed; i.e., the use of a weak base anion resin in the bicarbonate form. This resin effectively removes the sulfate anion as well as any free mineral acidity. The effluent water is then aerated to remove carbon dioxide gas, treated with lime to remove the metallic salts, and filtered as is normally required for producing potable water. Of interest is that the calcium and magnesium are in the bicarbonate form which enables them to be removed as insoluble compounds through the lime softening process. A flow sheet for the Modified Desal Process appears in Figure 20.3-1.




**MODIFIED DESAL PROCESS FLOW DIAGRAM**
**POTABLE WATER TREATMENT SYSTEM**
**PHILIPSBURG, PENNSYLVANIA (24,136)**
**Figure 20.3-1**

## EVALUATION

The Desal Process has inherent problems if considered for treating acid mine drainage. The economics of the process lie in the recovery of carbon dioxide for use as a regenerant. The process also requires alkaline waters with little iron content. The process has been successfully used to produce potable water where these conditions were met. In general, the process is not applicable to the treatment of acid mine drainage.

The Modified Desal Process uses the first principle of the Desal Process, the removal of the sulfate ion by a weak base anion resin in the bicarbonate form. This resin also removes free mineral acidity. The presence of iron in the ferric form may present fouling problems through the formation of insoluble precipitates in the anion bed. Product water quality from laboratory tests on the Modified Desal Process have been summarized and are presented on Table 20.3-1.

TABLE 20.3-1
TYPICAL WATER QUALITY
MODIFIED DESAL PROCESS

| Parameter* | Raw Mine Drainage | Weak Base Effluent | Final Effluent |
|---|---|---|---|
| pH | 2 - 4 | 6 - 7 | 8 - 9 |
| Alkalinity | 0 | 600 | 25 - 50 |
| Acidity, free | 600 | 0 | 0 |
| Iron, ferrous | 180 | 100 | 0 |
| Iron, total | 200 | 130 | <0.1 |
| Calcium | 180 | 180 | 15 - 25 |
| Magnesium | 30 | 30 | 10 - 20 |
| Manganese | 8 | 8 | <0.05 |
| Aluminum | 15 | 5 | 0 |
| Sulfate | 1500 | 100 | 75 |

*All results expressed in mg/l, except pH.

## COSTS

Some cost information is available for the Modified Desal Process. These are incomplete estimated costs, although the Commonwealth of Pennsylvania has undertaken the construction of a potable water production facility utilizing this process at Hawk Run near Philipsburg. This plant has had numerous start-up problems and is not in operation. The Hawk Run plant was designed to treat 1893 cubic meters a day (0.5 mgd) at a cost of $2,643,000. Operating costs are not available.

A study by the Culligan International Company provided capital cost estimates for unerected plants as follows:

| Capacity, $m^3$/day | Equipment Costs |
|---|---|
| 378.5 (0.1 mgd) | $156,000 |
| 1892.5 (0.5 mgd) | $323,000 |
| 3785.0 (1.0 mgd) | $465,000 |

The chemical costs for producing water by this process were estimated at 13 cents a cubic meter (48 cents per 1000 gallons).

## REFERENCES

20, 24, 83, 103, 127, 136

## 20.4 TWO RESIN SYSTEM

### DESCRIPTION

In a study by the Culligan International Company, a standard two resin system was investigated. In the first step of this system, acid mine drainage is passed through a strong-acid cation resin in the hydrogen form for removal of metallic cations. The water is then passed through a weak-base anion resin in the free base (hydroxide) form for removal of the sulfate anions and the free mineral acidity. The demineralized water is then processed through a standard coagulation-filtration process for the production of potable water.

### EVALUATION

The study cited was a laboratory investigation conducted on synthetic acid mine drainage. The system showed reasonable success although there appeared to be a potential problem with ferrous iron fouling in the cation bed. Hydrochloric acid was found to be a better regenerant than sulfuric acid, but its higher cost (45-60%) and problems with the chlorides in the spent solution discounted its use. The process significantly reduced cations and anions in the two beds, but chemical coagulation and filtration are required to reduce the iron and manganese to levels acceptable for potable use. Based on the chemical costs presented, the Two Resin Process appears to have higher operating costs than either the Modified Desal or Sul-biSul Processes.

### COSTS

The study conducted by Culligan in which this process was proposed presented chemical costs of 17 cents per cubic meter (63 cents per 1000 gallons). This did not include the chemical costs required for treatment of the spent regenerants. If hydrochloric acid is used to regenerate the cation unit, the chemical costs would be about 21 cents per cubic meter (78 cents per 1000 gallons).

REFERENCES

83, 156, 158, 160

# 21.0

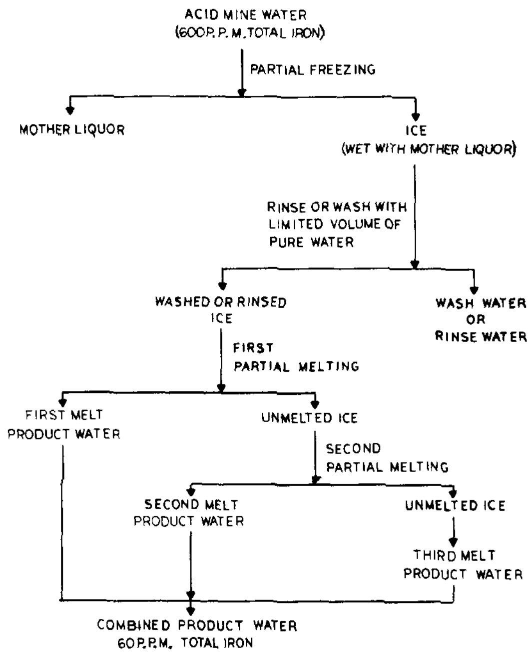
# FREEZING

# (CRYSTALLIZATION)

## 21.1 METHOD DISCUSSION

### DESCRIPTION

As mineralized water freezes, relatively fresh water ice crystals are formed, and the dissolved impurities have a tendency to remain in solution and concentrate. When the ice formed in this process is separated, washed and melted, fresh water is produced. This freezing process can be accomplished by two techniques: the freeze method; or the gas hydration method. Applied Science Laboratories, Inc. conducted a study of freezing techniques in 1971 which considered the effects of oxidation, reduction in ion concentrations, rates of freezing, effects of storage and other significant parameters. Reductions of more than 85% of the various metal and acid components were noted with little or no oxidation of ferrous iron. A flow diagram for the freezing process investigated in this study is presented on Figure 21.1-1.




**FLOW DIAGRAM FOR PARTIAL FREEZING OF ACID MINE DRAINAGE**

**Figure 21.1-1**

## EVALUATION

Considerable studies have been conducted on the purification of brackish water by freezing. Very little has been accomplished on the treatment of mine drainage by this process. A distinct energy advantage exists with this process because freezing (heat of fusion) requires approximately 1/6 of the energy required by the heat of vaporization. The freezing process appears to be technically feasible for mine drainage treatment but to date the method has not been demonstrated.

## COSTS

At this time, insufficient information exists on the economics of the freezing technique for mine drainage treatment. In 1966 Schroeder and Marchello estimated the costs of treating mine drainage by direct freezing as follows:

WATER COSTS PER 3.78 $m^3$ (1000 GALLONS)

| $m^3$/D | MGD | Direct Freezing |
|---|---|---|
| 378.5 | 0.1 | $3.10 |
| 3,785 | 1.0 | $1.32 |
| 37,850 | 10 | $0.85 |
| 378,500 | 100 | $0.68 |

## REFERENCES

5, 71, 139

# 22.0

# IRON

# OXIDATION

## 22.1 METHOD DISCUSSION

Many minerals that are mined occur with or adjacent to other minerals known as pyrites or iron sulfides. The exposure of these iron sulfides to the atmosphere and moisture causes them to oxidize to an iron salt, namely ferrous sulfate. These salts then dissolve into ground or surface waters forming mine drainage. If there is an over-bundance of these salts and little alkalinity available in the water, the mine drainage will be acid. Iron present in the mine drainage is as serious a pollutant as the acidity. The iron compounds coat the bottom of streams, leaving them uninhabitable for aquatic life.

As mine drainage is formed, iron is first present in the ferrous form. This form of iron is very soluble but will precipitate as a hydroxide as the water becomes alkaline. Minimum solubility occurs in a pH range of 9.3 to 12.0.

As the water becomes alkaline, ferrous iron will oxidize to the ferric form. This oxidation is dependent on the pH of the water, and is very slow at pH's less than 4.0, slow in the range of 4.0 to 6.0, moderate in the 6.0 to 8.0 range, and proceeds quickly above this point. Ferric iron is much less soluble than ferrous iron, and will precipitate as the hydroxide at a pH of 5.0 with minimum solubility at a pH of 8.0.

In a mine drainage treatment system, such as any of the chemical neutralization processes, it is most advantageous to oxidize any ferrous iron present to the ferric form so it can be removed as an insoluble hydroxide at near-neutral pH's. A number of methods are available to accomplish this oxidation process, and these are discussed in the following sections.

## 22.2 AERATION METHODS

### DESCRIPTION

Ferrous iron in mine drainage can be oxidized to the ferric form in the presence of oxygen. This oxidation is pH dependent with the reaction proceedingly rapidly at pH's above 8.0. In chemical neutralization systems, this pH requirement can be maintained through the addition of a suitable alkali. The oxidation of iron then becomes dependent on the availability of oxygen. The oxidation of ferrous iron occurs through the reaction:

$$4\ FeSO_4 + O_2 + 10\ H_2O \rightarrow 4\ Fe(OH)_3 + 4\ H_2SO_4.$$

In this reaction, the theoretical requirement for oxidation is one part of oxygen for seven parts of ferrous iron.

Oxygen has a low solubility in water. For the oxidation reaction to proceed as quickly as possible, oxygen must be intermixed with the water. Vigorous aeration is the simplest method to accomplish this. It has been found that the oxidation reaction can be accomplished within a 15 to 30 minute period under the proper conditions of pH and excess oxygen.

### EVALUATION

The aeration of water to accomplish oxidation of ferrous iron is accomplished by either diffused or mechanical aeration equipment. This equipment is usually mounted in tanks with a depth of 3.05 to 4.57 meters (10 to 15 feet). The efficiency of oxygen transfer in the process can be calculated from many factors involved in the design of the unit. Efficiencies of 10% for diffused aeration, and 1.5 kg of oxygen per kilowatt-hour (2.5 lbs. oxygen per horsepower-hour) are presented as average design factors. For a diffused aeration system, one kilogram of ferrous iron (2.2 pounds) will require about 5.5 cubic meters ( 196 cubic feet) of air to accomplish the complete oxidation. For mechanical aeration, a system containing one kilogram (2.2 pounds) per hour of ferrous iron would require a 0.11 kilowatt (0.15 horsepower) unit to accomplish this oxidation.

## COSTS

The capital costs involved in an aeration system consist of the aeration basin, which is usually of earthen or concrete construction, and the mechanical equipment involved; e.g., blowers, diffusers, turbine units, etc. Capital costs are available from a number of sources, but these vary considerably. One source published in 1967 seems to provide the best guide for estimating purposes, and capital costs as a function of plant capacity are presented in Figure 22.2-1.

Operating costs are a function of the power consumption of the equipment and the maintenance required which should be minimal. Operating costs will vary from 10% to 20% of the total plant operating cost.

## REFERENCES

29, 57, 71, 81, 114, 143, 144, 162

CAPITAL COST ESTIMATE
AERATION EQUIPMENT
VS.
PLANT CAPACITY (29)

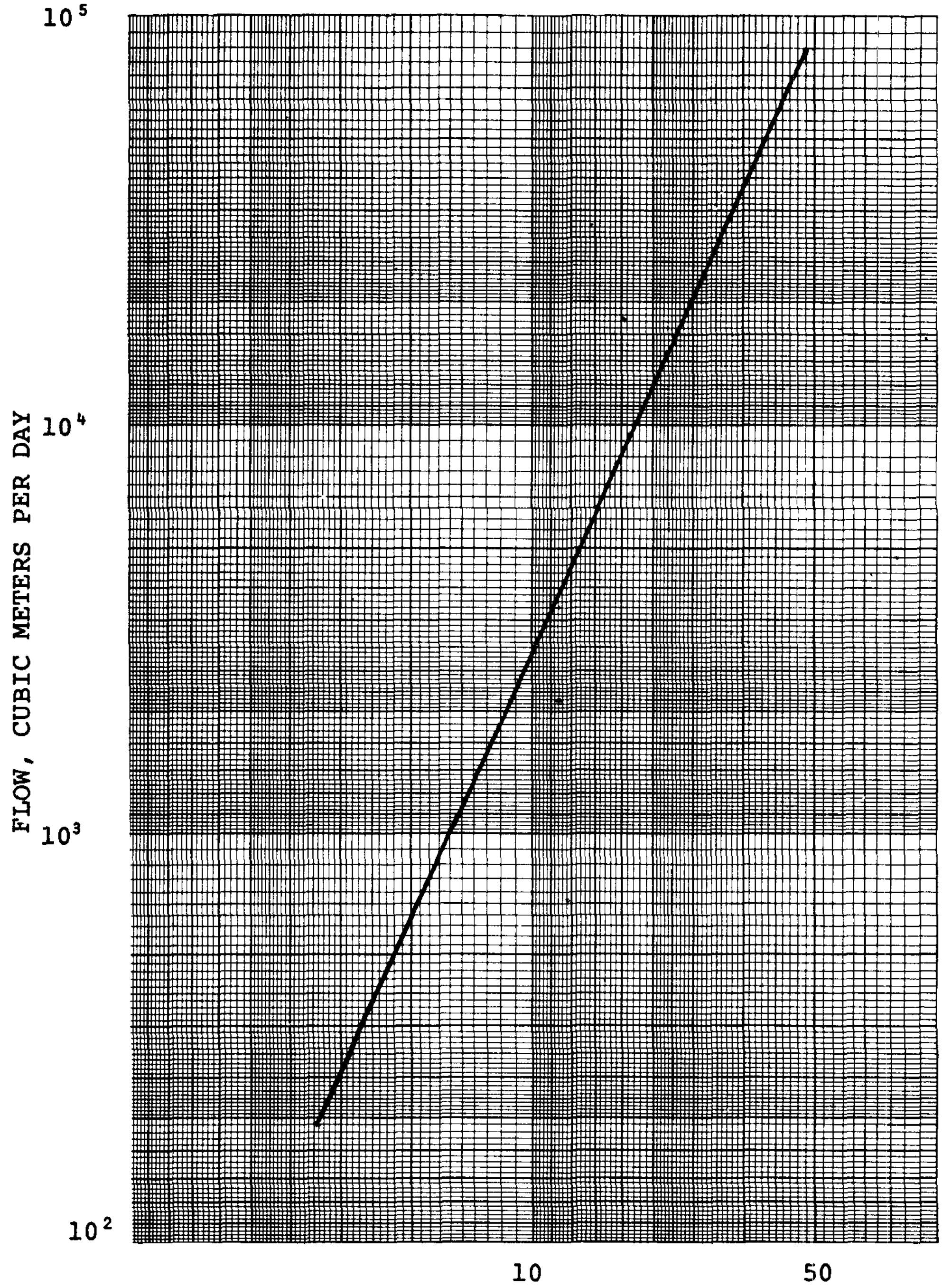



Figure 22.2-1

## 22.3 ELECTROCHEMICAL OXIDATION

### DESCRIPTION

The oxidation of ferrous iron to the ferrous form is an electrochemical reaction following established chemical and physical principals. The Tyco Laboratories, Inc. conducted a study using this method to oxidize ferrous iron under the acid conditions encountered in normal field conditions.

The oxidation studies were conducted, in a batch reactor on synthetic acid mine drainage with a pH = 2.7 and concentrations of ferrous iron varying from $2 \times 10^{-2}$M to $5 \times 10^{-4}$M in 0.02M sulfuric acid solutions. Carbon was selected as the anode, and type 316 stainless steel as the cathode. Ferrous iron was successfully oxidized at 95% levels at 0.8 Volt.

The method was then studied for use in various reactor configurations for field application. A packed bed reactor system was designed to determine capital and operating cost requirements.

The use of electrochemical means to oxidize ferrous iron was deemed successful and economical by the investigators. Oxidation of $>$ 95% of the ferrous iron was achieved under acid conditions. With this accomplished, it is then possible to achieve final neutralization of the acidity and precipitation of ferric iron in the drainage by using limestone in the conventional manner.

### COSTS

Modular electrical oxidation cells were used in estimating capital and operating costs for this process. Each of these units was estimated to cost $20,200 with a capacity to treat 22.7 cubic meters (6000 gallons) an hour at the 95% conversion level. For a 25 year life at 4½% interest rate, this amounts to a capacity cost of 0.69 cents per cubic meter (2.7 cents per 1000 gallons) treated.

Operating costs, including equipment depreciation, were estimated and found to be very comparable to conventional neutralization processes with hydrated lime.

REFERENCES

57, 164

## 22.4 OZONE OXIDATION

### DESCRIPTION

A study has been conducted by the Brookhaven National Laboratory of the U.S. Atomic Energy Commission on the use of ozone to oxidize ferrous iron to the ferric form. Ozone production was considered using electrical discharge, isotopic radiation and chemonuclear methods. Both on-site and central ozone production facilities were considered in preparing cost estimates for comparison to other processes. Following oxidation of ferrous iron by this method, limestone would be used for final neutralization of the acidity present in acid mine drainage.

### EVALUATION

The study concluded that ozone could be used to oxidize ferrous iron under acidic conditions to the ferric form. The process control is much simpler than with present aeration methods. The electric discharge method of ozone production gave the highest costs for on-site ozone production; however, this method is the only one for which production equipment is presently available.

### COSTS

Cost estimates were presented for the ozone-limestone system with comparison to a conventional treatment system using lime and forced-air aeration to accomplish the iron oxidation. For a 3785 cubic meter per day (1.0 mgd) plant, capital costs of $350,000 for the lime-air system and $280,000 for the on-site electrical discharge ozone-limestone facilities were presented. Operating costs were comparable at 4.5 cents per cubic meter (17 cents per 1000 gallons) treated.

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## V. GLOSSARY

Abatement (Mine Drainage Usage) - The lessening of pollution effects of mine drainage.

Aeration - The act of exposing to the action of air, such as, to mix or charge with air.

Alkaline - Having the qualities of a base; i.e., a pH above 7.0.

Alluvial - Describes earth material that has recently (geologic time scale) been deposited by moving water.

Angle of Repose - The angle which the sloping face of a bank of loose earth, or gravel, or other material makes with the horizontal.

Anions - An ion that moves, or that would move, toward an anode. Negative ion.

Aquifer - Stratum or zone below the surface of the earth capable of producing water as from a well.

Auger - Any drilling device in which the cuttings are mechanically and continuously removed from borehole without the use of fluids.

BCR - Abbreviation for Bituminous Coal Research, Inc., Monroeville, Pennsylvania.

Backfilling - The transfer of previously moved material back into an excavation such as a mine, ditch, or against a constructed object.

Bench - A level layer of earth or rock adjacent to a surface mine site.

Bentonite - A clay formed from the decomposition of volcanic ash. Also has great ability to absorb and adsorb water and to swell accordingly.

Bony - Rock that has a high carbon content - usually refers to dark colored coal mining waste material.

Bulkhead Seal - See illustration in Section 12.2.

Cation - An ion that moves, or that would move, toward a cathode. Positive ion.

Clarifier - A device for removing suspended solids.

Clay Seal - A barrier constructed of impermeable clay that stops the flow of water.

Cohesive Soil - A soil that when unconfined has considerable strength when air-dried and significant cohesion when submerged.

Colluvial - Describes gravity deposits of loose and incoherent material at the foot of slopes.

Daylighting - A term to define the procedure of exposing an entire underground mined area to remove all of the mineral underlying the surface.

Deep Mine - An underground mine.

Deep Well - A deep boring used for the disposal of waste materials to the underground strata to avoid contamination of higher ground waters.

Dissolved Solids - The difference between the total and suspended solids in water.

Dredging - The removal of material normally submerged in a body of water.

Drift - A deep mine entry driven directly into a horizontal or near horizontal mineral seam or vein when it outcrops or is exposed at the ground surface.

ENR - Abbreviation for Engineering News Record.

Ecosystem - A total organic community in a defined area or time frame.

Effluent - Any water flowing out of the ground or from an enclosure to the surface flow network.

Erosion - Processes whereby solids are removed from their original location on the land surface by hydraulic or wind action.

Evapo-transpiration - A collective term meaning the loss of water to the atmoshpere from both evaporation and transpiration by vegetation.

Flume - An open channel or conduit on a prepared grade.

Ground Water Table (or Level) - Upper surface of the underground zone of saturation.

Grout - A fluid mixture of cement, sand (or other additives) and water that can be poured or pumped easily.

Grout Curtain - Is created by inserting materials (usually cement) into rock units through boreholes to decrease their permeability.

Highwall - The exposed vertical or near vertical wall associated with a strip or area surface mine.

Homogeneous - Consisting throughout of identical or closely similar material whose proportions and properties do not vary.

Hydraulics - That branch of science or engineering which treats of water or other fluid in motion.

Hydrology - The science that relates to the water systems of the earth.

Hydroseeding - Dissemination of seed hydraulically in a water medium.

Impervious - Impenetrable. Does not allow fluid flow.

Infiltration - Water entering the ground water system through the land surface.

Leaching - The solution of the soluble fraction of a material by flowing water.

MSF Process - Abbreviation for Multi-stage Flash Evaporation Process.

mg/l - Abbreviation for milligrams per liter, which is a weight to volume ratio commonly used in water quality analysis. It expresses the weight in milligrams of a substance occurring in one liter of liquid.

Mulching - The addition of materials (usually organic) to the land surface to curtail erosion or retain soil moisture.

Neutralization - The process of adding an acid or alkaline material to waste water to adjust its pH to a neutral position.

Open Pit Mines - Mining facilities where the ratio of overburden to mineral is small.

Outcrop - The surface exposure of bedrock or strata.

Overburden - Nonsalable material that overlies a mineable mineral.

Oxidation - The removal of electrons from an ion or atom.

Permeability - The measure of the capacity for transmitting a fluid through the substance.

pH - The negative logarithm to the base ten of the hydrogen ion activity. pH 7 is considered neutral. Above 7 is basic - below 7 is acidic.

Photogrammetrics - The process of creating topographical mapping from stereo aerial photographs.

Pollution - Environmental degradation from man's activities.

Portal - The surface entrance to an underground mine.

Reclamation - The procedures by which a disturbed area can be reworked to make it productive, useful or aesthetically pleasing.

Regrading - The movement of earth over a surface or depression to change the shape of the land surface.

Riprap - Rough stone of various sizes placed compactly or irregularly to prevent erosion.

Runoff - That part of precipitation that flows over the land surface from the area upon which it falls.

Scarification - Decreasing the smoothness of the land surface.

Sediment - Solid material settled from suspension in a liquid medium.

Sludge - The precipitant or settled material from a wastewater.

Sludge Density - A measure of the weight of solids contained in the sludge in relation to total weight.

Spoil Material - The waste material removed from a mine facility that is not considered useful product.

Stratigraphy - The science of formation, composition, sequence and correlation of stratified rocks.

Strip Mine - A surface mine where the overburden is removed to expose the mineable material. Implies that there is a large amount of overburden with respect to the amount of mineable material.

Subdrain - A pervious backfilled trench containing a pipe or stone for the purpose of intercepting ground water or seepage.

Subsidence - The surface depression over an underground mine that has been created by subsurface caving.

Surface Mine - A mine facility that is generally conducted from the land surface. It does not have a mineral roof.

Suspended Solids - Sediment which is in suspension in water but which will physically settle out under quiescent conditions (as differentiated from dissolved material).

Tailings - Mineral refuse from a milling operation usually deposited from a water medium.

Terracing - The act of creating horizontal or near horizontal benches.

Transpiration - The normal loss of water vapor to the atmosphere from plants.

Underdrain - See subdrain.

Watershed - Surface region or area contributing to the supply of a stream or lake; drainage area, drainage basin, catchment area.

Weathering - Action of the weather elements in altering the color, texture, composition, or form of exposed objects.

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