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**A
REVIEW OF PROCEDURES
FOR SURFACE MINING AND RECLAMATION
IN AREAS WITH ACID.-PRODUCING
MATERIALS**

By

**J. G. Skousen, J. C. Sencindiver,
and R. M. Smith**

In Cooperation with
The West Virginia Surface Mine Drainage Task Force
The West Virginia University
Energy and Water Research Center
and
The West Virginia Mining and Reclamation Association

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COVER

The colors on this cover represent a standard pH color chart. The pH of the soil or water sample is approximated by matching the color of the sample when mixed with an appropriate indicator to the color chart.

Authors

*Jeffrey G. Skousen is extension specialist and assistant professor-Land Reclamation;
John C. Sencindiver is associate professor of Soil Science;
and Richard M. Smith is emeritus professor of Soil Science;
Division of Plant and Soil Sciences, College of Agriculture and Forestry,
West Virginia University, Morgantown, West Virginia.*

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Preface Table of Contents

The principles and guidelines in this report for acid mine drainage control are applicable primarily to surface mine operators in the Appalachian coal region. This report is based on experience and research by the West Virginia Surface Mine Drainage Task Force, the West Virginia Acid Mine Drainage Technical Advisory Committee, and other federal, state, and private agencies associated with coal mining and reclamation. Because every mine site is unique and requires special mining and reclamation procedures, specific recommendations for acid mine drainage control have not been made. This report is written to provide general information and emphasizes current research and new technology in order for operators to select appropriate procedures to limit acid mine drainage.

Acknowledgments

Grateful acknowledgment is expressed to the West Virginia Surface Mine Drainage Task Force and the WVU Energy and Water Research Center for funding this project, and for providing valuable advice during the preparation of this report. The authors thank the reviewers of the manuscript and recognize the ongoing contribution to acid mine drainage control and abatement by the West Virginia Surface Mine Drainage Task Force, and the West Virginia Mining and Reclamation Association, and the West Virginia Department of Energy. This document is published with the approval of the director of the West Virginia Agricultural and Forestry Experiment Station.

Disclaimer

Mention of trade names or commercial products does not constitute endorsement or recommendation by the authors, the Task Force, or the Energy and Water Research Center, but are included for information and convenience to the reader. This document is designed to provide a broad review of mining and reclamation procedures for reducing acid mine drainage. For details concerning specific techniques on individual sites, we request that you contact the persons listed that have expertise in that area. Because regulations vary from state to state, adoption of some techniques listed in this report may require approval by the local regulatory agency.

Introduction **Table of Contents**

In 1978, the director of the West Virginia Department of Natural Resources (DNR) appointed the Surface Mine Drainage Task Force (Task Force) to address the problem of acid mine drainage (AMD) associated with surface mining in several watersheds in Central West Virginia. Its members represent the coal mining industry, private consultants, West Virginia University, and the WVDNR Reclamation Division (now West Virginia Department of Energy, Division of Mines and Minerals). The Task Force was charged to define the AMD problem in these AMD-affected watersheds and outline procedures for control during and after mining. The Task Force developed a bulletin in 1979 entitled, "Suggested Guidelines for Method of Operation in Surface Mining of Areas with Potentially Acid-Producing Materials."

This bulletin defined several basic characteristics for which a mine site must be examined before mining and included consideration of-

1. ground and surface water,
2. overburden analysis,
3. topography and land use,
4. geology,
5. mining equipment, and
6. economic feasibility (Task Force, 1979).

The bulletin then identified specific techniques for handling surface water, ground water, and overburden during the mining process that would help control AMD, emphasizing procedures for:

1. accurately sampling and analyzing overburden to identify alkaline- or acid-producing materials,
2. mixing acid material with alkaline material or ameliorants for acid neutralization, and
3. strategically placing acid-producing materials in the backfill where air and water contact are minimized.

The bulletin represented state-of-the-art technology for the control of AMD and became the standard throughout Appalachia for mining activities that involved handling potentially acid-producing materials. Although the Task Force recognized that AMD problems were site-specific, application of the procedures presented in the bulletin during mining and reclamation was known to reduce AMD.

Prediction Methods

Accurate prediction of AMD requires a complete understanding of many components at a mine site. Three of the most important factors are:

1. overburden geochemistry,
2. the method and precision of overburden handling and placement in the backfill, and
3. the hydrology of the site.

The hydrology of a backfill and its effect on AMD is very complex, and research on the movement of water into and through a mine backfill has provided little information on how to control AMD. Overburden analysis and characterization can provide important information about overburden layers which are acid toxic, potentially acid-producing, neutral, potentially alkaline-producing, or alkaline. Identification of the chemical production potential of overburden layers aids in developing overburden handling and placement plans. It is then critical for each operator to carefully follow the overburden handling and placement prescription based on overburden characterization for his particular site. Prediction of the quality and quantity of AMD from a site is dependent upon these three factors.

Most of the work in AMD prediction has focused on methods which quantify the chemical production potential of overburden layers. Overburden analysis and characterization to predict overburden quality is not a new concept. The earliest studies on overburden characterization were probably developed in Germany during the 1950's (reported by Grube et al., 1973), and researchers in the US recognized the importance of overburden characterization as early as 1960 (Cornwell, 1966; May and Berg, 1966). Soon, the coal industry and state regulatory agencies acknowledged that information about the overburden in advance of mining was valuable in selecting more efficient mining equipment and mining methods, and also necessary in choosing overburden materials that would be useful as plant growth media.

2.1 ACID-BASE ACCOUNTING **Table of Contents**

Researchers under the direction of Dr. Richard M. Smith at West Virginia University developed a technique for overburden characterization in the late 1960's called Acid-Base Accounting (Grube et al., 1973; West Virginia University, 1971), which was adopted from similar studies used in Germany. During the ensuing years, Acid-Base Accounting became increasingly popular and commonly used as a method for overburden characterization. It is used in premining planning extensively in the Appalachian coal region, in the midwestern and western coal fields of the United States, and for overburden analysis in many other coal-producing countries (Canada, Germany, Poland, Russia, and Australia).

The objectives of Acid-Base Accounting are to provide a simple, relatively inexpensive, and consistent procedure for:

1. identifying toxic or potentially acid-producing materials,
2. identifying non-acid or calcareous materials that can be mixed with acid-producing material to neutralize the acid, and
3. identifying an alternative material in the overburden for placement on the surface for revegetation.

The first step of the Acid-Base Accounting procedure is to identify distinct horizons in an overburden column or highwall associated with the coal seam and to measure seven characteristics for each separate horizon (horizon thickness, rock type, fizz, color, percent total sulfur or percent pyritic sulfur, neutralization potential, and paste pH). Methods for identifying distinct horizons and techniques for collecting rock samples are presented in detail elsewhere (Sobek et al., 1978). Acid-Base Accounting is primarily based on three analytical measurements: paste pH, percent total sulfur or percent pyritic sulfur, and neutralization potential (Figure 1). The other four characteristics are useful in confirming analytical data and interpretation. (See the appendix for examples of Acid-Base Accounting and interpretations.)

There are several assumptions and limitations to consider when interpreting Acid-Base Accounting data (adapted from Perry, 1985):

1. The value for potential acidity and the value for neutralization potential represent maximum quantities from whole rock analysis. Complete reaction of all pyrite and bases probably does not occur in a mine backfill, and the total amount of acid or base which does result will be between the maximum acid-or alkaline-producing potential.
2. Sulfur exists in three chemical forms in coal-bearing rocks: sulfide sulfur, sulfate sulfur, and organic sulfur. Pyrites (mostly ferrous disulfides) are the dominant acid producing sulfur minerals. Total sulfur measurements generally overestimate pyritic mineral percentages because some sulfur usually exists as sulfate, organic, and trace mineral forms.
3. Acid-Base Accounting assumes concurrent weathering of pyrite and bases in the rock sample. Pyrite may oxidize faster or slower than alkaline material in the sample. Reaction rates of pyrite and alkaline material are not determined by this procedure.

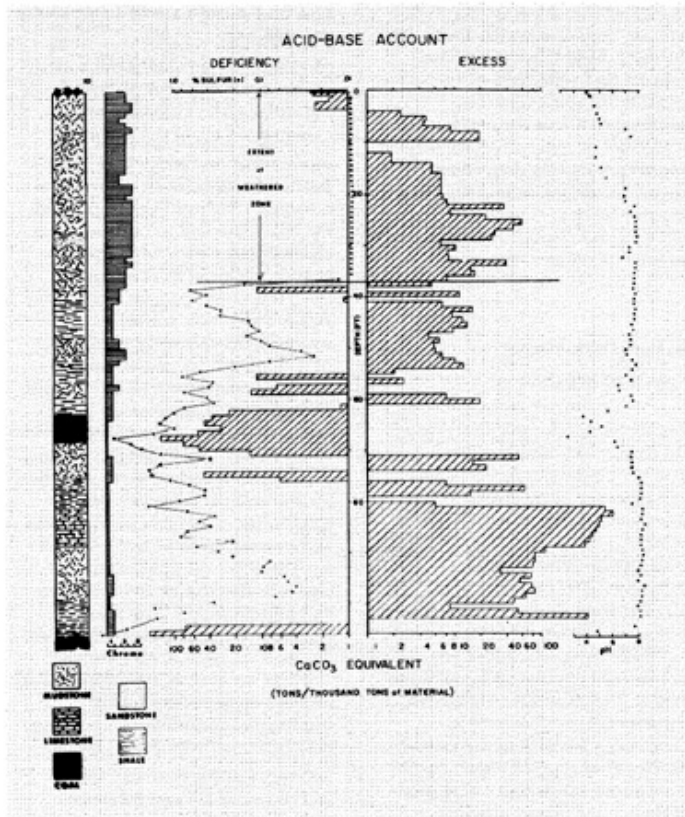


Figure 1: Graphic representation of overburden properties analyzed by Acid-Base Accounting. Rock type, color (chroma), percent total sulfur, deficient and excess alkalinity, and paste pH are shown for this Pittsburgh-Redstone overburden column.

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Figure 1: Graphic representation of overburden properties analyzed by Acid-Base Accounting. Rock type, color (chroma), percent total sulfur, deficient and excess alkalinity, and paste pH are shown for this Pittsburgh-Redstone overburden column.

Over the years, experience with the Acid-Base Accounting procedure has provided some broad recommendations. Generally, Acid-Base Accounting data which show an over-abundance of alkaline material in the overburden usually produce neutral or alkaline drainage. However, where the overburden shows the existence of pyritic sulfur and high values in the Maximum Needed column on the data sheet (Figure 2), AMD will undoubtedly occur unless the overburden is handled and treated to neutralize the excess acidity.

Experience over the last 15 years with Acid-Base Accounting has shown that layers which provide values greater than 5 tons/1000 tons in the Max Needed column (the column which represents excess acidity in the layer) produce acid, while values greater than 20 tons/1000 tons in the Excess column (the column which represents excess alkalinity in the layer) usually produce alkaline drainage. Layers which provide values

between 0 and 5 tons/ 1000 tons in the Max Needed column or less than 20 tons/ 1000 tons in the Excess column may produce alkaline or acid discharges. The layers with these low values in the Max Needed column or Excess column are those which require some other predictive method or analysis to ascertain the rock sample's chemical production potential. Where little or no pyritic sulfur exists (even with low amounts of alkalinity), little acid will be produced.

A common error when using Acid-Base Accounting as a predictive method of AMD production occurs when the Max Needed and Excess columns are summed together for the entire overburden above the coal (the Max Needed column representing a negative number and the Excess column representing a positive number). Even when volume adjustments are made for each horizon, summing the overburden column is an incorrect way to predict AMD using Acid-Base Accounting. Summing of the columns assumes thorough mixing of all overburden materials, uniform rates of weathering of all materials, and water contact throughout the backfill. These assumptions are not valid.

LAB DATE _____		SITE _____		NO. OF SAMPLES _____			
CaCO ₃ EQUIVALENT TONS/1000 TONS OF MATERIAL							
SAMPLE DEPTH NUMBER (FEET)	ROCK TYPE	FIZZ	COLOR	%S	MAX.	MAX.	PASTE pH
					FROM %S	AMT. NEEDED (pH 7) EXCESS	

Figure 2: Acid-Base Accounting reporting form.

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Figure 2: Acid-Base Accounting reporting form.

Acid-Base Accounting balances maximum potential acidity against total neutralizers in each overburden horizon sample. Even though the method has several assumptions which must be understood during interpretation, Acid-Base Accounting satisfies the need to identify which overburden horizons will or will not produce acid, and pinpoints those horizons which must be analyzed further. With accurate data and proper interpretation, practical mining and reclamation plans can be designed and implemented. In summation, Acid-Base Accounting is probably the fastest and easiest way to begin evaluation of overburden material but should be used within its limits, and in conjunction with other methods of overburden characterization and mining experience.

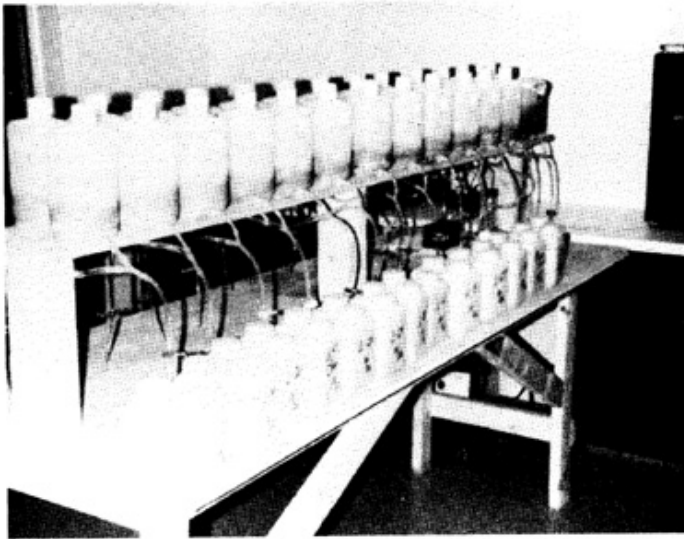
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2.2 LABORATORY LEACHING AND WEATHERING PROCEDURES

Leaching or weathering procedures were devised to predict the chemical responses of a rock to weathering conditions. The simulation tests are conducted over a predetermined length of time to estimate the rate of reaction or breakdown of minerals in the rock. Leaching methods consist of placing rock fragments or small laboratory-scaled overburden columns into water-tight containers, flushing or flooding the containers with water, and collecting and measuring the effluent for *pH*, total acidity, alkalinity, sulfate, iron, and other ionic concentrations (Figure 3). Different types of instruments or equipment may be used but the general idea and technique are the same.

A common leaching method is described in Sobek et al. (1978) and was derived from leaching methods developed by Hanna and Brant (1962), and Caruccio, (1967). This method places distinct rock types in a leaching chamber or humidity cell (made from plastic containers) which is periodically flooded with water. The leachate is drained from the chamber and analyzed, and the acid production versus time is plotted on a graph. After several cycles of flushing, rock weathering and acid generation can be estimated.



*Figure 3: A leaching test consists of placing rock fragments into a plastic container, flooding the container with water, then collecting and analyzing the leachate for *pH*, total acidity, alkalinity, iron and sulfate.*

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Figure 3: A leaching test consists of placing rock fragments into a plastic container, flooding the container with water, then collecting and analyzing the leachate for *pH*, total acidity, alkalinity, iron and sulfate.

A new laboratory leaching procedure was developed in West Virginia (Sturey et al., 1982) where various rock types are mixed, treated, and placed in columns to simulate the handling and placement of overburden in a backfill. Leaching the simulated backfill with acid water allows for accelerated pyrite oxidation and provides a small-scale model to help predict drainage quality. Due to the mixing of different rock types, individual rock responses to weathering cannot be evaluated; however, this method may simulate more accurately the processes within a backfill.

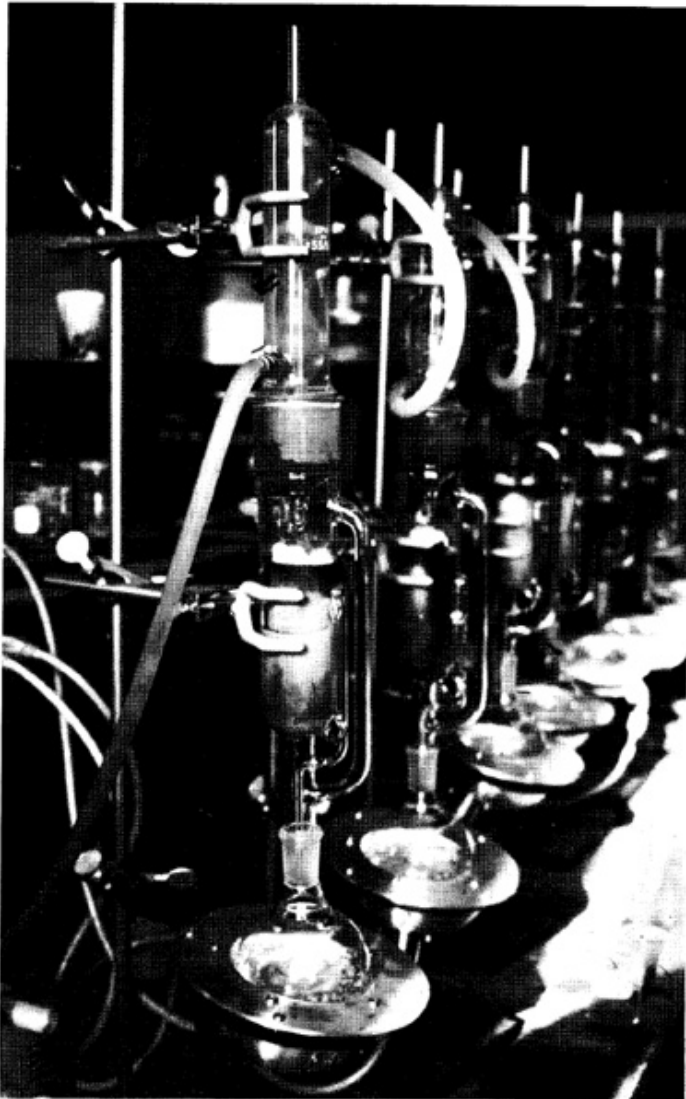
A laboratory method used for rock leaching and weathering is the Soxhlet Extractor (Henin and Pedro, 1965; Pedro, 1961; Renton and Hildalgo, 1973). In one Soxhlet method modified by Renton et al. (1984), a 100-g rock or coal sample is leached for 24 hours with 250 ml of water by constantly recycling the water through the sample during the leaching period (Figure 4). After the 24-hour period, the leachate is collected and measured for *pH*, total acidity, conductivity, and several elements. The sample is then placed in a drying oven at 105° C for two weeks and reoxidized. The procedure is repeated as many as five times to estimate the reaction rate and release of acidity or alkalinity contained in the rock sample.

The Soxhlet Extractor has also been modified by Sobek et al. (1982). This modification consists of moving the

extraction chamber away from the upward path of the refluxing solvent. Rocks analyzed by this weathering procedure showed wide variation in ionic products as time and temperature of the apparatus were increased. The researchers found that Soxhlet Extractors produced a faster and more accurate representation of water quality impacts than those obtained with the humidity cell (Sullivan and Sobek, 1982).

There are also assumptions which must be considered when interpreting data obtained from leaching/weathering procedures (adapted from Perry, 1985).

1. Laboratory leaching/weathering conditions are usually designed to provide maximum decomposition rates and levels of pyrite weathering which will probably not result under actual conditions.
2. Flushing cycles represented in the laboratory do not translate into weathering conditions in the field, and correlation between the laboratory results and the field is preliminary.
3. Results are different for each method and comparison of results between methods is difficult.



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Figure 4: The Soxhlet Extractor is a laboratory leaching method used to measure the rock sample's rate of weathering and oxidation.

Because of the assumptions associated with leaching tests, the amount of useful information on AMD production will vary from site to site. However, leaching and weathering procedures provide a method for measuring the rate of oxidation or weathering of overburden materials that cannot be determined by Acid-Base Accounting. One use of weathering tests is for evaluating overburden samples which, according to experience with Acid-Base Accounting, have low values in either the Max Needed or Excess columns. The weathering tests can provide an assessment of the reactivity of the overburden, and evaluate rates of pyrite

oxidation and acid generation that cannot be predicted with Acid-Base Accounting. If laboratory leaching tests are to be considered for widespread use in premining planning, it is necessary that leaching methods be standardized and calibrated to field conditions.

The US Bureau of Mines (Hammack, 1986) is developing a technique to measure the thermal decomposition of various rock types by evolved gas analysis (EGA) to estimate pyrite and carbonate reaction rates. Since each analysis requires 2 minutes, EGA provides a quick means of evaluating overburden samples that may affect water quality. Although this research is still preliminary, this method may offer some promise for further discrimination between acid-producing and nonacid-producing overburden samples.

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Several computer software programs are available to model hydrogeochemical systems and are designed for general application to coal mine drainage studies. The models usually contain two major features:

1. factors involved in pyrite oxidation and weathering, and
2. factors concerning movement of acid water out of the backfill.

A comprehensive computer model was developed by Jaynes and co-workers (1984) which predicts long-term pyrite oxidation under any series of conditions, and estimates the resulting leachate from the specified conditions. Major elements in this model include direct oxygen and ferric iron oxidation of pyrite, and calculation of bacterial-enhanced oxidation based on substrate energy availability and environmental conditions. Comparison of predicted values generated by the model to actual effluent values was not possible in the original study because a sufficiently complete data set was unavailable. However, simulations were run to test the sensitivity of the model, and the results indicated that key components of the model fell within values measured on mine sites.

Another type of modeling technique is called statistical prediction. Statistical prediction uses large data sets of overburden properties and effluent quality to generate relationships. The predictive equations give general relationships between rock types or certain rock properties and relate them to measured water quality values usually by regression analysis. The US Bureau of Mines (Erickson et al., 1985) is attempting to develop relationships based on Acid-Base Accounting data and leaching tests combined with information on mining and reclamation methods, geology, and hydrology.

In another method being developed, researchers (Renton et al., 1985; Sullivan et al., 1986) are sampling lithic units in the overburden that are commonly acid-producing and determining the acid production potential by Soxhlet Extractors. The location of the lithic units in the overburden (in relation to the coal seam) and the Soxhlet-measured water quality will be combined with rock properties to form a predictive model for premining planning.

Limitations of the modeling techniques include the following (adapted from Perry, 1985).

1. Large amounts of site-specific data are required to sufficiently describe the hydrogeochemical environment.
2. Widely ranging variables must be assigned an average value for implementation in the model.
3. Modeling does not presently reduce overburden sampling and water sampling during premining planning.
4. Summaries of large amounts of data may give only general relationships between rock properties and effluent quality and may still be too general for application to specific sites.
5. Correlation between predicted values and actual measurements in the field is limited.

Computer modeling and statistical prediction of hydrogeochemical systems are not commonly used by the coal industry in premining planning or in prediction of AMD. Despite the limitations and assumptions, modeling techniques are tools to help operators assess overburden impacts on water quality, and at this time should only be used in conjunction with other methods during premining planning. As more experience is acquired and more research is conducted, modeling techniques may become important in premining planning and eventually reduce the need for intensive sampling of the site.

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Sampling and Analytical Techniques

3.1 OVERBURDEN SAMPLING AND ANALYSIS [Table of Contents](#)

Premining analysis of soils, overburden, and coal pavement is required by regulation to ascertain the physical and chemical characteristics of the strata above and immediately below the coal seam. Rock cores are commonly used to sample the overburden and coal prior to mining. The number of rock cores necessary for overburden sampling on a particular site varies widely and depends on soils and geology of the area, name and number of coal seams to be mined, mining method, previous mining experience and knowledge in the area, current water quality in the area, and other factors.

In areas where acid-producing material is suspected, experience indicates that three cores in a triangular arrangement should be extracted for each 100 to 500 acres of the proposed permit area. If the three cores are similar in overburden characteristics, they probably represent the site and no other cores need to be taken. However, if one of the cores is widely divergent from the other two cores, then another one or two cores should be extracted.



Figure 5: Thin layers of dark gray or black material in the overburden should be sampled and analyzed separately to determine their acid-producing potential.

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Figure 5: *Thin layers of dark gray or black material in the overburden should be sampled and analyzed separately to determine their acid-producing potential.*

Where abrupt changes in overburden properties are known to occur, or in areas where knowledge and experience with the overburden is limited (particularly where acid-producing material is suspected), more than three cores may be necessary to evaluate the overburden. In areas where mining has demonstrated consistency in the overburden material, drilling and extracting rock cores for new, adjacent permits may be unnecessary. However, continued observation and monitoring of the overburden as mining progresses should take place and observed changes will indicate the need for additional overburden sampling. Because many factors enter into the frequency and spacing of rock cores needed to evaluate the overburden on a site, it must be emphasized that experience and knowledge of the proposed permit area is paramount. Depending on the shape of the permit area, all mining should be within 1 km of a properly sampled and analyzed rock core (Frost, 1981; Smith and Sobek, 1978).

Once the rock core is obtained, the entire column from below the coal seam to the soil is examined to distinguish differences between rock layers based on color, texture, hardness, and layering (Sobek et al., 1978). Having established the major rock layers, samples representative of the entire rock layer should be collected and labeled for further analysis. Even layers as thin as 12 cm, especially those having a low chroma gray or black color, should be sampled separately (Figure 5). Overburden sampling must be consistent for useful interpretations to be made.

Overburden analysis for surface mining begins with Acid-Base Accounting to determine toxic, potentially acid-producing, neutral, or alkaline-producing strata. On rock layers where low values in Max Needed or Excess columns give little information relative to the chemical production potential of the rock, it may be helpful to subject the sample to leaching/weathering analysis (see Acid-Base Accounting examples in the Appendix). The horizon thickness, volume, and chemical makeup of overburden strata in each category (alkaline-producing, neutral, and acid-producing) will help determine the level of special handling and blending techniques that are required during backfilling.



Figure 6: Sampling and analysis of overburden strata in the highwall are important in reconfirming premining overburden analysis or as new strata appear during mining.

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Figure 6: *Sampling and analysis of overburden strata in the highwall are important in reconfirming premining overburden analysis or as new strata appear during mining.*

Continued monitoring of the highwall is necessary to confirm premining overburden data or to analyze new strata that appear as mining progresses (Figure 6).

Observable variations in overburden strata may include changes in horizon thickness, rock type, color, presence of carbonates or pyrite, hardness, dip, and strike. As changes are encountered, interpretations must be made and alterations in the mining method or overburden handling techniques can be initiated.

Native soils on sites to be mined should be described and analyzed as a distinct part of the overburden column, and segregated during mining when required for replacement on the backfill. When the topsoil is too thin and/or infertile, Acid-Base Accounting and nutrient analysis will help distinguish appropriate non-toxic overburden materials which may be used as a substitute for topsoil. After the topsoil is replaced or a substitute material is spread on the surface, sampling the minesoil and analyzing for pH, lime requirement, and nutrient content will help determine amendments necessary to aid vegetation establishment and post mining land use (see Describing and Sampling Minesoils in Sobek et al., 1978).

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3.2 WATER CONSIDERATIONS, SAMPLING, AND ANALYSIS Table of Contents

Ground water characteristics are important in determining appropriate mining and reclamation procedures, and in choosing locations for fills to dispose of excess spoil. Data on ground water quality, quantity, and location are required prior to mining from all sources in the vicinity. Dip of the strata will help predict the amount and location of water discharge and will identify areas where toxic overburden may be placed for minimal water contact.

As with ground water, accurate premining data on surface water quality and quantity must also be accumulated. Location, source, and nature of streams (whether intermittent or perennial) should be considered in the mining sequence and in planning fill placement. When large watersheds and streams exist above the area to be mined, conveyance structures should be designed to divert surface flows through or around the disturbed area. Small watersheds with few and small streams above the site may require no special water handling provisions. Collection and analysis of water from all ground water sources and natural surface channels are important in documenting water quantity and quality before mining (Figure 7), and will aid in assessing probable hydrologic consequences (PHQ resulting from mining and reclamation.



Figure 7: Collection and analysis of surface water are required during premining planning to document water quality before mining.

Figure 7: Collection and analysis of surface water are required during Premining planning to document water quality before mining.

During active mining, all water discharged from the mining area is sampled monthly and analyzed according to the standards of the National Pollution Discharge Elimination System (NPDES) (EPA, 1983), and normally includes monitoring of flow rate, total suspended solids, total acidity, alkalinity, pH, sulfates, total iron, and total manganese. When any discharge from the mining area requires treatment during the operation to meet applicable water quality standards, monitoring of such discharges must continue following grading and reclamation until water quality standards are achieved with natural treatment.

There are several simple techniques for estimating the amount or degree of AMD contamination in a surface stream. Insect larvae and pupae in small streams have been shown to be sensitive indicators of AMD. Certain species are absent and species diversity is reduced when AMD occurs or has occurred in the stream (Wojcik and Butler, 1977). In severe cases of AMD, a few chironomid midge larvae (bloodworms) were the only living organisms, with a total absence of benthic macroinvertebrates.

A clear visual indication of AMD is the yellow-orange coloring on stream rocks and sediments. The coloring comes from ferric hydroxide (yellow boy) which precipitates and coats the stream bed as pyrite oxidizes.

Many people use the simple measurement of water pH as an index of AMD. However, AMD should not be defined solely on the basis of pH, but should include other parameters such as total acidity, conductivity, and iron, manganese, and sulfate concentrations in the water. Many streams in the Appalachian region not affected by AMD generally have pH values less than 6.0. Streams affected by AMD commonly have pH values below 5.0, total iron greater than 7.0 ppm, total manganese of 4.0 ppm or greater, and corresponding high values for total acidity, conductivity, and sulfates. An evaluation of these parameters in the water provides a much clearer understanding of AMD levels than pH alone.

Proper monitoring of overburden and water quality during all phases of the mining process with appropriate blending, segregation, handling, and treatment of acid-producing materials is the key to successful reclamation and control of AMD. Operators, mine employees, and consultants must be committed to implementing and improving technologies and procedures known to reduce AMD.

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New Developments in Acid Prevention Table of Contents

Research in AMD control since 1979 may be divided into several categories: hydrology, liners and seals, oxygen content, bactericides, metal precipitating agents, mining procedures, and topsoil and revegetation.

4.1 HYDROLOGY Table of Contents

Understanding the movement of water over the surface and into and through the backfill is not well understood, but is a significant factor in preventing and controlling AMD. Generally, the porosity and hydraulic conductivity of the materials in a backfill are greater than those of the consolidated rock

overburden that existed before mining, and changes in flow patterns and rates should be expected after mining. Often, the fine-grained topsoil placed over the fill conducts water more slowly than the underlying coarser material, and thereby determines the amount and rate of water movement into the backfill (Gardner and Woolhiser, 1978). As water moves into the coarse material in the backfill, it follows the path of least resistance, flowing through the more permeable acid sandstones and around the calcareous shales, and continues downward until encountering a barrier, the pavement, or other compacted or slowly-permeable layer. Water does not move uniformly through the backfill by a consistent wetting front. The chemistry of the water emanating from the backfill will reflect only the rock types encountered in the water flow path and will not be related to the geochemistry of the total overburden. (F.T. Caruccio and G. Geidel, personal communication to J.G. Skousen, 1987.)



Figure 8: The alkaline trench concept advocates surface water infiltration into the backfill. This trench is packed with sodium carbonate briquettes and limestone chips which will cause the water to be highly alkaline as it enters the backfill.

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Figure 8: The alkaline trench concept advocates surface water infiltration into the backfill. This trench is packed with sodium carbonate briquettes and limestone chips which will cause the water to be highly alkaline as it enters the backfill.

Caruccio and Geidel (1985a) dug 16 wells to the pavement in a backfill at a West Virginia surface mined site and found 13 of the wells to be dry. They suggested that this backfill contained highly permeable channels which were randomly located and interconnected within the backfill to create a "pseudo-karst" hydrologic setting (Caruccio and Geidel, 1985b). In this instance, surface water was moving through specific small channels in the backfill and flowing to the pavement. The water moving in these channels contacted only a very small portion of the total overburden volume in the backfill.

The prevailing approach to control AMD is to keep water away from pyritic material. Recommendations have focused on placing acid-producing material on top of a 4- to 6-foot layer of nontoxic material on the pavement (raising the toxic material above the water table), compacting the toxic material, and covering it with a clay cap or other type of sealant material to reduce surface water infiltration into the toxic material. Diverting surface water from above the site to decrease the amount of water entering the backfill is also recommended.

A change from this traditional approach is to deliberately channel water through holes or openings at the surface into the backfill. (Caruccio and Geidel, 1985a). Trenches or depressions are constructed around these natural gaps (recharge areas) in the backfill and filled with alkaline material to induce the surface water to be treated as it infiltrates into the backfill (Figure 8). On one site where trenches were filled with sodium carbonate briquettes and limestone chips, the investigators (Caruccio and Geidel, 1985b) report that red-colored seeps became clear with reductions in sulfate, total iron, and acidity. They indicate that the alkaline water is neutralizing some of the acid produced in the backfill, but also that the alkaline water is affecting pyrite oxidation and may be inhibiting the acid-producing reaction. Monitoring of water quality is continuing at this site treated with alkaline trenches to evaluate the long-term effectiveness of this

prevention/treatment technique.

Treatment of water as it enters the backfill, either through alkaline trenches, through ditches lined with carbonate materials, or through soil surfaces heavily limed, may be an effective way of neutralizing acidity already produced in the backfill and may help prevent further pyrite oxidation.

There are some problems associated with alkaline trenches:

1. It is possible that the acid loads in a backfill may be so large that neutralization would be impossible.
2. The frequency of alkaline trench repacking with alkaline material is uncertain.

However, the alkaline trench approach may prove to be an effective method for treating areas with acidic discharges as more sites are treated and experience is increased with this method, and as the understanding of backfill hydrology is improved.

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4.2 LINERS AND SEALS ^{Table} Contents

Most researchers who deal with clay barriers report that bentonite is superior to other clays because of its expanding and sealing characteristics (Herzog et al., 198 1; Lutton et al., 1979). However, bentonite has a tendency to crack during drought (EPA, 1978). Thin clay seats may be covered with several feet of soil to reduce cracking (Hawkins and Horton, 1967), but deep-rooted plants can penetrate the seal. Also, placing clay materials in contact with acid-producing materials can cause disintegration of the clay over time (Volclay Soil Laboratory, 1975). Studies with bentonite showed that 1 or 2 pounds per square foot of bentonite mixed with 3 inches of topsoil did not prevent water infiltration (Dyer and Crews, 1986).

According to specifications from the Task Force, a compacted clay cap was placed over toxic material in a backfill on a West Virginia mine site and monitored by Geidel and Caruccio (1985). The backfill covered with the clay cap was divided into three sections because of other treatments applied to the toxic material underneath. Water emanating from each section could be identified and its source determined. After three years, the clay seal covering two of the three sections prevented surface water from infiltrating into the toxic material. The clay seal over the third section leaked indicating a breach in the cap.

Synthetic liners have been used to restrict infiltration of water into toxic or hazardous materials. The most common types are:

1. asphalts and tars,
2. concrete and cements, and
3. plastic films or liners.

The first two types are expensive to buy and install, and are susceptible to chemical breakdown. They are normally used on sealing projects of underground mines (Brant et al., 197 1; Gallagher, 1985; Tolsma and Johnson, 1972).

All plastic liners are essentially impermeable when properly installed on a well-prepared base. Over irregular surfaces such as rocks or overburden material, the liner must have greater strength and better plastic properties to withstand the increased stress (Krupin et al., 1982).

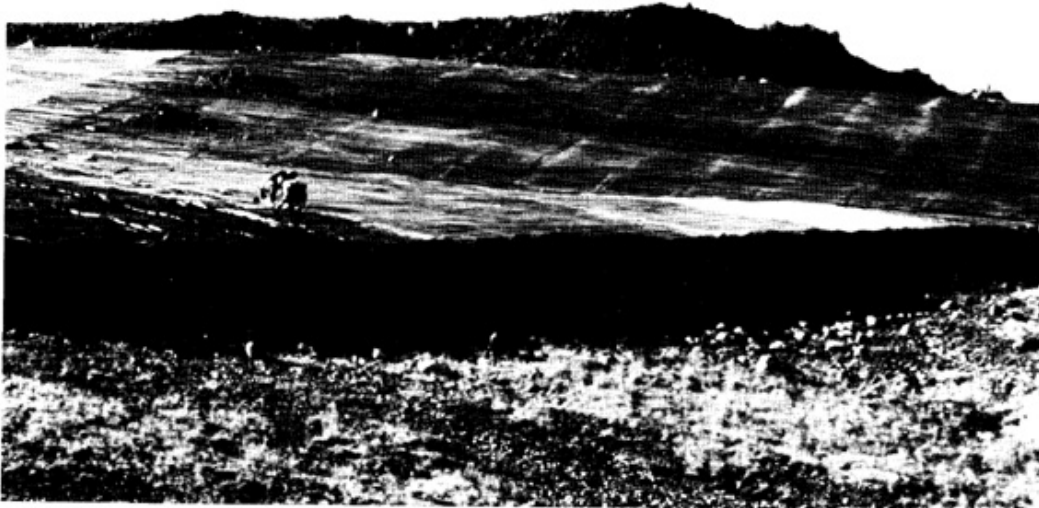


Figure 9: A PVC liner is being placed on a backfill in West Virginia to impede water movement into the backfill.

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Figure 9: A PVC liner is being placed on a backfill in West Virginia to impede water movement into the backfill.

Plastic liners have several advantages:

1. Many types are available.
2. The sheeting is uniform and consistent.
3. The material is relatively flexible.
4. They are simple to install.

Limitations of plastic liners include:

1. The liner may be damaged by equipment during installation.
2. Puncture may result from sharp, underlying objects.
3. The liner can deteriorate from sunlight, burrowing animals, and plant roots.
4. Covering large areas is expensive.
5. Experience with synthetic liners demonstrates limited longevity. Differential settling of the backfill over time may cause breaches in the liner creating a channel for water to move into the backfill.

In West Virginia, a polyvinyl chloride (PVC) liner was used to cover a 45-acre backfilled site to prevent seepage into acid-producing materials (Caruccio and Geidel 1983) (Figure 9). Results showed substantial decreases in flow and acidity from associated seeps (Caruccio, and Geidel, 1986). A further step in using this approach is to concentrate and totally encapsulate the toxic material within a plastic sheet. Even though expensive, this technique may be the only method to completely prevent oxygen and water from interacting with toxic material.

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4.3 OXYGEN CONTENT ^{Table} Contents

A 1971 EPA report (Robins and Troy, 1971) found that acid production is proportional to the oxygen concentration in contact with pyritic materials. Introducing nitrogen, methane, or carbon dioxide as blanketing gases reduced acid generation, but acid was still produced because of dissolved oxygen in the water.

Oxygen is required for the oxidation of iron and sulfur, and for the survival of *Thiobacillus*, an aerobic bacteria. Erickson (1985) measured the oxygen concentration in several backfills and found the concentrations to be in excess of that required for pyrite oxidation. A model describing four different oxygenated zones in a backfill was developed by Erickson and Ladwig (1986) (Figure 10). Zone 1 is located within 5 feet of the surface and is the most highly oxidized zone of the backfill. Zone 2 is the portion of the backfill where toxic material is placed where air and water contact is minimized. Zone 3 is the area of non-toxic overburden placement against the highwall, and zone 4 constitutes the pavement and saturated area above the pit floor. The investigators observed that zone 1 does not prevent oxygen diffusion into zone 2,

but oxygen concentrations are reduced 1 to 2 in down from the surface (Erickson, 1985).

Placing topsoil materials over toxic material does not completely prevent oxygen diffusion. However, thickness and degree of compaction of the surface can effectively reduce the amount and rate of oxygen influx. Covering refuse or spoil with an oxygen-consuming layer (revegetated soil with active microorganisms) is a good oxygen control strategy. Plastic liners are effective in eliminating oxygen diffusion, but the toxic material must be completely surrounded or oxygen enters from the bottom and sides.

Three steps may be taken to reduce oxygen replenishment into the backfill (Cathles, 1982):

1. The overburden materials should be buried and covered with topsoil as soon as possible after exposure.
2. The backfill must be compacted throughout construction, especially during toxic material placement, to reduce voids between rock fragments.
3. Compaction of the surface and outcrops is very important in decreasing oxygen diffusion and air convection into the backfill.

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4.4 BACTERICIDES ^{Table} of Contents

Laboratory experiments show that the presence of *Thiobacillus ferrooxidans* (iron-oxidizing bacteria) increases the rate of pyrite oxidation (Leathen et al., 1963; Singer and Stumm, 1969; Wilson, 1965; Wilson and Zuberer, 1976). Studies have reported acidity increases of 50 to 1,000,000 times due to the presence and activity of bacteria (Lundgren, 1971).

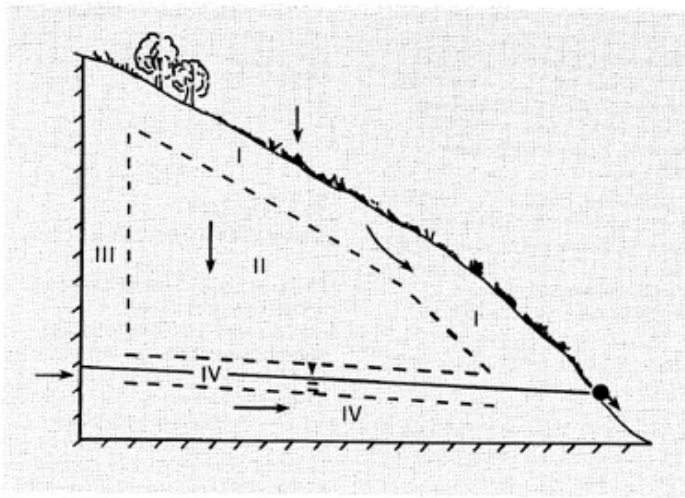


Figure 10: A model illustrating four zones in a backfill which contain different concentrations of oxygen. Zone 2 is the area of toxic material placement where oxygen concentrations are minimized. Zones 3 and 4 contain porous material and, depending on water content and saturation, may or may not be highly oxidized. (Erickson and Ladwig 1986, US Bureau of Mines).

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Figure 10: A model illustrating four zones in a backfill which contain different concentrations of oxygen. Zone 2 is the area of toxic material placement where oxygen concentrations are minimized. Zones 3 and 4 contain porous material and, depending on water content and saturation, may or may not be highly oxidized. (Erickson and Ladwig 1986, US Bureau of Mines).

Anionic surfactants, organic acids, and food preservatives have been used as antibacterial compounds (Erickson and Ladwig, 1985a; Kleinmann, 1981; Lundgren, 1971; Shearer and Everson, 1969). Surfactants work because they allow hydrogen ions in the acid environment to seep into the bacteria's cell membrane causing membrane deterioration, which subsequently kill the bacteria. One of the original surfactants, sodium lauryl sulfate (SLS), has demonstrated 60 to 90 percent reduction in acid drainage during field experiments on coal refuse (Kleinmann, 1983). Although SLS has been used in numerous experiments, it has not been registered by the US Environmental Protection Agency and therefore cannot be used as a bactericide in coal mine reclamation.

Most anionic surfactants are very soluble and degradable, presenting problems with widespread application to acid-producing material. Therefore, the treatment must be repeated periodically to prevent repopulation of the bacteria.

Timed-release formulas, which include the inhibitor inside of slowly degradable products to extend the life of the bactericide, have been studied (Erickson and Ladwig, 1985a; Shellhorn and Rastogi, 1985) and have been found to be effective (Sobek and Horowitz, 1986). Studies are continuing on the timed-release bactericides and some of these formulas have been registered by the US Environmental Protection Agency.

Two organic acids (sodium benzoate and potassium sorbate) have inhibited acid production in laboratory experiments (Erickson and Ladwig, 1985a). These organic acids inhibited iron-oxidation by *Thiobacillus*, but did not precipitate ferric oxide or ferric hydroxide onto pyritic surfaces as they were designed to do. The organic acids were also adsorbed to clay materials in the soil when applied to revegetated minesoils (Erickson and Ladwig, 1985b).

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4.5 METAL PRECIPITATING AGENTS **Table of Contents**

Phosphate may combine with ferric and ferrous iron in acid environments resulting in ferrous phosphate and ferric phosphate. Small-scale experiments show that rock phosphate reacts with the iron species, and the iron-phosphate compound precipitates from solution. Formation of this complex reduces the ferric iron concentration and thereby substantially reduces acid formation (Flynn, 1969; Stiller, 1982). Larger-scaled experiments with rock phosphate and other phosphate sources are being conducted currently. Preliminary results show that rock phosphate applied to acid-producing materials, including the pavement, reduces AMD (Meek, 1984; Stiller et al., 1986), and also reduces acid production when applied to the walls of underground mines (Hause and Willison, 1986).

Organic waste materials such as sewage sludge can also complex ferric and ferrous iron by chelation. The chelated material may precipitate and coat pyritic surfaces (Loomis and Hood, 1984). Organic materials will also absorb hydrogen ions resulting from pyrite oxidation and consequently raise pH. Because organic materials vary widely in properties and substance, selection of an appropriate organic material is critical. State regulations also vary concerning the use of waste materials for reclamation, and state regulatory agencies should be notified.

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4.6 MINING PROCEDURES **Table of Contents**

Improving techniques for segregation, handling, storage, and placement of acid- and alkaline-producing overburden in the backfill is a continual process during mining. It is important to segregate even the thin layers of highly-toxic material for special handling and treatment. Selective sampling of the highwall during mining is necessary to reconfirm or revise premining overburden sampling and analysis results, but it is also necessary to keep apprised of the ever-changing coal environment. The foreman and equipment operators need to know where the problem strata are located.

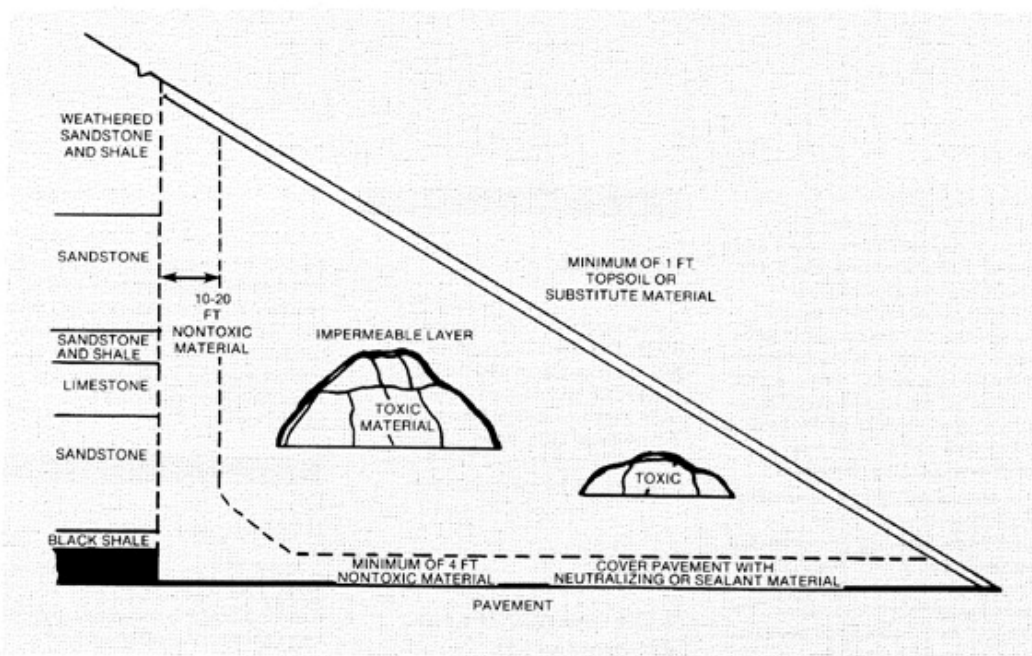


Figure 11: During construction of the backfill, toxic material should be placed off the pit floor, compacted, treated with neutralizing material, and capped with an impermeable layer to reduce air and water contact.

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Figure 11: During construction of the backfill, toxic material should be placed off the pit floor, compacted, treated with neutralizing material, and capped with an impermeable layer to reduce air and water contact.

As toxic material is encountered, it must be segregated and placed as quickly as possible in the backfill (high off the pit floor and away from the highwall), compacted, and treated with ameliorants which will neutralize the acid-producing potential. After the toxic rock is compacted and treated, it should be capped with a layer of impermeable material, and covered with nontoxic overburden and topsoil materials to reduce, as much as

possible, water and oxygen contact with acid-producing materials (Figure 11).

In areas where limestone or other alkaline layers occur in the overburden, blending of overburden materials may be used where the alkaline materials are capable of neutralizing the acidic materials. The topsoil should be limed to neutralize any acidity and to raise the pH. Water courses above the mined area can also be limed to improve water quality.

The pavement is commonly found to be acid-producing (in many cases, it is the most toxic material) and past recommendations of large lime applications to the pit floor have usually helped neutralize the acid. There is some evidence which suggests that limestone applied to pyritic material may actually accelerate acid production (Stiller et al., 1984). Placing a layer of clay (or other sealant) or a layer of rock phosphate on the pavement are current treatments being studied by operators in West Virginia.

Proper identification, handling, blending or treatment, and placement of acid-producing materials in the backfill are the key issues in controlling AMD. With correct identification of overburden materials and applications of appropriate mining procedures, AMD production would be substantially reduced.

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4.7 TOPSOILING AND REVEGETATION Table of Contents

Federal regulations require replacement of original topsoil or substitute material on the regraded backfill. Many native soils are shallow, acidic, and hold limited amounts of essential nutrients for plant growth. Therefore, certain nontoxic layers in the overburden may be crushed and applied to the surface as topsoil substitutes. Laboratory analysis or experience must demonstrate that the substitute material is a suitable replacement for the topsoil.

Once the topsoil or substitute is spread on the surface, it is imperative to rapidly establish vegetation on the site to control erosion and maintain soil stabilization. Thus, the ability of the soil or substitute to support plant growth is of paramount importance. Fugill and Sencindiver (1985) showed that crushed sandstone overburden material used as a substitute for topsoil was superior in vegetation production to a native West Virginia topsoil with the same amendments supplied.

The combined effect of spreading an appropriate growth medium and establishing vegetation is critical in reducing AMD and maintaining the site. These reclamation practices on surface-mined sites are essential in promoting stability of the site and enhancing future land use capabilities.

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Developments in Treatment Technology Table of Contents

Treatment of AMD to neutralize the acidity is commonly accomplished with limestone (CaCO_3), hydrated lime [$\text{Ca}(\text{OH})_2$], soda-ash briquettes (Na_2CO_3 or caustic soda (NaOH) (Ford et al., 1970, 1971; Kalb, 1980; Wilmouth, 1974). Recent developments in treatment of acid waters using different chemicals, equipment, and methods will be discussed briefly.

5.1 CHEMICAL INJECTION INTO MINES

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In conventional water treatment, alkalinity is added to mine water to neutralize acidity. However, injection of a chemical fluid into a surface mine backfill to treat or control AMD has some advantages over conventional water treatment (Ladwig et al., 1985):

1. Raising the pH of the water in the backfill may result in precipitation and filtering of some metals prior to discharge into ponds. This would limit leaching of metallic ions from the backfill and decrease sludge storage and removal requirements.
2. The metallic precipitates may coat pyrite surfaces, "armoring" them from further chemical weathering.
3. The alkaline environment within the backfill would be less favorable to continued pyrite oxidation and thus decrease bacterial activity.

This approach was tested by pumping hydrated lime as a slurry into wells at several surface mines in Pennsylvania (Ladwig et al., 1985). Although some modest improvement of water quality was noticed, overall impact of the injection was minimal. Poor results may be related Information Circular 9027. USDI, to inefficient mixing of the lime with Bureau of Mines, Pittsburgh, PA. the water in the backfill. The majority of the lime was in suspension rather than in solution, and suspended lime will settle rapidly in the absence of turbulence and mixing. Therefore, half or more of the injected lime may have settled out of suspension shortly after injection.

Since lime injection gave poor results, sodium carbonate was used because it is about 100 times more soluble than lime. In pilot-scale studies, sodium carbonate was much more mobile than lime and was effective in reducing acidity and metallic ion leaching (Kleinmann, 1986). However, the benefits were short term.

Critical to the success of alkaline injection is good mixing of the alkaline fluid and the contaminated water. This requires detailed understanding of site hydrology and acid-producing characteristics, including source material, flow paths, flow volumes, and geochemistry of the water. Chemical injection into surface mine backfills has not produced completely satisfactory results, but the US Bureau of Mines is continuing to study the technique.

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5.2 ANHYDROUS AMMONIA

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Anhydrous ammonia (NH_3) has occasionally been used to neutralize acidity in sediment ponds, and interest in using this chemical is growing. Ammonia is a stable, pungent, colorless gas at ordinary temperature and pressure. When compressed and cooled, it condenses to a colorless liquid. Ammonia vapor is very irritating to the mucous membrane of the eyes, nose, throat, and lungs. If improperly handled, liquid ammonia can cause severe injury to the skin by freezing and subjecting the skin to caustic action.

Injection of ammonia into water raises the pH rapidly because it enters the water as a vapor or a liquid. The solubility of ammonia is much greater in water than the solubility of solid neutralizing compounds. The high solubility results in a rapid reaction between ammonia and AMD, and makes acid neutralization possible with less waste than would be expected with other neutralizing agents. The metallic ion precipitates from the neutralization reaction are gelatinous (Whitehouse and Straughan, 1986) and can be easily pumped out of the treatment pond.

The cost of neutralizing AMD with ammonia is competitive with other neutralizing agents (Table 1). Ammonia is more expensive than lime or limestone, but less expensive than caustic soda or soda ash briquettes.

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<u>Chemical</u>	<u>Formula</u>	1 pound NH, <u>equals</u> <u>pounds</u>	<u>Cost/pound</u> <u>dollars</u>	Equivalent <u>cost</u> <u>dollars</u>
Ammonia	NH ₃	1.00	0.24	0.24
Limestone	CaCO ₃	2.94	< 0.01	0.02
Hydrated Lime	Ca(OH) ₂	2.18	0.06	0.13
Caustic Soda	NaOH	2.35	0.14	0.33
Soda Ash	Na ₂ CO ₃	3.12	0.15	0.47

Table 1: Comparison of ammonia to other commonly used bases (adapted from Whitehouse and Straughan,

<u>Chemical</u>	<u>Formula</u>	1 pound NH, <u>equals</u> <u>pounds</u>	<u>Cost/post</u> <u>dollars</u>	Equivalent <u>cost</u> <u>dollars</u>
Ammonia	NH ₃	1.00	0.24	0.24
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1986) Table 1: Comparison of ammonia to other commonly used bases (adapted from Whitehouse and Straughan, 1986).

Several operational adjustments improve the cost effectiveness of ammonia treatment. The ammonia supplier provides a pressure tank for a small fee and since ammonia is a compressed gas, it flows under its own pressure (Whitehouse and Straughan, 1986). The user never comes in contact with the chemical because the tank is filled by the supplier and ammonia is released to the water by simply opening a valve. The ammonia system can also be automated, with the capital outlay for automation paying for itself by preventing over-treatment and reducing labor (Whitehouse and Straughan, 1986).

Although ammonia is initially very effective in controlling acidity and raising pH, there are some possible chemical and biological reactions which may pose hazards downstream after discharge. First, un-ionized (unreacted) ammonia is toxic to fish and other aquatic life. Second, nitrification (the biological transformation of NH₄⁺ to NO₃⁻ by unique, specialized bacteria) can increase nitrate concentration and acidity (H⁺) downstream (Smith and Evangelou, 1982).

Grim and Hill (1974) found high levels of both ammonia and nitrate in water being treated with anhydrous ammonia. They suggest that anhydrous ammonia should only be used where small volumes of AMD are to be treated, and the treated water should be applied to revegetated minesoils as irrigation water.

Data collected for over two years at a mine site in West Virginia (Whitehouse and Straughan, 1986) suggest that the ammonia used for treatment did not increase acidity or nitrate concentrations downstream. The acidity or nitrate may have been diluted or the NH₄⁺ may have become adsorbed to the solid phase in the treatment pond. Rather than being released downstream, the NH₄⁺ may have been pumped out of the pond

with the solids and placed in a sludge disposal area.

Neutralization of AMD with ammonia appears to have a number of advantages over other systems, but potential safety and environmental hazards do exist. The pond water and the downstream water should be continually monitored if anhydrous ammonia is used. Since hazards do exist, the use of ammonia to treat water may not be acceptable in some areas. Anyone contemplating the use of ammonia should contact the local regulatory authority.

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5.3 IN-LINE AERATION AND TREATMENT Table of Contents

A simple, low-maintenance system to mix, aerate, and neutralize AMD in a pipeline has been recently developed by the US Bureau of Mines (Ackman and Kleinmann, 1985; Kleinmann et al., 1985). The In-Line Aeration and Treatment System (ILS) was designed to function in existing AMD pipelines using energy provided by existing mine water discharge pumps.

The ILS consists of a jet pump and a static mixer. Water enters the jet pump under pressure and is converted to a high-velocity stream which passes through a suction chamber. The suction chamber is open to the atmosphere for aeration and can serve as an injection point when chemicals are required for neutralization. Multiple jet pump units may be placed in series as long as water pressures of at least 20 psi are maintained.

The ILS has been tested in Pennsylvania and West Virginia where it significantly increased the oxidation rates of iron above theoretical limits. At low pH (4.6 to 5.5), iron oxidation was accelerated by a factor of 10 to 400; at near neutral pH (6.9 to 7.5), iron oxidation was accelerated by a factor of 1000. Manganese concentration has also been reduced to regulation standards at some sites after passage through the ILS at pH values below 7.5 when iron concentrations were 75 mg/L or higher. When iron content was below 75 mg/L, a pH of 10 was required (Kleinmann et al., 1985).

Initial cost of the ILS is less than other neutralization and aeration systems. In 1985 jet pumps cost \$900 each, static mixers \$2500 each, and associated PVC plumbing cost \$500. Since the ILS has no moving parts, operating and maintenance costs should be low.

The ILS appears to have several advantages over other systems. It has low initial cost, and low maintenance and operating costs. The system is small and can be portable. It requires no electrical power although the load on the mine water discharge pump is slightly increased. The design is simple and can be easily modified to fit local conditions. Oxidation of iron is accelerated, and although settling ponds are required, they do not serve as aeration basins and therefore do not need to be as large as when conventional treatment systems are used.

Another system similar to ILS is the TURBOJETT T". The TURBOJETT T" System is a high-intensity turbulent mixer and can be utilized to mix any combination of liquids, solids, and gases. The advantages are:

1. effective mixing reduces reagent amounts,

2. there are no moving parts and is easily maintained, and
3. the entire treatment system can be self-contained and portable (Barrett Haentjens and Co. of Pittsburgh, 1984).

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5.4 TREATMENT OF ACID MINE DRAINAGE BY WETLANDS Table of Contents

Chemical treatment of AMD can be both expensive and labor intensive. One alternative to continuous chemical treatment is the use of wetlands. Several studies have shown that AMD can be treated when the drainage flows through natural wetlands (McHerron, 1986; Mitsch et al., 1985; Snyder and Aharrah, 1984; Wieder et al., 1982). This knowledge has led to the building of wetlands, but the treatment results have varied (Huntsman, 1985, 1986; Kleinmann et al., 1983; Snyder and Aharrah, 1985; Wieder et al., 1985). Therefore, research on AMD treatment by wetlands is continuing. *Sphagnum* (moss) and *Typha* (cattails) wetlands have been the focus of most studies to date; however, other wetland species may be equally important. *Sphagnum* wetlands are most effective in treating AMD when the water entering the bog has a pH of 4 or less (Wieder et al., 1985). High pH water (pH between 6 and 9) will destroy *Sphagnum* (Wieder et al., 1984), but other wetland vegetation such as cattails thrive in neutral or alkaline water.

Studies on naturally occurring wetlands have shown that as AMD flows through the wetland, concentrations of iron, manganese, and sulfate have been reduced and pH has been raised (Kleinmann, 1985; Wieder et al., 1982). Efficiency of iron and manganese removal from AMD is primarily related to the pH of the water. Wetlands will remove 50 to 90 percent of total iron even when the pH is as low as 2.3, but very little manganese will be removed until the pH of the influent water is 5.5 or higher (Gerber et al., 1985; Kleinmann, 1985; Kleinmann et al., 1983). Concentrations of aluminum are apparently not significantly affected by wetlands, but will be reduced as pH of the water rises after leaving the wetland (Kleinmann et al., 1983).

Different types of wetland vegetation are being evaluated for their effects on treatment of AMD (Pesavento and Stark, 1986). Cattail-dominated wetlands are becoming increasingly popular. These wetlands are naturally more abundant than *Sphagnum* wetlands, and cattails tolerate a broader range of water pH than *Sphagnum*.

Size, shape, and type of wetland that will effectively treat AMD will vary from site to site. Some general design criteria were presented in a mini-course at the 1985 and 1986 National Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation in Lexington, Kentucky.

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Appendix

OVERBURDEN INTERPRETATION, HANDLING, AND PLACEMENT

EXAMPLES ^{Table} Contents

Planning overburden handling and placement is not an easy task. Many geological, analytical, and economical factors must be considered. Since these factors vary widely from site to site, it is impossible to present a generalized model or plan for overburden handling and placement that will be applicable to all sites. Every site unique. The following factors must be considered when developing an overburden handling and placement plan

1. Log and description of the overburden including roc type and thickness, hardness, color, presence of observable pyrite, and fizz.
2. Physical and chemical analyses of the overburden strata including, but not limited to, Acid-Base Accounting and leaching data.
3. History of AMD in the area.
4. Volumes of material to be moved.
5. Topography of the site.
6. Available equipment.
7. Surface and groundwater hydrology.

On some sites, knowledge of these factors is not enough to control acid mine drainage. Ameliorants are often required to neutralize excess acidity produced during and after mining. Ameliorants or neutralizing agents may be applied to potentially toxic or toxic materials to control acidity. Laboratory analyses in addition to standard Acid-Base Accounting may be necessary to determine the amounts of the ameliorants to apply. In some areas PVC or clay liners may be used to reduce the flow of water into acid-producing materials.

Acid-Base Accounting data are presented for three overburdens from West Virginia surface mines. The procedures used to develop Acid-Base Accounts are presented elsewhere (Sobek et al., 1978). A suggested method for placement of materials from each overburden is also presented. The reader should be aware that the overburden handling and placement plans presented here are based primarily upon the Acid-Base Accounting data. A variation in the handling and placement plan may be developed depending upon additional information on factors listed above. The information presented should be looked upon as only an example of how Acid-Base Accounting data may be used to plan for handling and placement of overburden materials.

Sample number	Bottom depth (feet)	Rock type	Fizz	Color	%S	CaCO ₃ equivalent			Excess	Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7)		
1	3	soil	0	7/3	.035	1.09	3.52		2.53	4.4
2	6	Ss	0	8/6	.029	0.91	-1.51	2.42		4.3
3	9	SS	0	8/2	.023	0.72	-1.59	2.31		4.6
4	14	SH	0	7/4	.009	0.28	-0.60	0.88		4.6
5	17	SS	0	7/4	.009	0.28	-0.09	0.37		4.7
6	20	SH	0	8/3	.011	0.34	-0.17	0.51		4.5

7	24	NIS	0	7/1	.263	8.22	-0.94	9.16		4.8
8	28	Ms	1	7/1	.179	5.59	78.33		72.74	7.8
9	35	MS	0	7/1	.028	0.88	15-77		14.89	7.9
10	39	Ms	1	7/0	.140	4.38	39-71		35.33	7.8
11	44	MS	1	7/1	.278	8.69	25.25		16.56	8.0
12	49	SH	1	7/1	.079	2.47	25-76		23.29	8.1
13	51	Ms	1	7/1	.665	20-78	32.45		11.67	7.9
14	55	SH	1	7/1	.610	19.06	25.88		6.82	7.8
15	58	SH	0	6/1	.355	11.09	17-78		6.69	7.3
16	59	SH	0	4/1	.800	25.00	3.80	21.20		4.2
17	64	Coal	*	*	*	*	*	*	*	*
18	67	MS	0	6/1	2.82	88.12	-2-78	90-90		3.5

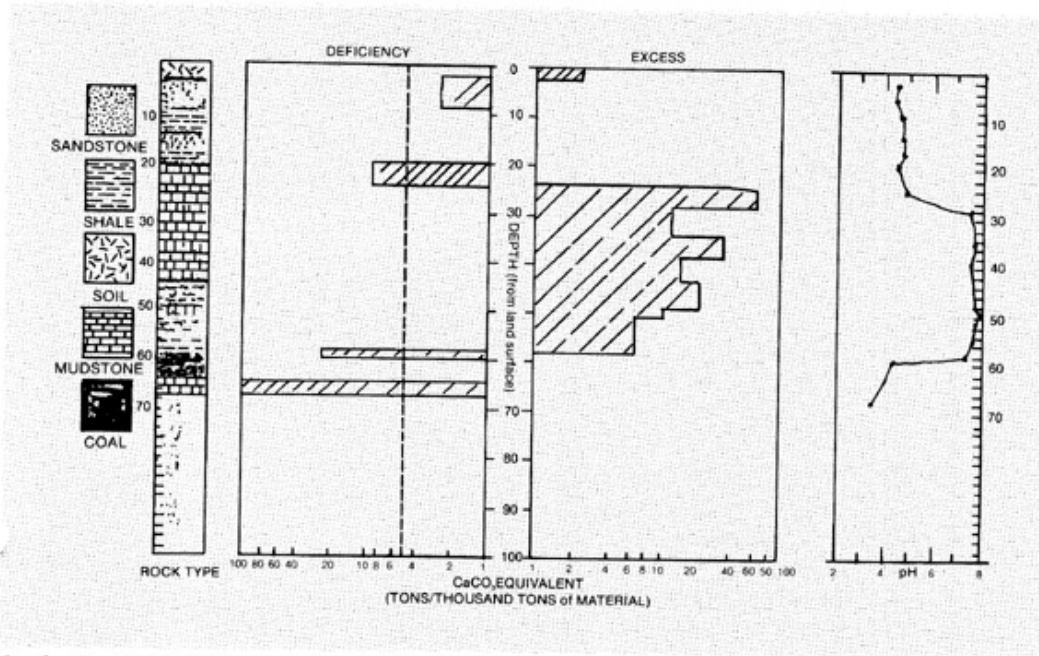
*Not sampled

Sample number	Bottom depth (feet)	Rock type	Fizz	Color	%S	tons/1000 tons of material			Excess	Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7)		
1	3	Soil	0	7/3	.035	1.09	3.52		2.53	4.4
2	6	SS	0	8/6	.029	0.91	-1.51	2.42		4.3
3	9	SS	0	8/2	.023	0.72	-1.59	2.31		4.6
4	14	SH	0	7/4	.009	0.28	-0.60	0.88		4.6
5	17	SS	0	7/4	.009	0.28	-0.09	0.37		4.7
6	20	SH	0	8/3	.011	0.34	-0.17	0.51		4.5
7	24	MS	0	7/1	.263	8.22	-0.94	9.16		4.8
8	28	MS	1	7/1	.179	5.59	78.33		72.74	7.8
9	35	MS	0	7/1	.028	0.88	15.77		14.89	7.9
10	39	MS	1	7/0	.140	4.38	39.71		35.33	7.8
11	44	MS	1	7/1	.278	8.69	25.25		16.56	8.0
12	49	SH	1	7/1	.079	2.47	25.76		23.29	8.1
13	51	MS	1	7/1	.665	20.78	32.45		11.67	7.9
14	55	SH	1	7/1	.610	19.06	25.88		6.82	7.8
15	58	SH	0	6/1	.355	11.09	17.78		6.69	7.3
16	59	SH	0	4/1	.800	25.00	3.80	21.20		4.2
17	64	Coal	*	*	*	*	*	*	*	*
18	67	MS	0	6/1	2.82	88.12	-2.78	90.90		3.5

*Not sampled

ACID-BASE ACCOUNTING INTERPRETATION-- OVERBURDEN No. 1

1. Samples 1 to 6 have low pH values, negative NP values and low sulfur values. These data indicate that this overburden has been weathered to a depth of approximately 20 feet. These samples should produce only light acidity, if any.
2. Sample 7 is potentially toxic and probably will produce acidity as indicated by the maximum needed value of 9+ tons of CaCO₃.
3. Samples 8 to 12 are part of the unweathered portion of the overburden. They have high pH values, moderately low sulfur values, a fizz rating of 1 (except sample 9) and generally have an excess of 15 to 73 tons of CaCO₃. These samples should produce some alkalinity upon weathering.
4. Samples 13 to 15 have excess CaCO₃ equivalents with high pH values, but they also have higher sulfur values than any of the samples above. These samples may or may not produce acidity. Leaching tests and/or pyritic sulfur analyses may provide more information.
5. Samples 16 and 18 are potentially toxic and will produce acidity.

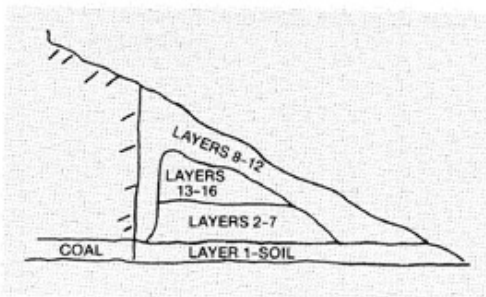


Overburden No. 1: Acid-base accounting.

Overburden No. 1: Acid-base accounting.

HANDLING PLAN-OVERBURDEN No. 1

The pit floor is acid toxic so it should be treated with a neutralizing agent or other ameliorant. If possible, it should be covered with a layer of compacted clayey soil to slow the movement of water to the pavement. The surface soil (sample 1) may be used for this purpose if it is clayey enough. Next, the material from layers 2 to 7 should be treated to satisfy the immediate lime requirement and placed on the compacted soil. Layers 13 to 16 should be treated to control acidity and placed next as the backfill is being built. Layers 8 to 12 should be placed next and prepared for revegetation. Except for the immediate surface, each replaced layer should be compacted to reduce the movement of water through the fill. If possible, instead of treating and segregating layers 13 to 16, these layers may be thoroughly blended with layers 8 to 12.



Overburden No. 1: Plan for placement.

Overburden No. 1: Plan for placement.

Sample number	Bottom depth (feet)	Rock type	Fizz	color	%S	CaCO ₃ equivalent tons/ 1000 tons of material			Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7) Excess	
1	5	soil	*	*	*	*	*	*	*
2	17	Ss	0	6/6	.005	0.16	0.57	0.41	5.0
3	29	SS	0	5/4	.005	0.16	0.62	0.46	5.9

4	30	SH/SS	0	4/0	.390	12.20	0.60	11.60		4.9
5	41	Ss	0	8/0	.005	0.16	0.70		0.54	5.4
6	49	SS/ CARB	0	4/0	.350	10.90	0.38	10.60		5.0
7	56	Ms	0	5/0	.590	18-40	1.10	17.30		4.5
8	60	SH/SS	0	5/0	.300	9.40	5.54	3.80		4.3
9	61	SS	0	8/0	.250	7.80	15.90		8.00	7.2
10	69	Coal	0	*	*	*	*	*	*	*
11	73	MS	0	5/0	.030	0.94	5.50		4.56	4.6
12	74	SH	0	3/0	.210	6.50	3.25	3.30		4.6
13	80	Coal	0	*	*	*	*	*	*	*
14	83	MS	0	3/0	.250	7.80	0.37	7.40		4.5
15	91	SS	0	6/0	0.60	1.90	0.47	1.40		4.9

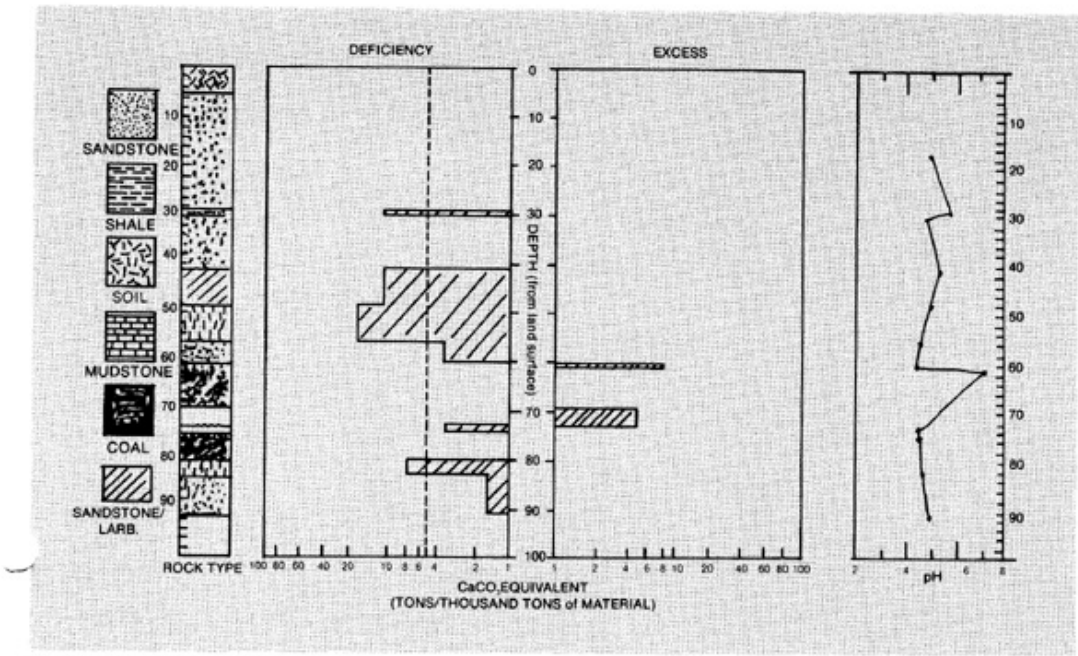
*Not sampled

Sample number	Bottom depth (feet)	Rock type	Fizz	Color	%S	CaCO ₃ equivalent tons/1000 tons of material				Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7)	Excess	
1	5	Soil	*	*	*	*	*	*	*	*
2	17	SS	0	6/6	.005	0.16	0.57		0.41	5.0
3	29	SS	0	5/4	.005	0.16	0.62		0.46	5.9
4	30	SH/SS	0	4/0	.390	12.20	0.60	11.60		4.9
5	41	SS	0	8/0	.005	0.16	0.70		0.54	5.4
6	49	SS/CARB	0	4/0	.350	10.90	0.38	10.60		5.0
7	56	MS	0	5/0	.590	18.40	1.10	17.30		4.5
8	60	SH/SS	0	5/0	.300	9.40	5.54	3.80		4.3
9	61	SS	0	8/0	.250	7.80	15.90		8.00	7.2
10	69	Coal	0	*	*	*	*	*	*	*
11	73	MS	0	5/0	.030	0.94	5.50		4.56	4.6
12	74	SH	0	3/0	.210	6.50	3.25	3.30		4.6
13	80	Coal	0	*	*	*	*	*	*	*
14	83	MS	0	3/0	.250	7.80	0.37	7.40		4.5
15	91	SS	0	6/0	.060	1.90	0.47	1.40		4.9

*Not sampled

ACID-BASE ACCOUNTING INTERPRETATION-- OVERBURDEN No. 2

1. Samples 2 and 3 have been weathered (colors 6/6 and 5/4) and the S values are extremely low (.005%), so these samples will not produce acid. Sample 5 (color 8/0) has not been weathered as much as 2 or 3 but it also has a low S value (.005%). Since this sample is a sandstone with very low S, it will not produce acid.
2. Samples 4, 6, 7, and 14 are potentially toxic and will produce acid. They should be treated to reduce acidity. If pyritic sulfur were to be determined, the calculated acidity may be reduced.
3. All other samples (8, 9, 11, 12, 15) may or may not produce acid. Leaching tests may provide additional information. Samples 11 and 15 have relatively low sulfur percentages so they would not be expected to produce much acidity. Pyritic sulfur analyses would probably reduce the calculated acidity values.

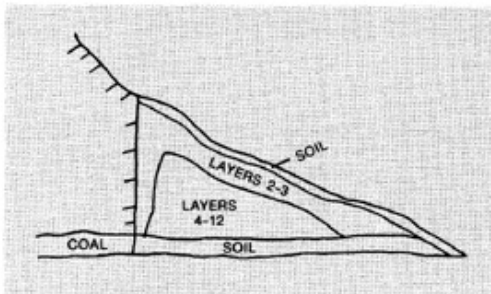


Overburden No. 2: Acid-base accounting.

Overburden No. 2: Acid-base accounting.

HANDLING PLAN-OVERBURDEN No. 2

Remove the top 5 feet (sample 1) and stockpile for later use as topsoil. After the overburden and coal have been removed, treat the pit floor with an ameliorant and cover with compacted clayey soil. Part of the stockpiled topsoil may be used if it is clayey. Since there are no major alkaline zones in this overburden, mixing unameliorated strata may not be very beneficial. After the pit floor has been covered with soil, mix layers 4 to 12, treat with an ameliorant, and place on the compacted soil. Mix layers 2 and 3, add an ameliorant, and place above layers 4 to 12. All layers should be compacted thoroughly as they are replaced in the backfill. Cap the fill with the topsoil, then lime, fertilize, and seed.



Overburden No. 2: Plan for placement.

Overburden No. 2: Plan for placement.

Sample number	Bottom depth (feet)	Rock type	Fizz	Color	%S	CaCO ₃ equivalent tons/ 1000 tons of material			Excess	Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7)		
1	0	Soil A	0	6/4	.010	0.31	-0.97	1.28		4.0
2	2	Soil B	0	8/4	.015	0.47	-0.74	1.21		4.7
3	5	Soil C	0	7/6	.010	0.31	-0.23	0.54		4.5
4	10	MS	0	7/4	.010	0.31	-1.99	2.30		5.0

5	12	SS	0	7/2	.015	0.47	2.52		2.05	5.1
6	26	SS	0	7/4	.005	0.16	3.26		3.10	5.1
7	32	SS	0	7/4	.005	0.16	4.77		4.61	5.6
8	37	SS	0	7/1	.020	0.63	4.51		3.88	5.4
9	39	SS	0	7/4	.005	0.16	4.03		3.87	5.7
10	43	SS	0	8/3	.005	0.16	4.03		3.87	5.9
11	44	SS	4	8/0	.005	0.16	228.20		228.04	6.6
12	46	SS	5	8/3	.005	0.16	294.25		294.09	6.7
13	48	SS	4	8/3	.005	0.16	289.22		289.06	7.7
14	53	SS	0	7/4	.005	0.16	2.52		2.36	6.7
15	58	SS	0	7/4	.005	0.16	3.52		3.36	6.5
16	63	SS	0	8/4	.005	0.16	3.01		2.85	6.5
17	69	SS	0	8/4	.005	0.16	4.03		3.87	6.1
18	76	SS	0	8/6	.005	0.16	3.77		3.61	6.0
19	80	SS	0	8/0	.095	2.97	3.01		0.04	5.0
20	81	SH	0	4/0	.180	5.63	0.76	4.87		4.1
21	85	Coal	*	*	*	*	*	*	*	*
22	89	MS	0	6/3	.005	0.16	7.01		6.85	6.6

*Not sampled

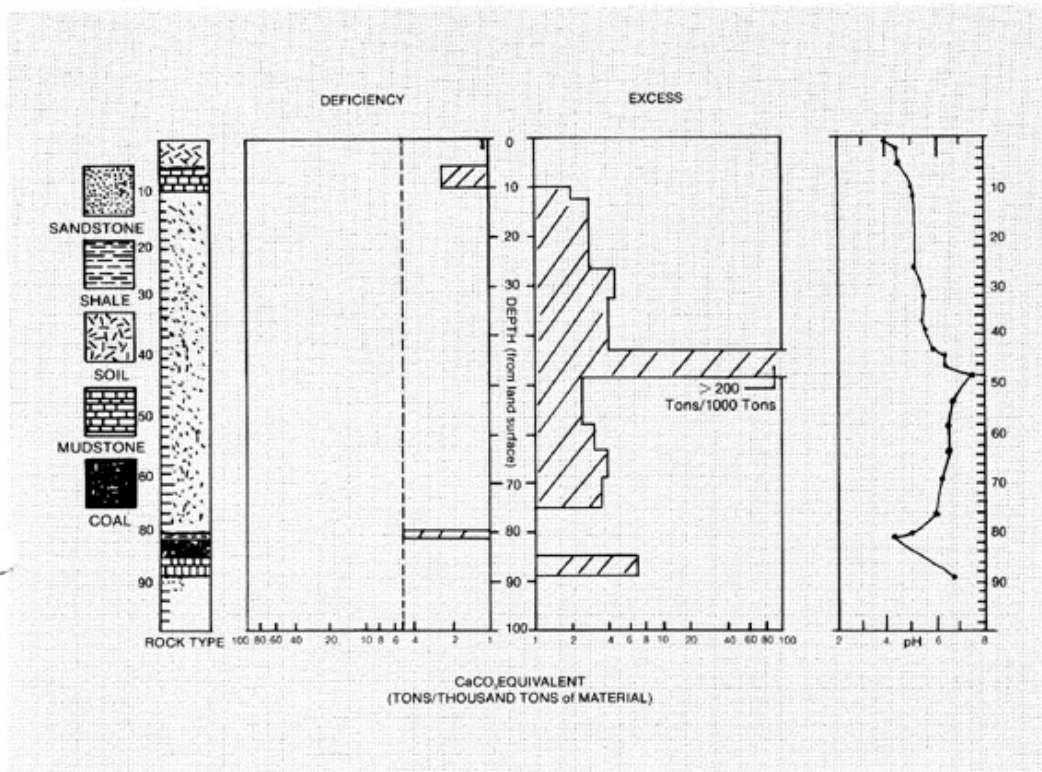
Sample number	Bottom depth (feet)	Rock type	Fizz	Color	%S	CaCO ₃ equivalent tons/1000 tons of material				Paste pH
						Max. from %S	Amt. present (NP)	Max. needed (pH7)	Excess	
1	0	Soil A	0	6/4	.010	0.31	-0.97	1.28		4.0
2	2	Soil B	0	8/4	.015	0.47	-0.74	1.21		4.7
3	5	Soil C	0	7/6	.010	0.31	-0.23	0.54		4.5
4	10	MS	0	7/4	.010	0.31	-1.99	2.30		5.0
5	12	SS	0	7/2	.015	0.47	2.52		2.05	5.1
6	26	SS	0	7/4	.005	0.16	3.26		3.10	5.1
7	32	SS	0	7/4	.005	0.16	4.77		4.61	5.6
8	37	SS	0	7/1	.020	0.63	4.51		3.88	5.4
9	39	SS	0	7/4	.005	0.16	4.03		3.87	5.7
10	43	SS	0	8/3	.005	0.16	4.03		3.87	5.9
11	44	SS	4	8/0	.005	0.16	228.20		228.04	6.6
12	46	SS	5	8/3	.005	0.16	294.25		294.09	6.7
13	48	SS	4	8/3	.005	0.16	289.22		289.06	7.7
14	53	SS	0	7/4	.005	0.16	2.52		2.36	6.7
15	58	SS	0	7/4	.005	0.16	3.52		3.36	6.5
16	63	SS	0	8/4	.005	0.16	3.01		2.85	6.5
17	69	SS	0	8/4	.005	0.16	4.03		3.87	6.1
18	76	SS	0	8/6	.005	0.16	3.77		3.61	6.0
19	80	SS	0	8/0	.095	2.97	3.01		0.04	5.0
20	81	SH	0	4/0	.180	5.63	0.76	4.87		4.1
21	85	Coal	*	*	*	*	*	*	*	*
22	89	MS	0	6/3	.005	0.16	7.01		6.85	6.6

*Not sampled

ACID-BASE ACCOUNTING INTERPRETATION-- OVERBURDEN No. 3

1. Samples 1 to 4 are taken from the soil and the weathered rock immediately below the soil. Sulfur values are relatively low. NP values are negative, but on these near-surface samples a negative NP indicates weathering. Although this indicates a lack of neutralizing material, it also indicates a lack of pyrite. Therefore, normal liming practices will neutralize the acidity of these samples.
2. Samples 5 to 10 are sandstone, have low S values and low NP values. They show a slight excess in neutralizing value, but in reality they will have very little if any neutralizing value. Likewise, because

- of the low S values, these samples will produce very little acid.
- Samples 11 to 13 will produce alkalinity because of high NP, low S, and fizz values of 4 and 5.
 - Samples 14 to 18 have very low S but also very low NP. These samples will react very similarly to samples 5 to 10.
 - Layers 19 and 20 have higher S values than the above layers. They also have low NP values. These samples may or may not produce acid. Leaching tests and/or pyritic sulfur analyses may provide additional information.
 - Sample 22 has such a low S value that it should not produce acidity.

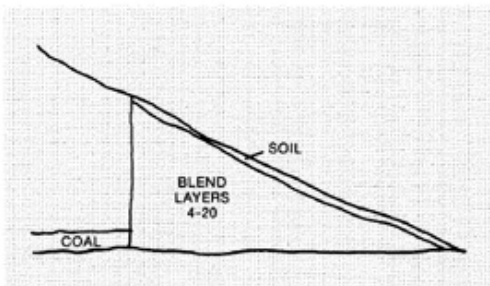


Overburden No. 3: Acid-base accounting.

Overburden No. 3: Acid-base accounting.

HANDLING PLAN-OVERBURDEN No. 3

Remove soil (layers 1 to 3) and stockpile. Since the pavement at this site should not produce acidity, special treatment should not be required. Except for layers 19 and 20, this overburden should produce very little acidity. Being careful to place layers 19 and 20 near the surface, the total overburden can be blended as it is replaced. All layers should be compacted to reduce the flow of water. Replace the topsoil, then lime, fertilize, and seed.



Overburden No. 3: Plan for placement.

Overburden No. 3: Plan for placement.

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