RESEARCH and DEMONSTRATION STUDIES in ACID MINE DRAINAGE ABATEMENT TECHNOLOGY

ACID MINE DRAINAGE TECHNICAL ADVISORY COMMITTEE
West Virginia Department of Natural Resources
Charleston, West Virginia

PROPOSAL
to
OFFICE OF SURFACE MINING
for
STUDIES IN ACID MINE DRAINAGE ABATEMENT TECHNOLOGY
by
ACID MINE DRAINAGE TECHNICAL ADVISORY COMMITTEE

West Virginia Department of Natural Resources
Charleston, West Virginia

Prepared by

Frank T. Caruccio

December, 1981

TABLE OF CONTENTS

I - SUMMARY AND PROGRAM ELEMENTS

Acid mine drainage is a problem common to surface coal mining in the northern portion of the Bituminous Coal field of Appalachia and in some areas is considered to be an unavoidable consequence of the mining operation. Consequently, aside from the long term and costly treatment processes necessary to neutralize the acidity and treat the mine drainages to acceptable quality standards, the solution to the problem is increasingly oriented toward the prohibition of mining those coals associated with the production of acid mine waters. As a result, a significant portion of our energy base may be withdrawn from recovery. In addition to the geographic limitations and market constraints imposed by the banning of mining of these coals, a severe economic impact is generated as well. In many areas in this part of the country, coal mining is the primary base of the economy and closing off specific regions to mining creates adverse economic effects.

In addition to environmental and economic problems associated with these acid-prone coals, there exists a fundamental fallacy in our reasoning behind the mining ban - and that is the assumption that these coal cannot be mined without producing acid mine drainage. To some extent this is a true statement if one accepts the basic premise *that these coals are mined by existing state-of-the-art techniques and current reclamation guidelines*.

It is conceivable, and many scientific research projects suggest possible, that coals in acid prone areas could be mined without producing perpetual acid mine drainage. Preliminary efforts along these lines, such as the guidelines established by the West Virginia Acid Mine Drainage Task Force, have been partially successful in achieving this objective. However, there have also been many demonstrated failures. The causes of these failures have never been fully identified and, consequently, the applicability of these techniques, or modifications thereof rendering them totally effective, are major unknowns and deficiencies in our understanding of acid mine drainage prevention.

To address this problem requires a re-examination of the kinetics of acid formation, a re-evaluation of existing reclamation technology and the design of unique and innovative methods to be used in conjunction with all elements of the mining operation (preliminary assessments, mining phase and reclamation). The effectiveness of the innovative methods to ameliorate acid mine drainage problems can be demonstrated by the response of existing acid seeps to a newly implemented application schedule. If successful, the method can be incorporated in future mine plans to prevent acid drainages from forming. At the initial stage of a three phase acid producing reaction, the amount of acid, and rate of pyrite oxidation are low. Thus, if the ameliorative technique proves adequate under the more adverse acid conditions, it will be successful in eliminating acid production during the mildly acidic initial stage. Alternatively, certain techniques will be applicable only in preventing acidification.

The following proposal outlines a study that is directed toward:

1. the formulation of in-situ techniques to remedy existing acid mine drainage conditions, and
2. identify and correct deficiencies in the current mining and reclamation practices to prevent the occurrence of acid mine drainage in future mines.

The major impetus behind this venture originates from the office of the Director of the West Virginia Department of Natural Resources (WVDNR). Under the direction of Mr. David C. Callaghan, an initial undertaking, with regard to the resolution of the acid drainage problem, came through the establishment of the Acid Mine Drainage Task Force. This group of 21 was comprised of scientists, consultants, coal industry representatives, and officials of the Mining and Reclamation Division of DNR, who were well versed with the coal related problems of West Virginia. The result of this group's efforts was the publication of a series of guidelines to minimize acid problems. However, the recommendations and suggestions advocated by the Task Force and incorporated in several mine plans, were partially successful in preventing acidic drainages. Recognizing deficiencies in the current methodology, the Director established a Technical Advisory Committee as an adjunct to the Task Force. The Committee of 11 is comprised of the Director of WVDNR, six scientists nationally and internationally recognized for their work in acid mine drainage, reclamation and rock-water geochemistry, two representatives from the coal industry distinguished by their service and experience in handling coal mine related problems and two officials of DNR concerned with the mine permitting and reclamation aspects of coal operations.

The Committee functions independently of the Task Force and has the capability and expertise to investigate all aspects of the acid mine drainage problem, ranging from the mine permitting stage (which includes overburden sampling and analysis, biochemistry and geochemistry of mine drainage and rock-water interactions), the mining phase (material handling, overburden manipulation, mining processes), reclamation efforts (hydrology, ground water geology, geochemistry of water recharge, reclamation, mine soil characterization, revegetation and overburden segregation and placement), to long term responses of the mine complex to reclamation efforts and their environmental impacts. In addition to the eleven member committee, outside consultants who provide knowledge and expertise in specific dimensions of the acid problem have been identified and invited to become involved with this venture.

The Committee has met on three separate occasions and in conjunction with field visits to several problem sites in Upshur County, West Virginia has had numerous and extended discussions regarding the acid problem of these areas. As individuals, each member of the Committee is knowledgeable and expert in a particular facet of the problem. As a group, the Committee affords a unique opportunity for total interaction by all its members and has led to the formulation of alternative methods of mining and reclamation and innovative ways of addressing the acid mine drainage problem.

The results of these meetings and group discussions are presented in the program elements of this proposal. The Committee has identified the nature of the acid problem at select mines in Upshur County and recognized several deficiencies in either the mine permitting processes, the material handling and analyses, and/or the reclamation strategy. The answers to the questions raised are necessary for the formulation of long term remedial actions. However, many of the studies proposed are structured to accommodate existing acid problems. Trials and material applications will be implemented at these sites, thereby gaining not only a data base for the study but an ameliorative effort as well.

Many of the coal companies have been introduced to this program and each has expressed enthusiastic cooperation as well as the willingness to provide the study with contractual support services, materials and in some cases, technical, analytical and financial assistance. The proposed budget does not reflect the cost of this support and it is important to realize the large costs involved with earth moving operations, monitoring network installation and material application when these activities appear in the work tasks but are not mentioned in the budget.

The program proposed will be administrated through the Director's office, which will coordinate and direct the studies outlined below. The Technical Advisory Committee will supervise the studies directly, either as a group, individual member involvement or laison with outside research specialists.

This initial venture is designed to gather data to answer questions which the committee felt would lead to the formulation of techniques with broad range applicability.

In the following proposed study the Committee has selected four manageable mines in Upshur County, West Virginia to be used as the demonstration and study base. With these mines specific problems have been recognized, deficiencies identified and program elements formulated. These have been integrated into a larger program that has been structured to accommodate the objectives of the study, that is, (1) solve the existing acid mine drainage problems and (2) formulate new methods to prevent future occurrence. The former emphasizes field demonstration projects designed for rapid, quickly discernible results. The data derived from these studies will complement laboratory results and will be used to develop corrective strategies with a broader base and regional approach. The latter blends the laboratory studies with field trials and requires more time. These phases of the study are attempts to reexamine the acid problem from a new perspective; the intent being to develop new ideas regarding acid production kinetics.

The proposed study is a beginning of a major effort to solve the acid mine drainage problem. Significant progress in research in this field has been made in the past decade and the opportunity now exists to bring these results together in a concerted effort toward the solution of this issue. The funds requested will be used to support the field demonstration trials and research efforts directed toward this goal.

II - INTRODUCTION

A - Background of the Problem

1 - Acid Drainage Occurrence

During earth moving operations (such as in coal strip mining, highway construction, foundation excavations, tunneling, etc.), rock strata, which up to this time were isolated from the atmosphere, are exposed to accelerated weathering processes and oxidizing conditions. Under these new weathering conditions the rocks disturbed become physically and chemically decomposed to various degrees. The products caused by weathering may affect the drainages with suspended sediment, highly dissolved solids contents, metal contamination and, in some cases, acidity. Acidic drainages, in addition to degrading the aqueous environment, have been known to decompose concrete structures and to dissolve and pit metallic structures in contact with these drainages.

Acid mine drainages, as the name defines, are highly acidic with pHs below 2.8, anion concentrations (usually sulfate) exceeding 10,000 mg/L, and acidities averaging 5,000 mg/L (as $CaCO_3$). They form when certain sulfide minerals are exposed to the atmosphere and allowed to oxidize. Commonly the problem is associated with coal mines where pyrite (or marcasite) is uncovered during the land disturbance. In the presence of oxygen and water the sulfides oxidize to form a series of soluble hydrous iron sulfates that commonly appear as white and yellow crusts on the weathered rock or sediment surface. Natural waters flowing over these crusts dissolve the salts which hydrolyze to form acidic drainages.

The chemical reactions explaining the oxidation of FeS_2 and the production of acidity (H^+) are given by the following equations:

$$2FeS_{2(s)} + 7O_2 + 2H_2O = 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \quad (1)$$

$$Fe^{2+} + 5/2H_2O = Fe(OH)_{3(s)} + 2H^+ \quad (2)$$

$$Fe^{2+} + 1/2O_2 + H^+ = Fe^{3+} + 1/2H_2O \quad (3)$$

$$FeS_{2(s)} + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

The stoichiometry of Eq. 1 shows that 1 mole of FeS_2 will produce 2 moles of H^+ (acidity). In turn, the Fe^{2+} generated by the reaction of Eq. 1 can readily oxidize into Fe^{3+} and produce an additional 2 moles of H^+ (Eq. 2). Alternatively, if the pH is low enough, the ferric iron can remain in solution (equation 3) in which case rapid ferric oxidation of pyrite (equation 4) occurs. When this occurs, iron oxidation (equation 3) is the rate limiting step. Iron bacteria enhance the ferrous iron oxidation and, therefore, serve as catalysts for Eq. 4. This catalytic function occurs primarily at pH below 3 and is generally not significant at near-neutral pH.

The principal bacterium involved in the catalysis of pyrite oxidation is <u>Thiobacillus ferrooxidans. Ferrobacillus ferroxidans</u> and F. <u>sulfooxidans,</u> once reported as significant, have been demonstrated to be strains of <u>T. ferroxidans. Thiobacillus thiooxidans,</u> although commonly found in acid mine drainage, oxidizes intermediate sulfur compounds rather than iron and so is not involved in the pyrite oxidation system. Another bacterium, <u>Metallogenium,</u> once implicated, has been shown to be negligible when <u>T. ferrooxidans</u> is present.

Whether a rock or sediment system produces acidic or alkaline drainages is dependent upon the presence of acid and alkaline producing components within that system. If the amount of alkalinity generated exceeds the acidity, then the system remains neutral or basic. The catalyzing bacteria are inhibited and solubility of Fe^{2+} and Fe^{3+} is greatly reduced, which collectively inhibits the acid production reactions. On the other hand, if the acidity generated within any part of the geochemical system exceeds the alkalinity, the oxidation of FeS_2 is enhanced and the acid production is increased. In addition, the low pH of the system, which controls the distribution of the catalyzing bacteria, will augment the amount of Fe^{3+} in solution, which increases the acid load. Once the acid reaction begins, it becomes self-propagating, and all acid-producing mechanisms begin to interact in a synergistic manner.

2 - Association of Acid Mine Drainage with Particular Coal Seams

On a regional scale there is an association between the occurrence of acid mine drainage and the coal seam being mined. In central Pennsylvania, for example, it has long been recognized that mines sited in coal seams at the base of the Allegheny (Clarion, Brookville and Lower Kittanning seams) commonly produced acid mine drainage whereas mining of the seams in the upper part of the Series (Upper Kittanning and Freeport coals) had few, if any, acidic drainages. A similar situation has been documented in the Buckhannon watershed of West Virginia.

A comparison of geologies of the acid prone and non-acid areas reveals a strong correlation between the occurrence of calcareous material and the absence of acid drainages. In general, mines sited in areas with abundant calcium carbonate (limestone), or calcium-magnesium carbonate (dolomite) strata tend to produce non-acidic drainages, regardless of the attendent sulfur (pyrite) contents. In addition to the high levels of alkalinity produced by these strata, recent research also suggests that the presence of these minerals (in abundance) supresses the oxidation of pyrite. Streams and rivers flowing in these areas tend to be buffered, alkaline and are able to withstand minor impacts of acid drainage inflows.

In contrast, the absence of calcareous material in the overburden and associated strata of a coal strip mine, causes the exposed pyrite to rapidly oxidize and produce copious amounts of acid. Streams in these calcareous deficient areas are generally poorly buffered, have little or no alkalinity and are severely degraded by even minor inflows of acid mine drainages.

B - Historical Perspective of the Acid Problem in West Virginia

Until the beginning of the past decade and throughout most of the Bituminous coal field of northern Appalachia, acid mine drainage was considered by many to be a problem indigenous to and an inherent part of coal mining. And although the environmental impacts caused by acid releases were great, the degraded areas were generally not readily visible to the public. Where noted, the "red water" was associated with the coal mining (the economic base of the area) and accepted as an adjunct to the mining.

In addition to the many laws and regulations that were implemented in the past decade to direct the reclamation efforts and establish performance standards for bond release, some states took a further initiative toward addressing the acid mine drainage issue. In some states application for surface mining permits in coals readily identified as acid producers were meticulously scrutinized by the permitting agencies and either granted with many conditions, or denied, thereby prohibiting the mining of specific coal seams. Through the repeated denial of permits, coal operators came to understand that certain coals, because of their associated acid mine drainage potential, could not be mined.

With time, and greater visibility, the acid mine drainage pr became a major issue in many states.

During 1977, in an effort to further resolve this problem the Director of the West Virginia Department of Natural Resources (WVDNR) established the Acid Mine Drainage Task Force (AMDTF), a 21 man group of scientists, coal operators, consultants and DNR representatives charged with the responsibility of establishing guidelines for surface mine operators mining in acid prone regions. The efforts of the AMDTF resulted in a field manual which contains recommendations for the analysis and identification of acid and alkaline strata, the selective handling and placement of acid material within the backfill, suggestions for managing the water entering the mine, liming the pit floors and blending of acid and alkaline material, and other advice for minimizing the generation of acid water and environmental impacts resulting therefrom.

The guidelines advocated by the AMDTF were incorporated in many mine plans and implemented by several coal companies mining the Kittanning coal seams in central West Virginia. As of this date the recommendations and guidelines that were followed have yielded mixed results, in some cases producing non acidic waters, in many other, acid mine drainage. This led to the reconsideration of permitting certain mines to continue to operate in the acid producing areas. Coincidentally with the production of acid waters these mines are also located in environmentally sensitive watersheds which can be severely impacted by acid water release.

After careful consideration of not only the environmental factors but of the economic consequences as well, the Director of the WVDNR restricted the granting of new permits to mines sited in the Kittanning seams in sensitive watersheds. One of the conditions for reopening these areas is for the coal companies to adequately demonstrate their ability to implement an acid abatement policy and effectively eliminate the existing acid problem. At the present time acid waters do not leave the mine site because the drainages are contained and channeled to central neutralizing treatment facilities and permitted to discharged only after meeting water quality standards. Such treatment is in many cases extremely expensive and results in higher coal costs to energy consumers.

To summarize the conditions in these areas, the mine operators are understandably concerned with regard to the mining suspension and somewhat consternated by the fact that they were following the guidelines prescribed by the AMDTF, which in some cases was now proving to be ineffective in preventing acidic waters. In addition, the areas affected by the ban are economically depressed and sustained primarily by the local mining industry. Further, the total coal reserves affected by the ban represent a substantial energy base of strategic importance in the overall energy supply of the immediate region.

Yet this situation discussed is not unique to this area, or for that matter, to the State of West Virginia. Many other regions within the Bituminous Coal field of Appalachia face the same problem and the conflict between providing a substantial economic base, recovering a much needed energy supply while minimizing the environmental impact has yet to be resolved. The solution to the problem currently existing in the Kittanning seams of West Virginia will have regional, and potentially national, implications.

C - Reevaluation of Existing Acid Mine Drainage Problems and Role of the Technical Advisory Committee

During the summer of 1981, the Director of the WVDNR assessed the status of the acid drainage problems in the Buckhannon and Little Kanawha watersheds and recognized the complexity of the situation and the need to address the acid problem from a new standpoint. To this end the Acid Mine Drainage Technical Advisory Committee (AMDTAC) was formed and charged with the responsibility of examining the acid problem in detail and devising innovative acid abatement techniques. The Committee, in addition to formulating procedures to ameliorate the existing acid problems, was to develop a long term program directed toward the permanent solution of the acid mine drainage problem and the capability to mine coals in acid prone areas without producing acidic waters.

The Committee of eleven members is composed of the Director of WVDNR, six scientists nationally and internationally recognized for their research efforts in acid mine drainage related problems, two officials of the Reclamation and Mine Permitting Divisions of WVDNR and two representatives of the coal industry. The size of the Committee is deliberately maintained at 11 members to optimize and effect idea interaction and formulation. All members of the Committee are thoroughly knowledgeable with acid mine drainage problems and have broad professional experiences with coal mining operations, related problems, and reclamation procedures (see attached table for Committee membership and background).

In addition to the working committee, other key personnel having expertise in particular facets of the acid mine drainage problem are brought in on a consulting basis and directed to pursue specific lines of research which are integrated in the overall program.

The Committee as a whole has met on three separate occasions in three different locations in West Virginia. During these meetings the Committee had the opportunity to visit several active and abandoned mine sites within the Buckhannon watershed and at each site were provided with all available information regarding the geology, overburden and water chemistry, hydrology, mine plan and other pertinent data. Field measurements of pH, temperature and specific conductance were taken at all accessible drainage outflows. In addition, mining personnel who had an intimate knowledge of the mining operation were on hand to answer questions and provide the history of operation of the mine site.

Following the field visitation, the Committee would reconvene and discuss the specific problems at each mine site. During these critique sessions the problem source was identified, in some cases errors uncovered, and potential solutions (in situ) formulated. These exercises led to the development of conceptual models which were used to characterize the occurrence of acid mine drainage at a particular mine site, partition the responsible acid generating factors according to their distribution within the hydrogeologic regime of the mined area and with which to design and recommend in-situ acid abatement techniques

ACID MINE DRAINAGE TECHNICAL ADVISORY COMMITTEE

Member	Organization	Background
Dave Callaghan	West Virginia Department of Natural Resources, Charleston, W.V.	Director
Frank T. Caruccio, Ph.D.	CARGEID and Department of Geology, University of South Carolina, Columbia, S.C.	Geochemistry of acid mine drainage, environmental hydrogeology
Gwendelyn Geidel, Ph.D.	CARGEID and Department of Geology, University of South Carolina, Columbia, S.C.	Applied Geochemistry, rock-water interactions, overburden analysis
Roger Hall, M.S.	West Virginia Department of Natural Resources, Charleston, W.V.	Reclamation, mine permitting, environmental protection
Bob Kleinmann, Ph.D.	Supervisor, Acid Mine Drainage Research Section, U.S. Bureau of Mines, Pittsburgh, PA	Geochemistry of acid mine drainage, microbiology of iron bacteria
Charles Miller, M.S., P.E.	Grafton Coal Company, Weston, W.V.	Industry representative; Chairman, W.V. Surface Mine Drainage Task Force
Hans Naumann, P.E.	Island Creek Coal Company, Craigsville, W.V.	Industry representative, engineering services manager
Pete Pitsenbarger	West Virginia Department of Natural Resources, Charleston, W.V.	Chief, Division of Reclamation
Jack Renton, Ph.D.	Geology Department, West Virginia University, Morgantown, W.V.; W.V. Geol. Survey	Mineral matter in coal, geochemistry of acid mine drainage
John Sencindiver, Ph.D.	Division of Plant and Soil Science, West Virginia University, Morgantown, W.V.	Overburden analysis, mine soils, reclamation
Alfred Stiller, Ph.D.	Department of Chemical Engineering, West Virginia University, Morgantown, W.V.	Iron sulfide geochemistry, oxidation kinetics, reactor processes

III - PROBLEM IDENTIFICATION AND PROPOSED DEMONSTRATION AND RESEARCH PROGRAMS

A - Deficiencies Identified by the Committee

(1) During the field visitations, the Committee was readily impressed by the responsible nature and the conscientious manner by which the coal operators managed their mining activities. In all cases the mine personnel were adhering to the guidelines and recommendations prescribed for mining in acid-prone areas. It was concluded that most of the problems could not be directly attributed to poor mining practices.

(2) One problem was related to the analysis and identification acid and alkaline strata. Because of its simplicity and rapidity of analysis, most, if not all, overburden analyses in this area are performed in accordance to the acid-base accounting technique outlined in EPA 600/2-78-054. The Committee concluded that in some cases, where sample has approximately equal blends of alkaline and acid fractions acid-base accounting is not an accurate predictor of the long term chemical weathering attributes of the sample.

(3) The blending technique used in reclaiming a mine whereby "equivalent weights" of alkaline and acid material are admixed to produce a neutral backfill has not always produced satisfactory results. This major deficiency may be due to (a) errors in analytical procedures which incorrectly identify alkaline or acid strata, (b) insufficient quantities of alkaline material added to the system, (c) poorly defined hydrology of backfilled areas so that recharge events are circumventing alkaline material, (d) the use of impure (non-alkaline) material purported to be highly neutralizing, (e) low solubilities of the admixed alkaline material so that the total neutralization potential (NP) is not realized at the same rate as the acid production, and other factors not yet readily apparent.

(4) The source of water constituting the acid mine drainage and the pathway from the recharge source to the discharge point are not clearly defined or understood. The drainage from a mine may be comprised of (a) recharge through the mine surface in response to precipitation events, (b) near surface interflow emanating from the highwall, flowing vertically along the coarse rubble highwall-backfill interface and subsequently flowing along the mine pavement or (c) ground water discharges along the base of the highwall which eventually emerge as seeps.

A knowledge of the hydrology of a backfilled mine is critical to the definition of the acid source in a mine. Highwall seeps (high and low) probably circumvent the alkaline material, encounter the acid zones only, will be difficult to contain, and will require a hydrologic solution. Surface recharge sources, however, should encounter both alkaline and acid material in which case the acid problem could be traced to either a shortcoming in the blending technique or a breaching of the hydrologic integrity of the medium used to isolate the acid material from air-water reactions. The answer to these questions is a necessary first step toward the formulation of long term permanent in-situ acid drainage abatement procedures.

(5) The hydrology of a valley fill structure and its inter-relationship with the rock core provides a critical element in understanding the source of acidity from these structures. The permeable nature of the rock core, designed to facilitate water movement from the rock mass to enhance its stability, permits an oxygen flux to permeate the interior of the valley fill. Because of the massive nature of these structures ameliorative methods implemented at these sites are to emphasize the strategic placement of alkaline materials in recharge areas or the manipulation of their internal hydrologic regime.

(6) The efficacy of material used to hydraulically isolate acid strata and the methods of emplacement are not adequate to prevent acid water formation. In the areas visited the overburden consisted of a massive, thickly bedded sandstone unit (around 70 feet thick), capping a shale sequence (averaging 25 feet thick), overlying the coal. The sandstone is blasted and removed to form an inert pad upon which the acid material is placed to prevent contact with the reestablished water table. The acid material is then capped with an impermeable medium and compacted. Because of the large voids occurring between the sandstone blocks, the opportunity exists for the acid material to migrate downward into the void space and collapse the impermeable capping layer. At one mine site it was obvious that runoff on the surface of the mine during precipitation events would travel a short distance and then drain into highly permeable zones randomly located on the mine surface. Thus a large percentage of the drainage emanating from the mine comes from a few recharge points and liming the entire surface of a mine has limited affect.

(7) Disproportionate mine surface infiltration rates generate recharge areas within the backfill of the mine that account for the majority of the water comprising a mine drainage. In essence, the bulk of the volume of water emanating from a mine comes from a few areas in the mine where the permeability is high and flow through times very fast. The identification of these recharge areas will be used for the selective placement of ameliorants to enhance acid abatement.

(8) Although many attempts are made to supplement the alkalinity of the mine complex, it appears that these efforts are not producing the desired results. Either because of impure carbonates, improper placement of alkaline material (in essence out of the main stream of major flow paths), solubility constraints (with respect to the mineral matter and the pore space gas composition), complexing reactions or random distribution of acid/alkaline material, alkalinity is not being produced in sufficient quantities to effectively affect the acidity of the mine drainages.

Aside from bactericides, whose primary use is to reduce the acid concentrations to better accommodate neutralization mechanisms, alkalinity is the primary abatement factor that can be used effectively to neutralize acidity generated and possibly affect major changes in pyrite oxidation kinetics. One strategy of acid abatement is concerned primarily with the methodologies of significantly increasing alkalinity loads within mine backfills.

B - Summary of Problem Elements and Program Objectives

In terms of addressing the acid mine drainage problem the Committee recognized two courses of action; first, identify areas that will respond quickly to innovative ameliorative methods and which can be used to demonstrate the effectiveness of the treatment and universal applicability. In these areas studies will be directed toward affecting or neutralizing the acidity or modifying the acid reactions through field trials. These trials are designed to rectify existing acid problems and at the same time provide an insight into the physics of performance.

The second course of action, to operate simultaneously with the field trials, involves the formulation of innovative methods that will prevent new sources of acidity from developing. This necessitates a fundamental reexamination of acid mine drainage kinetics, overburden analytical techniques, carbonate dissolution kinetics, selective strata placement methods, the hydrology of a strip mine and reclamation measures. In this phase, laboratory experiments will be coupled with controlled field trials such that all variables affecting mine drainage quality will be isolated to better define their role in the overall problem and understand their interactions and response to abatement techniques.

The following research and demonstration projects have been designed to address the deficiencies outlined by the Committee in their review of existing acid problems in the Buckhannon watershed of West Virginia. Each program element is, in turn, an integral part of a major effort to first, demonstrate through field trials the effectiveness of various acid abatement techniques as applied to ameliorate existing acid conditions and second, develop innovative techniques applied to the control and prevention of acid mine drainage occurrence in new mines.

IV - DEMONSTRATION AND RESEARCH PROGRAMS DIRECTED TOWARD SOLUTIONS OF EXISTING ACID PROBLEMS

In the following proposed studies, several coal companies have expressed a willingness to cooperate and participate with the Committee efforts. Because of the potential scrutiny that the proposal will receive in the review process, and the identification of acid problems with company names, the companies desire that their participation not be highly publicized. Therefore, references to company names have been omitted in this proposal, but will be made available to the proper authorities upon request.

A - Demonstration of the Effectiveness of Current Mining Practices and Identification of Deficiencies

Problem

During the past several years, some new mining techniques have been used in the Upshur County, West Virginia surface mining operations. This area contains the headwaters of sensitive watersheds and guidelines designed to prevent acidic drainages were used in the overall mine plan. In addition to the normal prudent mining practices, further steps are taken to mitigate the formation of acid. These include the placement of acid forming material on top of a 20-30 foot pad of inert sandstone (to remove the material from the water table) and capping the toxic strata with a clay seal, scraping of toxic material from the mine pavement and subsequent liming of the surface (to seal the pavement with iron hydroxide complexes), blending imported lime at rates designed to make up the base deficiency as determined from acid-base accounting procedures and placing a suitable substrata at the surface to enhance revegetation and reclamation efforts.

Based on the past performance of similar operations in adjacent areas of similar geologies, it is expected that these efforts may prove effective in some cases and not in others. The reasons for the failures may be related to the geologic variability, improper overburden sampling and imprecise analyses, hydrologic factors, ineffective acid material sealants, unsuccessful surface reclamation trials and the inefficient segregation and isolation of acid material. Prior to making any recommendations regarding corrective actions, the Committee must identify the existing deficiencies and relate their relative effects to the success and failure of the total reclamation procedure.

A portion of the coal mining operation is ideally suited for a detailed study of this problem. By a fortuitous combination of mining activity, topography, space and timing an elongated topographically isolated ridge (= 10 acres) is scheduled to be mined in the early part of 1982 and because of a road location this area is hydrologically isolated from the main mine complex. Consequently, drainages emanating from this area can be readily related to various portions of the mine and specific treatments.

Objectives

The objectives of the study based at this site are to:

(1) identify the sources of water within a backfilled mine site and their respective contributions to mine drainage seeps (a hydrologic assessment).

(2) test the efficacy of anionic surfactant bactericides

(3) determine the effectiveness of clay seals and their ability to contain acidic leachates.

(4) demonstrate the predictive capability of various overburden analyses

(5) demonstrate the effectiveness (or lack thereof) of alkaline ameliorants

Methodology

Prior to mining the area, cores will be drilled and samples of the overburden collected and analyzed to determine which strata are inert and potentially acid and alkaline producing. In addition, 10 soil sampling points will be randomly selected and the soil will be characterized by the following procedures:

1. A pit will be excavated to bedrock at each site.
2. A complete profile description written for each site.
3. Each described soil horizon will be sampled.
4. The following properties will be determined for each sample in the laboratory.

    a. Texture
    b. Moisture Retention
    c. Organic Matter
    d. Cation Exchange Capacity
    e. Extractable Bases (Ca, Mg, K, Na)
    f. Exchangeable Acidity and Al
    g. pH
    h. Extractable Manganese
    i. Extractable Phosphorus

Due to the large amount of sandstone in the overburden, a topsoil substitute for the final covering will most likely not be considered. Accordingly, the overburden will be analyzed for its acid-producing potential.

During the backfilling operation, the inert material will be used as a pad, the toxic material will be placed above the pad, treated with anionic surfactants and covered with a clay seal. The clay will be capped by the alkaline material or, if none is available, inert material. The mine surface will be graded, topsoiled and completed according to the reclamation plan. At the time of the backfilling process, the toxic material will be spiked with a bromide salt and the alkaline material or material above the clay layer will be spiked with an iodide salt. These will serve as ground water tracers and will be monitored as seeps develop at the toe of the spoil. These will serve as tracers to determine when or if the toxic material has been intercepted by recharge events. These indicators will be complemented by stable oxygen isotope tracers.

Each rainfall event has a specific $^{16}0$ to $^{18}0$ ratio and these ratios remain approximately constant as the water infiltrates through the spoil and emerges as a seep. By monitoring the rainfall for the $^{16}0/^{18}0$ ratio or (symb. DEC) $^{18}0$, a distinct pattern will be discerned with time. Monitoring the seeps for these ratios can be used to determine the travel times of ground water flow. And because the permeability of the highwall material is expected to be much less than that of the backfill material, the oxygen isotope patterns for a particular rain event will pass through the backfill at a faster rate than ground water flow through the highwall material. Samples of ground water from domestic wells in the area will confirm the pattern for a particular time interval. Thus sampling the rain for its isotopic ratios (to determine the pattern) and looking for a similar pattern in the ground water and mine seeps will reveal the relative proportions that each source contributes to the drainage flow. Monitoring the seeps for iodide and bromide reveals the internal flow paths within the backfill. Evaluation of halide and isotope data can be used to identify the sources of water that comprise the seeps, the effectiveness of the seals and the probable acid and alkaline sources within the mine complex.

The ground water in the area will also be monitored for the (symb. DEC)^{13}C. This value is relatively constant in the ground water because its source is primarily through the equilibrium with carbonates in the system. On the other hand, the (symb. DEC)^{13}C in the rainwater will fluctuate due to the carbon dioxide levels of the atmosphere. Monitoring seeps in the area for (symb. DEC)^{13}C is used to determine the sources of water and partition the flows in terms of ground water highwall bleed or surface infiltration of rainwater.

The presence of alkalinity in the overburden is known to deter acid production from pyritic material. This natural mechanism of AMD reduction is only effective if sufficient alkalinity is present. We propose to investigate the potential benefits of added alkalinity both during and after mining. Freshly exposed pyritic material at the mine site will be treated with sources of alkalinity to maintain unfavorable conditions for rapid oxidation. Acid producing sites will also be treated with alkaline material (hydrated or dry lime, Na_2CO_3, NaOH, etc.) at high application rates to return the systems to the neutral state. With infiltrating rainfall, then, an alkaline front will pass through the pyritic material, neutralizing acidity and precipitating dissolved iron. The latter effect may be useful in coating exposed pyrite in addition to breaking the ferric iron pyrite oxidation reaction cycle. Subsequent application of limestone will be used to maintain near neutral pH for long-term control of AMD formation.

B - Effects of Using Crushed Sandstone from the Overburden as the Topsoil Material

Problem

Some of the native soils on surface mine sites in West Virginia are shallow and leached of bases and nutrients. Therefore, these soils must often be heavily limed and fertilized when used as topsoiling materials on mined areas. Sometimes, because of the shallow soils, only a thin covering is available for the total site.

Some operators have used materials from the coal overburden to replace the original soil as a final covering. If a substitute for the original soil is used, the substitute must be as good as or better than the original soil according to state and federal regulations. This determination is usually based upon laboratory analysis of the two materials. Generally, the acid-base account, lime requirement, pH and extractable nutrients are determined for each material.

A surface mine in Upshur County, West Virginia is currently using a topsoil substitute. Past observations have indicated that free carbonates were present in some of the sandstone at this site. Therefore, the sandstone has been excavated, crushed and used for topsoil. More recently it has been indicated that results of a laboratory weathering test of a sandstone sample showed that acidity was slightly higher than alkalinity in the leachate. Observations made of the site on a recent visit indicated that some of the vegetation was stressed. The reason for this stress could have been a lack of fertilizer, a moisture problem or acidity. It was also noticed that this sandy material was highly erodible when placed on steep slopes.

Since some of the overburden materials at the site are potentially acid producing, it is imperative that optimum plant growth media be placed at the surface and that good vegetation be established as quickly as possible. A good stand of vegetation is necessary to increase the carbon dioxide content of the substrate and effectively increase the alkaline load. Vegetation will also reduce erosion that could expose some of the pyritic materials to the atmosphere. Thus, vegetation establishment is a valuable part of the total program to reduce or eliminate acid mine drainage.

Objectives

1. To determine the range of properties for the topsoiling materials (crushed sandstone and original soil) at this site.
2. To evaluate the establishment and growth of vegetation on three topsoiling materials:
    a. Original soil
    b. Crushed sandstone
    c. Mixture of original soil and crushed sandstone
3. To evaluate the effects of hydromulch, hay or straw and a soil stabilizer on erosion of the crushed sandstone placed on steep slopes.

Methodology

All topsoiling materials must be thoroughly characterized before use. Therefore, the crushed sandstone and the original soil at the site will be analyzed for the following properties:

1. Texture
2. Organic Matter
3. Cation Exchange Capacity
4. Extractable bases (Ca, Mg, K, Na)
5. Exchangeable Acidity and Al
6. Manganese
7. Phosphorus
8. Acid-Base Account
9. Moisture Retention

In an attempt to determine why the vegetation establishment was not uniform on this site, transects will be established across several of the areas. Minesoil samples will be collected at various spots along the transects and the properties listed above will be determined. The height, thickness, and general appearance of the vegetation at each sampling point will be noted.

Plots will be established to determine the suitability of the crushed sandstone for final covering material. Three kinds of cover material will be tested: (1) original soil, (2) crushed sandstone, and (3) a mixture of soil and sandstone. Several lime and fertilizer treatments will be used in the study, but actual treatments cannot be determined until the properties of the cover materials have been determined.

An additional set of plots will be established on the outslope to test the effectiveness of hydromulch, hay or straw, and a soil stabilizer in controlling erosion. The final selection of a soil stabilizer to be used at this site will be made after consultation with company representatives.

The grass and legume mixture to be seeded on each set of plots will be the mixture used by the company. All treatments will be replicated in a randomized block design.

The plots will be established in the spring of the first year of the study, if possible. The amount of vegetation in each plot will be determined at the end of the first, second, and third growing seasons. Soil samples will be collected from each plot and analyzed at the end of the second and third growing seasons. Vegetation samples will be collected for analysis at the end of the third growing season.

C - Induced Alkaline Recharge Zones to Mitigate Active Acidic Seeps

Problem

Acid seeps emerging from completed or abandoned strip mine operations are visible at many mine sites in West Virginia. Although the acidity is influenced by many factors, two of the critical ones are the presence of alkaline material and the hydrology of the site. Obviously, the lack of alkaline material precludes the generation of alkalinity. However, even if the alkaline material is present, it must be positioned such that water infiltrating the mine can generate alkalinity prior to contacting the acid material. Additionally, the alkaline material must be capable of producing sufficient concentrations of alkalinity to neutralize the acidity. The amount of alkalinity which can be generated by limestone or dolomite is limited by the solubility constraints and has been shown to have little affect on acid seeps if applied to the surface of a backfill. However, other materials are available which yield higher alkalinities such as lime, Na_2CO_3, $NaHC0_3$, etc. Although these have been used in the past primarily to treat acid discharge, they could be used in conjunction with limestone to provide both a short term highly alkaline source and a subsequent sustained low alkalinity flow. By strategically placing these materials in the recharge areas of a mine and by inducing surface water flow into these areas, the alkaline load within the mine backfill will be increased to enhance neutralization and inhibit pyrite oxidation. Alternatively, the carbon dioxide levels of the soil substrate accepting the recharge may be increased (to affect increases of alkalinity) through the addition of an enriched organic medium (i.e., sewage sludge, leaf debris, sawdust, etc.).

It has become increasing evident that ground water flow through a backfill is highly channelized and that the major acid load stems from the leaching of toxic rocks intercepted by these flow paths. By channelizing water into selected recharge zones that are loaded with alkaline material, the proportions of acid-alkaline flow paths are shifted in favor of the alkaline end. In so doing it (the alkaline flow) forms a greater percentage of the seeps emanating from the mine and will affect the quality accordingly.

A site in Upshur County, West Virginia is a completed mine with several acid seeps discharging from one small area along the toe of the spoil. The surface configuration of the predominant, highly pervious sandstone spoil allows the recharge zones and discharge points to be easily identified. This site is an excellent location for a demonstration project to test the effectiveness of inducing alkaline drainages through recharge areas of an acid producing spoil.

Objectives

The objectives of this study will be to determine which chemicals are best suited for admixing with limestone as a surface or near surface treatment, the affect of organic rich additives, and to test the effectiveness of selectively placing alkaline material in the recharge zones of a backfilled mine.

Methodology

All recharge and discharge points of the site will be identified and, after preliminary studies to determine which mixtures of carbonates, oxides or hydroxides provide the most optimum alkaline leachate, the recharge sites will be treated with a surface application of a mixture of limestone and the appropriate soluble alkaline material. A bromide salt will be incorporated in the limestone mixture during the application of the material (the bromide ion will serve as a tracer). Samples from seeps will be collected bimonthly and measured for flow, temperature, pH, acidity, alkalinity, specific conductance, sulfate and bromide. The presence of bromide in the water samples will indicate that surface water has contacted and passed through the alkaline horizon and that the seep quality is being affected by the limestone mixture. Once established organic rich media will be placed at selected recharge zones, spiked with another halogen (different than the one used previously) and the seep monitored for quality affects.

Due to the topography and seep configuration, a control site cannot be monitored. However, because of the time lag, from the time of application to discharge events, samples collected for several months before the seep is affected by the application will serve as comparative background data.

In addition to monitoring the seeps, the rainfall quality and quantity will be measured. Percolation tests will be conducted to estimate the infiltration rates in order to determine an approximate length of time required for flow through and volumes of water passing through the system. Based on preliminary information of the backfill techniques used, and the geology of the area, it is estimated that two to three years will be required for the complete effect of the application to be realized.

As an ancillary study, false color and infra-red imagery will be used in conjunction with the field study. The aerial photographs will be examined for thermal anomalies that reflect surface temperatures indicative of recharge zones. Patterns discerned on the surface, coupled with the hydrologic information gained from the field studies, will be used to identify recharge areas and as a guide for the strategic placement of acid abatement ameliorants.

D - Elimination of Acidic Seeps Through Surface Sealing of Mine Sites

One plausible, though expensive, method of eliminating acid mine drainage is through the surface sealing of a mine site. If effective, water, which would naturally infiltrate the ground surface and contact the acid producing materials, is diverted from the mine by impermeable devices and collected along the periphery of the site. Through this diversion, ground water recharge and the acid drainages are eliminated.

A coal company has experienced some extremely acid minesoils and waste materials on a surface mine site in Upshur County, West Virginia. Not only are some of the surface materials too acid for optimum growth of vegetation, but acid seeps have also developed at the site.

The coal company has tried to control the acid production by several methods with little or no success. Therefore, it was decided to completely cover approximately 40 acres of extremely acid material with an impervious PVC liner to keep water out of the fill material. Although this liner has been used in a number of different sealing operations, it has never been used on a surface mine to control acid mine drainage. To determine the effectiveness of the seal various aspects of this project should be monitored for several years.

D - 1 - Soil Development, Moisture Relations and Root Growth and Distribution in the Topsoil Above the Liner

Problem

A major concern to a soil scientist is the fate of the "topsoil" material placed on the PVC liner for growth of vegetation. The plan at the site is to place 18 to 24" (45 to 60 cm) of topsoil on the liner. This immediately raises several questions. Will the soil remain in place without slippage occurring on the undulating site? How will the soil respond when saturated with water? Will trees and other deep rooted plants be able to survive without adversely affecting the liner? What is the useful life expectancy of the liner? This project addresses these questions and will provide the data base for evaluation of the effectiveness of this ameliorative technique.

Objectives

1. To evaluate soil development in the topsoiling material above the liner.
2. To evaluate the effects of the liner on root growth and distribution, and the effects of roots on the liner.
3. To determine the water relations of the topsoil, especially at the point of contact with the PVC liner.
4. To determine the stability of soils on the PVC liner.
5. To evaluate the long term effectiveness of the PVC line

Methodology

Any study of soil development and root growth in newly deposited and vegetated earth material is, by necessity, long term. Some data will be available at the end of one year, but it is assumed that at least two years, and maybe longer, will be required before any conclusions can be formulated.

Initially, ten sites will be randomly selected from a grid pattern for detailed sampling and observations on the mine. Soil pits will be dug at each of these ten sites and the soil will be described. Samples will be collected from five depths (0-7 cm; 7-15 cm; 15-30 cm; 15-45 cm; 45-60 cm) for laboratory characterization. The following analyses will be included in the characterization.

Physical Analyses

1. Texture
2. Bulk Density
3. Moisture Retention
4. Shrink swell
5. Atterberg Limits
6. Aggregate Stability

Chemical Analyses

1. CEC
2. Exchangeable Bases (Ca, Mg, K, Na)
3. Exchangeable Acidity and Al
4. Base Saturation (Calculation)

5. Free Iron
6. pH
7. Organic matter
8. Phosphorus
9. Manganese

Soil moisture determination devices will also be established at three depths at each of the original 10 sites and at 10 additional randomly selected sites. These moisture devices will be placed at 15 cm below the soil surface, 30 cm below the soil surface, and 7 cm above the soil contact with the liner. Moisture readings will be taken twice a month and approximately 48 hours after each rainfall event of 1/2 inch (1.25 cm) or more for the first two years of the study. The data will be evaluated at the end of two years to determine if further monitoring is necessary.

Soil data will also be collected at the end of the second and third years. Soil pits will be excavated at the 10 sampling sites, and the soils will be described and sampled at the five depths. Special emphasis will be placed on observations of root growth and distribution. At the end of the second year, all soil samples will be analyzed for the chemical constituents listed above. Aggregate stability will also be determined for the surface horizons of each pit. After three years, all of the physical and chemical properties listed above will be determined. Conclusions of early soil development will be drawn from comparisons of the laboratory and field data.

Periodic visits will be made to the site throughout the period of the study. On these visits observations will be made of the vegetation to determine if it appears to be stressed in any way. Observations will also be made on the quality and effectiveness of the liner. Any failures that might have occurred on the site will be noted, located, measured and described.

D - 2 - Evaluation of the Use of Bentonite as a Surface Seal of Mine Sites

Problem

The concept of preventing ground water recharge to eliminate acid mine drainage is structurally valid. Obviously if the mines are kept dry, mine drainage cannot occur. The major shortcoming of this technique, as exemplified by the PVC liner method, is the cost involved in applying the sealant.

An alternative to the plastic seal is the use of bentonite clay as the sealant. The clay has the capacity to expand fifteen times its volume when wetted and can easily be tilled into the mine surface with conventional equipment. Although more cost efficient than the plastic liner, the long term effectiveness of a clay seal has not been demonstrated.

Objectives

1. To determine the cost-benefit analysis of a PVC liner versus bentonite mine surface seal
2. Compare the effectiveness of a PVC liner versus bentonite seal in terms of surface soil ground affects
3. Assess the effectiveness and long term stability of a bentonite seal

Methodology

A small (~ 5-10 acres) portion of the mine where the PVC liner is being emplaced, which is deemed to provide sufficient hydrologic control and is isolated from the main body of the mine will be selected for this test. At this site, the reclaimed mine surface will be scarified to provide a relatively uniform surface layer and bentonite clay pellets admixed with clay will be disced into the surface mine soil. Problems normally encountered by boulders of rock penetrating the surface are eliminated at this site because of the thick soil that will be applied to the reclaimed mine surface. The application rate will be determined in consultation with a representative of the supply company and through vertical constant head permeability tests on mine soils having various percentages of bentonite clay added.

Soil water piezometers approximately 2 meters deep will be installed in the treated areas and in an untreated (control area). In addition, the mine surface will be formed to accommodate runoff into channels that lead to Parschal flumes. A rain gage will be installed in the area and following significant precipitation events the soil piezometers will be monitored with a neutron source to determine the rate and degree of wetting front that develops in response to a particular precipitation event. Runoff will be monitored and related to the amount of precipitation, estimated evapo-transpiration and soil moisture to ascertain the effectiveness of the bentonite seal. These data will be compared to the control plot and the PVC lined area for a cost-benefit analysis.

E - Bactericidal Control of Acid Drainage From Inactive and Abandoned Mined Lands

Problem

The importance of iron-oxidizing bacteria in the formation of acid mine drainage has been established in the laboratory and in the field. Most laboratory research regarding the kinetics of acid formation has shown the oxidation of ferrous to ferric iron to be the rate limiting reaction. Further, it has been shown that the oxidation of pyrite by ferric iron is the principal control on the rate of acid production and that it significantly magnifies the acid problem.

A technique has been developed to kill the iron-oxidizing bacteria using anionic surfactants; field tests have indicated that the technique is inexpensive and effective in reducing acid concentrations. Surface application of the bactericide has been used on active mine sites but may be of questionable value on many inactive sites where rainfall infiltration is limited by regrading, compaction and revegetation.

At sites where ground water recharge through the highwall predominates, an alternative method of application is required. A trench excavated along the highwall should allow the surfactant solution to intercept the ground water flow.

Objectives

1. To confirm the apparent source of recharge of an inactive mine site to allow effective bactericidal treatments.
2. To test the effectiveness of bactericidal treatment using a trench excavated along the old highwall and sodium lauryl sulfate applied both as a liquid solution and incorporated into rubber for long-term release.

Methodology

An appropriate field site near Buckhannon, W.V. has already been selected for this test. Baseline water quality data has been collected intermittently over the past year. Percolation tests conducted at the site indicate that very little infiltration is occurring but a consistently acid spring exists. During mining, ground water flow from the highwall was significant; it is likely that ground water recharge through the pyritic spoil material is responsible for the spring.

Piezometers will be installed at the site and a tracer test will be conducted using a halide ion measured with a specific ion probe. In addition, surface geophysical methods described elsewhere in this proposal will be used to identify specific areas of acid production.

Excavation of the trench and application rates for the bactericide will be based on the hydrologic information. After treatment, it is anticipated that at least 12 months of monitoring of the spring and the piezometers will be necessary to judge the effectiveness of the treatment.

F - Evaluation of Surface Geophysical Methods for Locating Acid Mine Drainage Source Areas

Problem

Remedial actions to abate acid mine drainage (AMD) from refuse piles and strip mine spoils are greatly hindered by a lack of information regarding the subsurface generation and spreading of constituent pollutants. Conventional means of obtaining subsurface information, such as drilling a grid of monitoring wells, is effective but also relatively expensive and labor intensive. As an alternative to large scale drilling, the use of surface geophysical methods to delineate subsurface pollution problems is becoming increasingly widespread. Surface electrical methods are commonly applied to define the nature and extent of ground water degradation at landfill sites, and electromagnetic methods are being experimented with for similar applications. These techniques offer the advantage of gathering a significant quantity of subsurface data more rapidly and at less cost than is possible with conventional methods. With this information, appropriate remedial actions could be determined at minimum cost.

Objectives

To develop the use of surface geophysical techniques for application to the AMD problem associated with refuse piles and spoil material. Coupled with a knowledge of the basic site geology and hydrology, preliminary geophysical surveys can be used to locate primary AMD source areas and migration paths.

Methodology

Site selection will consist of reviewing the geology and drainage characteristics of abandoned or reclaimed refuse piles posing a significant AMD problem, and selecting two sites for study. Criteria for site selection will include size (50 acres or less), topography, drainage characteristics, and accessibility. The two sites chosen ideally will be similar to each other in terms of coal seam mined and preparation and disposal procedures.

One of the selected sites will be fully instrumented to evaluate surface and subsurface flow directions and water quality. Instrumentation will include piezometers, multilevel samplers, a surface water gaging station and a rain gage. Refuse samples will be collected during piezometer installation, and water samples will be collected monthly. .This site will be used as a control site for correlation with geophysical data.

Electrical resistivity and electromagnetic conductivity surveys will be conducted on both sites. Data from the test site will be interpreted based on the correlations obtained from the control site. The interpretation will be confirmed with test holes and the geophysical data related to the source of acidity. The occurrence of the acid plume and the delineation of its shape will show the probable movement in the ground water regime and identify the region or zone of acid production. This will guide the location of remedial applications and subsequently the water quality, and associated geophysical changes, will be monitored.

V - DEMONSTRATION AND RESEARCH PROGRAMS DIRECTED TOWARD THE PREVENTION OF ACID MINE DRAINAGE

A - Characterization of Overburden Materials and Rates of Acid and/or Base Production

Problem

Procedures designed to evaluate the acid producing potential (or neutralization potential) of rock materials provide inconsistent results. Surface mine sites reclaimed based upon accepted E.P.A. procedures for material evaluations have too often resulted in acid being produced from these reclaimed sites. Recent work suggests that the E.P.A. procedures for the evaluation of the acid producing potential of rock materials does not take into account all of the acid species present. An additional severe limitation of the E.P.A. procedures is that it does not evaluate the rate at which the acid (or neutralizing) solutions will be released from the rock materials. Adequate reclamation procedures must take into account both the amount of acid and/or neutralizing solutions and their relative rates of production.

Historically, pyrite has always been considered the precursor to AMD through a straightforward oxidation-hydrolysis reaction. Other work has also showed pyrite to be oxidized by oxygen and ferric ion and can occur simultaneously and kinetically independent in the same system. The oxidation of the ferrous ion to ferric ion is the slowest reaction and is therefore the rate limiting step. At pH levels below 4 and in the absence of a catalyst, the generation of ferric iron is so slow that its affect on the oxidation of pyrite is of little consequence. However, a variety of ions could serve as catalysts including $(S0_4)^{-2}$, Cu^{+2}, Mn^{+2} and $A1^{+3}$. Other potential catalysts listed included charcoal, clay, light and micro-organisms.

Based upon the reactions listed above, it would seem that the amount of AMD generated should be directly proportional to the abundance of pyrite in the rock material; but it is not. Comparisons made between the amount of acid generated under standardized laboratory conditions of leaching (synthetic weathering) and pyrite content both in the presence of and excluding bacteria showed little or no correlation. It is a commonly observed fact both in field and laboratory studies that rocks with high pyrite content may produce little or no acid while other coals with seemingly insignificant amounts of pyrite produce a disproportionate amount of acid.

A significant characteristic of pyrite in coal-related rocks is the fact that it occurs in various morphological forms. Terminology used to describe these various forms differ but generally, pyrite falls into two major classes. The first class consists of framboids, independent euhedral crystals and aggregates of euhedral crystals. The second class consists of the massive occurrences; dendritic and irregular.

Based upon the results of synthetic acid generation studies and field observations, the framboidal pyrite is generally recognized as the most reactive. The increased reactivity of framboidal pyrite has been attributed to a variety of reasons, from increased surface area resulting from its micro-crystallite fabric to trace element contaminations of the crystal structure. Although the correlation is far from perfect, field and laboratory evidence does indeed indicate that, for whatever reason, coals and rocks which contain abundant framboidal pyrite generally produce more acid than these which are dominated by the more massive varieties and have little or no framboidal pyrite.

The standard procedure for evaluating the acid producing potential of rock materials consists of two separate analyses. The base content of the rock is assumed to be calcareous materials consisting largely of the carbonates of calcium and magnesium (calcite and/or dolomite). Another common carbonate in coal associated rocks is siderite. However, siderite upon hydrolysis will produce a neutral solution, not a basic one.

The base content is determined by treatment with standard HC1 followed by back titration with standard NaOH to obtain tons $CaCO_3$ equivalent per thousand tons of rock material. Samples low in iron and other metals which react with the hydroxide ion yielding insoluble hydroxides seem to yield reasonable analytical results by this method. However, the amount of calcareous material cannot be determined in samples that have high contents of iron, aluminum or other metals capable of forming insoluble hydroxides or complex hydroxo species. In these samples, simple acid-base titrimetric methods will therefore yield results dependent upon the amount of metal ions as well as the amount of carbonate present and will therefore not yield a true base potential.

Samples containing these metals also give unstable endpoints. For example, consider a sample containing a large amount of Fe^{+2} . As dissolved oxygen oxidizes Fe^{+2} to Fe^{+3}, the pH of the solution will slowly decrease and a stable endpoint of pH 7 will not be achieved until all the ferrous iron is air oxidized to the ferric state.

To further complicate the situation, large quantities of metals are leached from the sample during the original heating of the sample in the presence of the O.lN HC1 and an accurate base potential determination for these samples would be impossible because of the presence of the dissolved metals in the HCl solution.

The standard procedure for the determination of acid potential is based upon a LECO determination of pyritic sulfur followed by a subsequent calculation of equivalent H_2SO_4 using the stoichiometry from the reaction of the oxidation and hydrolysis of FeS_2 to H_2SO_4. The only acid assumed to be in the system is H_2SO_4.

As shown previously, however, some samples contain appreciable amounts of metal ions such as ferric and aluminum ions that must be considered if an accurate acid potential is to be determined. Although these metal ions are not protic acids, they nevertheless react with hydroxide ion to form insoluble hydroxides and hydroxo complexes.

The assumption that the only base species present is carbonate and the only acid species present is H_2SO_4 is invalid in samples containing appreciable amounts of metal ions. It is imperative, therefore that all the acid and base species present in reclamation materials be determined and accounted for and that an anlaytical technique be developed which will quantify these species.

In addition, a knowledge of the relative rate of acid (and base) production of rock materials involved in reclamation is essential in the prediction of the actual acid output from these materials as they weather in Nature. If the calcareous material is to neutralize the ferric ion and/or sulfuric acid produced within the system, the relative rates of acid and base production must parallel each other. If for example, the relative rate of carbonate ion production is slower than acid formation, acid will escape into the system without being neutralized. If on the other hand, the solubility of the carbonate producing material is much higher than that of the acid producing materials, the base producing materials may be exhausted before all of the acid producing materials are oxidized and hydrolyzed. As a result, a reclamation system which at first appeared successful, slowly begins to seep acid waters. In other words, it is not enough to know and balance the total acid or base potential of the system, their rates of acid/alkaline production must also be taken into account. A study of the relative rates of acid production would also be helpful in verifying present chemical theory regarding the oxidation of iron disulphides to sulfuric acid, i.e. comparison of a "reactive" and "non-reactive" pyrite species.

Objectives

This program element will direct efforts toward each of three basic areas:

1. 1. Pyrite as a source of acid mine drainage
2. 2. The evaluation of the acid/base potential of coal associated rocks and their rates of acid/alkaline production and
3. The development of a procedure to accurately evaluate the acid/base producing potential of rock materials and the rate of production..

Methodology

A suite of rock samples will be collected which represent the variation in lithology and, if known, acid-base potential from surface mine sites. The samples will be collected from sites which the Committee has visited and are known to be of acid producing potential. It is anticipated that the total number of experimental samples will be about one hundred.

The following analyses will be performed on all samples:

(1) thin section analysis

(2) radiographic characterization

(3) bulk mineralogy by XRD

(4) elemental analysis by XRF and/or AA

(5) S.E.M. analysis (photos, microprobe analysis)

(6) LOI 550^0C (to determine organic content)

(7) LOI 1000^0C (to determine total carbonates)

(8) EPA acid/base account

(9) acid (HC1) soluble iron

Each sample will be subjected to synthetic weathering utilizing a Soxhlet reactor. The subsequently generated solutions will be analyzed for:

(1) elemental constituents: Na,K, Ma, Ca, Mn, Fe_T, Fe^{+2} , Fe^{+3} , Al, Si, $SO_4^=$

(2) specific conductance

(3) pH

(4) acidity

(5) alkalinity

Several Soxhlet arrangements will be tested

(1) standard operation

(2) distilled water pumped from external reservoirs

(a) cold

(b) hot

(c) with reactor unheated

(d) with reactor heated

(3) chemical oxidants pumped from external reserviors

(4) sample fine (<325 mesh) pulverized

(5) sample fine pulverized and pelletized

(6) Soxhlet condenser flooded with oxygen

Samples will be subjected to successive leachings to obtain rate of acid/base production decrease and data synthesized to oxidation rate experiments. To assess the kinetics of acid/base reactions and determine the rates of alkaline and acid production, selected overburden samples will be used to rate evaluation studies using one basic analytical technique. A sample will be stirred in water with the temperature of the mixture maintained constant. A regulated volume of oxygen will be bubbled through the system and pH versus time measurements will be taken. Temperature and oxygen flow will be added to the mixture to determine if there are any catalytic effects on pH. If possible, a relative rate law will be extrapolated from these data.

B - Formulation of Pyrite Sealants and Inhibition of Acid Formation

Problem

Acid seeps and "burnout" of vegetation are a major problem on surface mined lands. Three types of acid seep problems exist: The first is a localized problem caused typically by pyritic material placed too near the surface; the second results from oxidation of buried pyrite over a large area with subsequent acid discharge; the third is a result of an acid recharge which flows through the material and emerges as an acid seep or spring.

In the first case, the problem is local so that treatment procedures which would be too expensive to use over a large area can be considered. Chemical sealants which react with either the acid or the iron in the drainage can be used to coat the pyritic material and reduce flow between the pyrite and the land surface.

If the problem is not localized, it is necessary to identify the source and quality of recharge. Under these circumstances the oxidation site of the pyrite must be modified or armored to inhibit the oxidation process. Many laboratory and bench scale experiments have demonstrated the plausibility of arresting pyrite oxidation on a small scale. The difficulty lies, however, in identifying which of the physical or chemical ameliorants, shown to be effective under laboratory conditions, can be scaled up to accommodate field conditions.

Objectives

(1) Evaluate the chemical agents that can be used to inhibit pyrite oxidation and the concentrations necessary to be effective

(2)Determine the application rates and concentrations required for field scale applications

(3)Demonstrate the effectiveness of the treatment through field trials.

Methodology

Laboratory and pilot scale tests of potential sealing and coating materials will be started during a preliminary phase and will continue, as necessary, during the entire study period. Chemical sealants which react with either the acid or the iron in the drainage can be used to coat the pyritic material or to increase the effective hydrologic distance between the pyrite and the land surface. Alternatively, physical surface seals may be appropriate to reduce diffusion of oxygen. Initially, chemical agents such as gel materials, highly alkaline solutions and phosphate material will be investigated but other materials which have the potential of interfering with the reaction system will be considered.

Column leaching studies will be conducted with both fresh and acid-producing pyritic material to evaluate the effectiveness of added ameliorants in reducing acid production. The type of material used and its placement in relation to the pyritic material will be varied in these tests. For each set of conditions the duration of AMD control will be determined.

The possibility of pyrite armoring by iron hydroxide coating will be investigated with a gel technique. Crushed pyrite will be suspended in a clear gel matrix and treated with various alkaline materials. Armoring of pyrite would be directly visible. Subsequent leaching with acidic solutions will allow estimation of the stability of iron hydroxide coatings.

Following completion of the preliminary phase, several field sites will be selected and will include an active surface operation anticipating or currently dealing with acid production during mining and an abandoned AMD producing source. The latter could be an old mine or a refuse pile. At the sites experimental control could be in the form of well-kept AMD records including water quality and quantity or in the form of hydrologic division of the site and treatment of one section. Recharge and discharge points must be identifiable in the acid producing sites.

The nature of the material and the method of application for each site will depend on laboratory results from Phase I. At the active mining site the pyritic material would be treated as soon as possible after exposure of the stratum. At the abandoned site, surface application of the material is anticipated unless laboratory studies indicate the necessity for an infusion approach.

A separate study in this phase will include the use of alkalinity as the primary agent for pyrite oxidation impediment. A two-stage treatment is planned for the acid producing site: initial application of highly soluble alkalinity (sodium carbonate, bicarbonate) to return the system to near neutral pH and possibly armor the pyrite and subsequent application of a sparingly soluble alkalinity source (limestone, dolomite) for long-term control of acid production.

In addition, the first of several field studies will be initiated to evaluate potential methods of identifying the type of seep problem. The first field test will be conducted at a site recommended by West Virginia DNR. A mined area near Buckhannon has acid seeps flowing out along a spoil embankment. A potential source of the acidity is an acidic last-cut pond at the highwall, although the acid may also be coming from the embankment itself. The pond will be pumped down to eliminate the potential source of the recharge and the location, flow and water quality of the seeps will be monitored. The original source of the acid in the pond (i.e., pavement, highwall or spoil material) will be identified. If the source of the acid seeps is spoil material within the embankment, corrective action will involve the interception of infiltrating rainwater with either bactericidal, surface sealing or pyrite coating agents.

Drainage quantity and quality from both sites will be monitored, initially on a continuous basis and less frequently after drainage quality has stabilized. The monitoring system may entail the use of wells if the drainage is not on the surface. An attempt will be made to select sites which can be monitored easily and economically. The results will be analyzed in terms of the effectiveness of the method and cost comparison with other AMD abatement techniques.

C - Control of Acid Mine Drainage by Ferric Iron Complexing

Problem

Pyrite oxidation occurs in a multistage sequence dependent upon Eh and pH. Most of the acid production occurs at pH less than 3 as the decreased rate of $Fe(OH)_s$ precipitation results in increased ferric iron activity. The ferric iron is reduced to ferrous iron as it rapidly oxidizes the pyrite but iron oxidizing bacteria regenerate the ferric iron.

Two alternative control mechanisms exist: 1) elimination of the bacteria, thereby limiting ferric oxidation and 2) decreasing the availability of the ferric iron so that it can not oxidize the pyrite. The first alternative is addressed elsewhere in this proposal; the second can be accomplished by selective precipitation or complexing of the iron species. Phosphate, for example, ties up ferric iron and thereby reduces pyrite oxidation; if tertiary treatment sewage sludge is available, phosphate becomes economically attractive.

Any material which decreases the solution potential of the ferric pyrite couple below the critical value needed to produce acid mine drainage becomes a potential control agent. For example, we have recently shown that soap materials precipitated from waste water of commercial laundries electrochemically arrest the acid producing reaction. A study of potential ferric ion complexes in acid drainage is required to determine if such electrochemical coordination reactions represent an economical acid drainage control mechanism.

Objectives

1. A laboratory bench-scale evaluation of ferric iron complexing agents to establish reaction stoichiometry and electrochemical controls.

2. A pilot scale study to evaluate the effectiveness and economics of those materials which appear appropriate for control of acid drainage.

3. A full-scale field test on a small active surface mine using pilot test reaction parameters to establish application rates.

Methodology

By applying a constant current to a pyrite electrode, products of the pyrite oxidation reaction can be characterized and quantified. Chemical analysis of the products will establish their identity for mass balance. The integrated results provides a complete description of pyrite electrochemistry. Once this is accomplished, the effect of various complexing agents can be readily evaluated, using electrode measurements to define chemical parameter changes.

Materials determined to be potential acid inhibitors will be tested in 10 to 150 gallon containers on pyritic overburden material. The overburden will be screened to eliminate particles greater than 3/4", and will be homogenized and sized for surface area calculations. Bed parameters such as bulk porosity, diffusivity, liquid retention and size distribution will be determined. The pilot runs will be conducted both under natural weathering conditions and in the laboratory under controlled leaching conditions. Effectiveness of abatement techniques and cost effectiveness will be evaluated.

Field tests will be conducted in cooperation with the Bureau of Mines, Pittsburgh Research Center, and will consist of the selection of an appropriate field site, baseline monitoring, treatment and evaluation. The material selected for application will necessarily by only slightly soluble so that retreatment will not be necessary. Monitoring will consist primarily of water quality evaluation, including trace metals, relative ferrous-ferric concentrations and concentration of the complexing agent.

D - Assessing the Alkaline and Acid Loads of Coal Mine Overburden and the Prediction of Mine Drainage Quality

Problem

The variables that affect the quality of mine drainage produced by a sequence of rocks disturbed at a strip mine site are numerous and complex. Commonly, some of these variables interact to produce secondary affects that add to the complexity of the problem and confuse attempts to predict the mine drainage quality that would be expected from the land disturbance. Any model that attempts to make such a prediction must consider the hydrology of the area (both pre and post mining), the geochemistry of the ground water regime, the chemistry of the overburden and the interactions of these and other factors.

Much work has been done regarding the definition of the hydrologic regime that would be expected to develop in a backfilled mine and the nature and character of the ground water geochemistry. Additionally, the chemistry of the overburden (and methods of analysis) has been documented. With regard to the latter, the existing techniques offer projection of the quality (acid, alkaline or neutral) of drainage or leachate that would be expected from a rock with a peculiar chemistry. However, the quantity (load), as well as the quality, of the effluent must be known to predict, with some degree of accuracy, the nature of the mine drainage that could be expected from a mine site.

Specifically, an assessment of the rock-water interactions that will take place in the voids of a completed backfill is in order. The nature of the voids, in themselves, are complicated, multivariate and dependent upon the type of rock, method of mining and manner of replacement. In turn, the voids radically affect the character of the drainage. The study outlined below deals primarily with the relationship between the voids of a rock mass and the quality and quantity of acidity or alkalinity that the rocks would be expected to produce. This information is critical to the accurate prediction of mine drainage quality.

In addition to being a source of alkalinity, calcareous material plays an important role in controlling the reaction rates of pyrite. All things being equal, the greater the calcareous material - pyrite ratio present in a sample, the less likely the sample to produce acidity. This relationship, coupled with the results of many leaching experiments and whole rock analyses has led to a technique that can characterize a rock's chemical weathering attributes. This is not the same as the now widely used "Smith technique" which balances the neutralization potential against the iron sulfur content to generate an acid-base account. For reasons presented above, in terms of the different reaction kinetics for pyrite and calcareous material, the acid-base account, which ignores the rates of release of the acid and alkaline components does not always give an accurate assessment of a rock's capability to produce acidity or alkalinity. The technique developed relates the empirical results of the leaching tests to the laboratory analyses and whole rock composition. In so doing, a series of graphs are constructed that identify the regimes of acid or alkaline production potential for different rocks with varying calcareous-pyrite ratios.

The identification of potentially alkaline and acid producing strata is central to the everyday operation of the mine and the final phase of mine reclamation. This information is then used to guide the operator in strata handling and placement to enhance reclamation efforts. In addition, potentially toxic material can be quickly identified and managed to minimize environmental impact.

Whole rock analyses generally express the composition of the material in terms of a weight percent; which is related to the volume of the material (Volume = mass over density). However, the mineralogic components exposed on the surface of the particle are the ones that weather and affect the leachate quality. Thus, the particle size distribution and the porosity of the backfill material determine to a large extent the amount of acid or alkaline material that is placed in contact with the water. The intrinsic permeability of the rock material is assumed to be small and negligible when compared to the permeability of the backfill mass, i.e. water will flow around the rock particle and not through it. We are also assuming that the chemical diffusion of ions does not penetrate the entire rock mass but is restricted to the near surface layer.

If the surface-area to volume ratios of various particle sizes and shapes were known, it would be possible to relate the surface area produced by the various size fractions to the manner in which a rock breaks apart. This could be done through digitization of the various shapes and sizes of particles of different rock types and analyzing the surface-area volume ratios unique to each rock type.

In turn, the variations in surface area for each chemical rock group could be related to the quality and quantity of leachate produced by each group. This could be done by leaching various size fractions of one chemically similar rock sample. By knowing what percentage of the total rock pile is made up by each size fraction, the acid or alkaline load generated per unit weight (or thickness) of rock can then be predicted by adding the loads of each fraction.

Samples of sandstones, limestones and shales will be chosen for a preliminary study because these rocks have a tendency to break apart into a variety of shapes but having shapes common to the group. Sandstones, for example, would tend to break into angular and massive blocks, as will the limestone. The shales however will tend to break along planar features and produce slabs. By taking photographs of these rock types and digitizing the shapes a surface area to volume (size) relationship can be derived.

Objectives

1. To field test the laboratory generated technique now used to predict rock weathering behavior (in terms of producing alkalinity or acidity) and determine its applicability to field conditions and analysis.

2. To develop "loading indices" for the groups of sandstones, shales and limestones having varying calcareous-pyrite ratios for different sizes and shapes.

3. To compare the levels of acidity and alkalinity that may be expected from different rocks having varying calcareous-pyrite ratios for different thickness.

4. To assess the concentrations of acidity and alkalinity that would be expected from 2 and 3 above in terms of threshold values for acid mine drainage production.

Methodology

The rock masses used in the study will be analyzed for total pyritic sulfur and calcareous material content to make certain that they are representative of the units to be tested. The rock masses will be subdivided according to different sizes and sorted into separate piles. Each pile will be photographed and the images used for digitization to obtain surface-area to volume ratios.

Samples of sandstone, limestone and shale will be placed in large inert containers and allowed to weather under natural conditions. The drainage emanating from the containers will be monitored for flow rates and a host of chemical parameters including temperature, pH, specific conductance, alkalinity, acidity, iron, calcium, magnesium, and sulfate. These parameters were chosen because of the geochemical reactions that are identified to be taking place by their presence and used to explain the pathways and types of rock weathering that will be taking place.

The rock samples chosen for the study will be allowed to weather under natural conditions for at least one year. During this time, following each rain event, samples of the rain and leachate produced by each pile of rock will be collected and analyzed for temperature, pH, specific conductance, alkalinity.

The samples of rock will be selected, processed and tested by the following method:

1.With the operator's cooperation, the stratigraphic sequence in an open cut (unweathered samples) will be described and lithologies identified.

2.Preliminary representative samples of a specific rock layer (sandstone, limestone or shale) totaling around 5 to 10 pounds will be collected and analyzed for calcareous-pyrite ratios.

3.Based on the calcareous-pyrite ratios, samples of each rock type will be identified as to their capacity to produce acidity, alkalinity or remain inert.

4.Samples having a capability to produce acidity or alkalinity will then be chosen (i.e. the sandstones that produce acidity, the shales that produce acidity, etc.) and the source stratum identified from the preliminary information gathered in #1

5.At this point a truck will be contracted to pick up a load of one specific rock type collected at the mine face. The truck will be weighed empty and again loaded to determine the total weight of the rock collected.

6.The load of rock will then be taken to a cement plant and about half of the load crushed and graded to the following size fractions: less than 1/2", 1/2" to 3/4/", 1" to 1-1/2", 2-1/2" to 3" and greater than 6". The uncrushed portion will remain on the truck and be weighed.

7. The various fractions will be loaded into 55 gallon drums and transported along with the uncrushed load to a field station The station will have a continuous recording rain gage and a series of plastic rain gages.

8. The various size fractions will be hand loaded onto separate inert chambers each having different depth and exposed to rainfall. Each load will be weighed and placed into a separate chamber. In this manner the effluent from various thicknesses of material of one size fraction can be collected.

9. The uncrushed load will be dumped on a plastic lined paved surface that is channeled into a large collector. The collector will record the total volume of leachate produced and the overflow will be piped into a central treatment facility.

10. At each collector outflow a water sample splitter will be installed to collect samples of effluent produced. The volume of effluent produced will depend upon the amount of rainfall and the sample splitter is designed to collect all of the effluent during small rainfall events and provide represen tative samples of overflows during high rainfall events. All overflows from these collectors will also be channeled into a central treatment facility through PVC pipes.

11. Each fraction of rock material will be sampled again and analyzed for calcareous-pyrite ratios to insure that the chemistry of the material is similar to the material that was intended for the tests. Part of this fraction will be subjected to simulated weathering tests.

12. The volumes of each fraction will be measured and combined with the weight of the material, the porosity of the rock load can be determined.

13. All piles of rock will be photographed from different angles. These images will be processed for surface-area to volume ratios by a digitizer.

14. Following each rain event that produces a significant quantity of leachate the volume in the large collector will be measured and related to the amount of precipitation. The leachate will then be drawn off to a central treatment facility before being discharged.

15. The split sample will be collected and chemically analyzed.

By monitoring the volume and chemistry of the rainfall and the leachates, rates of alkalinity or acidity production for each size fraction can be derived. The acid or alkaline loads can be calculated by multiplying the concentrations (mg/L) by the total volume of leachate produced (L) to yield mgs of acidity or alkalinity produced per weight of rock material.

In turn, the acid or alkaline loads can be related to each size fraction for various thickness. From the digitized surface-area to volume relationships, the various loads can be quantified in terms of mgs of acidity or alkalinity produced per thickness of a size fraction of rock having a particular calcareous-pyrite ratio. This is turn can be extrapolated to a predicted acid or alkaline load produced for large volumes of mixed fractions of a specific rock type for a given rainfall event. The data from the large uncrushed pile of material will provide the opportunity to check the predicted loads.

The simulated weathering test data generated in the lab will then be compared to the field derived test data to determine the degree of correlation of the two. This will provide an insight as to the applicability of laboratory results to field conditions (at least as a first approximation). In turn, these data will be used to test the accuracy of the predictions by comparison with observed rock weathering behavior.

The extrapolation of the results may show that rocks greater than a certain size or with a certain shape have surface-area to volume ratios that do not substantially contribute to the drainage quality (when compared to the smaller size fraction). This information will be used to enhance the anticipated acid or alkaline loads produced by rocks that break apart in different ways (i.e. shales, sandstones and limestones). In so doing an acid or alkaline load may be predicted for a thickness of a specific rock type, having a certain calcareous-pyrite ratio and breaking apart in a certain way in response to the mining technique. For example, the same shale, with similar chemical composition may be moved with a bulldozer and front end loader and in the process be broken up into a predominant fine size fraction, whereas in a drag line operation, the shale would tend to remain large and blocky. In the former, due to a higher surface-area to volume ratio, the shale as a unit would tend to be more reactive than shale particles produced in the latter case.

Finally, an attempt will be made to determine the loads and levels of alkalinity that may be produced under a given set of rainfall conditions for various rocks with different calcareous-pyrite ratios. These alkaline loads will be compared to the acid levels to ascertain, in a realistic manner, the degree of acidity that can be accommodated by alkaline rock systems before degrading to acid pollution.

Attempts will be made to minimize the use of acid producing material thus reducing the amount of acid that may be generated and treated. All acid drainages generated in this study will be neutralized with portable sodium hydroxide treatment bins and the effluent diluted with the non acid drainages before being released to a degraded stream. The tanks containing the acid producing material will have covers that can be placed over the sample (to prevent water contact) in the remote event that the acid leachates cannot be treated.

VI - PROJECT ADMINISTRATION, COORDINATION, AND EVALUATION

The project and program elements described in the proposal will be administered through the Mining and Reclamation Division of the West Virginia Department of Natural Resources, Charleston, West Virginia. The major contract will be awarded to the central office of DNR which will, in turn, sub-contract to the appropriate institution through which the principal investigator functions.

The Acid Mine Drainage Technical Advisory Committee will review all program elements to insure that the work tasks undertaken by the principal investigators will interface with the specified program needs and research objectives. At monthly intervals, the Committee will hold meetings to summarize the activities completed and evaluate the results obtained for that time period. This will serve to integrate the results of the various research programs and allow the Committee as a whole to review and counsel each study. In this way, each research program will benefit by the expertise and experience of each Committee member.

At quarterly intervals, each principal investigator will submit a progress report to the Department of Natural Resources. These progress reports will be synthesized and integrated into one quarterly report that will summarize the progress made toward achieving the program objectives and the work tasks remaining to be completed. Coupled with the monthly meetings, these status reports afford the Committee the opportunity to not only monitor the progress of the various research programs but participate in its development as well.

The extensive analyses that will be performed in conjunction with these studies will generate a large data base. To facilitate storage and retrieval of specific elements associated with each project, a centralized data bank will be established at DNR's computer facility.

At the end of each phase of the ancillary studies proposed, the data will be analyzed and the results evaluated in terms of the principal objectives stated. For specific mine sites the factors responsible for the corrective actions will be isolated and identified in terms of their applicability to other problem areas. Should the program element be site specific, the study will be adjusted by the necessary modifications to give the ameliorative technique a broader base of application.

Concurrent with the field results the laboratory studies will emphasize the specifics of the treatment. Within these trials many of the variables contributing to the confusing background noise can be controlled and the effects of specific elements more carefully observed and monitored. These results should corroborate the findings of the field trials or explain the divergence from predicted responses.

As the study progresses and a data base is formulated, many of the deficiencies identified by the Committee will be better understood and questions central to the success and failure of the existing techniques will be answered. At this point, the project will be evaluated and either terminated because of inconclusive finding or expanded and restructured to further the positive results generated. Under these conditions the Committee will expand the scope of work and begin to affect regional studies.

Where demonstrable success in the abatement of acid water occurs, in response to definitive and feasible ameliorative methods, the Committee will formulate the concepts and fundamentals of an education module. Through these modules the methods and plans shown to be beneficial will be transmitted to the coal industry through workshops, symposia and extension services that will be administered through DNR. These avenues of communication will insure that the abatement methods developed by the Committee will be made readily available to the coal companies for regional use.

VII - BUDGET

As outlined in the beginning of the proposal the following budget does not include the costs for earth ' moving equipment use and technical and analytical services that many of the coal companies are willing to provide. The monies requested are used primarily to underwrite personnel, supplies, travel and overhead expenses which will be incurred by the principal investigators. Each program element described in Section IV, the associated principal investigator(s), the institution through which the study will be subcontracted, and the proposed budget is outlined below. Because some investigators will be associated with more than one project, it is difficult to partition the budgets to each project. Instead, the budgets are assigned to the principal investigators.

PRINCIPAL INVESTIGATORS OF PROPOSED STUDIES

IV - A - Demonstration of the Effectiveness of Current Mining Practices and Identification of Deficiencies

Principal Investigators:

Dr. John Sencindiver - Division of Plant and Soil Science, West Virginia University

Mr. Hans Naumann Island Creek Coal Company

Dr. Bob Kleinmann U.S. Bureau of Mines, Pittsburgh, Pennsylvania

Drs. Frank T. Caruccio, Gwendelyn Geidel and Doug Williams - Department of Geology, University of South Carolina

IV - B - Effects of Using Crushed Sandstone from the Overburden as the Topsoil Material

Principal Investigator:

Dr. John Sencindiver - Division of Plant and Soil Science, West Virginia University

IV - C - Induced Alkaline Recharge Zones to Mitigate Active Acid Seeps

Principal Investigators:

Drs. Frank T. Caruccio, Gwendelyn Geidel - Department of Geology, University of South Carolina

IV - D-1 - Soil Development, Moisture Relations and Root Growth and Distribution in the Topsoil Above the Liner

Principal Investigator:

Dr. John Sencindiver - Division of Plant and Soil Science West Virginia University

IV - D-2 - Evaluation of the Use of Bentonite as a Surface Seal of Mine Sites

Principal Investigator:

Mr. W. Curtis - North East Forest Experimental Station, Berea, Kentucky

IV - E - Bactericidal Control of Acid Drainage from Inactive and Abandoned Mined Lands

Principal Investigator:

Dr. Bob Kleinmann - U.S. Bureau of Mines, Pittsburgh, Pennsylvania

IV - F - Evaluation of Surface Geophysical Methods for Locating Acid Mine Drainage Source Areas

Principal Investigator:

Dr. Bob Kleinmann - U.S. Bureau of Mines, Pittsburgh, Pennsylvania

V - A - Characterization of Overburden Materials and Rates of Acid and/or Base Production

Principal Investigator:

Dr. Jack Renton - Department of Geology, West Virginia University

V - B - Formulation of Pyrite Sealants and Inhibition of Acid Formation

Principal Investigators:

Dr. Bob Kleinmann, U.S. Bureau of Mines, Pittsburgh, Pennsylvania

Dr. Alfred Stiller - Department of Chemical Engineering, West Virginia University

V - C - Control of Acid Mine Drainage by Ferric Iron Complexing

Principal Investigator:

Dr. Alfred Stiller - Department of Chemical Engineering, West Virginia University

V - D - Assessing the Alkaline and Acid Loads of Coal Mine Overburden and the Prediction of Mine Drainage Quality

Principal Investigators:

Drs. Frank T. Caruccio and Gwendelyn Geidel - Department of Geology, University of South Carolina

BUDGET SUMMARY

	Year 1	Year 2	Year 3	Total
Dr. John Sencindiver	44,275	37,170	43,995	125,340
Mr. W. Curtis	8,700	7,700	3,600	20,000
Drs. G. Geidel and D. Williams	62,150	63,250	66,880	192,280
Dr. Jack Renton	38,318	39,703	41,830	119,851
Dr. F. Caruccio	40,205	20,130	14,575	74,910
Dr. Robert Kleinmann	124,000	55,000	21,000	200,000
Dr. Al Stiller	39,292	30,013	28,614	97,919
Totals	$356,940	$252,966	$220,494	$830,300

BUDGET SUMMARY

	Year 1	Year 2	Year 3	Total
Dr. John Sencindiver	44,275	37,170	43,995	125,340
Mr. W. Curtis	8,700	7,700	3,600	20,000
Drs. G. Geidel and D. Williams	62,150	63,250	66,880	192,280
Dr. Jack Renton	38,318	39,703	41,830	119,851
Dr. F. Caruccio	40,205	20,130	14,575	74,910
Dr. Robert Kleinmann	124,000	55,000	21,000	200,000
Dr. Al Stiller	39,292	30,013	28,614	97,919
Totals	$356,940	$252,966	$220,494	$830,300

BUDGETS OF PRINCIPAL INVESTIGATORS

Dr. John Sencindiver, Department of Plant and Soil Science, West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				

Release Time	10,000	10,000	10,000	30,000
Technician	9,000	6,600	10,900	26,500
Part time help	2,925	2,150	2,925	8,000
Subtotal	$21,925	$18,750	$23,825	$64,500
Supplies	3,500	3,500	2,000	9,000
Travel	3,000	1,500	2,000	6,500
Fringe	3,200	2,800	3,600	9,600
Overhead	-12,650	10,620	12,570	35,840
Total	$44,275	$37,170	$43,995	$125,340

Dr. John Sencindiver, Department of Plant and Soil Science,
West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				
Release Time	10,000	10,000	10,000	30,000
Technician	9,000	6,600	10,900	26,500
Part time help	2,925	2,150	2,925	8,000
Subtotal	$21,925	$18,750	$23,825	$64,500
Supplies	3,500	3,500	2,000	9,000
Travel	3,000	1,500	2,000	6,500
Fringe	3,200	2,800	3,600	9,600
Overhead	12,650	10,620	12,570	35,840
Total	$44,275	$37,170	$43,995	$125,340

Mr. W. Curtis - N.E. Forest Experimental Station, Berea, Kentucky

	Year 1	Year 2	Year 3	Total
Personnel	7,700	7,200	3,600	18,000
Supplies	1,000	500	-	2,000
Total	$8,700	$7,700	$3,600	$20,000

Mr. W. Curtis - N.E. Forest Experimental Station,
Berea, Kentucky

	Year 1	Year 2	Year 3	Total
Personnel	7,700	7,200	3,600	18,000
Supplies	1,000	500	-	2,000
Total	$8,700	$7,700	$3,600	$20,000

Drs. Gwendelyn Geidel and Doug Williams, Department of Geology, University of South Carolina

	Year 1	Year 2	Year 3	Total
Personnel				
Technicians	26,000	29,000	32,300	87,300
Part time help	15,000	15,000	15,000	45,000
Subtotal	$45,000	$48,000	$51,300	$132,300
Supplies	7,000	5,000	5,000	17,000
Travel	4,000	4,000	4,000	12,000
Contractual Service	4,500	4,500	4,500	13,500
Overhead	5,650	5,750	6,080	17,480
Total	$62,150	$63,250	$66,880	$192,280

Drs. Gwendelyn Geidel and Doug Williams,
Department of Geology, University of South Carolina

	Year 1	Year 2	Year 3	Total
Personnel				
Technicians	26,000	29,000	32,300	87,300
Part time help	15,000	15,000	15,000	45,000
Subtotal	$45,000	$48,000	$51,300	$132,300
Supplies	7,000	5,000	5,000	17,000
Travel	4,000	4,000	4,000	12,000
Contractual Service	4,500	4,500	4,500	13,500
Overhead	5,650	5,750	6,080	17,480
Total	$62,150	$63,250	$66,880	$192,280

Dr. Jack Renton, Department of Geology West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				
Technician	11,016	12,393	13,943	37,352
Part time help	10,000	10,000	10,000	30,000
Subtotal	$21,016	$22,393	$23,943	$67,352
Supplies	1,500	1,500	1,500	4,500
Travel	1,200	1,200	1,200	3,600
Contractual Service	10,500	10,000	10,000	30,000
Overhead	4,102	4,610	5,187	13,819
Total	$38,318	$39,703	$41,830	$119,851

Dr. Jack Renton, Department of Geology
West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				
Technician	11,016	12,393	13,943	37,352
Part time help	10,000	10,000	10,000	30,000
Subtotal	$21,016	$22,393	$23,943	$67,352
Supplies	1,500	1,500	1,500	4,500
Travel	1,200	1,200	1,200	3,600
Contractual Service	10,500	10,000	10,000	30,000
Overhead	4,102	4,610	5,187	13,819
Total	$38,318	$39,703	$41,830	$119,851

Dr. Frank T. Caruccio, Department of Geology, University of South Carolina

	Year 1	Year 2	Year 3	Total
Personnel	13,800	10,200	8,450	32,450
Supplies	12,250	3,100	2,800	18,150
Travel	2,500	3,000	2,000	7,500
Contractual Services	8,000	2,000	-	10,000
Overhead	3,655	1,830	1,325	6,810
Total	$40,205	$20,130	$14.585	$74,910

Dr. Frank T. Caruccio, Department of Geology, University of South Carolina

	Year 1	Year 2	Year 3	Total
Personnel	13,800	10,200	8,450	32,450
Supplies	12,250	3,100	2,800	18,150
Travel	2,500	3,000	2,000	7,500
Contractual Services	8,000	2,000	-	10,000
Overhead	3,655	1,830	1,325	6,810
Total	$40,205	$20,130	$14,575	$74,910

Dr. Robert Kleinmann, U.S. Bureau of Mines, Pittsburgh, Pennsylvania

	Year 1	Year 2	Year 3	Total
Personnel				
Professional	30,000	12,000	5,000	47,000
Technical	12,000	12,000	4,000	28,000
Subtotal	$42,000	$24,000	$9,000	$75,000
Supplies	20,000	6,000	5,000	31,000
Travel	8,000	8,000	4,000	20,000
Contractual Services	40,000	91000	-	49,000
Overhead	-14,000	8,000	3,000	25,000
Total	$124,000	$55,000	$21,000	$200,000

Dr. Robert Kleinmann, U.S. Bureau of Mines, Pittsburgh, Pennsylvania

	Year 1	Year 2	Year 3	Total
Personnel				
Professional	30,000	12,000	5,000	47,000
Technical	12,000	12,000	4,000	28,000
Subtotal	$42,000	$24,000	$9,000	$75,000
Supplies	20,000	6,000	5,000	31,000
Travel	8,000	8,000	4,000	20,000
Contractual Services	40,000	9,000	-	49,000
Overhead	14,000	8,000	3,000	25,000
Total	$124,000	$55,000	$21,000	$200,000

Dr. Al Stiller, Department of Chemical Engineering, West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				
Research faculty	5,800	2,700	2,700	11,200
Graduate research asst.	7,200	7,200	7,200	21,600
Part time help	4,800	4,800	4,800	14,400
Secretarial	2,106	2,106	2,106	6,318
Subtotal	$19,906	$16,806	$16,806	$53,518
Supplies	4,000	2,000	1,000	7,000
Travel	2,000	1,000	1,000	4,000
Overhead and fringe benefits	13,386	10,207	9,808	33,401
Total	$39,292	$30,013	$28,614	$97,919

Dr. Al Stiller, Department of Chemical Engineering,
West Virginia University

	Year 1	Year 2	Year 3	Total
Personnel				
Research faculty	5,800	2,700	2,700	11,200
Graduate research ass't.	7,200	7,200	7,200	21,600
Part time help	4,800	4,800	4,800	14,400
Secretarial	2,106	2,106	2,106	6,318
Subtotal	$19,906	$16,806	$16,806	$53,518
Supplies	4,000	2,000	1,000	7,000
Travel	2,000	1,000	1,000	4,000
Overhead and fringe benefits	13,386	10,207	9,808	33,401
Total	$39,292	$30,013	$28,614	$97,919