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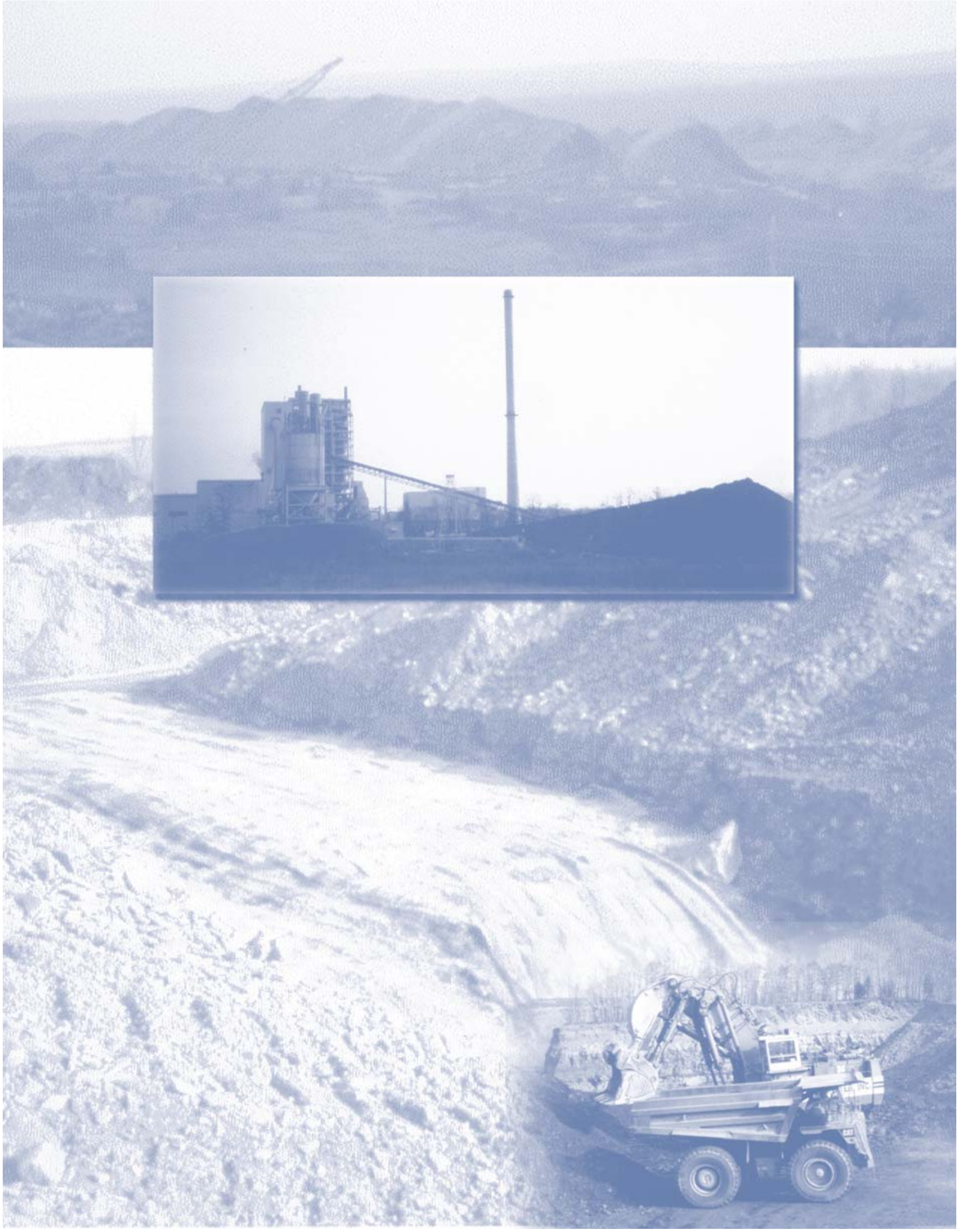

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COAL REMINING
BEST MANAGEMENT PRACTICES
GUIDANCE MANUAL

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Office of Water
Office of Science and Technology
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Glossary and Acronyms

Abiotic: Pertaining to the absence of plant, animal, bacterial, or fungal activity or mode of living.

Acid-Forming Materials (AFMs): Rocks (enclosing strata) and processed mine wastes that have appreciable amounts of reactive sulfides. These sulfides are mainly iron disulfides in the form of pyrite and marcasite, and will oxidize and subsequently combine with water to produce acidity and yield significant amounts of iron and sulfate ions.

Aerobic: A term used to describe organisms that only live in the presence of free oxygen. It is also used to describe the activities of these organisms.

Alkaline addition: The practice of adding alkaline-yielding material into a mine site where the overburden analysis indicates that there is a net deficiency of natural alkalinity. Alkaline material used to perform this task is commonly limestone, various lime wastes, or alkaline CCW.

Anaerobic: A term used to describe organisms that live in the absence of free oxygen. It is also used to describe the activities of these organisms.

Anoxic: An environment (gaseous or aqueous) with virtually no available free oxygen. Oxygen required for chemical reactions or for organisms is severely limited. Little or no chemical or biological activity that requires oxygen can occur. Water with less than 0.2 mg/L dissolved oxygen may be considered anoxic.

Anoxic Limestone Drains (ALDs): Drains composed of limestone that are constructed and covered to prevent the introduction of atmospheric oxygen to the system. Mine drainage is diverted through these drains to increase the alkalinity and without the armoring of the limestone by the iron in the water. The iron in the mine water must be in the ferrous state (Fe^{2+}) and the aluminum concentration must be relatively low in order for these systems to work properly over the long term.

Anionic surfactants: Any of a number of cleansing detergents that act as bactericides, thus inhibiting the presence of iron-oxidizing bacteria.

Anisotropic: A medium that exhibits different properties (e.g., hydraulic conductivity, porosity, etc.) in each direction measurement.

Anticline: A generally convex upward fold in sedimentary rocks where the rock in the core of the fold is older than those on the flanks. The opposite of a syncline.

Aquifer: A relatively permeable rock unit or stratigraphic sequence. Aquifers are saturated units that are permeable enough to produce economic quantities of water at wells or springs.

Aquifer tests: A variety of hydraulic tests conducted with the use of a well to determine porosity, permeability, and other properties of the rock unit tested. These tests usually involve the addition or removal of a measured volume of water or a solid with respect to time, while the response of the aquifer is measured in that well and/or other nearby wells.

Aquitard: Less permeable units in a stratigraphic sequence. These units are not impermeable, but only permeable enough to be important on a regional ground-water system basis. Wells in aquitards are not able to produce sufficient amounts of water for domestic or commercial use.

Auger mining: To extract coal from a highwall by drilling into the coal by the use of a horizontal augering equipment. This is employed when removal of additional (thicker) overburden is not economical.

Bactericide: Any of a number of materials that are used to kill bacteria, such as anionic surfactants.

Baseline: Pre-mining environmental conditions, specifically, pre-mining pollutant loading in pre-existing discharges. Baseline levels of pollutants can be used for comparison monitoring during mining activity.

Bench: This term can be used in at least two distinct contexts in regards to mining. First it can refer to a particular part of a coal seam split by a noncoal unit (e.g., shale, claystone), for example a "lower bench." A second definition can refer to a land form where a nearly flat level area is created along a slope with steeper areas above and below.

Bentonite: An encompassing term for variety or mixture of clays (primarily montmorillonite) that swell in water. Bentonite is used commercially used as a sealant in wells and for creating low permeability barriers.

Best Management Practice (BMP): Relative to remining, and as used in this document, BMPs are mining or reclamation procedures, techniques, and practices that, if properly implemented, will (1) cause a decrease in the pollution load by reducing the discharge rate and/or the pollutant concentration, (2) reduce erosion and sedimentation control problems, and/or (3) result in improved reclamation and revegetation of abandoned mine lands.

Biosolids: A general term for the residual solid fraction, primarily organic material, of processed sewage sludge. A similar term is biosludge, which can be derived from other organic sources, such as paper mill waste.

Biotic: Pertaining to plant, animal, bacterial, or fungal activity or mode of living.

Bone coal: A relatively hard high-ash coal grading toward a carbonaceous shale. A high-organic content shale.

Buffer: The ability of a solution to resist changes in pH with the addition of an acid or a base.

Calcareous shale: A shale with a significant calcium carbonate content. The calcium carbonate content is sufficient to yield alkalinity with contact with ground water.

Carbonaceous: An organic-rich (carbon) rock, such as coal, “bone” coal, and organic-rich black shale.

Cast-blasting: A method of directional overburden removal blasting.

Check dam: An above-grade structure placed bank to bank across a channel/ditch (usually with its central axis perpendicular to flow) for the purpose of controlling erosion. Check dams are commonly composed of rip rap, earthen materials, or hay bales.

Chimney drain: A highly transmissive vertical drain composed of large rock fragments that will intersect ground water coming in from the highwall or the surface and rapidly directing this water through and away from the main body of the mine spoil.

Claystone: A clay-rich rock exhibiting some of the induration of shales, but without the thin layering (laminations) or fissility (splits easily into thin layers).

Coal Combustion Wastes (CCW): The residual material remaining from the process of burning coal for power generation and for other purposes. CCW includes fly ash, bottom ash, flue gas desulfurization wastes, and other residues. CCW may also include the by-product of limestone used for desulfurization during the combustion process.

Coal refuse: The waste material cleaned from freshly-mined coal after it is excavated from the pit or brought from underground. Coal refuse is commonly composed of carbonaceous shale, claystone, bone coal, and minor to substantial amounts of “good” coal.

Confidence interval: The range of values around a statistic (e.g, the median) in which the true population value of the statistic occurs with a given probability (often 95 percent).

Culm: Term used in the anthracite district of Pennsylvania when referring to coal refuse.

Daylighting: Surface mining through abandoned underground mine workings by the removal of the overlying strata to access the remaining coal. Overburden removal exposes the remaining coal pillars.

Diagenesis: The chemical, physical, and biological actions (e.g., compaction, cementation, crystallization, etc.) that alter sediments after deposition, exclusive of metamorphism and surficial weathering.

Dragline: A large crane-like type of earth-moving equipment that employs a heavy cable or line to pull a excavating bucket through the material to be removed (overburden rock), thus filling it. The bucket is then lifted, moved to away, and dumped.

Drawdown: The measured lowering of the water level in a well (or aquifer) from the withdrawal of water. It is reported as the difference between the initial water level and the level during or after the withdrawal.

Diversion ditch: A ditch engineered and installed to collect surface water runoff and transport it away from down gradient areas. These ditches are commonly installed to control runoff.

Evapotranspiration: The water loss from the land surface to the atmosphere caused by direct evaporation and transpiration from plants.

Exsolve: The process by which where two materials, such as a gas and a liquid, unmix. For example, when carbon dioxide (CO_2) comes out of solution from water into the atmosphere.

Geotextiles: Any of a variety of manufactured materials (e.g., plastic sheeting) that are used to prevent erosion or to prevent or impede the movement of ground water vertically or laterally.

Ground-water diversion well: A water well installed and designed to intercept and collect a significant amount ground water, thus preventing the ground water from reaching an undesirable area down gradient.

Grout curtain: A low or nearly impermeable barrier created in strata or fill by the use of pressure grouting via a series of injection wells. In theory, the fractures and other pore spaces are filled with a low permeability grout thus impeding ground-water movement.

Highwall: The highest exposed vertical face of the coal and overburden of a surface mine at any given time during mining. The final highwall is the maximum extent of surface mining.

Hummocky: Used to describe highly uneven topography, commonly composed of a series of small irregularly-rounded hills or hummocks.

Hydraulic conductivity: The flow rate of ground water through a permeable medium. The flow rate is given in distance over time (velocity), such as meters per second (m/s).

Hydrologic: Pertaining to ground and/or surface water systems.

Hydrologic unit: A term used to describe an area where infiltrating waters will drain to a point or a series of related points. The area is hydrologically distinct and isolated from adjacent hydrologic units.

Hydrolyze: Chemical reactions involving water, where H^+ or OH^- ions are consumed in the process.

Hydrothermal: Chemical and physical activity pertaining to hot ground water associated with underlying igneous activity.

Induced alkaline recharge: Systems installed in surface mines to introduce recharge of alkaline charged waters to treat or abate the production of acid mine drainage. Surface water is diverted to where it contacts trenches or “funnels” filled or lined with alkaline rocks (e.g., limestone). These trenches are closed systems that induce this water to infiltrate and recharge the spoil.

Infiltration: The downward flow of water into the land surface through the soil or lateral ground-water flow from one area to another.

Interaction: The effect of a variable (e.g., the presence or absence of a BMP) on a variable of interest (e.g., the change in a discharge) is significantly effected by a third variable (e.g., the presence or absence of another BMP).

Interfluves: Regions of higher land lying between two streams that are in the same drainage system.

Logistic regression model: A statistical method of evaluating the relationship between one or more variables on a variable with a discrete (countable) number of outcomes.

Lowwall: An exposed vertical face of the coal and overburden generally representing the lowest cover to be encountered. Common in mines where the coal is not mined completely out to the coal outcrop and frequently spatially opposite to the location of the highwall.

Metamorphic: The mineralogical, chemical, and structural alteration of buried sediments and rock from heat and pressure.

Mine spoil: Overburden strata (rock) broken up during the course of surface mining and replaced once the coal is removed. Particle sizes in the backfill (spoil) range from clay-size to those exceeding very large boulders.

Odds: The probability of an event occurring divided by the probability of an event not occurring.

Odds ratio: The odds of an event occurring divided by the odds of a second event occurring, used to compare how likely two different events are.

Oxic: An environment (gaseous or aqueous) with readily available free oxygen. Oxygen is not limiting for typical chemical reactions or for organisms that require it.

Oxic Limestone Drains: These are limestone drains that are partially open to the atmosphere. These drains induce elevated CO_2 concentrations to build up, which in turn causes an aggressive limestone dissolution and alkalinity production, thus preventing armoring from the iron in the water.

Open Limestone Channels: These are limestone drains that are open to the atmosphere. Some research has indicated that even armored with iron these drains may impart 20 percent of the alkalinity that unarmored limestone will yield.

Outcrop: The exposure where a specific rock unit intersects the earths surface. The outcrop can be covered with a thin layer of surficial material such as colluvium.

Parting: A noncoal unit that commonly separates parts (benches) of a coal seam. Parting rock commonly consists of shale, claystone, or bone coal. Sometimes called a binder.

Passive treatment: Methods of mine drainage treatment requiring minimal maintenance after the initial installation. Passive treatment systems include but are not limited to aerobic and anaerobic wetlands, successive alkaline producing systems, and anoxic limestone drains.

Permeability: The ability of a rock or sediment to transmit a fluid (e.g., water). It is directly related to interconnectedness of the void spaces and the aperture widths.

Pillar: A solid block of coal remaining after conventional underground mining (room and pillar) mining has occurred.

Piping: The action of substantial volumes of ground water transporting fine-grained sediments through unconsolidated materials, such as mine spoil, leaving large conduits or voids in the process.

Pit cleanings: Noncoal material (e.g., seat rock, roof rock or parting material) separated from the saleable coal at the mine pit. This material commonly contains elevated sulfur values and is usually potentially acid producing.

Pit floor drains: As the name implies, these are drains that are installed in or along the pit floor to collect and rapidly transmit ground water through and away from the spoil. They are commonly constructed of perforated drain pipe covered in limestone or sandstone gravel.

Pore gas: Gases located and stored in the interstitial or pore spaces in soil, spoil, or other earthen materials above the water table.

Porosity: The ratio of open or void space volume compared to the total volume of rock or sediment. Commonly given in units of percent.

Pozzolonic: A property of a material to be, to some degree, self-cementing.

Pre-existing discharge: Pollutional discharge resulting from mining activities prior to August 3, 1977 and not physically encountered during active mining operations. Under the Rahall Amendment to the Clean Water Act, a pre-existing discharge is defined as any discharge existing at the time of permit application.

Probability: On a scale of 0-100, how frequently a given event (for example, a discharge improving) would occur.

Pyrolusite® systems: A large open limestone bed that mine water is allowed to slowly pass through. The system is inoculated with "specially developed bacteria" to promote the formation pyrolusite (an manganese oxide), thus removing manganese from solution. More recent research indicates that the mineral formed is todorokite (a hydrated manganese, calcium, magnesium oxide) and the bacteria that aid this mineral formation most likely exist within the system naturally without inoculation.

Remining: Surface mining of abandoned surface and/or underground mines for which there were no surface coal mining operations subject to the standards of the Surface Mining Control and Reclamation Act. Remining operations implement pollution prevention techniques while extracting coal that was previously unrecoverable.

Rill: Small erosional gully or channel created by runoff.

Rip rap: Materials (rock, cobbles, boulders, straw) placed on a stream bank, ditch or filter as protection against erosion.

Rivulet: A small stream or streamlet that develops from rills, commonly located on steep slopes.

Sample median: In a set of numbers, the value where the number of results above and below the value are equal.

Scarification: The act of making a series of shallow incisions into the pit floor, topsoil, or other surface to loosen or break up the material to foster beneficial actions, such as exposure of alkaline material or promote plant growth.

Seep: A low-flowing surface discharge point for ground water. A low-flow spring.

Shoot and shove mining: A pre-SMCRA mining method that involved shooting or blasting the overburden and pushing (shoving) it down the hillside. This type of operation was most common in steeply-sloped regions and resulted in abandoned highwalls, exposed pit surfaces, and steep abandoned spoil piles below the mine.

Shotcrete: A mixure of portland cement, water, and sand that can be pumped under pressure applied (sprayed) via a hose. It is commonly used for sealing in underground mines and for surface features, such as streams. Also called gunite.

Special handling: The placement of potentially acidic or alkaline material within mine spoil, such that acidity production is minimized and/or alkalinity production is maximized. Typically this material is placed in lifts or pods that are isolated from water (placed above the water table) or oxygen (placed below the water table).

Spoil swell: The increase in volume exhibited by mine spoil over the original volume the material prior to mining. Swell values can approach 25 percent in some regions.

Stemming: Inert material placed in blast holes above and between the explosive material to confine the energy of the explosion and maximize the breaking of the rock.

Stoichiometric: Used to describe the proportions of elements that combine during, or are yielded by, a chemical reaction.

Stress-relief fractures: Fractures in rock which form at relatively shallow depths caused by relaxation from the removal of the overlying rock mass from erosion. The retreat of glaciers in the northern Appalachian Plateau also may have aided the formation of these fractures. They are most common at depths of 200 feet or less.

Subaerial: Used to describe processes or resulting conditions from exposure to the atmosphere at or near the lands surface.

Suboxic: An environment (gaseous or aqueous) with very low concentrations of free oxygen. The levels are not low enough to be considered anoxic, but they are suppressed to the degree that chemical and biological activities are controlled and attenuated.

Successive Alkaline Producing System (SAPS): A series of passive treatment systems that mine water is passed through by which alkalinity is imparted from sulfate reduction and limestone dissolution.

Syncline: A generally concave upward fold in sedimentary rocks where the rocks in the core of the fold are younger. The opposite of a anticline.

Tipple refuse (cleanings): The waste material left after raw coal is run through a “cleaning plant.” It usually has an elevated sulfur content.

Turbulent flow: Flow characterized by irregular, tortuous, and heterogeneous flow paths.

Vadose zone: Zone of aeration above the water table. Unsaturated zone.

Water year: According to the United States Geological Survey (USGS), a water year occurs between October 1 and September 30.

Acronyms and Abbreviations

ABA: acid-base accounting
AFM: acid-forming material
ALD: anoxic limestone drains
AMD: acid mine drainage
AML: abandoned mine land
AMLIS: Abandoned Mine Land Inventory System
AOC: approximate original contour
ASTM: American Society for Testing and Materials
BAT: Best Available Technology Economically Achievable
BMP: Best Management Practice
BPJ: Best Professional Judgement
BPT: Best Practicable Control Technology
C: centigrade
CCW: coal combustion wastes
CFR: Code of Federal Regulations
cfs: cubic feet per second
CWA: Clean Water Act
cm: centimeter(s)
DO: dissolved oxygen
DOE: Department of Energy
ENR: Engineering News Record
EPA: Environmental Protection Agency
EPRI: Electric Power Research Institute
FIFRA: Federal Insecticide, Fungicide and Rodenticide Act
fps: feet per second
FRP: Federal Reclamation Program
gdm: grams per day per meter squared
GIS: Geographic Information System
gpm: gallons per minute
IMCC: Interstate Mining Compact Commission
L/min: liters per minute
lbs/day: pounds per day
lbs/ft^3: pounds per cubic feet

mg/L: milligrams per liter
MPA: maximum potential acidity
m/s: meters per second
mt: metric tonnes
NNP: net neutralization potential
NP: neutralization potential
NPDES: National Pollutant Discharge Elimination System
NSPS: New Source Performance Standards
OBA: overburden analysis
OLD: oxic limestone drain
OLC: open limestone channel
OSMRE: Office of Surface Mining and Reclamation Enforcement
PA DEP: Pennsylvania Department of Environmental Protection
ppt: parts per thousand
psi: pounds per square inch
PVC: polyvinyl chloride
RAMP: Rural Abandoned Mine Program
RUSLE: Revised Universal Soil Loss Equation
SAPS: successive alkalinity-producing systems
SLS: sodium lauryl sulfate
SMCRA: Surface Mining Control and Reclamation Act
SOAP: Small Operator Assistance Program
SOS: Standard of Success
TCLP: Toxicity Characteristic Leaching Procedure
TMAT: Total Mined Area Triangle
TSS: total suspended solids
TVA: Tennessee Valley Authority
USBM: United States Bureau of Mines
USDA: United States Department of Agriculture
USGS: United States Geological Survey
USLE: Universal Soil Loss Equation
WPA: Works Progress Administration

Executive Summary

Purpose

This manual was created to support EPA's Coal Remining Subcategory under regulations for the Coal Mining industry at 40 CFR part 434. The purpose of this guidance manual is to assist operators in the development and implementation of a best management practice (BMP) plan specifically designed for a particular remining operation. This guidance manual also was developed to give direction to individuals reviewing remining applications and associated BMP plans. This document is not intended as a substitute for thoughtful and thorough planning and decision making based on site-specific information and common sense.

Organization

This manual is organized to function as a user's guide to meet remining plan requirements and to improve abandoned mine land conditions during remining operations. The manual is divided into the following sections:

- Introduction - presenting state-specific abandoned mine land conditions, industry profile information, the status of remining operations, and general information regarding remining BMPs; the scope of pre-Surface Mining Control and Reclamation Act (SMCRA) mining and associated acid mine drainage contamination;
- Sections 1.0 through 5.0 - describing hydrologic, sediment, and geochemical control BMP implementation practices, site assessment required to determine implementation of these practices, implementation guidelines, design considerations, and case studies;

- Section 6.0 - detailing the efficiency of remining BMPs with regard to the water quality of pre-existing discharges;
- Section 7.0 - providing BMP implementation unit cost information;
- Appendix A - presenting EPA Coal Remining Database and including summary data and information from 61 state remining and abandoned mine land (AML) project data packages;
- Appendix B - presenting summary data from the Pennsylvania Remining Study of 112 closed remining operations affecting 248 pre-existing discharges; and
- Appendix C - presenting responses to the Interstate Mining Compact Commission (IMCC) remining solicitation sheet from 20 member states.

Details of the contents of each section are provided in the Section Outline.

Limitations

This manual provides information on many hydrologic and geochemical control BMPs which can be used to prevent or reduce pollution loading from abandoned mine lands during remining operations. This manual describes the best management practices and controls, provides guidance on how, when, and where to use them, and recommends maintenance procedures. However, the effectiveness of these controls lies fully in the hands of those individuals responsible for site operations. Although specific recommendations are offered in the following chapters, careful consideration must be given to selecting the most appropriate control measures based on site-specific features and conditions, and to properly installing the controls in a timely manner. Finally, although this manual provides guidelines for maintenance, it is up to the responsible party to make sure controls are carefully maintained or they will prove to be ineffective.

This manual is not intended as a stand-alone document in terms of BMP plan development and implementation. Additional information sources pertaining to remining and various aspects of

BMPs can and should be consulted. Many of these information sources are referenced throughout this guidance manual. This manual is intended for use by individuals with the background or experience to adequately understand the technical aspects detailed herein. Individuals charged with developing, reviewing, implementing, and enforcing remining BMP plans must be knowledgeable of all aspects of remining operations (e.g., hydrology, geochemistry, mining operations, etc.), and must be able to modify them when appropriate.

Results Summary

Review of existing data and information that was used to prepare this document indicates that remining operations accompanied by proper implementation of appropriate BMPs is highly successful in reducing the pollution load of mine drainage discharges. The information also shows that remining BMPs typically are used in combination as part of an overall and site-specific BMP plan. Critical to the effectiveness of a BMP plan in terms of water quality and AML improvement is that the plan is well designed and engineered, implemented as proposed, and that the implementation and subsequent post-mining results are verifiable.

Introduction

Environmental Conditions

Acid drainage from abandoned underground and surface coal mines and coal refuse piles is the most chronic industrial pollution problem in the Appalachian Coal Region of the Eastern United States. It has been estimated that, as of 1998, there are currently over 1.1 million acres of abandoned coal mine lands, over 9,709 miles of streams polluted by acid mine drainage (AMD), 18,000 miles of abandoned highwalls, 16,326 acres of dangerous spoil piles and embankments, and 874 dangerous impoundments (IMCC, 1998; Lineberry and others, 1990; OSMRE, 1998). Prior to the passage of the federal Surface Mining Control and Reclamation Act (SMCRA) of 1977 reclamation of mining sites was not a federal requirement and therefore, often was not done. However, some states did have reclamation requirements prior to 1977. Of the land disturbed by coal mining between 1930 and 1971, roughly only 30 percent has been reclaimed (Lineberry and others, 1990). Ninety percent of AMD comes from abandoned coal mines (mostly underground mines) where no individual or company is responsible for treating the water (Skousen and others, 1999).

One of SMCRA's goals was to promote the reclamation of mined areas left without adequate reclamation prior to the enactment of SMCRA and which continue, in their unreclaimed condition, to substantially degrade the quality of the environment, prevent or damage the beneficial use of land or water resources, or endanger the health or safety of the public.

Waters Impacted by Pre-SMCRA Mining

Problematic mine drainage forms when air and water come into contact with certain minerals in rocks associated with mining. Pyrite and other sulfide minerals in rocks associated with coal react with oxygen and water to form acid and yield dissolved metals (such as aluminum, iron, and manganese). The acidity and dissolved metals then contaminate surface and ground water. The production of acid mine drainage can occur during several phases of the mining process, and can continue well after the mine has closed. In Great Britain, for example, Roman mine sites dating back 2,000 years continue to generate acid mine drainage today (USGS, 1998).

Streams that are impacted by acid mine drainage characteristically have low pH levels (less than 6.0, standard units) and contain high concentrations of sulfate, acidity, dissolved iron, and other metals. These conditions commonly will not support fish or other aquatic life. Even if the acid is neutralized (pH raised), the metals will precipitate and coat the stream bed, making it unsuitable for supporting aquatic life. Additionally, the impact of mine drainage on the waterway aesthetics results in undesirable conditions for visitors and recreational users (EPA Region III and OSM, 1997).

Acid mine drainage can result from both surface and underground coal mining and from coal refuse piles. In surface mining, the rock overlying the coal (overburden) is excavated, and in the process, broken into a range of large to small rock fragments that are replaced in the pit after the coal is removed. This exposes the acid-forming minerals in some rocks to air and water resulting in a high probability of AMD formation, if such minerals are present in sufficient quantities. In underground mining, large reservoirs of AMD may form in the cavern-like passageways below the earth surface. These reservoirs are constantly replenished by ground-water movement through the mineral-bearing rocks, creating more AMD. Water from these “mine pools” seeps through hillsides or flows freely from abandoned mine entries, enters streams, and deposits metal-rich precipitates on the substrate downstream. Coal refuse piles often contain excessive amounts of pyritic materials, and water flowing through the piles can become highly acidic.

Mine drainage discharges can be as small as an unmeasurable flow, or they may be huge torrents of thousands of gallons per minute. Receiving streams frequently do not contain sufficient alkalinity to neutralize the additional acid, thus its water quality may be adversely impacted and the stream’s uses impaired. Even if the stream has sufficient alkalinity to improve pH, precipitation of iron, manganese, and/or aluminum may occur.

303(d) List

Pursuant to Section 303(d) of the Clean Water Act, States biannually submit a list of water bodies not presently supporting designated uses to the U.S. Environmental Protection Agency (EPA). As required by 40 CFR 130, 7(b)(4), States biannually compile a 303(d) list of streams affected by such pollution sources as acid mine drainage. Priority and non-priority stream lists are generated on the basis of analytical and benthic investigations. Acid mine drainage impacts approximately 9,709 stream miles (IMCC, 1998). Table 1 contains a summary of the stream miles affected by AMD, according to the 1998 303(d) lists for each state.

Table 1: Number of Stream Miles Impacted by AMD

State	Stream Miles (Source A)	Stream Miles (Source B)	Stream Miles (Source C)*
Alabama	65	--	50+440 acres
Illinois	NA	--	--
Indiana	0	--	--
Kentucky	600	--	141+219 acres
Maryland	430	152	--
Missouri	139	--	--
Ohio	1,500	607	--
Pennsylvania	3,000	3,239	2,149
Tennessee	1,750	--	726+ 510 acres
Virginia	NA	17	44
West Virginia	2,225	1,100	2,019
Totals	**>9,709**	**>5,115**	**>5,129 + 1,169 acres**

* May include area of affected lakes and reservoirs

Source A: IMCC, 1998

Source B: Faulkner & Skousen, 1998

Source C: State 303(d) lists, 1998.

NA = Not Available

Abandoned Mine Land Program and AMLIS

Title IV of SMCRA established the Abandoned Mine Land (AML) program, which provides for the restoration of eligible lands and waters mined and abandoned or left inadequately restored. The AML program stipulates that a tax of $0.35 per ton of surface mined coal, $0.15 per ton for underground mined coal, and $0.10 for lignite coal be paid into the AML fund. These funds are deposited in an interest-bearing Abandoned Mine Reclamation Fund which is used to pay reclamation costs of AML projects. When Congress passed SMCRA, it realized that AML fees would not generate enough revenue to address every eligible site, and it left the States and Indian Tribes the choice of which projects to select for funding.

Expenditures from the AML fund are authorized through the regular congressional budgetary and appropriations process. SMCRA specifies that 50 percent of the reclamation fees collected in each state be allocated to that State for use in its reclamation program. SMCRA further specifies that 50 percent of the reclamation fees collected annually with respect to Indian lands be allocated to the Indian tribe having jurisdiction over such lands, subject to the Indian tribe having eligible abandoned mine lands and an approved reclamation plan. The remaining 50 percent is used by the Office of Surface Mining Reclamation Enforcement (OSMRE) to fund emergency projects and high-priority projects in states and Indian tribes without approved AML programs under the Federal Reclamation Program (FRP); to fund the Rural Abandoned Mine Program (RAMP); to fund the Small Operator Assistance Program (SOAP); to supplement the State-share funding for reclamation of abandoned mine problems through State/Indian tribe reclamation programs; and for Federal expenses to collect the AML fee and administer the AML program.

The Office of Surface Mining’s Abandoned Mine Land Inventory System (AMLIS) catalogs AML areas by problem type and estimated reclamation cost. The most serious problems are those posing a threat to health, safety, and general welfare of people (Priority 1 and Priority 2, or “high priority”). These are the only problems which the law requires to be inventoried. The 17 Priority 1 and 2 types are:

- Clogged Streams
- Clogged Stream Lands
- Dangerous Highwalls
- Dangerous Impoundments
- Dangerous Piles & Embankments
- Dangerous Slides
- Gases: Hazardous/Explosive
- Hazard. Equip. & Facilities
- Hazardous Water Bodies
- Ind./Residential Waste
- Portals
- Polluted Water: Agri. & Ind.
- Polluted Water: Human Consump.
- Subsidence
- Surface Burning
- Underground Mine Fires
- Vertical Openings

AML problems impacting only the environment are known as Priority 3 problems. While SMCRA does not require OSMRE to inventory every unreclaimed Priority 3 problem, some states and Indian Tribes have chosen to submit such information. There are 12 Priority 3 problem types in AMLIS and they are:

- Benches
- Equipment/Facilities
- Highwalls
- Mine Openings
- Pits
- Slurry
- Industrial/Residential Waste
- Gob
- Haul Road
- Slump
- Spoil Areas
- Other

Of the $3.6 billion of high priority (Priority 1 and 2) coal-related AML problems in the AML inventory, $2.5 billion, or 69 percent, have yet to be funded and reclaimed. Priority 1 and 2 AML problems are those that pose a significant health and safety problem, and does not include environmental problems such as AMD. Estimates as of 1998 indicate that ninety percent of the $1.7 billion coal related environmental problems (Priority 3) in the AML inventory are not funded and reclaimed (OSMRE, 1999). An important note is that the AMLIS Priority 3 inventory represents only a small part of the total environmental problem as states are not required to inventory Priority 3 problems in general. In addition, the AML inventory is more complete for some states than for others, and the frequency of occurrence of different types of problems varies widely between states. Table 2 lists inventories of abandoned mine land conditions in nine Eastern Coal Region states.

Table 2: AML Inventory Totals of 4 Major AML Problem Types in Appalachia and the U.S., as of September, 1998 (OSMRE, 1998)

State	Clogged Stream Lands (acres)	Dangerous Highwalls (linear feet)	Dangerous Piles or Embankments (acres)	Dangerous slides (acres)
Alabama	0	177,945	2,209	21
Indiana	0	1,650	25	0
Kentucky	7,936	64,718	1,137	1,519
Maryland	5	8,250	156	8
Ohio	11,850	56,453	29	99
Pennsylvania	570	1,116,071	5,294	7
Tennessee	0	36,560	779	92
Virginia	1,717	91,889	154	117
West Virginia	164	1,358,616	1,928	346
Appalachia Total	22,242	2,912,152	11,711	2,209
% of U.S. Total	93%	68%	72%	98%
U.S. Total	24,028	4,252,115	16,282	2,253

The cost of remediating AML problems far exceeds the amounts that may ever be collected; hence, alternative solutions should be found to reclaim remaining AML sites. AML funds fall far short for may states, especially for those that were extensively mined prior to SMCRA. For example, in Virginia, an estimated $432 million in Priority 1, 2, and 3 AML liabilities remain while annual funding in recent years has been on the order of $5 million (Zipper and Lambert, 1998). At current rates, it will take better than 80 years to reclaim Virginia’s abandoned mine land problems.

Remining can be one of the tools used to help the AML funding shortfall. A report by Skousen and others (1997) compared the cost of remining ten sites in Pennsylvania and West Virginia to the costs of reclamation to AML standards. All ten remining operations resulted in environmental benefits. In all but two cases, the coal mined and sold from the remining operation produced a net profit for the remining company. Remining of these ten sites saved the AML program over $4 million (Skousen and others, 1997).

Industry Profile

The U.S. coal mining industry has its commercial roots back to approximately 1750 when coal was first mined from the James River coalfield near Richmond Virginia. More recently, U.S. coal production set record levels in 1997, when a record 1.09 billion short tons were mined. The electric power industry used a record 922 million short tons (85 percent of coal mined) that year. The three highest ranking coal producing states in 1997 were Wyoming (26 percent), West Virginia (16 percent), and Kentucky (14 percent), which together accounted for 56 percent of the coal produced in the United States (DOE, 1997).

Estimates available as of 1997 on coal production by state in the U.S. are summarized in Table 3. In 1996, the Energy Information Administration estimated that the United States has enough coal to last 250 years (USGS, 1996). They estimated that the demonstrated reserve base of coal in the United States was 474 billion short tons. Although recoverability rates differ from site to site, an estimated 56 percent (or 265 billion tons) of the demonstrated reserve base is presently recoverable (DOE, 1999).

Regulatory History

On October 13, 1982, EPA promulgated final effluent guidelines under the Clean Water Act to limit the discharges from the coal mining industry point source category. The rule amended previously promulgated effluent limitations guidelines based on “best practicable control technology currently available” (BPT) and “new source performance standards” (NSPS), and established new guidelines based on “best available technology economically achievable” (BAT).

Table 3: Coal Production by State (Short Tons) (DOE, 1997)

State	Underground	Surface	Total	Mines
Alabama	18,505,000	5,963,000	24,468,000	51
Alaska	--	1,450,000	1,450,000	1
Arizona	--	11,723,000	11,723,000	2
Arkansas	--	18,000	18,000	3
Colorado	17,820,000	9,628,000	27,449,000	14
Illinois	34,824,000	6,334,000	41,159,000	28
Indiana	3,530,000	31,967,000	35,497,000	39
Kansas	--	360,000	360,000	3
Kentucky	96,302,000	59,551,000	155,853,000	529
Louisiana	--	3,545,000	3,545,000	2
Maryland	3,301,000	859,000	4,160,000	18
Missouri	--	401,000	401,000	4
Montana	8,000	40,997,000	41,005,000	8
New Mexico	--	27,025,000	27,025,000	6
North Dakota	--	29,580,000	29,580,000	6
Ohio	16,949,000	12,205,000	29,154,000	81
Oklahoma	212,000	1,409,000	1,621,000	11
Pennsylvania				
Anthracite	419,000	4,259,000	4,678,000	131
Bituminous	54,410,000	17,110,000	71,520,000	272
Tennessee	1,396,000	1,904,000	3,300,000	27
Texas	--	53,328,000	53,328,000	12
Utah	26,683,000	--	26,683,000	12
Virginia	26,929,000	8,907,000	35,837,000	191
Washington	--	4,495,000	4,495,000	3
West Virginia	116,523,000	57,220,000	173,743,000	349
Wyoming	2,846,000	279,035,000	281,881,000	25
Appalachian Total	**308,360,000**	**159,418,000**	**467,778,000**	**1,602**
Interior Total	**64,941,000**	**105,923,000**	**170,863,000**	**149**
Western Total	**47,357,000**	**403,934,000**	**451,291,000**	**77**
East of Miss. River	**373,089,000**	**206,281,000**	**579,369,000**	**1,716**
West of Miss.	**47,569,000**	**462,994,000**	**510,563,000**	**112**
U.S. Total	**420,657,000**	**669,274,000**	**1,089,932,000**	**1,828**

The October 1982 rule established four subcategories for promulgation of effluent limitations based on BAT: (1) preparation plants and associated areas; (2) acid mine drainage; (3) alkaline mine drainage; and (4) post-mining discharges. The limitations of acid mine drainage, post-mining discharges at underground mines, and coal preparation plants and associated areas were based on neutralization and settling technologies. The limits for alkaline mine drainage were based solely on settling technology. For the coal mining category, BAT and BPT effluent limits were identical.

The issue of remining was raised during the comment period following the 1982 proposal of the final rule. Comments addressed the fact that technology-based standards would likely serve as a deterrent to remining activities, since the operator would have to assume responsibility for treating effluent from previous operations that already may be significantly contaminated. However, the question of the appropriate effluent limitations for remining operations was not a subject of the proposal, and was therefore not addressed in detail in the final rule. Instead, EPA stated that generally, effluent limitations guidelines and standards are applicable to point source discharges even if those discharges pre-dated the remining operation.

In 1987, the Clean Water Act (CWA) was amended to provide incentives for remining abandoned mine lands that were mined prior to the 1977 passage of the Surface Mining Control and Reclamation Act (SMCRA). The modification of the CWA (known as the Rahall Amendment) established that BAT effluent limitations for iron, manganese, and pH are not required for discharge conditions existing prior to remining activities.

Remining

Development of modern surface-mining techniques has allowed for more efficient and effective removal of coal deposits; consequently, mining is now feasible in areas where mining was previously uneconomical. A report prepared for the U.S. Department of Energy estimates that

460 million to 1.1 billion tons of coal could potentially be recovered from remining in mine states (PA, WV, MD, VA, KY, TN, OH, IN, IL) (Veil, 1993).

In 1987, Congress passed the “Rahall Amendment” to the Clean Water Act. The CWA was amended to include section 301(p) in order to provide remining incentives for permits containing abandoned mine lands that pre-date the passage of SMCRA in 1977. The Rahall Amendment established that BAT effluent limits for iron, manganese, and pH (40 CFR part 434) are not required for pre-existing mine drainage discharges. Instead, site-specific BAT limits determined by Best Professional Judgement (BPJ) are applicable to these pre-existing discharges, and the permit effluent limits for iron, manganese, and pH (or acidity) may not exceed pre-existing “baseline” levels. The Rahall Amendment established new effluent guidelines for pre-existing discharges for remining operations potentially freeing the operators from the requirement to treat degraded pre-existing discharges to the statutory BAT levels. “Remining,” as defined in the 1987 Rahall Amendment and this document, refers to a coal mining operation which began after the enactment of the Rahall Amendment at a site on which coal mining was conducted before the effective date of the Surface Mining Control and Reclamation Act of 1977.

On September 3, 1998, the Interstate Mining Compact Commission (IMCC) distributed a Solicitation Sheet to member states in support of continuing efforts to collect data and information required for proposal of a remining subcategory under 40 CFR 434. The solicitation sheet was intended to gather information necessary to assess current industry remining activity and potential. The results of the solicitation are summarized in numerous tables in this report.

IMCC member states have estimated that there are currently 150 mining companies in ten states actively involved in remining activities. These companies are producing at least 25.1 million tons of coal annually; and employing approximately 3,000 people (Table 4). As of 1998, there were approximately 1,072 active remining permits and 638 AML projects, (Table 5). Of these 1,072 permits, 330 (31 percent) are Rahall-type permits where the effluent standards for pH, iron, and manganese have been relaxed.

Table 4: State by State Profile of Remining Operations (IMCC, 1998)

	Number of mining companies with remining permits	Total employment at remining operations (Number of employees)	Annual coal production from remining sites (tons)	Estimated coal reserves (tons)
Alabama	20	ND	ND	ND
Alaska	0	0	0	0
Colorado	0	0	0	ND
Illinois	35	70	200,000	10,000,000
Indiana	2	NA	720,000	NA
Kentucky	4	ND	ND	ND
Maryland	13	150	650,000	ND
Missouri	2	0	0	ND
Mississippi	0	0	0	ND
Montana	0	--	--	--
New Mexico	0	0	0	0
Ohio	3	ND	ND	ND
Pennsylvania	50	2,345	17,530,000	100,000,000+
Tennessee	10	75 - 100	3,000,000	50,000,000
Texas	0	0	0	0
Utah	0	0	0	ND
Virginia	3	300	3,000,000+	ND
West	8	ND	ND	ND
Wyoming	0	0	0	ND
Totals	**150**	**>2,940-2,965**	**>25,100,000**	**>160,000,000**

NA = Not Available; -- = No Response; ND = No Data.

Table 5: Types of Remining Permits Issued by State (IMCC, 1998)

State	Number of Rahall Permits	Number of Non-Rahall Permits (a)	"Other" Remining Permits/Projects (b)	Remining Permits (% of Total)
Alabama	10	61	1	ND
Alaska	0	0	0	0
Colorado	0	0	15	0
Illinois	0	41	0	0
Indiana	0	1	1	1
Kentucky	4	N/A	1	40
Maryland	2	21	0	30
Missouri	0	20	0	15
Mississippi	0	0	0	0
Montana	0	0	14	0
North Dakota	0	--	--	--
New Mexico	0	--	--	0
Ohio	3	ND	101	60-70
Pennsylvania	300	40	3	95(c)/50(d)
Tennessee	0	350-450	0	60
Texas	0	0	0	0
Utah	0	0	0	0
Virginia	3	158	501	75-80
West Virginia	8	--	1	0.4
Wyoming	--	--	--	--
Totals	**330**	**692-792**	**638**	

(a) Where operators accept liability for all discharges.
(b) (e.g., AML)
(c) Anthracite
(d) Bituminous

N/A = Not Applicable
-- = No Response
ND = No Data

Table 6 provides information on the type of remining being conducted at the existing remining operations (i.e., refuse piles, surface mine, or underground mines).

Table 6: Characteristics of Existing Remining Operations by State (IMCC, 1998)

	Number of coal refuse piles		Number of surface mine sites		Number of underground sites		Number of remining permits meeting BAT	
State	**Active Mines Under Permit**	**AML Projects**	**Active Mines Under Permit**	**AML Projects**	**Active Mines Under Permit**	**AML Projects**	**Active Mines Under Permit**	**AML Projects**
Alabama	4	1	54	--	13	--	ND	1
Alaska	0	0	0	0	0	0	0	0
Colorado	0	4	0	12	0	2	0	0
Illinois	40	0	1	0	0	0	0	0
Indiana	1	0	34	--	2	--	0	--
Kentucky	3	1	1	--	2	--	5	--
Maryland	0	--	17	--	21	--	2	--
Missouri	0	0	2	0	0	0	0	0
Mississippi	0	0	1	0	0	0	0	0
Montana	1	--	11	--	1	--	0	--
New Mexico	0	0	0	0	0	0	0	0
Ohio	0	--	2	1	1	--	0	--
Pennsylvania	173	0	1,278	0	655	2	616	0
Tennessee	5-10	0	135-180	0	210-260	0	0	0
Texas	0	0	0	0	0	0	0	0
Utah	5	0	2	0	32	N/A	0	N/A
Virginia	33	38	77	117	107	104	0	2
West Virginia	1	--	7	--	1	--	9	--
Wyoming	--	--	--	--	--	--	--	--
Totals	**266- 271**	**44**	**1,622-1,667**	**130**	**1,045-1,095**	**108**	**632**	**3**

N/A = Not Applicable; -- = No Response; ND = No Data.

Best estimates of potential remining activities according to IMCC member states are provided in Table 7.

Table 7: Potential Remining Operations by State (IMCC, 1998)

	Number of coal refuse piles	Number of surface mine sites	Number of underground mined sites
Alabama	1	--	--
Alaska	3	5	1
Colorado	~400	~50	~850
Illinois	30	10	12
Indiana	150	453	615
Kentucky	~200	400-600	800 - 1,000
Maryland	10	75	75
Missouri	0	0	0
Mississippi	0	1	0
Montana	1	11	1
New Mexico	N/A	N/A	N/A
Ohio	(1,095 acres)	(23,000 acres)	4,000
Pennsylvania	858	(158,960 acres)	(31,587 acres)
Tennessee	(182 acres)	(46,000 acres)	800
Texas	0	0	0
Utah	5	2	32
Virginia	400-450	750	800
West Virginia	--	3	--
Wyoming	0	0	0
Totals	**2,058 - 2,108 and 1,277 acres**	**1,760 - 1,960 and 227,960 acres**	**7,986 - 8,186 and 31,587 acres**

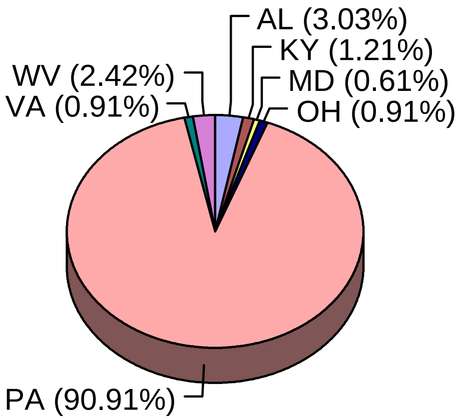
-- = No Response; N/A = Not Applicable

Existing State Remining Programs

After more than ten years of success with state remining permit programs, abandoned mine land reclamation, and water quality improvements in Pennsylvania and other coal mining states, it is time to re-evaluate the regulatory conditions that were originally developed, advance the process by offering new remining incentives, and remove disincentives embedded in the current remining program. The goal is to develop a more efficient remining permitting process, with design-based permit standards, that incorporates critical BMPs. The permitting incentives should be integrated with watershed-scale approaches to abandoned mine land reclamation and AMD abatement. Risk assessment protocols should be developed to minimize liability and risk concerns of mine operators, state and federal regulatory agencies, watershed groups, and landowners.

The 1998 IMCC Solicitation indicates that 7 states have issued Rahall-type permits (Refer to Table 5). Pennsylvania's remining program has issued more than 300 remining permits, accounting for 91 percent of all the Rahall permits (Figure 1). The remaining states have issued ten or less remining permits each.

Figure 1: Percentage of Total Number of Rahall Permits Issued by State



Below is a brief history of the development and requirements of each state's remining program.

Pennsylvania

Prior to the federal law changes in 1987, the Pennsylvania (PA) legislature amended PA SMCRA in 1984 (Senate Bill 1309) to include remining incentives. Under the PA law and related regulations [25 PA Code Chapter 87, Subchapter F (bituminous coal) and Chapter 88, Subchapter G (anthracite coal)] a baseline pollution load is established, a pollution abatement plan is submitted incorporating best technology, and the effluent limits for the pre-existing discharges are determined by the BPJ process. From 1984 to 1988, PA Department of Environmental Resources (PA DER), now PA Department of Environmental Protection (PA DEP), EPA, and OSMRE, were involved in a cooperative research and development project with the Pennsylvania State University and KRE Engineers concerning elements of the BPJ process. The project resulted in the development of the REMINE computer program and related publications by Smith (1988) and Pennsylvania Department Of Environmental Resources and others (1988).

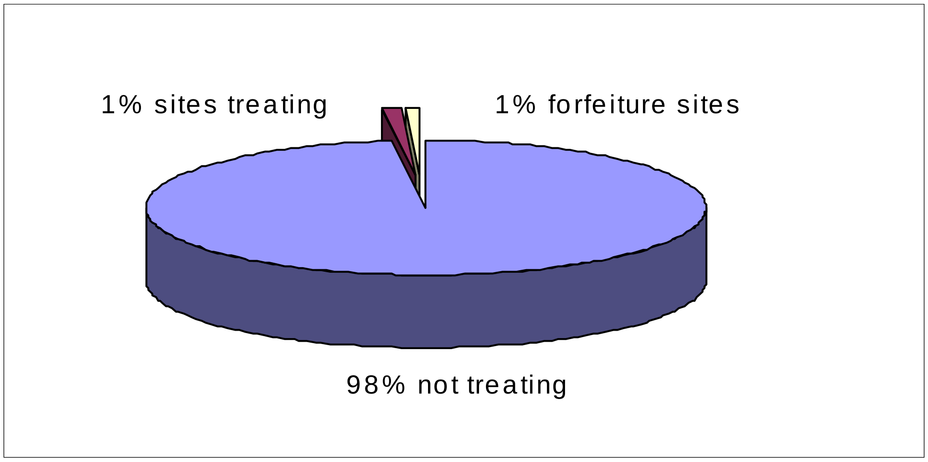
Between 1985 and June 1997, PADEP issued 260 remining permits (Table 8 and Figure 1), based on the following three-step process: (1) development of baseline loads; (2) submittal of a pollution abatement plan (technologies and BMPs); and (3) development of water quality limitations and standards based on BPJ. Of the 260 facilities issued permits, only three are required to treat pre-existing discharges on a long-term basis to achieve compliance with the baseline pollutant levels. Treatment can also be required to treat short-term excursions from the baseline. Only eleven permits (4.2 percent) have ever required treatment on a temporary or long-term basis in Pennsylvania.

An independent evaluation of the success of the PA remining program was performed by Hawkins (1995) of the U.S. Bureau of Mines. As of 1995, the Pennsylvania remining program successfully permitted for reclamation approximately 4,000 acres of abandoned mine land, which led to the production of 36 million tons of coal from acres deemed "untouchable" under pre-remining regulations (Hawkins, 1995). Site-specific data and a project description for a key remining site (Fisher Mining Company, Lycoming County) are found in publications by Plowman (1989) and Smith and Dodge (1995). The authors reported that pre-remining data from the main discharge from the Game Land site showed a medium net acidity in excess of 100 mg/L. Post-remining data showed the same discharge to be net alkaline, and the receiving stream now supports brook trout. Another independent evaluation of water quality improvements and costs of remining in Pennsylvania and West Virginia was performed by Skousen and others (1997), including data from ten sites, of which the largest and most significant is Solar mine near Pittsburgh. The water quality improved at all ten sites. In all but two cases, coal mined and sold produced a net profit for the mining company.

Table 8: Pennsylvania Remining Permits Which Required Treatment, June, 1997 (IMCC, 1997)

	Bituminous Region	Anthracite Region	Totals
Permits Issued	248	12	260
Currently Treating	3	0	3
Forfeited due to AMD	2	0	2
Required Treatment	11	0	11

Figure 2: Status of 260 Pennsylvania Remining Permits (IMCC, 1997)



Pennsylvania has taken additional steps to encourage remining and reclamation of abandoned mine lands. In 1997, SMCRA and 25 PA Code Chapter 86 were revised to authorize bonding incentives, including reclamation bond credits and financial guarantees. A qualified mine operator can earn bond credits by performing voluntary reclamation of additional mine lands. The credit is the operator’s cost to reclaim the proposed area or DEP’s cost, whichever is less. Credits may then be applied as bond on any coal mining permit, and may be transferred and used once after their first use.

West Virginia

West Virginia has issued eight remining permits with modified water quality requirements. The basic elements of their program are similar to those in Pennsylvania in that the applicant must conduct water quality and quantity monitoring to establish a baseline pollutant load and must submit an abatement plan.

In order to receive remining approval, operators must demonstrate that their proposed abatement plan represents the best available technology and that the operation will not cause additional surface water pollution and will result in the potential for improved water quality. Effluent limits in the remining permit do not allow a discharge of pollutants in excess of the baseline pollutant load. Also, a remining water quality standard variance must be approved prior to issuing the National Pollutant Discharge Elimination System (NPDES) remining permit. If the variance is denied, the NPDES Remining Permit will also be denied.

Maryland

Although Maryland has a relatively small coal industry, the State actively implemented the Rahall Amendment, which allows for a modified NPDES permit for remining operations. Maryland also implemented EPA revegetation standards allowing for bond release after 2 years, and offers reduced bonding rates for an NPDES remining permit. Currently, Maryland has issued two remining permits with relaxed effluent limits. Maryland has numerous remining operations on previously mined areas with no pre-existing discharges.

Virginia

Virginia has regulations for remining and has issued three permits with relaxed effluent limits for remining operations. Operators must show that remining operations have the potential to improve water quality. To obtain a remining permit, the applicant submits baseline monitoring data, a module of REMINE, and an abatement and reclamation plan. Permits are based on BPJ determined by the output of REMINE and must result in a reduction in pollutant loading to the stream.

Kentucky

Kentucky has regulations for remining and has issued four permits with relaxed effluent limits for remining activities. The Kentucky procedure is much like that described for the other states above. The applicant submits baseline monitoring data, an abatement and reclamation plan, and may submit a module of REMINE. Operators must show that remining operations have the potential to improve water quality. Permit limits are based on BPJ and must result in a reduction in pollutant loading to the stream (Veil, 1993).

Tennessee

Tennessee does not administer its coal mining program. OSMRE maintains the authority to issue coal mining permits. As of 1993, about 60 percent of all coal mining permits in the state involved remining, however, no permits were issued with relaxed effluent limits.

Ohio

Ohio has regulations for remining and has issued three permits with relaxed effluent limits for remining activities. Remining approvals are limited to sites with pre-existing discharges. Operators must submit baseline monitoring data along with a pollution abatement plan and supplemental hydrological information. Permit approval is contingent on the abatement plan representing BAT and having the potential to reduce the baseline pollutant load (Veil, 1993).

Alabama

Alabama has issued 10 permits with relaxed effluent limits for remining operations. To qualify for a remining permit an operator must show:

- Original mining/disturbance must have occurred prior to 1977.
- Subsequent permitted/legal disturbance could not have occurred after 1977.
- Areas that have had a SMCRA permit or bonding at any time are not eligible.
- Substantive showing must be made that water quality can be improved (a pollution abatement plan must be submitted).
- Effluent limits must at least meet ambient water quality standards.

Modified requirements for pH, iron and manganese must apply the best available technology economically achievable on a case-by-case basis, using best professional judgement, to set specific numerical effluent limits in each permit.

Regulatory agencies for states where remining is not currently practiced may be inclined to start and promote remining programs if such programs can be shown to be successful in terms of enhanced coal recovery, reclamation of abandoned mine lands, and reduction of (or no net increase in) mine drainage. Mine operators also may be more inclined to enter into remining projects with the knowledge that the potential of incurring liability for long-term treatment of mine waters from prior mining activities is low.

Introduction to Best Management Practices

Remining is the mining of abandoned surface mines, underground mines, and/or coal refuse piles that were mined prior to the environmental standards imposed by the Surface Mining Control and Reclamation Act of 1977. There are four types of abandoned mine lands available for remining operations: (1) sites that were previously surface mined, (2) sites that were previously underground mined, (3) sites that were previously surface mined and underground mined, and (4) sites that had coal refuse deposited on the surface. These sites were typically left unreclaimed and unvegetated, sometimes pose safety hazards, and are often associated with pollutional discharges or sedimentation problems. Because of associated environmental problems, these areas cannot be re-affected or remined without the implementation of minimal best management practices (BMPs) in an attempt to correct past problems.

BMPs implemented during the remining and reclamation of these sites are designed to reduce, if not completely eliminate, pre-existing environmental problems, particularly water pollution. The types and scope of BMPs are tailored to specific operations based largely on pre-existing site conditions, hydrology, and geology. BMPs are designed to function in a physical and/or geochemical manner to reduce the pollution loadings.

In this guidance document, BMPs have been placed into four categories: hydrologic and sediment control, geochemical, operational, and passive treatment, although there is some question whether passive treatment is a true BMP. These categories have been designed for ease of discussion, and each BMP has been placed in the category that is most appropriate. In several cases, a BMP serves more than a single function. For example, induced alkaline recharge trenches are discussed as a geochemical BMP, but they also influence hydrology and are closely related to some passive systems. Adding to this complexity is the fact that remining operations nearly always employ multiple BMPs in an effort to abate pollution.

Physically performing BMPs function to limit the amount of ground water that is ultimately discharged from the mine and by reducing erosion and subsequent off-site sedimentation by controlling surface-water runoff. Discharge reduction is performed by limiting the amount of ground water and surface water that laterally or vertically infiltrates into the backfill. Water is routed away from spoil via regrading, diversion ditches, low-permeability seals and caps, and highwall and pit floor drains. Ground water that has entered the spoil is collected and drained away via floor drains. Some physical BMPs are performed to reduce ground-water flow, some to reduce erosion and sedimentation problems, and some serve both purposes. Physical BMPs are addressed in Section 1.0 (Hydrologic and Sediment Control Best Management Practices). Below is a list of physically performing BMPs and an indication of whether they influence ground-water hydrology (gw), erosion and sedimentation (e&s) or both (gw, e&s).

- Regrading of spoil (gw, e&s)
- Revegetation (gw, e&s)
- Diversion ditch installation (gw, e&s)
- Installation of low-permeability caps (gw)
- Stream sealing (gw)
- Underground mine daylighting (gw)
- Mine entry and auger hole sealing (gw)
- Highwall and pit floor drains (gw)
- Grout curtains (gw)
- Ground water diversion wells (gw)
- Advanced erosion and sedimentation controls (e&s)

Geochemically performing BMPs function to inhibit pyrite oxidation, reduce the contact of water with acid-producing materials, inhibit iron-oxidizing bacteria, or increase the amount of alkalinity generated within the backfill. Pyrite oxidation is inhibited by limiting its exposure to the atmosphere and preventing the proliferation of iron-oxidizing bacteria with bactericides. Acidic materials are specially handled or capped to isolate them from the ground-water flow path. Alkaline materials are imported, redistributed, and strategically placed in the ground-water flow path in order to increase and/or accelerate alkalinity production. Geochemical BMPs are discussed in Section 2.0 (Geochemical Best Management Practices). Geochemically performing BMPs include:

- Alkaline addition
- Alkaline redistribution
- Mining into highly-alkaline strata
- Induced alkaline recharge
- Special handling of acid-forming materials
- Special handling alkaline materials
- Use of bactericides

Operational BMPs are mining practices that can reduce the risk of pollution, erosion, and sedimentation problems. Rapid mining and concurrent reclamation limit the exposure of acid-forming materials to weathering and promote rapid reclamation and revegetation that can reduce erosion and sedimentation problems. Coal refuse reprocessing removes an acid-producing material. This material is burned to produce electricity, and the ash that is produced, which is frequently alkaline, is returned to the site where it can neutralize acid. Operational BMPs are discussed in Section 3.0 (Operational Best Management Practices). They include:

C Coal refuse reprocessing
C Rapid mining and concurrent reclamation
C Limited or no auger mining
C Off-site disposal of acid-forming coal cleanings, pit and tipple refuse

The last category, passive treatment technologies, encompasses a variety of engineered treatment facilities that require minimal maintenance, once constructed and operational. Passive treatment generally involves natural physical, biological, and geochemical actions and reactions. The systems are commonly powered by water pressure created by differences in elevation between the mine discharge point and the treatment facilities. Passive treatments do not meet the standard definition of BMPs in that they are typically end-of-pipe (treatment) solutions. They are included in this manual because they can be used as part of the overall abatement plan to reduce pollution loads discharging from remining sites. Passive treatment methods are discussed in Section 4.0 (Passive Treatment Technologies). Types of passive treatment include:

C Anoxic limestone drains
C Constructed wetlands
C Successive alkalinity-producing systems
C Open limestone channels
C Oxic limestone drains
C Alkalinity-producing diversion wells
C Pyrolusite® systems

Site Characteristics and BMP Selection

Factors that influence which BMPs can be employed effectively at remining sites include previous types of mining activities, geologic and hydrologic characteristics of the site, the quality and quantity of pre-existing discharges, economics, and regional differences. Listed below under these categories are examples of associated BMPs and some of their limitations.

Previous mining history

- Daylighting only occurs where previous underground mining was conducted.
- Mine sealing is used where underground mines or auger holes are not completely daylighted.
- Regrading and revegetation are performed on abandoned and reclaimed surface mines.
- Coal refuse reprocessing occurs where there are abandoned coal refuse piles.

Geologic and hydrologic characteristics

- Alkaline addition is conducted where there is an inadequate quantity of naturally-occurring alkaline rocks.
- Alkaline redistribution takes place where only a portion of the site has a significant amount of alkaline material which is then distributed more evenly across the site.

- Alkaline material that is located stratigraphically high above the coal may require mining into higher cover to access it or may require a reorientation of the pit so that the alkaline material is encountered with every mining cut.
- Special handling of acidic material occurs where there is a significant amount, but not an over-abundance, of this material that can be field-identified and segregated.
- Highwall drains are not an option where no up-gradient final highwall remains.
- Hydrologic controls, such as floor drains or ground-water diversion wells, are not necessary unless lateral recharge is present.
- The site may be capped with a low-permeability material, if vertical recharge is predicted to be the main source of water to the backfill and a low-permeability material is readily available.
- Passive treatment may be used, if the topography to drive the system is present and sufficient construction space is available.

Pre-remining water quality and quantity

- Large volumes of severely degraded water may not be suitable for a passive treatment BMP.
- High volumes of water flowing from underground mines that will not be completely daylighted may be suited to rerouting (piping) through the spoil.
- Highly acidic pre-remining discharges associated with pyritic overburden may require substantial alkaline addition and/or special materials handling.

Economics

Cost plays a substantial role in determination of which BMPs are employed and the degree to which they are implemented. Remining sites are commonly economically marginal because of reduced coal recovery rates compared to virgin sites. These sites also generally entail greater reclamation costs due to pre-existing site conditions. Therefore, economics plays a significant role in the development of a BMP plan. The BMP plan is weighed against these costs. If the cost of BMP implementation is prohibitive the site will not be remined. Mining only occurs on sites where a profit can be made.

Regional Differences

There are also regional considerations that play into the decision of which BMPs to use at a particular site. Differences in the geology, geochemistry, hydrology, and topography between coal regions cause distinct problems requiring differing solutions. Regional differences include:

- Geologic conditions that effect the type (lithology), chemistry/mineralogy, and the structure (e.g., folding, faulting, and fracturing) of rocks.
- Hydrologic conditions, such as differences in local and regional ground-water flow systems and precipitation amounts, frequency, and/or duration.
- Differences in topography (such as amount of relief and steepness of slopes).
- Differing surface and underground mining techniques, thus abandoned sites will exhibit distinct problems regionally.

Acid Mine Drainage

It has been recognized for decades that acid mine drainage (AMD) is to a large extent a regional problem that is most prevalent in the northern Appalachians. Upon closer examination it was evident that the problem was frequently associated with the Allegheny Group coals (Appalachian Regional Commission, 1969). Figure 3 illustrates the percentage of streams within various Appalachian watersheds that had pH less than 6.0. Figure 4 shows the percentage of streams for these same watersheds that have sulfate greater than 75 mg/L. The cut-offs of pH 6.0 and 75 mg/L sulfate were chosen by the US Geological Survey because low pH and elevated sulfate can indicate impacts from coal mine drainage.

Watersheds with 35 percent or more of streams with pH less than 6.0 occur in the northern Appalachians and are associated with the outcrop areas of the Allegheny Group. Typically the watersheds in the southern Appalachians have 10 percent or less of steams with pH less than 6.0.

The distribution of watersheds with a high percentage of streams with greater than 75 mg/L sulfate does not necessarily correspond with the low pH areas. For example, one of the watersheds in eastern Kentucky had 57 percent of streams with sulfate greater than 75 mg/L, but no stream measured had pH less than 6.0. Other watersheds show similarly high percentages of streams with sulfate greater than 75 mg/L, but with few streams with pH less than 6.0. This type of water is characteristic of neutralized acid mine drainage.

No full explanation of the water quality differences within the Appalachian Basin has been provided to date, but there is little question that it is due to geologic differences. Cecil and others (1985) examined sulfur data for coals from southern West Virginia to Pennsylvania. The stratigraphically older coals, which occur in southern West Virginia, have lower sulfur than the younger coals that occur in the northern Appalachians (Figure 5). Cecil and others attribute these differences to climatic factors at the time of peat (coal) deposition that influenced the chemistry of the swamp, which ultimately influenced the sulfur content of the coal.

The production of acidity from pyritic sulfur is only half the story. The other half of the story is the production of alkalinity from carbonate dissolution. Calcareous rocks neutralize acid and they are the explanation for the water quality in streams that have pH greater than 6.0 and sulfate greater than 75 mg/L (i.e., neutralized mine drainage).

It is evident that in some regions AMD is a significant problem, while in other areas it is rare. This difference is an important factor in remining. Where AMD is prevalent, water quality is an important remining issue. Where AMD is rare, water quality typically less of a concern, with the possible exception of sedimentation problems.

Figure 3: **Percentage of Streams with pH < 6.0 for 24 Watersheds in the Appalachian Basin (data from Wetzel and Hoffman, 1983).**

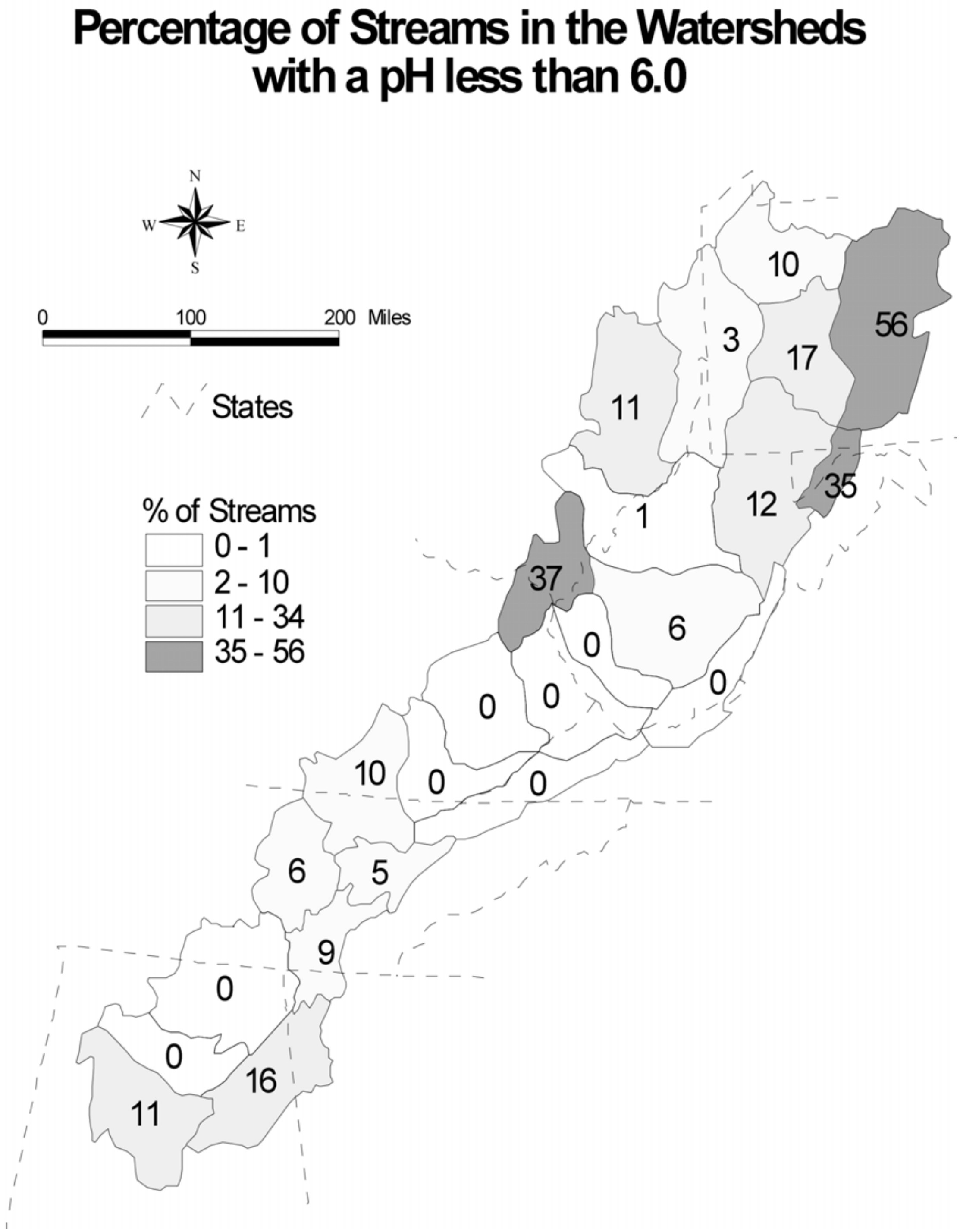


Figure 4: **Percentage of Surface Water Sample Stations with Sulfate Greater than 75 mg/L for 24 Watersheds in the Appalachian Basin (data from Wetzel and Hoffman, 1983).**

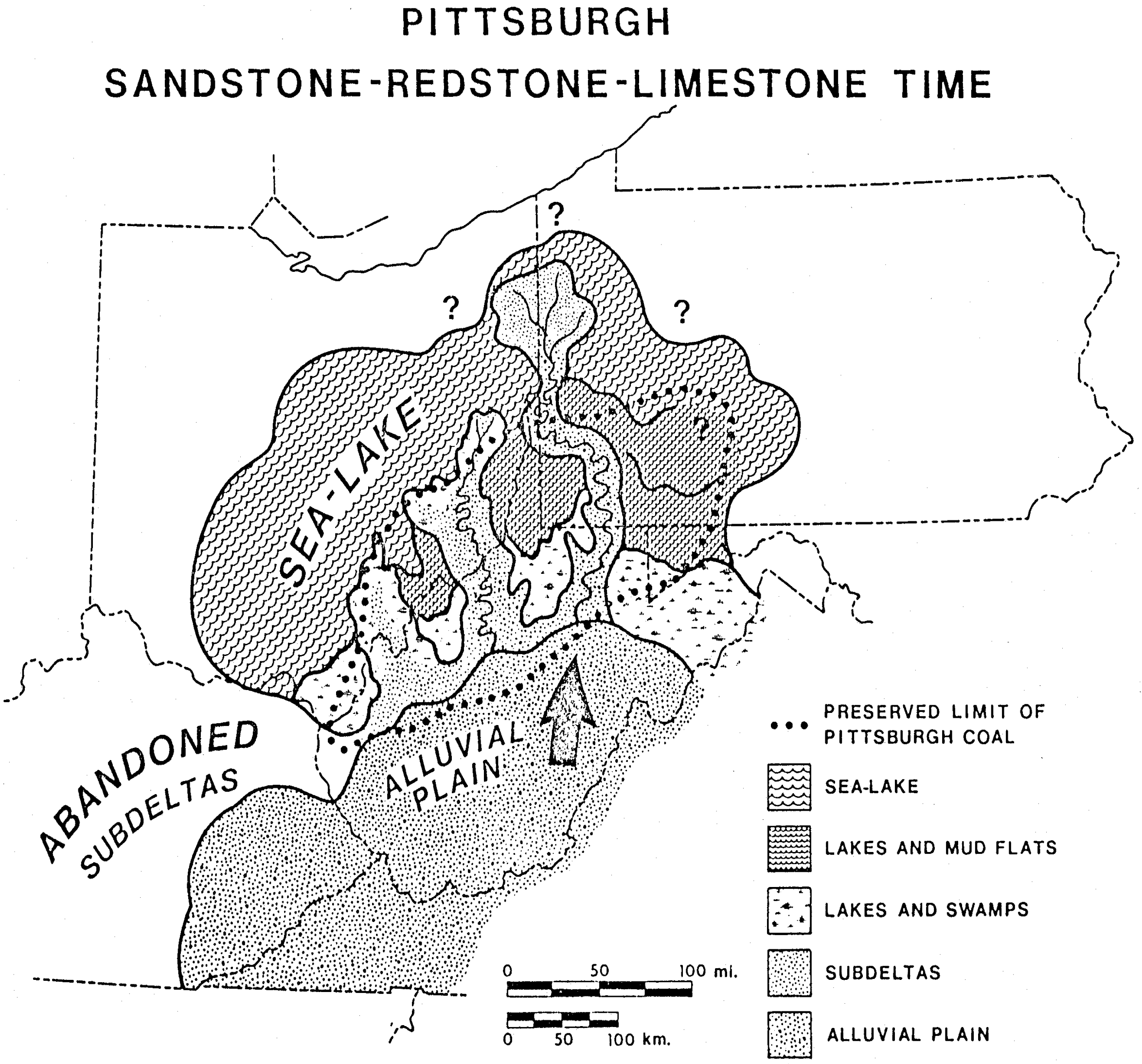
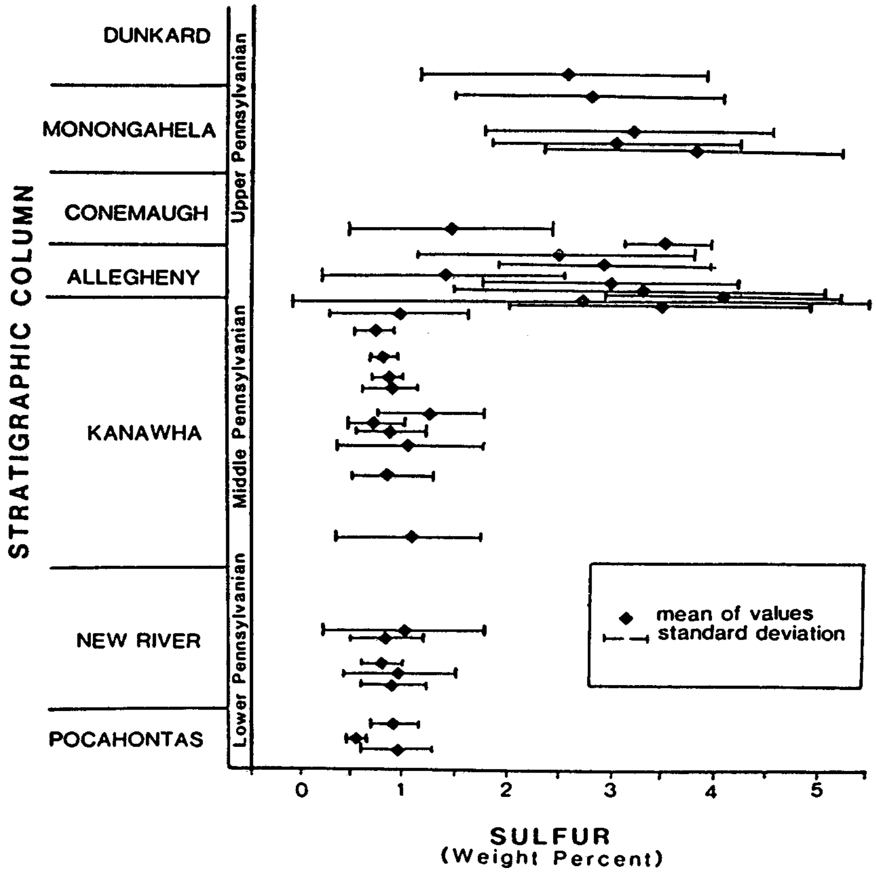


Figure 5: Stratigraphic Variation of Sulfur Content of 34 Coal Beds of the Central Appalachians (Figure from Cecil and others, 1985).



Hydrology

The ground-water hydrology is similar throughout much of the Appalachian Plateau, however there are some subtle differences between regions. Some of these differences are related to changes in major rock types associated with the coal which in turn directly impacts the fracturing density, interconnectedness of fractures, depth of fracturing, and aperture size of the fractures. For example, experience has shown that in shallow cover (# 200 ft), the massive, well-cemented sandstones commonly associated with coals of eastern Kentucky tend to exhibit much less fracturing than is observed in the more thinly-bedded, poorly-cemented sandstones associated with the Pittsburgh coal in northern West Virginia. These differences will be reflected in the ground-water flow systems (location of ground water, amounts in storage, and ground water movement velocity) of the respective areas.

Additionally, the ground-water systems associated with the mid-western coals in Indiana and Illinois are primarily regional in nature and near surface, whereas ground-water systems in the Appalachian Plateau are characterized by a series of limited-area perched aquifers underlain by deeper more regional systems that discharge to the major rivers and creeks of the area (e.g., Monongahela, Kanawha, or Tug Fork rivers).

Topography and Geomorphology

Regional differences in topography and geomorphology can impact the types of BMPs employed. For example, the topography of southern West Virginia, western Virginia, and eastern Kentucky is generally steep with narrow V-shaped valleys and sharp-peaked hills and mountains. Figure 6 shows this type of topography in Kanawha and Raleigh Counties in southern West Virginia. The topography of northern West Virginia and western Pennsylvania is not nearly as steep-sloped, with broader valleys and more flat-topped hills and mountains. Figure 7 illustrates this topography in Jefferson County in west-central Pennsylvania. These differences have resulted in distinctive mining techniques and post-mining configurations. For example, the steep sloped areas tended to promote contour surface mining (Figure 8), whereas in shallower sloped areas, block cut or area mining was used more frequently (Figure 9).

Mining Methodology

Differences in mining methods can result in greatly differing abandoned mine site conditions, and thus may require distinct BMP engineering plans to effect water quality improvement. For example, the steep-sloped areas may require additional ditches, check dams and ponds for stabilizing, while regrading and revegetating a shallower sloped area may be adequate to stabilize erosion. Abandoned mines in southern West Virginia, western Virginia, and eastern Kentucky frequently exhibit down-slope spoil disposal, open pits, and exposed highwalls making reclamation back to the approximate original contour (AOC) impractical in most cases. Abandoned mines in northern West Virginia and western Pennsylvania often have some open pits and exposed highwalls, but they are commonly characterized by a series of unreclaimed spoil piles and ridges. Returning the site to AOC is generally more feasible on these sites. The "shoot and shove" method of past mining on the steep slopes of the central Appalachian Plateau has resulted in erosion and sedimentation problems.

Figure 6: Example of Steep Topography and High Relief in Southern West Virginia Showing Multiple Contour Strip Mines on Steep Slopes.

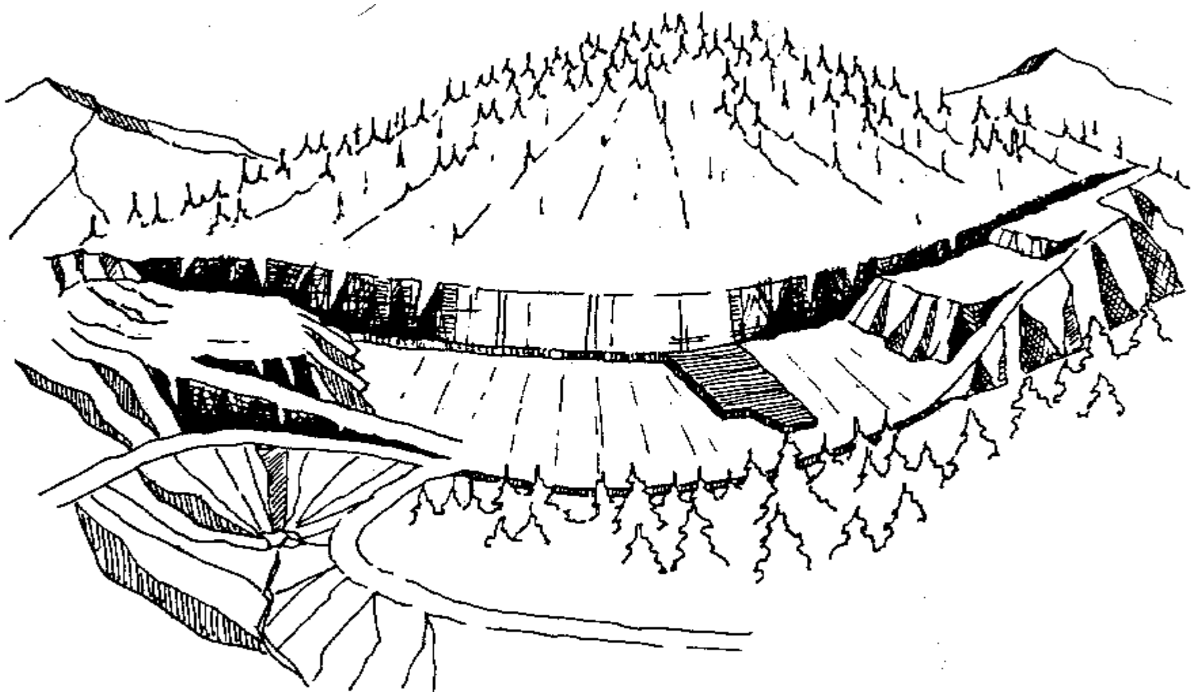


Figure 7: Example of Moderate Slopes and Broader Valleys and Hilltops in West-central Pennsylvania Showing Small Area Mines.

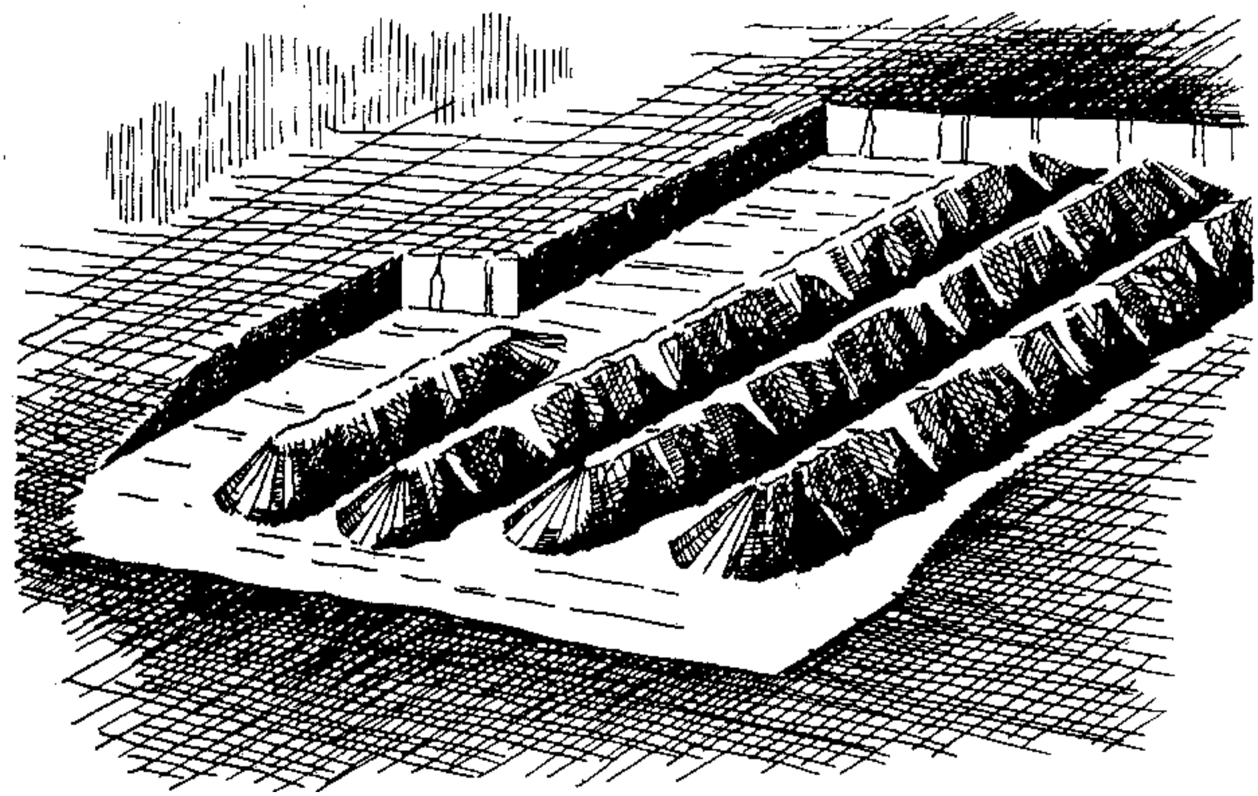


Figure 8: Topographic Map Illustrating Contour Surface Mining.

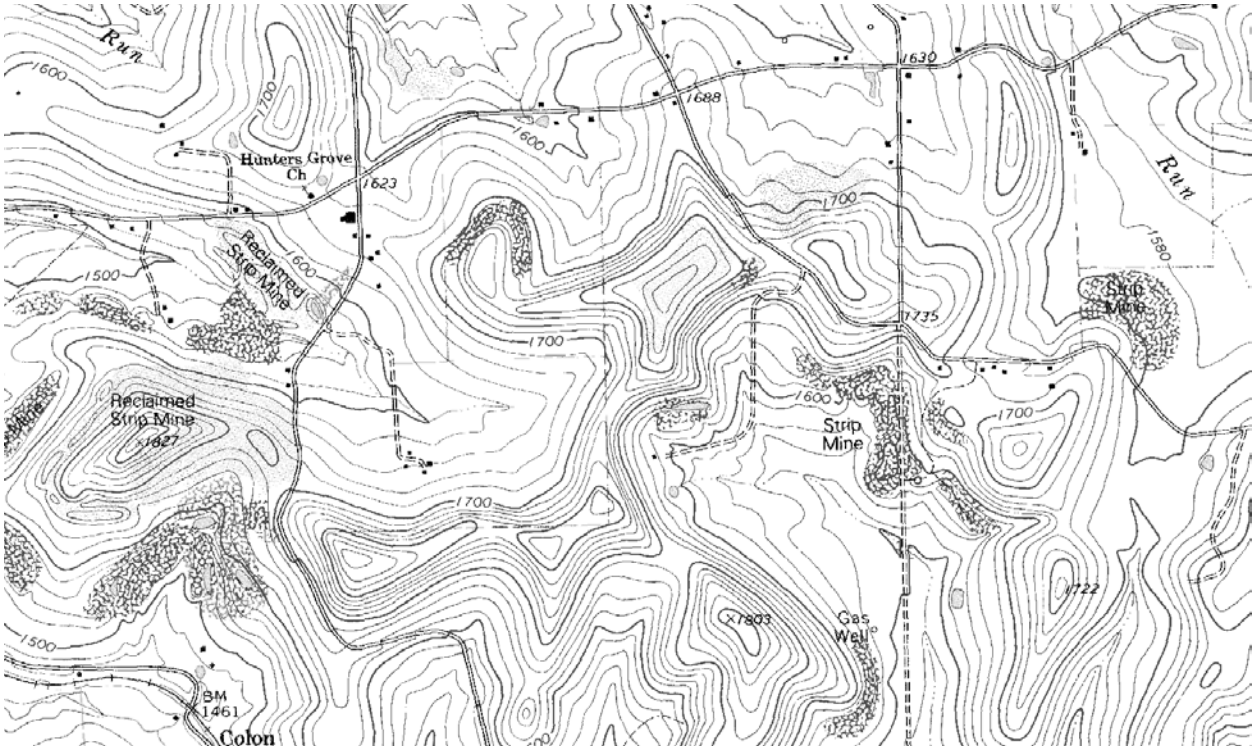
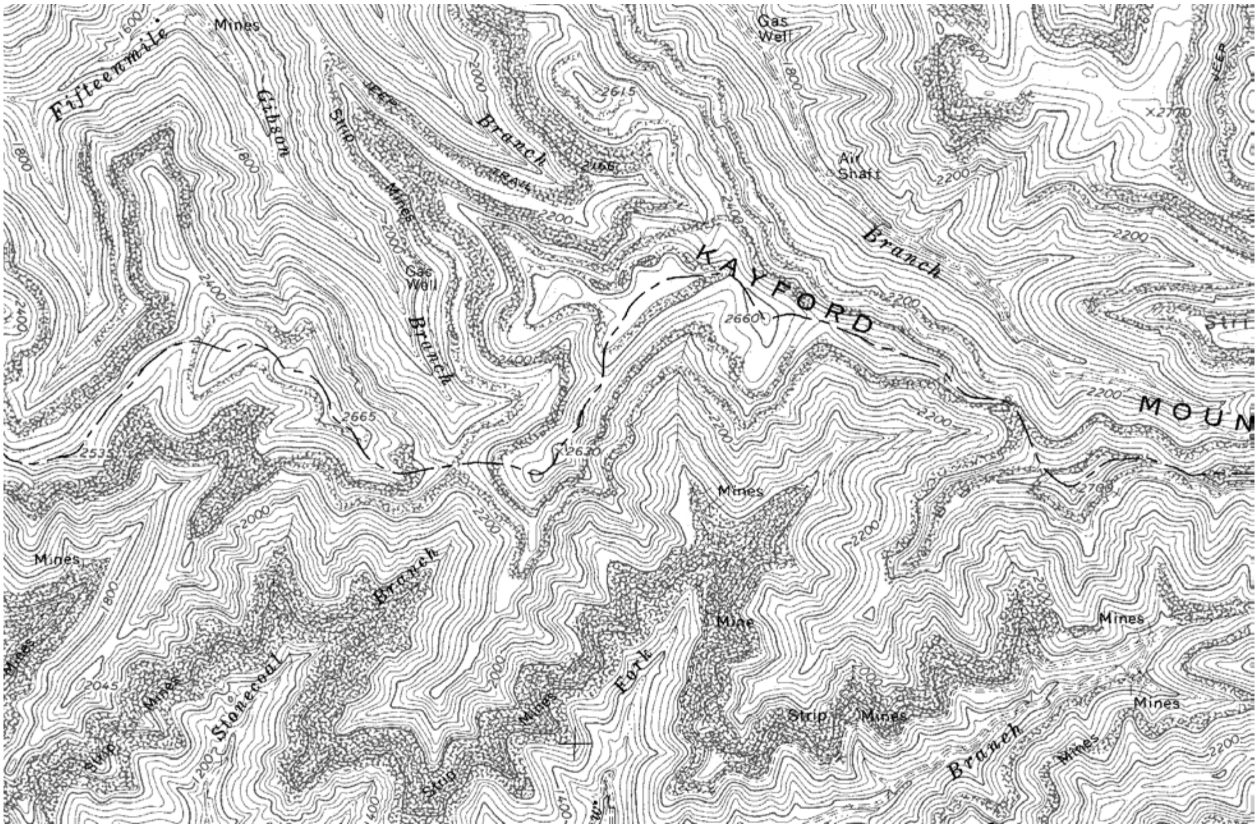


Figure 9: **Topographic Map Illustrating Area Surface Mining.**



BMP Implementation

The best BMP plan may fail if it is not implemented as designed (e.g., conducted properly, adequately, and on a timely basis) and as approved by the permitting authority. To facilitate field implementation, the BMP plan should be clearly thought out and designed for site-specific conditions during the permit application process. A well-designed plan can eliminate the need for revisions once the permit is issued and will provide guidance to ensure proper implementation. However, a well-designed plan also provides a degree of flexibility to allow for "mid-stream" changes caused by unforeseen circumstances.

An effective BMP plan hinges greatly on a detailed site assessment. Site assessment data and information should be sufficient to identify which strata will require handling, potential sources of ground water, probable reasons for existing AMD, the scope of previous mining, and other salient data. Site assessment will typically, at a minimum, require extensive field work and mapping, multiple bore holes with appropriate vertical sampling, ground-water level measurements, surface water flow measurements, and representative ground- and surface-water samples.

A BMP plan should be realistic. It should be appropriate to the site, workable in the field, economically feasible, and based on sound scientific principles. Plans should be clearly designed with appropriate maps, cross-sections and narrative. The ultimate viability of a BMP plan depends heavily on the individual(s) that develops the BMP plan, the one(s) that review and approve it, those who implement it, and those who enforce it. The BMP plan should be verifiable and enforceable by those individuals who inspect the site. Implementation guidelines are provided for each category of BMPs in the appropriate sections.

Efficiency

The efficiencies of BMPs or groups of BMPs, with regard to decreasing pollution loadings, are based on limiting one or more of the following factors:

- Amount of pyritic material
- Availability of oxygen to the pyritic material
- Contact of water with the pyritic material

Previous studies (Smith, 1988; Hawkins, 1995) have shown that controlling (decreasing) the flow of AMD discharges exerts the largest influence on the reduction of pollution load. Flow reduction is best accomplished by reducing surface- and ground-water infiltration. However, prevention of additional acid formation by use of geochemically based BMPs can also decrease the pollutant concentration which will likewise decrease the associated loading. BMPs can also function by treatment (neutralization) of AMD after it has formed. This treatment can be *in situ* neutralization from contact with additional alkaline materials or can be in the form of end-of-the-pipe treatment performed by passive treatment systems.

Some BMPs function in more than one way. Underground mine sealing will not only inhibit ground-water movement, it will also attenuate oxygen infiltration. Alkaline addition can prevent AMD through inhibition of iron-oxidizing bacteria, and it can neutralize acidity once it has been produced. Surface- and ground-water controls can reduce erosion and sedimentation, while inhibiting infiltration into the spoil.

Efficiencies of BMPs are discussed in the sections dealing with each BMP category and are evaluated through observations and the statistical approaches described in Section 6.0 (Efficiencies of Best Management Practices).

Verification

Proper implementation of BMPs can be critical to the environmental success or failure of a remining site. Thus, it is imperative that the BMPs be implemented as planned. It is the role of the regulatory inspection staff to verify and enforce the provisions outlined in the BMP plan of a remining permit. In general, the inspector does not need to be present at all times to assess the implementation of the BMPs in this document. However, some BMPs will require more detailed and more frequent inspections than others. It is also incumbent on the mine operator to ensure that the BMPs are implemented as designed and to provide the proper documentation (e.g., material weigh slips, receipts, laboratory analyses, etc.) where necessary. Guidelines for verification for each BMP category are provided in the appropriate section of this manual.

Monitoring of the water quality and quantity is the truest measure of BMP effectiveness. If the discharges exhibit lower pollution loadings, it is an indication that the BMPs were successful with all other factors being equal.

Monitoring and inspection of BMPs to verify site conditions and implementation should be a requirement of any remining operation. Verification includes:

- Direct measurement of flow and water sampling for contaminant concentrations before, during, and after reclamation;
- Continuation of monitoring beyond the initial water table re-establishment period (e.g., at least two years after backfilling);
- Evaluation of water quality and quantity data at hydrologically connected units and/or discrete individual discharges, so trends caused by remining can be assessed;
- Review of hydrologic data with respect to climatic (i.e. precipitation) conditions;
- Assessment of deviations from the approved implementation plan.;
- Inspection of critical stages of the BMP implementation plan, such as during special materials handling, alkaline addition, drain installation, or mine entry sealing;
- Inspection to assure that proper maintenance is performed where required;
- Review of material weigh slips, receipts, laboratory analysis, and other necessary documentation;
- Assessment of BMP stability over time;
- Periodic site evaluation to ensure the BMP plan is appropriate to on-site conditions. This evaluation should include, at a minimum, assessment of water quality and quantity, site physical and geologic conditions, and impacts of significant storm events.

Adequate inspection and verification are necessary to ensure that BMPs are being performed as proposed. Remining operation inspections will also provide information as to changing site conditions (anticipated and unanticipated) as well as unexpected developments.

Verification also will provide additional data for on-going assessment of the efficiency of individual BMPs as well as BMP combinations. The analyses of these data will foster continuing improvement of the BMPs which will ultimately lead to more efficient ways of decreasing pollution loadings.

This manual is designed to:

- Describe the BMPs that are available for remining operations;
- Define the appropriate circumstances for the BMPs;
- Explain how each BMP functions to diminish the pollution load;
- Discuss how a BMP works or in conjunction with other BMPs;
- Give details of BMP construction and installation specifics, size and scope of a particular BMP, and the required materials;
- Present actual data from remining case studies employing various BMPs;
- Discuss relative frequency of use for each BMP;
- Give estimates of the cost of employing each BMP; and
- Present projected efficiencies of specific BMPs based on a database of 116 completed sites in Pennsylvania, case studies, and published research.

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Section 1.0: Hydrologic and Sediment Control BMPs

Introduction

Controlling physical hydrologic aspects constitutes a substantial portion of the Best Management Practices (BMPs) that are employed at remining sites. Reduction of the pollution load yielded from abandoned mines by remining has shown that reduction of the flow rate is the most salient factor (Smith, 1988; Hawkins, 1994). Where site conditions permit recharge to the ground-water system to be controlled through mining practices and engineering techniques, the discharge flow rate will likewise be reduced. The diminished flow rate will, in a majority of cases, cause a quantifiable decrease in the pollution load. Although contaminant concentrations from coal mining sources frequently exhibit an inverse relationship to flow, pollution load reductions are more commonly recorded, even when moderate increases to the contaminant concentration occur in conjunction with a discharge flow rate reduction.

BMPs that ultimately are responsible for reducing discharge flow rates include various means of reducing the infiltration of precipitation and surface waters, impeding or intercepting the movement of ground water from adjacent areas unaffected by remining activities, and providing a means to collect and rapidly remove ground water (Hawkins, 1995a). There are a battery of BMP methods that can be employed to impede recharge to mine spoil. These BMPs are subdivided into two main categories: the exclusion of infiltrating surface water and the exclusion of laterally migrating ground water.

1.1 Control of Infiltrating Surface Water

Methods that decrease surface-water infiltration include, but are not limited to, spoil regrading (for elimination of closed-contour depressions and the promotion of runoff), installation of diversion ditches, capping the spoil with a low-permeability material, surface revegetation, and stream sealing. Prior to remining, abandoned sites commonly have unreclaimed pits and closed-contour depressions in poorly-sorted spoil that serve as recharge zones for significant quantities of infiltrating surface water. For many abandoned surface mines, the act of regrading, resoiling, and revegetating spoil significantly reduces surface-water infiltration and increases runoff just by the elimination of recharge zones and enhanced evapotranspiration. These three actions are the more commonly employed BMPs during remining operations, because they are an integral part of the remining and reclamation process. Additional means by which surface-water infiltration can be restricted are: prevention of surface water infiltration by the installation of diversion ditches, stream reconstruction and sealing, and capping of the backfill with an low-permeability material.

Theory

Initially after reclamation, diffuse recharge from the surface through soil is generally well below pre-mining levels, because of the destruction of soil structure, soil compaction by mining equipment, and low-vegetative growth, all of which tend to promote surface-water runoff rather than infiltration (Razem, 1983; Rogowski and Pionke, 1984). Wunsch and Dinger (1994) noted that spoil within a few inches of the surface was dry during re-excavation, indicating that little infiltration was occurring. Decreases in recharge also may be facilitated by increases in porosity in the unsaturated zone (Razem, 1984). Flow-duration curves show that after mining receiving streams have reduced base flows, which indicate that recharge is decreased (29 percent less than pre-mining levels) and surface runoff is increased (Weiss and Razem, 1984). After this initial period, as soil structure and vegetation are re-established, diffuse recharge from the surface begins to increase. This may coincide with observed increases in hydraulic conductivity after 30 months. The slow recovery of the water table during this period may be linked to decreased recharge shortly after reclamation and to increased effective porosity and permeability of the spoil. Increased porosity permits more of the infiltrating water to become stored within the aquifer.

Some of the recharge from the surface during this early period occurs through discrete openings or voids that are exposed at the surface (Hawkins and Aljoe, 1991; Wunsch and Dinger, 1994). Surface-exposed voids facilitating ground-water recharge also have been observed at a surface mine in central Pennsylvania that has been reclaimed for over 15 years. Surface runoff flowing across the mine surface enters the spoil through these exposed voids and flows rapidly downward via conduits to the saturated zone. This observation illustrates that these exposed voids continue to receive significant amounts of recharge long after final reclamation, re-establishment of the soil structure, and successful revegetation.

Other researchers contend that mining may improve the recharge potential from undisturbed areas (Cederstrom, 1971). Herring (1977) observed that overall recharge and surface water runoff to reclaimed surface mines in the Illinois Basin were greatly increased. Herring attributes the increased recharge to the dramatic increase in permeability of the cast overburden. Herring also observed a four-fold increase in recharge from mining one-half of a watershed in Indiana. It is important to note that these two studies did not address the impact of mining on the soil horizon as discussed by Razem (1983, 1984). Once infiltrating water has passed through the soil horizon, it appears that the recharge potential is dramatically increased. In order for surface water infiltration to be prevented, the water should be intercepted before it percolates through the soil and enters the highly permeable spoil beneath.

Strock (1998) wrote:

> The practical reality of this is that in ... humid areas where precipitation exceeds evapotranspiration, virtually all mine sites will receive ground water recharge and generate drainage - acidic or alkaline. That there may be no obvious springs or seeps does not imply that there is no drainage from the site. To illustrate what 15 inches (38 cm) of infiltration per year means in terms of the quantity of mine drainage which can be generated, each acre of spoil surface would produce an average flow rate of 0.75 gpm (2.84 L/min). A 100-acre surface mine, then, would yield 75 gpm (284 L/min) of ground water flow.

Unreclaimed abandoned spoil piles and ridges may permit infiltration approaching 100 percent of the precipitation falling on the site. Some of this water will be removed as direct evaporation, but most will recharge the spoil. Infiltration rates and amounts are directly related to ground slopes, particle sizes, sorting, lithology, and degree of weathering. Larger particles tend to create larger pore spaces, thus permitting more rapid infiltration of substantial volumes of water. Poorly sorted spoils likewise permit large volumes of water to infiltrate quickly, compared to well-sorted fine-grained spoils. Well-cemented sandstones tend to break into and remain as large fragments, thus forming a relatively transmissive material. Conversely, many shales of the Appalachian Plateau tend to break and weather rapidly to relatively small fragments and clays creating a somewhat poorly transmissive environment (Hawkins, 1998a).

Mine spoil is a poorly sorted, unconsolidated material composed of angular particles ranging from clay-sized (less than 2 microns) to those exceeding very large boulders (greater than 2 meters). Because of the broad range of particle sizes and poor sorting, spoil tends to be highly porous and transmissive. Testing in mine spoil has recorded porosity values exceeding 15 percent for mine sites reclaimed for more than 10 years (Hawkins, 1995a). The porosity of recently reclaimed spoil may approach a spoil swell factor of 20 to 25 percent (Cederstrom, 1971). Aquifer testing in the Appalachian Plateau indicates that the transmissive properties of spoil tend to be more than two orders of magnitude (100 times) greater than those of undisturbed parent rock (Hawkins, 1995a). Some of the recharge from surface water occurs through discrete openings or voids exposed at the surface across a backfill (Hawkins and Aljoe, 1991; Wunsch and Dinger, 1994). Surface runoff from a precipitation event, flowing across the mine surface, will combine in rivulets, enter the spoil through these exposed voids, and flow rapidly downward via conduits to the saturated zone. The action of this water rapidly flowing in from the surface tends to increase the size and conductivity of these holes through the piping of finer grained sediments. In some instances, infiltrating water will reappear a short distance away (e.g., 300 feet) as a high-flowing ephemeral spring, but in most cases the water recharges the spoil aquifer and is more slowly released at perennial discharge points. Also aiding surface water infiltration is the characteristic high porosity of mine spoil, which permits rapid acceptance and storage of relatively large quantities of ground water.

Site Assessment - Backfill Testing

Spoil characteristics, such as hydraulic conductivity, porosity, and infiltration rates, are by-and-large dependent on site-specific conditions. Even with site-specific testing, these parameters can vary widely and are only predictable within a broad range. A wide range of hydraulic conductivity values (up to 3 orders of magnitude) can be recorded within a single mine site (Hawkins, 1998a). Prediction of these values prior to mining is exceedingly difficult.

Hawkins (1998a) conducted aquifer tests on several mine sites across the northern Appalachian Plateau in an attempt to predict mine spoil hydraulic properties. He found that the best correlation occurs between the age of the spoil and the hydraulic conductivity. The impacts of other factors (e.g., lithology, spoil thickness, and mining types) on spoil properties appear to be masked by a variety of factors introduced during the operation.

Given the broad range of mining types, spoil lithology and age, and other factors, it is doubtful a narrowly defined prediction model will ever be available. In addition to the aforementioned testing problems, spoil will at times exhibit turbulent flow which does not obey Darcy's Law, invalidating the aquifer testing procedures.

Materials used in sealing or grouting may require analysis to ascertain their hydraulic properties, and thus, determine suitability of use. Field testing for compaction or density may also be needed. This testing can be performed via a standard penetration test, using a penetrometer.

1.1.1 Implementation Guidelines

There are very few, situations where the proper implementation of the surface water infiltration reduction BMPs discussed in this chapter will not have a positive impact toward the reduction of pollution loads. A reduction of recharge ultimately reduces discharge rate, and discharge and pollution load rates commonly exhibit a strong positive correlation. Therefore, with a reduction in flow rate, pollution loads usually exhibit a reduction commensurate with the decreased flow (Hawkins, 1995b). Until the present, however, these BMPs have been implemented almost entirely with the intention of aesthetically pleasing reclamation in mind. The prevention of surface water infiltration has not been a specifically targeted concern, thus the true potential to reduce discharge rates with these BMPs has not been determined.

Regrading Abandoned Mine Spoil

A significant amount of surface-water infiltration can be reduced by regrading abandoned mine spoil. Abandoned spoil piles commonly exhibit poor drainage. Closed-contour depressions and poorly vegetated surfaces facilitate the direct infiltration of precipitation and other surface waters. Closed-contour depressions permit the impounding of surface water which in turn promotes infiltration into the spoil. Rough, unreclaimed spoil ridges and valleys with exposed rock fragments facilitate the direct and immediate infiltration of precipitation as it occurs. Removal of closed-contour depressions, elimination of spoil ridges and valleys, and the resulting creation of runoff-inducing slopes greatly reduces surface-water infiltration into spoil.

Skousen and others (1997) observed an average flow rate reduction of 43 percent of a discharge that averaged 188 gpm at a remining operation in Butler County, Pennsylvania. The main BMP was regrading and reclamation of approximately 8.7 acres of abandoned surface mine land. A second remining operation in Butler County, Pennsylvania, reclaimed about 12 acres of abandoned spoil as its primary BMP. Flow reduction of the discharges ranged from complete elimination of one, 70 percent reduction of two others, and 25 percent reduction of a fourth. While regrading and revegetation were not the exclusive BMPs employed, these flow reductions are indicative of what can be achieved with these BMPs.

Regrading of abandoned mine spoil is one of the most frequently employed BMPs in the operation of remining permits. Older mining operations were not as efficient as present day operations, and could not economically excavate as deeply as more modern equipment allows. Regrading is an integral part of most remining permits. In order to achieve a minimum reclamation standard as statutorily mandated, abandoned spoil piles are regraded to return the site to the approximate original contour or to at least achieve a more natural looking post-mining condition. In order to maximize the efficiency of this BMP, the spoil should be regraded in a manner which promotes runoff of precipitation and other surface water. This is achieved by creating slopes of a sufficient grade to induce runoff, but not to the degree that the runoff water velocity causes undue erosion.

The application of topsoil or an available soil substitute to newly regraded spoil improves the ability of spoil to impede surface-water infiltration. Several factors that directly impact changes in the infiltration rate between bare spoil and top-soiled and revegetated spoil, are lithology of the spoil material, composition, structure, roughness, and texture of the soil, density of vegetation, and surface slope. Soil freshly replaced on spoil exhibits an infiltration rate that is considerably less than that for unmined areas (Rogowski and Pionke, 1984; Jorgensen and Gardner, 1987). Therefore, it is not unexpected that the infiltration rate in resoiled spoil will be significantly below that in unreclaimed spoil. These low infiltration rates are related to the lack of soil structure, reduced root density, and the lack of other naturally occurring infiltration pathways that are present in undisturbed soils. Over time, the infiltration rates of mine soils increase. However, after four years, Jorgensen and Gardner (1987) observed that infiltration rates for mine soil were still below those of natural soils. Potter and others (1988) noted that significant differences between reclaimed soil properties and those of undisturbed soils still existed 11 years after reclamation.

Potter and others (1988) observed that the saturated hydraulic conductivity of reclaimed topsoil was approximately one fourth of that measured in undisturbed topsoil. Reclaimed subsoil exhibited a hydraulic conductivity about a tenth of undisturbed subsoil. Silburn and Crow (1984) observed that subsoils composed of shale and clay spoils are 10 and 100 times less permeable than from natural subsoils, respectively. Thus, runoff from reclaimed mine spoils is much greater than natural soils. The reasons for these differences are attributed to decreased percentage of large pores resulting in density increases, loss of soil structure, and reduced depths to low permeability layers (Silburn and Crow, 1984).

Effective regrading of abandoned and unreclaimed spoils, commonly an integral part of reclamation, will reduce the amount of surface water that will infiltrate into the backfill. However, there may be situations where site conditions indicate that re-affecting the spoil could cause an increase in the pollution load. These are sites where the original mining was conducted several decades earlier, the spoil has been naturally revegetated, and the backfill is in a state of geochemical equilibrium. Re-affecting the site would subaerially expose a significant portion of the backfill material, allowing additional oxidation of pyritic material that was otherwise relatively stable. Remining (in this case, regrading abandoned and unreclaimed spoil) could reinvigorate the production of acid-mine drainage and cause more problems than it abates. In these situations, the anticipated amount of reduced flow would have to be weighed against the projected increase in contaminant concentration.

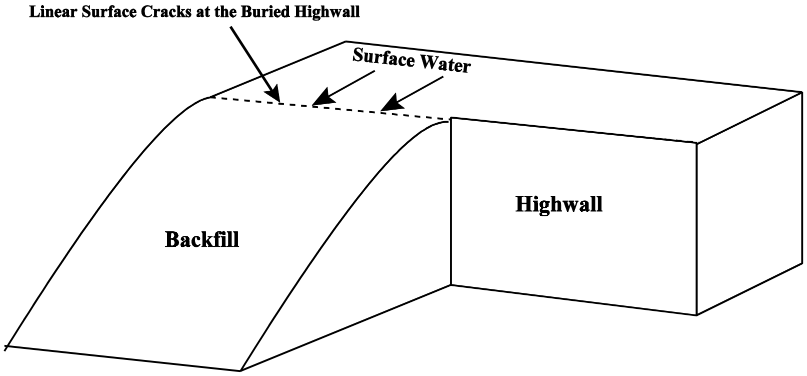
Installation of Surface Water Diversion Ditches

Diversion ditches can be constructed in two different locations, both of which reduce surface-water infiltration into the backfill. First, diversion ditches can be constructed above the final highwall or open pit to prevent surface water from adjacent unmined areas from entering the reclaimed site and infiltrating into the subsurface. Second, diversion ditches can be constructed within the backfill area to promote the efficient and rapid removal of direct precipitation prior to infiltration into the spoil.

Diversion ditches can be installed on top of reclaimed mine spoil to control the rate and pathway of runoff in the prevention of soil erosion. Diversion ditches also can be installed as part of a BMP plan to reduce pollution load. These ditches should be constructed to collect as much surface water as possible and to subsequently and expeditiously transport it from the site. Properly constructed (lined and sloped) ditches installed on the backfill will transport runoff from the backfill to the nearest drainage way.

A significant potential for recharge exists at the interface of the highwall and the spoil. For years and probably for decades after backfilling, spoil tends to settle, compact, and undergo other volume-reducing actions. While this settling occurs, the adjacent unmined highwall does not change appreciably. Because of this differential settling, it is common for linear surface gaps or cracks to run along or near this interface (Figure 1.1.1a). These cracks create an ideal infiltration zone for surface water. If surface water from unmined areas can be intercepted prior to flowing across a highwall and on to the spoil, a substantial amount of infiltration can be prevented. The installation of diversion ditches above the highwall is an effective BMP to preclude recharge to the spoil from adjacent surface water runoff.

Figure 1.1.1a: Diagram of the Location of Surface Cracks Between Highwall and Backfill



Because of the transmissive characteristics of mine spoil, diversion ditches need to be lined or sealed to preclude infiltration of the water that they are designed to collect and transport away. Lining of these ditches can be performed using a variety of natural and man-made materials, such as existing on-site clays, bentonite, coal combustion wastes (CCW), sheet plastic or other geotextiles, and cement (shotcrete). Regardless of the material used to line the ditches, it will need to be durable. The integrity of these ditches should be maintained for a considerable length of time or until the mine drainage discharges no longer exceed applicable effluent standards.

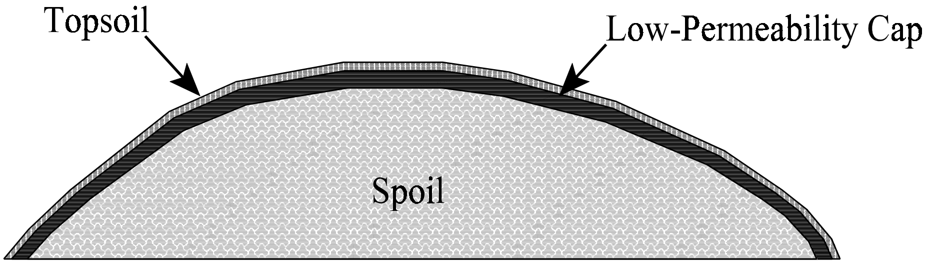
By and large, there are very few situations where properly constructed diversion ditches will not be beneficial in terms of reducing surface-water infiltration into the reclaimed site. Diversion ditches constructed above the final highwall across undisturbed ground are unlikely to be problematic in terms of leakage. The underlying subsoil and rock are less permeable than that encountered in disturbed areas. Diversion ditches constructed across reclaimed spoil are more prone to leak and allow substantial amounts of surface-water infiltration. The aforementioned porous and permeable nature of spoil can facilitate rapid infiltration of significant amounts of water over a short linear distance or at discrete points. Measures should be taken to insure the integrity of these ditches. The emplacement of some type of ditch-lining material, natural or manmade, is recommended. Where water velocities are sufficient to cause erosion, an erosion-resistant material should be placed as a cover for the liner material.

Lining diversion ditches with a relatively impervious material reduces the amount of infiltration through the bottom of the ditch, thus reducing recharge to the underlying strata. Reducing recharge to areas adjacent to reclaimed mines can indirectly reduce the amount of recharge to the mine spoil. When the adjacent strata receives increased recharge, some of this ground water will flow toward and enter the spoil. Therefore, if surface-water infiltration from the diversion ditch is impeded, recharge to adjacent spoil aquifers may also be reduced.

Low-Permeability Caps or Seals

There have been few studies performed to determine the efficiency of sealing or capping the surface of backfilled surface mines. The intention of sealing or capping is to preclude area-wide surface-water infiltration by placing a low-permeability cap over the backfill material, before the soil is replaced (Figure 1.1.1b). Because of the large surface area to be covered and the generally low profit margin at remining sites, the capping material should be readily available and inexpensive to make this BMP a viable option. Capping materials generally should be composed of a locally available waste product, such as pozzolonic (self-cementing) coal combustion waste or a naturally occurring clay within a short hauling distance.

Figure 1.1.1b: Schematic Diagram of a Cap Installed on a Reclaimed Surface Mine



The installation of low-permeability caps over the top of mine backfills can be an effective BMP for reducing surface-water infiltration. However, installation of these caps can be an expensive operation. Before approving the use of this BMP, the reviewer needs to ascertain whether it is economically feasible. The reviewer also needs to determine that the capping materials are readily available and of sufficient quality to complete the operation. Additionally, because mine spoil continues to subside with time, as has been observed beyond ten years after reclamation, the cap should be made to withstand the expected subsidence as much as possible.

In order to prevent the movement of water and atmospheric oxygen, Broman and others (1991) determined that capping materials need to have a hydraulic conductivity of 5×10^{-9} m/s or less. Broman and others developed a mixture of 35 percent biosludge from a paper mill and 65 percent coal fly ash. Lundgren and Lindahl (1991) specified a hydraulic conductivity of 1×10^{-9} m/s or less for a capping material for waste rock piles in a copper-producing area of Sweden. They successfully used a grouting cement-stabilized coal fly ash material, with a hydraulic conductivity approximately one order of magnitude lower than this specified value. Hydraulic conductivity values ranging from 10^{-10} to 10^{-12} m/s were recorded by Gerencher and others (1991) for shotcrete used to cap and seal waste rock dumps in British Columbia. Based on these studies, the hydraulic conductivity values necessary to create an effective cap are in the range of 10^{-9} to 10^{-10} m/s. These values are similar to values recorded for extremely impervious igneous rock, such as dense unfractured basalt (Freeze and Cherry, 1979). Spoil, on the other hand, is substantially more transmissive, exhibiting a median hydraulic conductivity of 2.8×10^{-5} m/s. However, the hydraulic conductivity of spoil exhibits a very broad range, 10^{-9} to 10^{-1} m/s, depending on the parent rock lithology and other geologic- and mining-related factors (Hawkins, 1998a).

A 20 hectare mine site in Upshur County, West Virginia was covered with PVC sheeting in an effort to reduce the pollution load. The result was a 50 to 70 percent reduction of the acidity load. Even though additional BMP techniques (e.g., special handling, lime and phosphate addition) were employed at this site and may have contributed some to the acid load reduction, the bulk of the pollution load reduction appeared to be directly related to the subsequent flow reduction (Meek, 1994).

A layered-composite soil cover was used to cover waste rock piles near Newcastle, New Brunswick, Canada, in an attempt to preclude infiltration of atmospheric oxygen as well as water.

The system consisted of a sand base overlain by compacted glacial till covered with sand and gravel. The top layer of cover consisted of 10 cm of well-graded gravel to prevent erosion. This system permitted between 1 and 2 percent of precipitation falling on the site to infiltrate into the waste rock below the cap. The cap's low-permeability material was glacial till with a hydraulic conductivity of 1.0 x 10^{-8} m/s (Bell and others, 1994).

Yanful and others (1994) constructed a cover for tailings piles in Canada to prevent the infiltration of surface water and atmospheric oxygen. A 60-cm compacted clay layer was placed between two 30 cm sand layers. The clay had an initial hydraulic conductivity of 1.0 x 10^{-9} m/s, which did not change during the three-year monitoring period. A thin gravel layer was placed over the top of the cap for protection. This cover excluded over 96 percent of the total precipitation from infiltrating into the tailings.

These studies indicate that if a cap is placed on top of a reclaimed backfill, a significant reduction of surface-water infiltration can be achieved. For example, if a hypothetical unreclaimed and unvegetated site permits infiltration of 75 percent of the precipitation (this number is likely higher) and continues to allow 35 percent infiltration after it is regraded, the addition of an effective cap should decrease the infiltration rate to between 2 and 4 percent. Let us assume that a 100 acre site receives 40 inches of precipitation per year and all of the infiltrating water discharges at one point. In the unreclaimed state, the average discharge rate would be 155 gpm. Once regraded the discharge will yield approximately 72.3 gpm. If a cap is installed the discharge rate should be reduced to 8.3 to 12.4 gpm. If the initial acidity concentration is 120 mg/L, the loading rate for the unreclaimed site would be 225.4 lbs/day. However, with regrading and cap installation, even if the acidity concentration increased by 10 percent to 132 mg/L, acidity loading would still show an overall decrease to a range of 13.3 to 19.8 lbs/day or 91.2 to 94.1 percent.

Revegetation

Revegetation of mine spoil can dramatically reduce the amount of surface water that would otherwise eventually make it to the underlying ground-water system. Vegetative cover also can decrease the amount of atmospheric oxygen that can enter the subsurface, because biological activity in the soil, such as decay of organic matter, can create an oxygen sink. A well-developed soil with a dense cover of vegetation can retain a significant amount of water. Eventually, this water evaporates or is transpired by the plants and does not recharge the spoil aquifer. Because this BMP is a statutory requirement of all mining permits, it is one of the most frequently employed. However, attempts to specifically tailor the vegetative cover to maximize evapotranspiration are rare to nonexistent.

Evapotranspiration of surface water entering mine spoil will be enhanced as the vegetative cover is increased (Strock, 1998). A thick forested area will permit more than twice as much evapotranspiration (35 inches per year) as barren rocky ground (15 inches per year) in the same area (Strock, 1998). The actual water loss depends on several factors including density, type of plants, and length of the growing season.

Revegetation of a reclaimed mine will in most cases be beneficial toward reducing surface-water infiltration. Caution should be used to prevent vegetative cover from providing conductive avenues for surface-water infiltration. In some cases, the root systems of plants will create areas where water can infiltrate in to the spoil. However, a lush vegetative growth may allow for greatly increased evapotranspiration rates that can offset the increased infiltration along root zones.

Stream Sealing

The sealing of streams reconstructed across backfill areas is intended to preclude direct infiltration into the spoil. The increased permeability and porosity of spoil by comparison to undisturbed strata promotes streams that have been reconstructed in mine spoil to lose water to the underlying aquifer. The water table in surface mine spoil is commonly suppressed compared to the water table at the site prior to mining and/or in adjacent unmined areas (Hawkins, 1995a).

A hydraulic gradient from the reconstructed stream to the suppressed underlying water table is frequently present, thus facilitating infiltration. Therefore, reconstruction of these streams should be conducted with the assumption that they will leak unless sealed or lined.

The primary and probably most inexpensive method of sealing streams is with plastic sheet lining. Shotcrete can also be used for lining limited sections of stream beds in a relatively cost-effective manner. One of the problems associated with plastic lining is that the plastic sheeting eventually breaks down chemically and ruptures or is punctured by sharp rock fragments.

Stream sealing also has been performed by excavating and emplacing a clay liner along the stream reach (Ackman and others, 1989). In this case, the stream was disrupted by subsidence from a shallow abandoned underground mine. The effectiveness of the clay seal was less than 100 percent. The section of stream that was clay lined exhibited a 4 percent loss of flow over approximately 170 feet, whereas the preceding section of stream exhibited an 8 percent flow decrease over a similar distance.

Another method of stream sealing involves injecting polyurethane to grout-targeted sections of streams. Similar grouting has been successfully conducted on losing streams situated over the top of abandoned underground mine workings. In these cases, the underlying mine was relatively shallow (25 to 50 feet) and losing stream sections were located by use of electromagnetic terrain conductivity surveying equipment. Once located, zones of significant infiltration were targeted for grouting (Ackman and Jones, 1988). Given the length of stream that would require grouting and the high porosity of the spoil, it is doubtful that polyurethane grouting would be economically viable for most remining operations.

Stream sealing as a BMP is appropriate only where a section of a stream is mined through and subsequently reconstructed. Like diversion ditches that cross a reclaimed mine, these streams should be rebuilt in such a manner that they do not leak water into the subsurface. The stream bed should be underlain with a liner material to preclude surface water infiltration. However, erosion-resistant material should be placed over the top of the liner to prevent future liner breaching.

Design Criteria

The design and implementation plan of BMPs intended to reduce the infiltration of surface water into mine spoil and adjacent undisturbed areas depends a great deal on site conditions (i.e., amount of precipitation, location of surface water streams or drainage areas, original contour, indigenous vegetation, soil type, and readily available materials). Recommended design criteria for the implementation of surface-water infiltration control BMPs are included in the following list. This list is by no means all-inclusive. Permit writers, regulatory authorities, and designers should consider all site conditions, with the intent of implementing the most cost-effective means of reducing pollutant loading during remining operations.

Regrading
- Controlled runoff of precipitation and other surface waters should be promoted
- The site should be returned to the approximate original contour
- Regrading should be performed along the contour to minimize erosion and instability

Diversion Ditches
- Runoff should be diverted away from disturbed areas
- Rapid runoff from disturbed areas should be promoted
- Diversion ditches should be adequate to pass the peak discharge of a defined storm event such as a 2-year, 24-hour storm (temporary ditches) or a 10-year, 24-hour storm (permanent ditches)
- Diversion ditch construction in landslide prone areas or where severe erosion is possible should be performed with extreme care, if at all

Caps or Seals
- Readily available materials (e.g., on-site clays or CCW) should be used

- Material with hydraulic conductivity of 10^{-9} m/s or less should be used
- Caps or seals should be able to withstand anticipated subsidence without breaching

Revegetation

- Root systems should retain water and not provide infiltration pathways
- Local and native plant species that will thrive and create a lush cover should be selected

Stream Sealing

- Chemically inert materials that are not prone to erosion or puncture damage should be used
- Readily available materials (e.g., on-site clays or CCW) should be used

1.1.2 Verification of Success or Failure

Verification that BMPs have been properly and completely implemented during remining operations is crucial to effective control or remediation of pollutant loading. In other words, monitoring should ensure that the as-built product is the same as that originally proposed by the operator and approved by the regulating authority. The importance of field verification of all aspects of a BMP cannot be overstated. It is the role of the mine inspector to enforce the provisions outlined in the permit. The mine inspector does not need to be present at all times to assess the amount of regrading for abandoned and unreclaimed spoils, the elimination of closed-contour depressions or revegetation. The completion of these tasks should be evident from visual inspection or if required, from a survey of the area.

The actual installation of diversion ditches or stream replacements should be self evident from a visual inspection. However, whether the ditch or stream was properly constructed and will not leak requires a bit more work on the part of the mine inspector or hydrologist. If a liner was prescribed for proper stream installation, the inspector can require weigh slips or receipts for material brought into the site. If on-site material is to be used, a marked material stock pile can be required. An inspector also can require notification of liner installation and completion dates.

Failure of a ditch or a stream to hold water can be determined by conducting flow measurements. If the flow shows a significant decrease (e.g., outside the known error of the flow measurement method) or disappears altogether, there is an indication that water is infiltrating and recharging the backfilled site.

Determining the implementation level of some of the BMPs discussed in this chapter after the fact is not always an easy procedure. It can be difficult to verify that a capping seal was installed properly, without being present during the operation. However, if the capping material is trucked in from an outside source, weigh slips or receipts can be obtained to confirm the amount of material used. If on-site material is to be used, a marked stockpile of the material can be required. Given the amount of work involved in spreading and compacting, it is likely a mine inspector will visit the site at least once during the capping process. If there is great concern that the cap will not be properly installed, the permit can be conditioned to require notification of the mine inspector at predetermined salient points during the procedure.

The efficiencies of BMPs need to be monitored in order to improve and effect future refinements of the processes. Not only does the type of BMP need to be assessed, but the scope and degree of BMP implementation needs to be related to the degree of improvement (e.g., flow or pollution load reduction). The mechanism to determine the effectiveness of BMPs discussed in this chapter is similar to any abatement procedure research project. In the case of these surface water control BMPs, a significant portion of the monitoring will consist of measuring the flow rates of discharges emanating from the site. It is fully realized that the locations of discharges may, and frequently do, move from their pre-remining locations. Therefore, a hydrologic-unit approach is recommended. The mine site should be divided into hydrologic units, that is, portions of the mine that contribute to one or more discharges. Discharge data (flow and/or loading rate) can be mathematically combined to permit pre- versus post-mining comparisons.

Given the nature of mine spoil and the time that it takes for a water table to re-establish and reach equilibrium, post-mining monitoring may need to continue for at least three to five years. In eastern Ohio, water-table re-establishment at three reclaimed surface mines was observed to be nearly complete approximately 22 months after reclamation was completed (Helgesen and Razem, 1980). Recovery of the water table after mining may take 24 months or longer in Pennsylvania (Hawkins, 1998b). The rate of water-table recovery is related to several factors including precipitation, infiltration and discharge rates, porosity, topography, and geologic structure. Additionally, short-term changes in flow and/or contaminant concentration commonly occur during the initial one to three years after backfilling because of substantial physical and chemical flux within the spoil aquifer. During this period, the water table is re-establishing, and the spoil is undergoing considerable subsidence, piping, and shifting. Sulfate salts, created by oxidation when cast overburden is exposed to the atmosphere during mining, are flushed through the system (Hawkins, 1995b). It is important to monitor these sites beyond the initial re-establishment period, in order to accurately assess the true changes due to remining and BMP implementation. The length of the post-mining monitoring period may vary from site to site depending on climatic (e.g., precipitation) and hydrogeologic (spoil porosity and permeability, topography, etc.) conditions, and should be at the discretion of the professional in charge of project oversight.

Implementation Checklist

Monitoring and inspection of BMPs, in order to verify appropriate conditions and implementation, should be a requirement of any remining operation. Though BMP effectiveness is highly site-specific, it is recommended that implementation inspections of hydraulic control BMPs include the following:

C Measurement of flow and sampling for contaminant concentrations (before, during, and after mining)
C Monitoring should continue well beyond initial water-table re-establishment period (e.g., about two years after backfilling)
C Assessment of hydrologically connected units as well as individual discharges
C Review or inspection of sealing-material weigh slips, receipts, or marked stockpiles
C Review of implementation initiation and completion dates

- Assessment of any deviation from an approved implementation plan
- Inspection of salient phases of the BMP implementation
- Inspection of diversion ditches, caps and seals for leakage
- Inspection of vegetation for viability

1.1.3 Case Studies

Presented below are results from three completed remining operations for which a significant portion of the site had abandoned and unreclaimed spoils regraded, closed-contour depressions eliminated, and more natural runoff-inducing slopes created. It is important to note that the full potential of these BMPs may not have been realized because regrading was performed primarily as part of the perfunctory reclamation process. These BMPs were not necessarily implemented with the minimization of surface-water infiltration as a primary intention. Evaluation of these sites may tend to underestimate the potential for infiltration reduction that can be achieved. Minor implementation modifications can dramatically affect efficiency. Future efforts which employ these BMPs to their greatest potential should be closely monitored and analyzed in an attempt to ascertain true BMP efficacy and to develop methods for fine tuning and improvement.

There are several factors that make pre-mining versus post-mining comparison difficult. One of the main pitfalls in comparing the discharge rates is the assumption that the pre- and post-mining periods have had similar precipitation preceding the measurements. Precipitation amount, duration, and intensity can vary widely from event to event, season to season, and year to year, serving to complicate pre- to post-mining comparisons. This is especially true when the sampling periods before and/or after mining are relatively short (e.g., a year or less). Another complicating factor is that post-mining sampling often will include a period of time when the water table is re-establishing and much of the infiltrating water is going into storage. Under ideal conditions, an evaluation of flow reduction from BMPs discussed in this chapter would entail similar climatic conditions, preclude data collected during water-table re-establishment, and include several years of pre- and post-mining monitoring. These criteria are seldom met in real-world situations. The location of the pre-existing discharges commonly move because of the physical disruption of the yielding aquifer and ground-water flow paths, and the change of the flow system from a fracture-flow dominated system to a dual-porosity system as exhibited in mine spoil. These caveats and potential problems should be considered while reviewing the case studies below.

Case Study 1 (Appendix A, EPA Remining Database, 1999, PA(6))

This mine was located in Armstrong County, Pennsylvania, where the remining was performed on abandoned surface mines in the Upper Freeport and Lower Kittanning coal seams. All 24.8 acres of abandoned surface mined land within the permit boundary was reclaimed by the operation. According to the permit application, the total area to be affected by mining operations was 126.5 acres. The operation also eliminated 1,700 feet out of a possible 2,600 feet of highwall. Originally, two remining discharge points were included in the permit. However, a third discharge point was added later. The BMPs listed in the permit included regrading of abandoned mine spoil (24.8 acres), underground mine daylighting (5 acres), special handling of acid-forming materials, and revegetation. The most predominant BMP component by far was the regrading. The site was completed in August of 1996 and post-mining water quality data has been collected since. A synopsis of the data is shown in Table 1.1.3a.

The changes in flow rates from remining of this site are somewhat inconsistent. Discharge point MD-2 exhibits a statistically significant increase in flow, but the acidity and iron loads are not significantly higher. This is caused by decreases in concentrations and a relatively broad range of values, resulting in a wide 95 percent confidence interval about the median, as is commonly associated with mine drainage. Discharge points C-3A and C-17A exhibit only very minor differences in the discharge rate after remining. The acidity concentration decreases caused the median acidity loads to be substantially lower, but only the decrease in the median acidity load of C-17A is statistically significant.

Table 1.1.3a: Synopsis of Water Quality Data at Case Study 1 Site

	Discharge Points					
	MD-2		C-3A		C-17A	
Parameter	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining
Sample Number (n)	22	22	24	22	6	17
Flow (gpm)	2.4	27.1	14.2	16.3	12.5	9.1
Acidity Load (lbs/day)	1.93	4.76	16.17	0.75	8.56	0.07
Iron Load (lbs/day)	0.0016	0.0044	0.09	0.10	0.003	0.003
Sulfate Load (lbs/day)	5.57	85.78	23.15	60.01	21.06	25.45

All numbers are median values.

The lack of better flow reduction may predominantly be due to precipitation differences during the two comparison periods and, to a lesser degree, to a rerouting of ground-water flow paths. The reclamation area comprised a small amount (slightly under 20 percent) of the total area to be disturbed by remining. In addition, the post-remining period is relatively short (less than two years) in terms of allowing complete re-establishment of the water table and post-remining stabilization of the entire hydrogeologic system. Additional monitoring of the site will likely illustrate more clearly the true impacts of regrading and revegetation.

Case Study 2 (Appendix A, EPA Remining Database, 1999, PA(7))

This mine was located in Clearfield County, Pennsylvania. Remining was performed on abandoned surface mines in the Upper Freeport and Lower Kittanning coal seams. Ten acres (32 percent) of the 30.8 acres of abandoned surface-mined land within the permit boundary was reclaimed by the operation. Of the 101.1 acres of abandoned underground mines on the Lower Freeport coal, 17.3 acres (17 percent) were daylighted during the remining operation. According to the permit application, the total area to be affected was 139.3 acres. Two remining discharge points were included in the permit. The BMPs listed in the permit included regrading of abandoned mine spoil (10 acres), underground mine daylighting (17.3 acres), sealing of exposed mine entries, special handling of toxic materials, and revegetation. The predominant BMP components were regrading, revegetation, and daylighting. The site was completed in May of 1996, and was assessed using monthly water-quality data collected through August 1997. A synopsis of the data is shown in Table 1.1.3b.

Table 1.1.3b: Synopsis of Water Quality Data at Case Study 2 Site

	Discharge Points			
	MD-12		**MD-13**	
Parameter	**Pre-Remining**	**Post-Remining**	**Pre-Remining**	**Post-Remining**
Sample Number (n)	44	16	47	16
Flow (gpm)	0.55	0.40	31.6	35.9
Acidity Load (lbs/day)	2.48	0.59	176.2	133.7
Iron Load (lbs/day)	0.047	0.006	9.99	6.31
Sulfate Load (lbs/day)	2.87	2.65	273.79	289.8

All numbers are median values.

Analysis of the data indicates that the flow rates of the two discharges were not significantly changed by the remining (regrading and revegetation); there is no statistical difference. The acidity and iron concentrations at MD-12 were significantly reduced, but the lack of significant flow changes prevented concomitant acidity and iron load reductions. Figures 1.1.3a and 1.1.3b illustrate an example of these observations. The lack of overlap of the notches indicating the 95 percent confidence intervals about the medians indicate that the medians of acidity data before and after remining operations are significantly different, with a definitive decrease in acidity following remining site closure.

Figure 1.1.3a: Acidity Concentration at Discharge Point MD-12 Before and After Remining

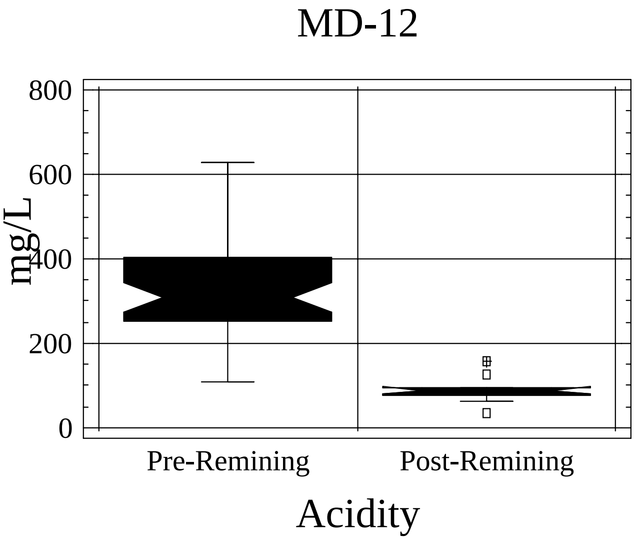
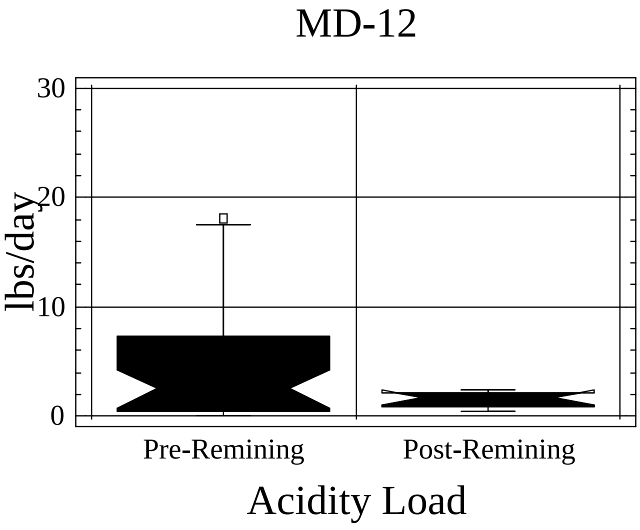


Figure 1.1.3b: Acidity Load at Discharge Point MD-12 Before and After Remining



Some of the same caveats that apply to Case Study 1 also apply to this site. The climatic differences (e.g., precipitation) for the two sampling periods should be considered as part of the overall evaluation of flow changes due to remining. For example, the period of pre-remining sampling (12/86 through 9/89) averaged 2.83 inches of precipitation per month, while the post-remining period (5/96 through 8/97) averaged 3.36 inches of precipitation per month. This is an increase of about 19 percent. The precipitation values were compiled from the Pittsburgh International Airport which is approximately 90 miles southwest of the site. However, the data can be used for the general precipitation trends during pre- and post-remining sampling periods at this site. The increase in flow from the combined discharges (about 13 percent) is not commensurate with the recorded precipitation increase. Additionally, the post-remining period is relatively short (less than two years) in terms of allowing complete re-establishment of the water table and post-remining stabilization of the entire hydrogeologic system. Additional monitoring of the site over a longer time period and with similar precipitation amounts will likely clarify the true impacts of regrading and revegetation.

Case Study 3 (Appendix A, EPA Remining Database, 1999, PA(10))

This site is located in Somerset County, Pennsylvania. Remining was conducted on the Lower Bakerstown coal seam. According to the permit application, a total of 85.8 acres was to be affected by the operation and 48.8 acres of coal removed. BMPs employed at this site included regrading of abandoned spoils, alkaline addition, hydrologic controls, revegetation, and scarification of the calcareous pavement (seat rock). Of the 32.2 acres of abandoned mine lands within the permit boundary, 15.6 acres, or 48 percent, were to be reclaimed. Approximately 1,800 feet (84 percent) of a total of 2,150 feet of abandoned highwall were eliminated. The alkaline addition rate was 3 tons per acre applied at the interface of the spoil and the topsoil. Hydrologic controls consisted of a clay barrier placed between remining operations and adjacent unreclaimed areas. The seat rock was found to be alkaline and was scarified to increase the surface area of the alkaline material exposed to ground water. Reclamation was completed by

November 1995, and monitoring has continued since that time. Table 1.1.3c is a synopsis of the flow and loading data for this site.

Table 1.1.3c: Synopsis of Flow and Pollutant Loading Data at Case Study 3 Site

Parameter	**Discharge Points**									
	SP-10		**SP-11**		**SP-12**		**SP-18**		**SP-23**	
	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining	Pre-Remining	Post-Remining
Sample Number (n)	8	34	8	34	8	34	8	35	4	34
Flow (gpm)	7.47	5.15	11.3	3.0	1.0	0.7	0.88	1.20	0	0
Acidity Load (lbs/day)	2.72	8.18	20.5	7.4	1.04	0.95	0.31	1.97	0	0
Iron Load (lbs/day)	0.006	0.008	0.03	0.01	0.004	0.003	0.003	0.004	0	0
Sulfate Load (lbs/day)	21.6	49.4	71.1	57.2	11.3	6.06	3.04	9.51	0	0

All numbers are median values.

This site exhibited a cumulative discharge median flow reduction of 10.6 gpm or slightly over 51 percent. However, only SP-11 exhibited a statistically significant flow reduction on an individual basis. According to the precipitation history from the Pittsburgh International Airport, precipitation during the two sampling periods was dissimilar, with precipitation during the post-remining period (a mean of 3.29 inches per month) being about 15 percent below the background sampling period (a mean of 3.85 inches per month). Roughly 15 percent of the flow reduction may be attributable to reduced precipitation, but the remainder appears to be related to regrading, highwall elimination, and revegetation. The same caveats discussed in Cases 1 and 2, for using precipitation data from a site somewhat removed from the actual mine sites, apply here. These results illustrate that substantial flow reduction (approximately 35 percent) may be realized by a 50 percent reduction in abandoned mine lands, even with additional mining of virgin areas (49 acres) occurring in conjunction with the operation. The post-mining monitoring period is considerable, exceeding three years, but additional monitoring is required to determine whether the trends observed are genuine and can be expected to continue. Additional flow reduction may be possible if regrading and revegetation are designed specifically with the intent of preventing surface-water infiltration, rather than solely with the intent of returning the site to an aesthetically pleasing approximation of the original pre-mining contours and conditions. Specific operations to reduce surface-water infiltration may include, but are not limited to: 1) additional compaction of the spoil to reduce permeability, 2) final slopes that may differ from the approximate original contour but are more efficient in promoting runoff, and 3) plants that promote runoff and/or utilize substantial amounts of the water that does manage to infiltrate into the soil horizon.

Even with the aforementioned reductions in discharge flow, two of the discharges (SP-10 and SP-18) exhibited a statistically significant increase in median acidity and sulfate loads. This difference is caused by substantially higher acidity and sulfate concentrations after reclamation. Discharge points SP-11 and SP-12 also exhibit significantly increased concentrations of acidity, but the reduced flows prevent the median loadings from being significantly different from the baseline levels. This indicates that the site may be producing more acidity, but the reduced flow moving through the site has prevented the combined discharge acid load from exceeding baseline. Geochemical conditions within this reclaimed operation have worsened or become more acidic. The causes of this possible failure will be discussed in detail in the section on alkaline addition.

To obtain a more definitive determination of the efficiency of regrading and revegetation to reduce discharge rates, additional studies are needed on sites where these BMPs are employed specifically to preclude surface-water infiltration. The case sites discussed above utilized these BMPs during remining operations, but they did not specifically design or implement them to minimize infiltration of surface water. Thorough evaluation of these studies also requires site specific precipitation data for background sampling as well as post-mining sampling periods. A sufficient post-mining sampling period of at least three to five years, depending on climatic and site-specific conditions, is required to permit a true assessment of BMP efficiency. With these data, prediction of load reduction based on the amount of regrading, revegetating, and other BMPs may be possible.

1.1.4 Discussion

The BMPs discussed in this chapter, when properly employed under the right conditions, will successfully reduce the infiltration of surface waters and should subsequently reduce the discharge yield. However, these BMPs cannot be viewed as a panacea for all pre-existing problems at a site. There are limits to what can be physically achieved and/or economically attempted. The two lists below (Benefits and Limitations) include, but are not limited to, what can and cannot be expected of these BMPs.

Benefits

- Reduce pollution loading from abandoned mine land
- Establish a hydrologic balance to site
- Restore land to approximate original contour and creates an aesthetically pleasing post-remining configuration
- Require little additional cost to the operation because they are often already implemented as a statutory requirement during remining operations

Limitations

- Current implementation of hydraulic control BMPs focuses primarily on reclamation. A complete evaluation of the effectiveness for pollution prevention, in terms of reducing the discharge rate, is needed.
- Careful consideration should be made to the implementation of surface-water control BMPs in areas abandoned for long periods or with some degree of natural remediation (e.g. stabilized spoil, natural vegetative cover).
- Complete exclusion of infiltrating surface waters is not likely, therefore the discharges will not be entirely eliminated.

Efficiency

Analysis of completed remining sites in Pennsylvania (Appendix B, PA Remining Site Study) indicated that at sites with regrading as a BMP, 46.1 percent of 154 discharges were eliminated or were significantly improved in terms of acidity loadings. Over half the discharges (53.2 percent) were unchanged and less than one percent (0.6 percent) were significantly degraded with respect to acidity loadings.

For iron loadings, 42.3 percent of 137 discharges were eliminated or significantly improved from remining. Over half (52.6 percent) of the discharges were unchanged, while 5.1 percent showed significant degradation for iron loadings.

The manganese loadings for 39.6 percent of the 111 discharges were significantly improved or eliminated, while 52.3 percent were unchanged. The manganese loading failure rate was the highest for the parameters analyzed, with 8.1 percent significantly degraded. This has been a common trend for all the BMPs. Manganese loadings exhibited the highest failure rate (9.0 percent for 155 discharges) regardless of the BMP employed.

The bulk (60.7 percent) of the aluminum loadings for 84 discharges were unchanged, while 36.9 percent of the discharges were significantly improved or eliminated. Discharges that were significantly degraded, in regards to aluminum loadings, amounted to 2.4 percent.

1.1.5 Summary

Studies have shown that the extent of pollution reduction from remining is largely dependent on reducing the discharge rate, which in turn is dependent on controlling the infiltration of surface water into the backfill. The commonly observed positive correlation between flow and loading rates illustrates the close relationship between the two. BMPs that are designed and implemented to prevent surface-water infiltration will be successful in reducing the pollution load.

The case studies above illustrate that regrading and revegetating can yield mixed results unless differences in precipitation rates are taken into account and the post-mining monitoring period is of sufficient length to accurately reflect site conditions. However, it is well known that these BMPs, when properly implemented, will reduce the contaminant load from remining operations.

1.2 Control of Infiltrating Ground Water

Methods to control the lateral infiltration (recharge) of ground water into remining sites from adjacent mines and undisturbed strata include, but are not limited to, daylighting of underground mine workings, sealing exposed mine entries, auger holes, highwalls and pit floors, and installing diversion drains, vertical highwall (chimney) drains, pit-floor drains, grout curtains and diversion wells. These BMPs are designed to work in one of two ways to reduce the ultimate discharge flow rate: (1) to preclude or divert the lateral movement of ground water; and (2) to intercept and collect laterally migrating ground water and channel it away from the backfilled areas. These BMPs are effective singly or when used in conjunction with others, but are seldom used alone during remining operations.

Currently, these BMPs are being used as a part of the general mining and reclamation processes, but they are not being implemented with ground-water handling as the primary concern. Therefore, the results of the case studies (discussed below) and other remining data (Appendix B: Pennsylvania Remining Site Study) may tend to underestimate the potential for lateral infiltration reduction that can be achieved. Minor implementation modifications toward ground-water handling can dramatically effect the efficiency of these BMPs with little additional time or expense introduced.

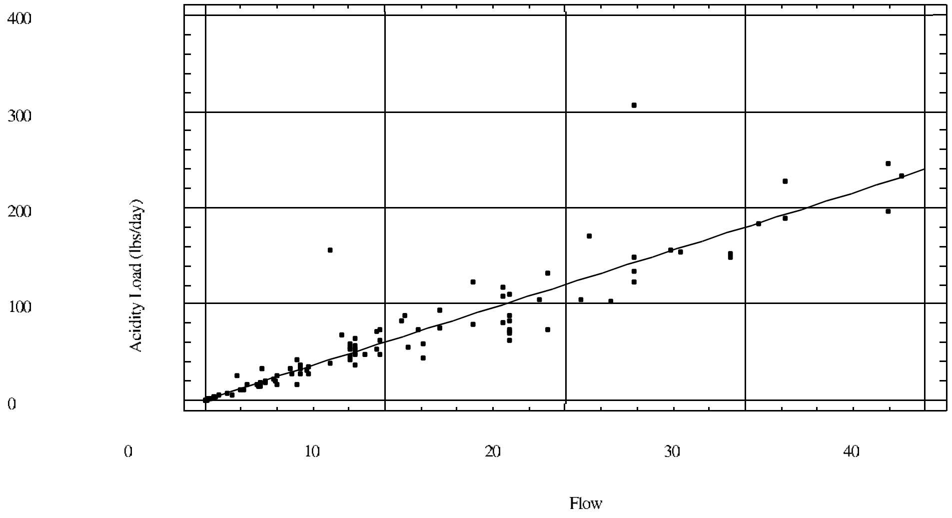
Theory

Ground-water modeling of reclaimed surface mines has shown that a substantial portion of ground-water infiltration into mine spoil comes from adjacent areas. Infiltration from adjacent areas can originate from other surface mines as well as from unmined strata. The nature of this lateral recharge can be continuous or episodic. Adjacent areas tend to permit lateral ground-water movement somewhat continuously under baseflow conditions, long after the last precipitation event. However, rapid, high-volume lateral recharge also can occur immediately following significant rainfall events (Hawkins and Aljoe, 1990). Fractures in the adjacent strata can yield substantial amounts of water during or shortly after significant precipitation. The BMPs discussed in this section need to be able to accommodate this bimodal, lateral ground-water infiltration.

Unlike many of the BMPs implemented to prevent surface-water infiltration, most of the BMPs for preventing lateral ground-water movement are implemented on and above standard reclamation practices. These BMPs tend to be more labor and material intensive than standard reclamation practices, and therefore, can be more costly. One exception is underground mine daylighting, which is performed as a consequence of the remining process. However, the time and effort required to clean the waste rock from around the remaining coal pillars entails additional cost during mining, the percentage of coal recovery is less than that for virgin areas, and additional acid-forming materials should be special handled. Some of the BMPs discussed in this section are mandated by regulation, such as sealing of auger holes and exposed mine entries.

The effectiveness of many of the ground-water control BMPs relies largely on the use of proper engineering techniques. As with BMPs implemented for the prevention of surface-water infiltration, there are very few situations in which these BMPs will fail. If the ultimate discharge flow rate is reduced through reduced lateral infiltration, there is a high probability that the pollution load will be diminished. Figure 1.2a shows the strong correlation between flow and pollution load commonly exhibited by mine drainage discharges. There are hydrogeologic conditions where some of these BMPs could exacerbate the production of acid mine drainage (AMD). In these cases, the BMP should be eliminated or modified to prevent additional pollution. In situations where the BMP is an integral part of the entire operation (e.g., daylighting), additional BMPs will need to be added or designed to compensate for possible deleterious side effects of the others.

Figure 1.2a: Typical Correlation Between Discharge Flow and Pollutant Loading in Mine Drainage Discharges (Appendix A, EPA Remining Database, 1999 PA(6), MP-A)



Site Assessment

Assessment of spoil characteristics is site-specific for each operation. Even with on-site testing, spoil hydraulic parameters can be highly variable. Hawkins (1998a) observed that hydraulic conductivity can range widely (up to 3 orders of magnitude) within a site. This makes prediction of spoil characteristics prior to mining extremely difficult. However, there are some general conclusions that can be drawn about mine spoil.

Hawkins (1998a) conducted aquifer tests on several mine sites across the northern Appalachian Plateau in an attempt to predict mine spoil hydraulic properties. He found that the best correlation occurs between the hydraulic conductivity and age of the spoil. The impacts of other factors (e.g., lithology, spoil thickness, and mining type) on spoil properties appear to be masked by a variety of factors introduced during the operation.

Given the broad range of mining types, spoil lithology and age, and other factors, it is doubtful a narrowly defined prediction model will be available. In addition to the aforementioned testing problems, spoil will at times exhibit turbulent flow which does not conform to Darcy's Law and causes aquifer-testing procedures to become inapplicable.

Prior to the engineering and installation of highwall and pit floor drains, an assessment as to the amount of ground water to be collected and piped needs to be made. This determination can be performed by empirical testing of observed recharge while the pit is open or can be performed by conducting a hydrologic budget exercise. The hydrologic budget will require, at a minimum, knowledge of the size of the recharge zone, precipitation and evapotranspiration rates, storage capacity, and aquifer characteristics.

Materials used in sealing or grouting may require analysis to ascertain the hydraulic properties, and thus, the suitability of use. Field testing for compaction also may be necessary. This testing can be performed via a standard penetration test, using a penetrometer.

Assessment of ground-water diversion (interceptor) wells may require aquifer testing. Performing a constant-discharge test while monitoring other wells will yield insight as to the efficiency of these wells. Aquifer testing will also yield data on well and aquifer interconnection.

1.2.1 Implementation Guidelines

Daylighting of Underground Mines

Underground mining has been conducted in some areas of the United States for over 200 years. Although limited surface mining was conducted in the early part of the 20th century, surface mining did not become prominent until after the Second World War. Surface mining into higher cover coal (greater than 30 to 40 feet) only became commonplace in the 1960s with the proliferation of mining equipment capable of moving large amounts of rock efficiently. Early underground mining operations have left a considerable amount of abandoned underground mines that are now candidates for remining. These underground mines have been producing untreated mine drainage since abandonment and, if left unchecked, will continue to do so for decades or even longer. Daylighting of abandoned underground mines is one of the more frequently employed BMPs during remining operations.

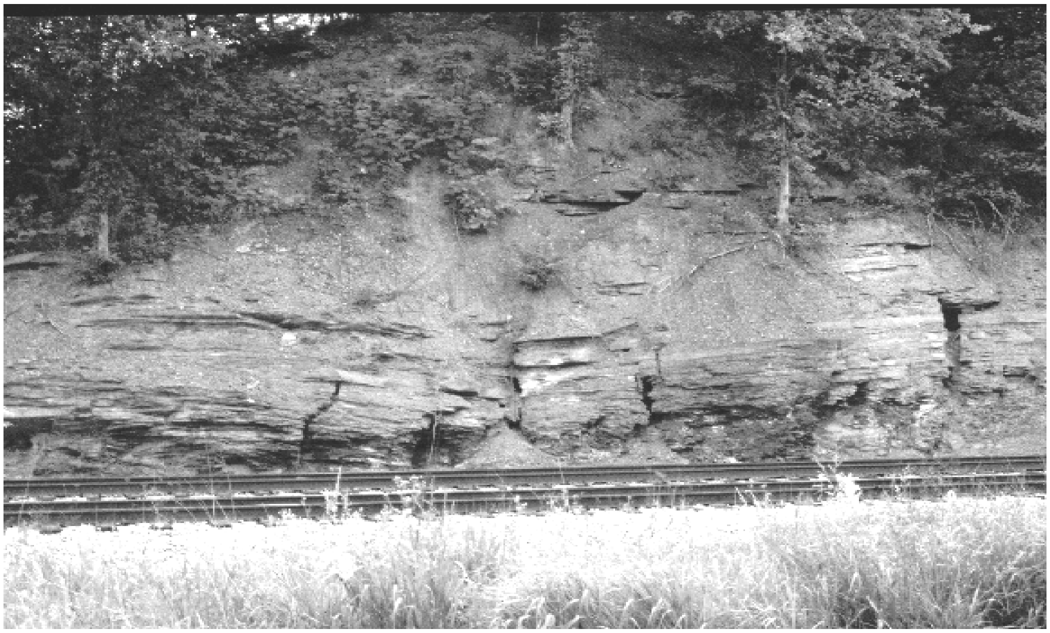
Daylighting operations are often economically marginal. This is because the same volume of overburden associated with virgin coal needs to be removed, but the coal recovery rates are greatly diminished. A coal recovery rate of 50 percent is usually the maximum observed at daylighting operations, but this level is seldom achieved. Recovery rates are more commonly in the range of 20 to 35 percent, because many of the mines were retreat-mined (high coal extraction from partially mining through pillars as the operation withdraws from the mine) prior to abandonment. Because of this reduced recovery, the thickness of overburden that can be removed economically is less than that for solid coal areas.

The act of daylighting is the removal of the strata above the coal (overburden), the removal of the collapsed rock (gob) around the existing pillars, and the loading out of the coal. Once the coal is removed, the site is reclaimed. Daylighting works to reduce lateral ground-water infiltration in several ways. Abandoned underground mines are recharged, to a large degree, from fractures in the overlying rock. The fractures are created primarily by stress relief of erosional rock mass removal and to a lesser extent by tectonic (mountain building) activities (Wyrick and Borchers, 1981). One of the more prominent results of daylighting is that avenues for vertical recharge are eliminated, and water that once recharged the underground mine is no longer available. Daylighting of approximately one-half of a 380 acre abandoned mine in Allegheny County, Pennsylvania, reduced the flow by about 50 percent (Skousen and others, 1997).

Subsidence and collapse of abandoned mine workings can create additional fractures and increase the size of existing fractures, also increasing their transmissive properties. Evidence of subsidence is frequently observed at the surface as cracks, damage to surface structures (e.g., house foundations, roads, and utilities), and sinkholes (closed-contour depressions).

Figure 1.2.1a is a photograph illustrating exposed fractures accentuated due to mine subsidence. The degree of surface disturbance depends to a large extent on the thickness and lithology of the overburden and the size of the mine void. Daylighting removes the highly transmissive avenues for ground water to enter underground mine workings. Even when the underground mine has not been completely eliminated, daylighting can dramatically reduce this recharge. Empirical observations indicate that there is an exponential decrease in recharge to underground mines with increasing overburden thickness. Shallow cover areas tend to yield more water to the mines than deeper (thicker) cover areas and are more commonly eliminated through remining. In shallow overburden, stress-relief fractures are more frequent and generally more transmissive than in deeper overburden (Borchers and Wyrick, 1981; Hawkins and others, 1996). Because of more extensive fracturing with shallow cover, the overlying rocks are more susceptible to the impacts from mine subsidence. For example, daylighting 20 percent of a mine, which is the shallowest cover, will likely reduce infiltration by an amount much greater than 20 percent.

Figure 1.2.1a: Example of Mine Subsidence and Exposed Fractures



The storage capacity of underground mines is considerable, and can approach 65 percent of the original coal volume. However, a storage capacity of 20-40 percent is more likely. A 100-acre underground mine with 50 percent of the coal mined, a 5 foot thick coal seam, and no significant subsidence has a potential storage volume of over 81 million gallons. If the mine workings are only one-third flooded, the mine water stored exceeds 27 million gallons. Storage of vast amounts of mine water in underground mines allows for continuous lateral recharge to adjacent operations, even during dry periods. Daylighting decreases the amount of storage available for ground water and therefore prevents lateral movement into adjacent areas.

Abandoned underground mines are commonly ideal environments for AMD formation. If acidic, metal-laden ground water is infiltrating into an adjacent surface remining operation, it can cause the formation of more AMD than the sum of what the two mines would produce separately. For example, it is known that ferric iron (Fe^{3+}), a product of acid-mine drainage formation, can become the main oxidant of pyrite. Additional pyrite oxidation can occur even under suboxic or anoxic conditions (Caruccio and Geidel, 1986). Therefore, AMD entering into pyritic-rich zones in spoil can produce more pollution than the spoil would produce on its own.

By and large, the water quality of underground mines is much poorer than that of surface mines on the same seams (Hawkins, 1995b). AMD formation is facilitated by the configuration of an underground mine which permits ground water to preferentially encounter commonly acid-forming units (seat and roof rock and the coal). Over time, roof falls and pillar deterioration continue to introduce additional acid-forming materials into the system. Daylighting is radically different than the mining processes that allow the underground mine to create AMD, because the coal mine entries are eliminated, and the gob is mixed with the remainder of the overburden. The post-remining configuration of the daylighted sections becomes that of a reclaimed surface mine. However, because of roof falls and pillar deterioration, there may be a higher amount of unrecoverable coal mixed in with the spoil associated with daylighting than with remining surface mines. After daylighting, and in the absence of selective spoil handling, ground water flowing through the reclaimed portions will encounter acidic, alkaline, and/or relatively inert spoil materials at a frequency based on the volumetric content of the spoil and on the ground-water flow regime. With these changes to the ground-water flow and the materials contacted, mine water is likely to be less acidic, especially with the presence of alkaline units in the overburden.

Daylighting of an abandoned underground mine on the Pittsburgh Coal seam in Allegheny County, Pennsylvania resulted in turning mine discharge water from “extremely acidic” to alkaline with low metal concentrations. The areas of the mine that were not daylighted continued to produce acidic mine water similar to the premining water quality (Skousen and others, 1997).

Daylighting of underground mines can reduce pollution loads through the reduction of ground-water infiltration and through changing the geochemical and physical properties of material that the ground water contacts. Daylighting eliminates potential recharge sources by mining out subsidence features. The original ground-water flow path is interrupted by the subsequent installation of seals and/or drainage systems. The potential amount of mine water storage is likewise reduced.

Before an underground mine is daylighted, the ground-water system exhibits primarily open conduit flow with water encountering seat rock, roof rock, and coal. All three of these units are typically pyritic, and thus possible acid generators. Once daylighting has occurred, the lithology and particle size of the overburden, whether alkaline, acidic, or inert, is greatly modified. This modification of the overburden strata substantially increases the amount of freshly exposed rock surfaces that are accessible to the ground water. Following daylighting, the ground-water flow regime is a dual porosity system, in which ground water is stored in large conduits and voids between spoil fragments and exhibits overall intergranular flow characteristics through the finer-grained spoil (Hawkins, 1998a). With this change in the ground-water flow regime, the probability of ground water encountering alkaline or acidic material is proportional to the volume and surface area of that material in the spoil, whereas, prior to daylighting, the water almost exclusively contacted acid-forming materials. The intergranular flow through the fine-grained spoil exhibits the lowest transmissivity and is the controlling factor of the speed of ground-water flow in the backfill. Therefore, contact time with rock surface areas also is altered, and generally lengthened by daylighting. These flow regime changes can have a significant impact on groundwater geochemistry.

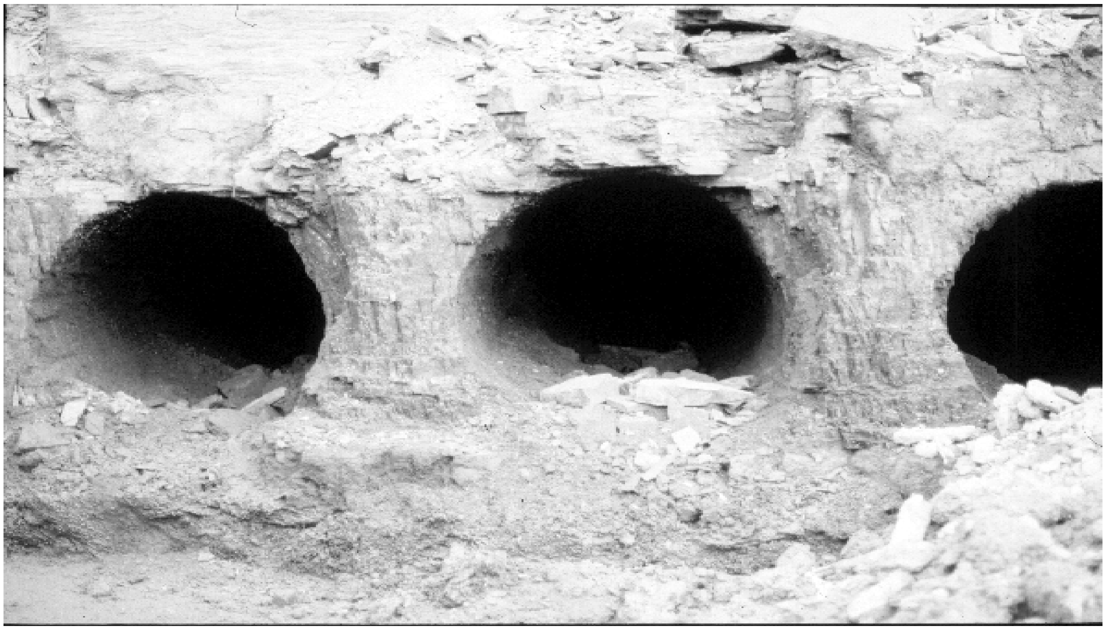
Potential problems do exist with daylighting. Overburden material can be highly acidic, and disturbing it would allow for additional pyrite exposure and oxidation, release additional acidity, and possibly increase the pollution load. To prevent this scenario from occurring, potential acid-producing and alkaline-yielding zones, as well as the net acidity or alkalinity of the overburden, should be determined prior to remining. If the overburden is acidic, the anticipated reduction in flow that can result from daylighting may be offset by the additional acid production. In this case, alkaline addition or some other ameliorating BMP would be required. In addition, coal itself can be acidic (with total sulfur concentrations greater than 0.5 percent). The acidity potential of unrecoverable coal needs to be included in the acid-base accounting conducted for the site. Additional coal mixed in with the spoil and left in the backfill can be problematic for marginal sites.

Another potential problem associated with daylighting is that underground mine workings have often collapsed and pillars have crushed, causing coal to spall off. Under these situations, separating coal from the waste rock can be difficult, and some of the coal will be unrecoverable. Industry estimates range between 5 and 20 percent of the coal may be left during daylighting.

Sealing and Rerouting of Mine Water from Abandoned Workings

As an integral part of daylighting, abandoned mine entries and auger holes exposed at the final highwall are sealed with a low-permeability material. Sealing these abandoned workings inhibits the infiltration of atmospheric oxygen. Sealing also prevents ground-water movement into these workings from the mine spoil and from these mine workings into the mine spoil. Figure 1.2.1b shows exposed auger holes that require sealing. The most common method of sealing an exposed mine entry or auger hole is by pushing, and compacting as much as possible, a low-permeability material into the abandoned workings with a bulldozer or other appropriate equipment. Compaction of the material is difficult to achieve because the inside of the seal is open ended. When a material is pushed into the opening, there is nothing on the inside to push against to aid compaction.

Figure 1.2.1b: Exposed Auger Holes



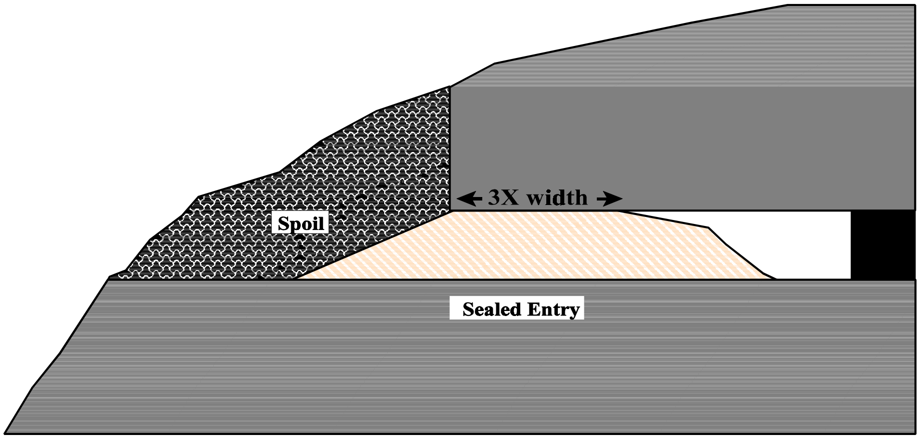
Achieving water-tight seals for auger holes and mine entries that have not been daylighted is extremely important. If these seals leak, a fluctuating water table may be created for the undaylighted portion of the underground mine. A fluctuating water table is possibly one of the worst conditions in an underground mine environment. When the water table drops, pyritic material is subaerially exposed, permitting oxidation. When the water table rises again, salts that were created by the pyrite oxidation, are hydrolyzed and mobilized, creating additional AMD. The importance of sealing these mine workings should not be taken for granted.

In some regions, constructed mine seals may be permitted. In Tennessee, a “brick wall” has been approved as a means of sealing exposed underground mine entries (Appendix A, EPA Remining Database, 1999). On a site-specific basis, other types of constructed water seals may be approved.

It is highly recommended, and in some states statutorily mandated, to seal mine entries and auger holes to a depth equaling three times the widest dimension of the opening. For example, if the auger hole is 3 feet in diameter, the depth of the seal should be at least 9 feet. Figure 1.2.1c is a schematic illustration of a mine entry seal. Determining the depth of a seal is extremely difficult, if not impossible. It is doubtful that a mine entry that is 10 feet wide is sealed to a depth of 30 feet.

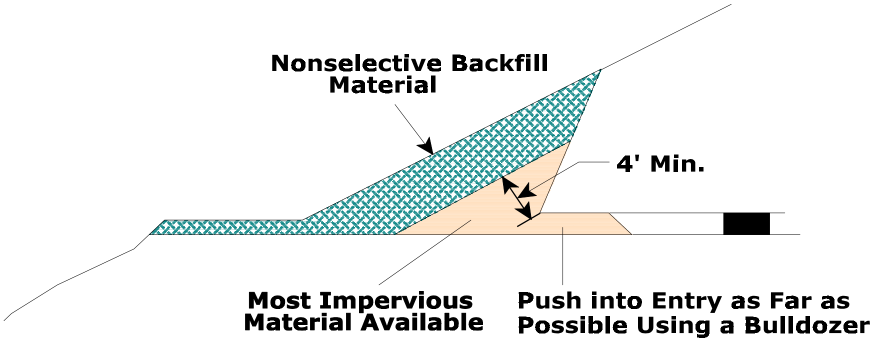
Not all states require that these mine workings be sealed to three times the widest dimension. Some require that the sealing material be pushed into the entry as far as possible with a bulldozer or other piece of equipment. Figure 1.2.1d illustrates this type of seal, as approved in Virginia.

Figure 1.2.1c: Example of a Mine Entry Seal



Schematic Drawing of a Sealed Mine Entry

Figure 1.2.1d: Example of a Virginia-Type Mine Entry Seal



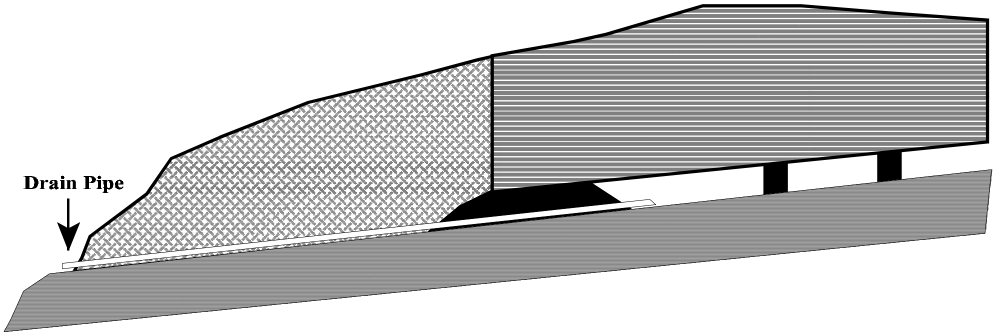
There are other problems with assessing the effectiveness of these seals. Daylighting abandoned workings often exposes numerous mine entries. Sealing of all exposed entries can require a large amount of material and is difficult to achieve because the inside of the seal is open-ended. For example, if daylighting exposes 20 entries with average dimensions of 10 feet wide and 5 feet high, sealing will require over 1,100 cubic yards of material. This is a considerable amount of material to stockpile and handle, even if it is locally available. If not locally available, the material should be obtainable at a minimal cost.

The permeability of this material should be similar to that required for surface capping or stream lining material. The material should exhibit hydraulic conductivities of 10^{-10} to 10^{-9} m/s or lower to effectively inhibit ground-water movement. By comparison, coals in the northern Appalachian Plateau may have hydraulic conductivity values ranging from 10^{-6} to 10^{-5} m/s (Miller and

Thompson, 1974). If these mine workings are sealed properly with a low-permeability material, ground-water movement is more likely to be through the more permeable coal than through the entry seals.

Daylighting operations commonly encounter mine discharge points and/or water pathways during mining operations. The mine water will continue to flow through portions of the mine that have not been daylighted. Therefore, sealing of mine entries can cause extensive flooding of the remaining mine workings behind the seals. Under these hydrogeologic conditions, considerable hydrostatic head eventually will rest against these seals, causing a substantial amount of mine water to infiltrate into the backfill. This infiltration can occur even when seals are properly installed. These flooded areas can be dewatered by installation of a free-draining piping system to collect and transport the water through the entry seals and bypassing the backfill. The drain system prevents mine water from being exposed to the spoil. Figure 1.2.1e illustrates this potential-sealing scenario with the drain system in place. The system should be designed to accommodate the maximum flow anticipated.

Figure 1.2.1e: Example of a Mine Drain System



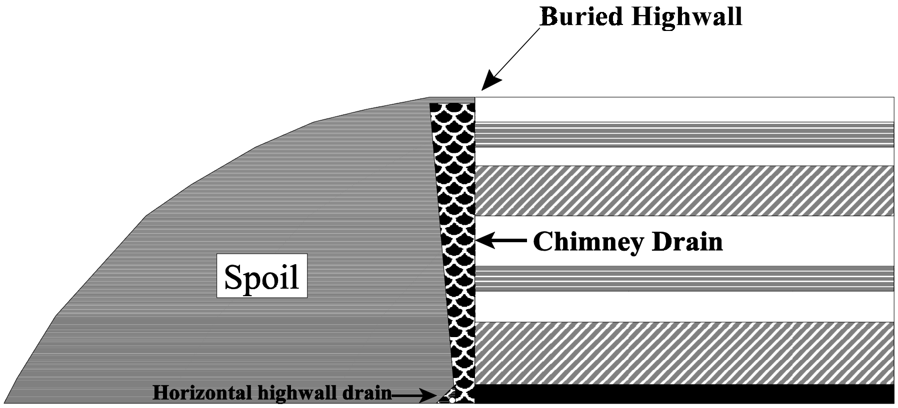
Highwall Drains

There are two basic forms of highwall drains (horizontal and vertical) that work together or separately to collect ground water entering the spoil from the highwall. Horizontal drains can be installed to work on a stand-alone basis. Vertical (chimney) drains usually are not installed as stand alone, but are commonly tied into a horizontal drain. Highwall drain systems work to minimize or prevent the contact between ground water and potentially acid-forming spoil by interception, collection, and transport away from the spoil. If the water quality is within compliance standards, the water can be discharged directly. If not, it will require treatment prior to release.

Highwall-drain systems can also function to collect surface water prior to infiltration at the interface between the highwall and spoil. This horizontal-pipe system is installed with a perforated pipe running along the surface or just below the surface, parallel to the highwall. The surface pipe is connected to a solid pipe that runs from the surface to the pit floor, where it is tied into a horizontal highwall drain (Gardner, 1998).

Chimney drains are highly-transmissive linear zones of rock installed vertically at the highwall. Chimney drains collect ground water as it enters spoil from the highwall and channel it downward toward the pit floor (Figure 1.2.1f). These drains are usually installed at a known inflow point (observed during mining), such as a ground-water bearing fracture or fracture zone exposed at the final highwall. Chimney drains are usually tied into a horizontal drain installed at the base of the highwall in order to channel the water away from the bulk of the backfill. Water captured by a chimney drain is channeled to an integral horizontal drain located at the base of the highwall. This water is then drained laterally and is subsequently discharged away from the spoil. In some cases, a highwall drain also be constructed of perforated pipe buried vertically at the highwall. If a pipe drain is used, it should be surrounded by coarse rock to facilitate drainage.

Figure 1.2.1f: Cross Section of an Example Chimney Drain

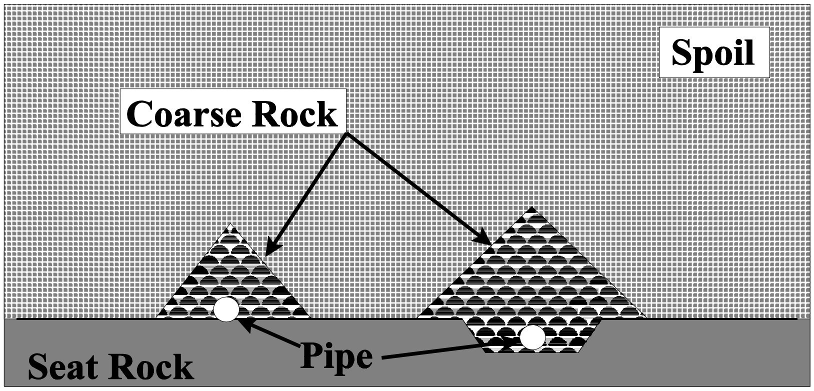


For chimney drains to work effectively, they need to be substantially more transmissive than the spoil is anticipated to be. A median hydraulic conductivity of 1.7×10^{-5} m/s was determined from aquifer testing of 124 wells in mine spoil from 18 mines tested in the northern Appalachian Plateau (Hawkins, 1998a). Drains should have a hydraulic conductivity two orders of magnitude (100 times) higher than this value. The need for this difference in hydraulic conductivity is based on the difference in the definitions of an aquifer and an aquitard. With a hydraulic conductivity difference of two orders of magnitude, ground water tends to move through the aquifer and not through the adjacent aquitard. The relatively high hydraulic conductivity required for the drain necessitates that the material be a uniform coarse-sized durable rock. Rock size can vary, but should be large enough to ensure long term drain integrity and preclude piping of the drain material. Drains comprised of rock one inch or larger have been successful. Inert, well-indurated (cemented) sandstone or a limestone is frequently employed to ensure the desired life span.

Horizontal drains are commonly installed at or near the base of the final highwall to collect ground water entering from undisturbed strata or adjacent unrelated surface mine areas. Ground and surface water often infiltrate into mine spoil at the highwall. If this water is not collected by a chimney drain, it tends to migrate downward taking a path close to the highwall toward the pit floor. Horizontal highwall drains are installed to intercept this water and remove it from the site before the water encounters additional spoil. If present, chimney drains are tied into the horizontal drain.

Horizontal drains are either constructed directly on top of the pit floor or are incised a few feet into the seat rock. The latter appears to be a more efficient method for collecting water. Figure 1.2.1g illustrates two common types of horizontal highwall-drain construction. These drains consist of a perforated pipe placed into a core of coarse-grained rock. Rock composition and size should be similar to that used for chimney drains. Pipe diameter should be large enough to easily transmit more water than the predicted highest flow. Four or six inch diameter, flexible perforated plastic pipes are the most common pipes used for horizontal drain construction. At sites where extreme flows are anticipated, a larger pipe diameter may be necessary.

Figure 1.2.1g: Cross Section of Horizontal Highwall Drains



Cross Sectional View of Horizontal Drains

Drain orientation depends to some degree on the structural dip of the pit floor. Horizontal highwall drains, as with pit floor drains (discussed in a later section), need to have sufficient grade to properly drain water from the spoil. Once ground water enters the drain, it should flow rapidly through the pipe and be discharged away from the site. These drains are designed to prevent the formation of a defined ground-water table. If the drain system is ineffective, a water table will form and some of the ground water will bypass the drain, continue to flow through the spoil, and eventually discharge as mine drainage at some point down gradient at or near the toe of the spoil. The drain outflow point should have an air trap installed to prevent atmospheric oxygen from migrating back into the backfill and possibly oxidizing additional pyrite.

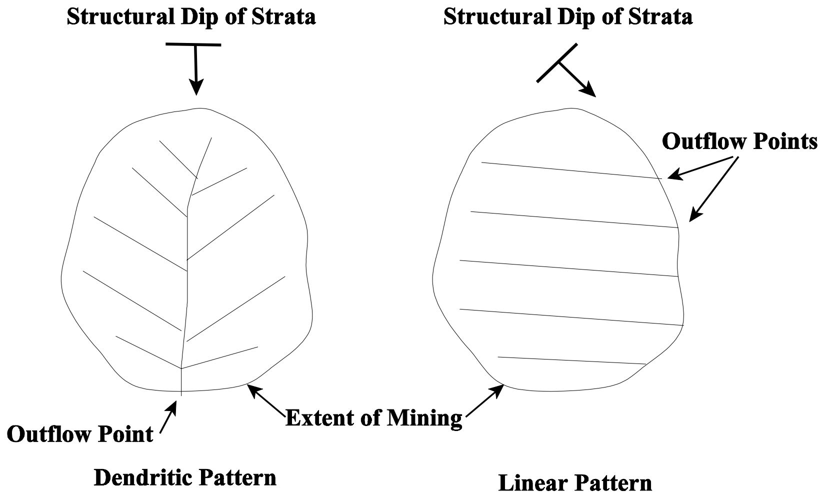
An important factor in the implementation of highwall drains is the collection and transportation offsite of as much water as possible, before it encounters the spoil. A clear understanding of the surface water drainage system and the ground water-bearing zones or fractures is imperative. A good idea of the origin of infiltrating water is required to design and install an efficient highwall drain system. However, some spoils are so highly conductive that a properly installed drain will collect the water shortly after it enters the spoil, regardless of infiltration points or zones. Care should be taken to ensure that the drains have sufficient grade to efficiently drain water away from the spoil and discharge it freely.

Pit Floor Drains

Pit-floor drains are similar in construction to and perform a similar function as horizontal highwall drains. Depending on the dip of the pit floor, they can be tied into each other to create a common drainage system. Pit-floor drains are designed to capture ground water that has entered the backfill either through lateral or vertical infiltration. The water is then rapidly drained from the site without intercepting additional spoil material.

Pit floor drainage patterns should be designed so that the majority of the ground water in the backfill is collected and the ground-water table is greatly suppressed, if not eliminated. Construction of pit floor drains is similar to construction of highwall drains, but the orientation and layout design are substantially different. Figure 1.2.1h illustrates the cross-sectional view of two common methods for constructing pit floor drains, and two of the more common pit floor drainage patterns. Efficient pit floor drainage is not exclusive to these two patterns. There are a multitude of drain plan view layout designs that should work effectively to collect ground water. The drainage pattern employed should be site-specific.

Figure 1.2.1h: Pit Floor Drain Patterns



The dendritic pattern is similar to stream drainage patterns. There is a main stem with a series of tributaries that intersect it at angles less than 90 degrees. This drainage pattern contains one common outflow. Drain tributaries need to be positioned with respect to the dip of the pit floor to allow water to drain freely. Tributaries also need to be at an oblique angle to the dip so they will intercept as much ground water as possible, yet still drain properly. Air traps should be placed at the outflow point to prevent atmospheric oxygen from migrating freely back into the spoil.

The linear pattern is composed of a series of evenly spaced parallel drains with each drainpipe having a discrete outflow point. These drains, like those of the dendritic pattern, need to be at an oblique angle to the dip, where a substantial amount of the ground water is intercepted, while maintaining sufficient grade to allow free drainage off of the site. Air traps should be placed at the outflow points to prevent atmospheric oxygen migrating freely back into the spoil.

Determination of the probable transmissive properties of spoil and the appropriate spacing of drains is critical to the effectiveness of this BMP. Parallel pit floor drains installed on a site in Westmoreland County, Pennsylvania, were spaced at roughly 500 to 600 foot intervals. Figure 1.2.1i shows the construction of a pit-floor drain at this site. Preliminary monitoring results indicated that this spacing may be too broad. Monitoring wells indicated the presence of a defined water table in parts of the backfill, and water levels in the monitoring wells were typically 3 to 5 feet above the pit floor. The drains installed were not completely suppressing the ground-water levels, but were keeping them lower than expected for nondrained spoil. The spoil at this site is comprised almost entirely of shales, which caused the backfill to be less transmissive than originally anticipated. Sandstone-rich spoils are expected to be more transmissive, requiring a wider drain spacing than shale-rich spoils. In this case, the drain spacing was inadequate for the given site conditions. Future operations should be specifically engineered to account for the expected spoil hydraulic properties.

Figure 1.2.1i: Example of a Pit Floor Drain

The engineering and construction of pit-floor drains are critical to their efficient use. These drains should be installed so they intercept the ground water flowing across the pit floor, with sufficient grade to drain water freely. Too broad a spacing between drains with regard to the spoil hydraulic conductivity and expected heterogeneity will permit the formation of a water table between the drains. Drain spacing and configuration should be based on a forecast of the spoil hydraulic conductivity and heterogeneity based on overburden lithology, mining equipment employed, direction of mining, and direct aquifer testing on nearby reclaimed surface mines.

There is a caveat with incising drains in to the pit floor. Excavation into a pit floor can breach the integrity of the seat rock and facilitate infiltration of mine water into underlying aquifers. Once ground water infiltrates into underlying units, it is less controllable and can eventually discharge at a point far removed from the site.

Grout Curtains

Grout curtains are vertical or nearly vertical, tabular-shaped, low-permeability layers that are emplaced to prevent or divert ground-water movement. In remining operations, grout curtains can be installed at and against the highwall, or they can be installed in the undisturbed strata above the highwall. A limiting factor for the installation of grout curtains in remining situations is that they tend to be more expensive than some of the alternative BMPs. It is doubtful that grout curtains will be used often as a BMP, because the profit margin is narrow in most remining operations.

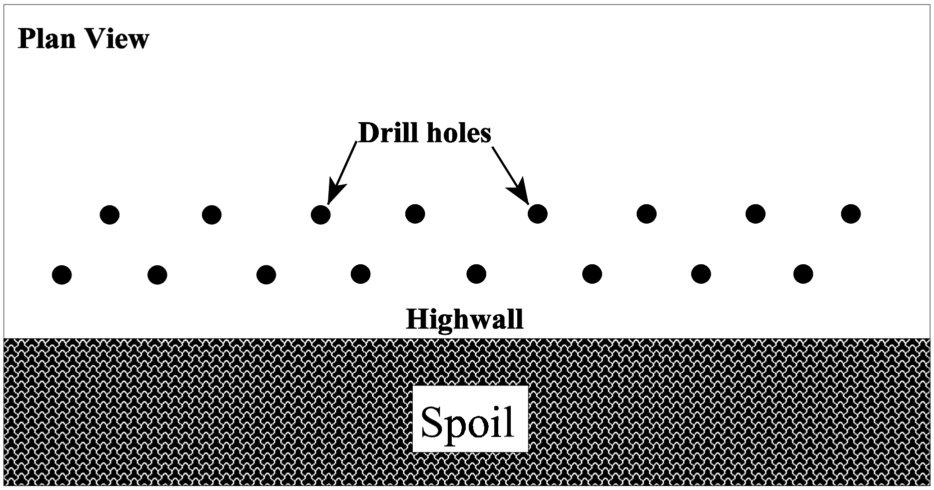
Grout curtains or barriers can be installed during reclamation by pushing and compacting a low permeability material (grout, clay, coal combustion waste, and other materials) against the highwall as reclamation progresses. This is conducted in lifts with each lift tied into the previous one. Grout curtain material is typically either an on-site material (clay) or an inexpensive waste material, such as coal combustion waste (CCW). Clays commonly have hydraulic conductivities ranging between 10^{-12} to 10^{-8} m/s (Freeze and Cherry, 1979). Yanful and others (1994) recorded an initial hydraulic conductivity of 10^{-9} m/s for compacted clay used to cap an acid-producing waste rock site. The importance of compaction of the barrier material in the creation of a low-permeability barrier should not be overlooked. A continuous barrier is needed to effectively prevent ground-water movement. Any breach in this barrier can permit ground-water movement from the strata into the spoil.

The “haulback” of CCW to a mining operation is often a provision of the sale of coal to electrical generating facilities. With the addition of water, CCW is often pozzolonic (self-cementing). The permeability of this material, once hardened, is sufficiently low to nearly preclude all ground-water flow. The Electric Power Research Institute (EPRI) reported a range of hydraulic conductivities for “self-hardening ashes” of 3.2×10^{-9} to 1.8×10^{-7} m/s (EPRI, 1981). These values were determined after a 28 day set-up period. Hellier (1998) reported a hydraulic conductivity of 10^{-9} m/s for a fluidized bed combustion ash used for a surface mine capping project in north central Pennsylvania.

At some mining locations, the installation of a grout curtain at the highwall after reclamation has been completed. In these cases, the spoil directly adjacent to the highwall has to be re-excavated, and a slurry-type grout is used to fill the trench. Though grout types can vary considerably, grouts containing high percentages of CCWs and cement or bentonite and cement are frequent choices. Potential problems can arise from highly permeable spoil. If the grout is watery and flows too freely, it will enter the spoil and construction of a continuous, effective barrier is difficult. This after-the-fact grout curtain would be expensive and probably cost-prohibitive for remining operations.

Grout curtains also can be installed above the highwall in undisturbed strata by performing a pressure grouting operation. A series of boreholes is drilled across the site parallel to the highwall. These holes are often drilled in a staggered pattern to maximize the grouting potential by accessing as many natural fractures as possible (Figure 1.2.1j). Spacing of boreholes varies depending on fracture density and transmissivity and on the propagation characteristics of the grout. Grout holes drilled on ten foot centers have been suggested for sealing underground mines (U.S. Environmental Research Service, 1998). Given the common orientation and density of stress-relief fractures in the Appalachian Plateau, drilling grouting holes at a slight angle (up to 3 degrees) from vertical will help to optimize efficiency. A commonly used pressure grouting material is a commercially available polyurethane. The polyurethane is a two component material that is injected simultaneously in equal amounts (Ackman and others, 1989). Other materials suitable to this type of grouting are neat cement or bentonite.

Figure 1.2.1j: Common Drilling Pattern for Pressure Grouting Wells



Problems with the implementation of grout curtains are often related to the continuity of the emplaced grout. Ground water is expected to impound behind a grout curtain and eventually flow laterally away from the spoil. If the grout curtain is not continuous, ground water eventually will flow through a breach, following the path of least resistance. Pressure grouting in fractured rock aquifers is particularly problematic, because the fractures are not continuous, are not all interconnected, and do not necessarily interact with one another. It has been observed that individual fractures may represent discrete aquifer zones and may have distinctly different piezometric surfaces (Booth, 1988). Rasmuson and Neretnieks (1986) estimated that only 5 to

20 percent of the fracture plane transmits 90 percent of the water. A study of overburden material at a surface mine in Clearfield County, Pennsylvania, illustrated that only a few discrete fractures intercepted by a borehole actually contributed to the well yield. The remainder of the fractures appeared to be unconnected or poorly connected to these active fractures (Hawkins and others, 1996). Grout hole spacing, grouting material, and grouting pressures need to be designed to overcome these potential fracture discontinuity problems. It is recommended that grouting wells be drilled at a slight angle from true vertical to increase the likelihood of encountering vertical or near vertical water-bearing fractures.

Ground-Water Diversion (Interceptor) Wells

Diversion wells are installed specifically to intercept and collect ground water prior to infiltration into the reclaimed backfill. These wells are drilled up-gradient of the backfill area and can be oriented vertically or horizontally. Care should be taken not to over-pump these wells, which can cause a reversal of ground-water flow. If the water table is lowered so that ground water is drawn from the reclaimed operation, the water may require treatment prior to discharging. Diversion wells should prevent water movement into the strip, not create a pump-and-treat operation.

Vertical diversion wells require a pumping system operated by a consistent power supply. In order for vertical diversion wells to effectively intercept ground water, a series of wells drilled normal (perpendicular) to the structural dip and up gradient are required. Spacing of these wells depends on site-specific conditions, such as fracture density, hydraulic conductivity, and structure. Well depth is generally to or a short distance below the top of the seat rock. In relatively shallow wells (less than 200 feet) of the Appalachian Plateau, the highest well production occurs at the shallowest depths (Hawkins and others, 1996). However, there are circumstances where substantial ground water flows in from deeper fractures. In competent rocks in the Appalachian Plateau, the entire borehole should be left open to prevent restriction of any ground-water inflow points. As with grouting boreholes, these wells may be more efficient if they are drilled at a slight angle (1 to 3 degrees) to increase the probability of intercepting vertical fractures.

Diversion wells should be configured so that pumping will initiate when the water reaches a pre-defined level above the bottom of the coal and that pumping will cease once the water is drawn down to second pre-defined level, commonly at or near the base of the coal. Pump cycling times depend on the amount of ground water present, transmissivity of the strata, and the efficiency of the well. Diversion wells are relatively inexpensive to drill, but can be expensive to complete and maintain over a period of time. Therefore, they will seldom be an economically viable option for remining.

Horizontal diversion wells, when properly installed, may be more efficient and effective than a series of vertical wells, depending on the size of the area to be dewatered. The initial cost of a horizontal well will be dramatically more than the equivalent footage of vertical wells. However, there are definite advantages to horizontal wells. They can be drilled to allow for free drainage. No pumping system or power is required with a free-drainage system, and thus, very little maintenance is required. Horizontal wells access water from a continuous horizontal line, rather than from discrete well points, and are more likely to intersect water-bearing fractures. Because of the high cost of outfitting and maintaining the pumping systems of vertical well sets and the initial high cost of drilling horizontal wells, it is doubtful that diversion wells will be an economically viable option at more than a few remining operations.

The installation of diversion wells encounters some of the same poor fracture interconnection problems as are incurred during the installation of grout curtains. Because individual fractures can represent discrete piezometric zones (Booth, 1988), diversion wells need to be drilled in a configuration and at a spacing that accesses all of the discrete ground-water flow systems. A common occurrence in the Appalachian Plateau is for shallow water wells (less than 200 feet) a short distance apart (less than 100 feet) to show little interconnection based on an aquifer test. Drawdown at a pumping well may exceed 100 feet, while a well 50 to 80 feet away may only exhibit a drawdown of a fraction of an inch over the length of a pumping test lasting 2 hours or more. It is advised to drill to the vertical diversion wells at a slight angle from true vertical to increase the likelihood of encountering vertical or near vertical water-bearing fractures. It is also recommended to drill horizontal diversion wells at an angle to the preferred orientation of the vertical stress-relief fractures. Because vertical fractures are created by tensional forces and tend to be oriented parallel to the strike of the adjacent valley (Borchers and Wyrick, 1981), horizontal diversion wells should be drilled at an angle that is subparallel to the valley orientation.

Design Criteria

These BMPs should be designed and implemented to preclude the lateral infiltration of ground water into the backfill areas of reclaimed remining operations. Some of the salient design criteria for each of the BMPs discussed in this chapter are included in the list below. Site-specific conditions will ultimately dictate which BMPs should be used and the scope of BMP implementation required in order to reduce or eliminate lateral ground-water inflow, discharge rate, and pollution load. It should be noted that although grout curtains can be employed as a BMP, they are rarely used, and the technology is unproven.

<u>Daylighting</u>

- Subsidence-induced ground-water infiltration zones should be eliminated.
- Vast ground-water storage areas should be eliminated.
- The amount of ground-water contact with acid-forming materials should be reduced.
- The probability of ground water contact with alkaline materials should be increased.
- Special handling of acid-forming materials should be facilitated.
- The oxygen flow to the subsurface should be greatly reduced.

<u>Sealing and Ground Water Rerouting of Mine Workings</u>

- Atmospheric oxygen infiltration into mine workings inhibited.
- Low permeability sealing material (e.g., equal to or less than 10^{-9} m/s) should be used.
- Seals should be installed to preclude ground-water movement into or out of the mine workings.
- Drains should be installed to control the ground-water buildup, bypass the spoil, and discharge off site.

Highwall Drains

C Ground-water infiltration at the highwall should be intercepted and collected.
C Ground water from the spoil should be quickly drained and discharged off-site.
C Drains should be made more permeable than the surrounding spoil.

Pit Floor Drains

C Drains should be oriented and constructed to collect ground water within the backfill.
C The ground-water table within the backfill should be suppressed or eliminated.
C Drains should be oriented and constructed to quickly drain ground water from the spoil and discharge it off site.

Grout Curtains

- Grout curtains should prevent or redirect ground water away from the backfill.
- Low-permeability grouting material (e.g., equal to or less than 10^{-9} m/s) should be used.
- Continuity should be maintained across the potential infiltration zone.
- Grout holes should be drilled at an angle of up to 3 degrees (depending on site strata) to increase the interception of vertical fractures.

Diversion Wells

C Diversion wells should be located up-gradient of the mine to intercept ground-water flow.
- Intersection of water-bearing fractures or zones should be a priority.
- Low or no-maintenance systems should be used, if possible.
- Horizontal wells should be installed at an angle subparallel to valley orientation.

1.2.2 Verification of Success or Failure

The cumulative discharge rate of the post-reclamation discharges compared to pre-mining discharges is, as with all of the physical hydrogeologic BMPs, the truest indication of the effectiveness of ground-water control BMPs.

Daylighting

Verification of the amount of daylighting that has occurred is relatively easy. The acreage disturbed can be viewed during mining and after reclamation and compared to underground mine maps. If there is uncertainty of the exact amount of daylighting that occurred, the area can be surveyed.

Sealing

Verification of the implementation of sealing of abandoned mine workings will require the inspection staff to be present during different phases of the operation. Once seals are in place, they will be covered. If there is concern that the mine workings will not be properly sealed, the permit may be conditioned to require notification when sealing will occur or will be completed. The material to be employed to seal the openings may need to be stockpiled on site to confirm the type of material and the amount to be used. The stockpile should be marked to distinguish it from spoil or topsoil piles. To be sure that the material has a sufficiently low permeability, the relative hydraulic conductivity also may need to be certified by laboratory testing. As previously stated, it is extremely difficult to verify the depth to which the seal is emplaced. If this parameter is deemed important enough, boreholes can be drilled behind the seal and a borehole video camera can be lowered to view the seal from the inside and/or to monitor the flooding of the remaining mine voids. It is doubtful that this step will be necessary.

Drains

If drains are installed in conjunction with the seals, drain piping can be viewed as it is installed. Drain outflow can be monitored to determine if it is yielding the anticipated volume of mine water. That is, does the drain yield a similar volume before and after mining. A mine consistently yielding 300 gpm prior to mining and drain installation and a median flow of 85 gpm after reclamation would indicate that the seals and/or the drain are not functioning properly. The existence of toe-of-spoil seeps may also indicate that the drains are working improperly.

Pit floor drains are installed as mining progresses, and tend to be extended with each phase (cut) of the mining operation. Pit floor drains can usually be inspected during several phases of the operation. Effectiveness of these drains can be determined once the backfilling is complete. If the drains are yielding water and unexpected discharge points (seeps) are nonexistent, it is an indication that the drains are effectively collecting ground water. Monitoring wells installed in the backfill provide the best indication that the water table is being suppressed as designed. Site monitoring should be continued for a period beyond the anticipated water table re-establishment, and monitoring through several wet seasons is important. In the Appalachian Plateau, the backfill water table can require at least two years to completely re-establish.

Grout Curtains

The type of grout curtain installation monitoring depends on the method used to install the grout curtain. If the curtain is created as the site is backfilled, an inspection staff can review portions (lifts) of the installation as it progresses. In situations where the installation of a grout or clay curtain along a significant portion of a highwall takes a protracted period of time, and the inspection staff cannot be present for every stage implementation, estimates of the amount of material required should be submitted as part of the reclamation plan. Marked stockpiles or weigh slips equaling the proposed volume can be used to determine if the proper amount of material was used.

Determination of the success of grout curtains emplaced via pressure grouting drill holes is substantially more difficult. Grouting effectiveness can be evaluated indirectly by comparing the estimated porosity of the strata, the total volume of the strata, and the volume of grout employed. The ultimate effectiveness of grout curtains, regardless of how they were installed, is whether they preclude ground-water movement through them. To make this determination, monitoring wells can be installed on each side of the grout curtain.

Diversion Wells

There is little that can be viewed at the surface during the installation and use of diversion wells to ascertain their efficacy. The effectiveness of diversion wells can be estimated by the amounts of water pumped from them and monitored by the construction of monitoring wells both up and down gradient of the pumping wells. If the down-gradient wells exhibit a suppressed ground-water table over the anticipated levels, it is indicative that the diversion wells may be functioning properly. Ultimately, if discharge rates are reduced, the diversion wells are effective.

Implementation Checklist

Monitoring a site for anticipated changes is a critical and inherent aspect of BMP implementation and efficiency determination. Monitoring should continue well beyond initial water table re-establishment period (e.g., about 2 years after backfilling). The list below is a recommended guideline for an inspection staff to monitor and evaluate ground-water control BMPs.

- Measurement of flow and sampling for contaminant concentrations at time-consistent intervals.
- Assessment of hydrologically-connected units, as well as individual discharges, for pollution load changes.
- Review or inspection of sealing material weigh slips, receipts, or marked stockpiles.
- Review of implementation initiation and completion dates
- Assessment of any deviation from an approved implementation plan.
- Inspection of salient phases of the BMP implementation for:
    - a. integrity of seals.
    - b. drain construction, location, and orientation.
    - c. grout curtain integrity and continuity.
    - d. diversion well locations and productivity (yield).

1.2.3 Case Studies

<u>Case Study 1</u> (Appendix A, EPA Remining Database, 1999 PA(3))

Remining was performed on an abandoned surface mine and abandoned underground mines in the Pittsburgh coal seam. A total of 33.8 acres (48 percent) of the 69.6 acres of abandoned surface mine land within the permit boundary were reclaimed by the operation. Of the 90 acres of abandoned underground mines in the Pittsburgh coal seam, at least 49 acres (54 percent) were daylighted during the remining operation. More than 203 acres were impacted by the remining operation. Fourteen pre-existing mine drainage discharge points were included in the permit. BMPs listed in the permit included regrading of abandoned mine spoil and highwalls, underground mine daylighting, sealing of exposed mine entries, special handling of toxic materials, and revegetation. The most predominant BMP components were regrading/revegetation and daylighting. The site was completed in June of 1998. Ten discharge points were used to determine the impacts of remining. The remaining four discharges were low flow and discharged intermittently during pre- and post-mining periods.

Because this site has been reclaimed relatively recently and post-remining data are limited, the resulting pollution load analysis is less than ideal and subject to change. However, this site is worth evaluation because of the large percentage of daylighting that was implemented and because it drains to a stream that is used as a public water supply. Additionally, considerable discharge reductions were observed prior to final backfilling for several of the monitoring points.

Two of the main discharges (MP-1 and MP-4) began to exhibit significant flow reduction prior to the completion of reclamation. Prior to October, 1992, MP-1 ranged in flow from 0 to 139 gpm with a median of 18 gpm. Since October of 1992, MP-1 ceased to flow, except for one monthly sample where the flow rate was 0.25 gpm. The flow rate of MP-4 ranged from 0 to 132 gpm with a median of 6.9 gpm prior to April of 1994. After that time, the flow ranged from 0 to 18 gpm with a median of 0.1 gpm. Figures 1.2.3a and 1.2.3b illustrate the flow reduction exhibited by these two discharges over time.

Figure 1.2.3a: **Change in Flow Over Time (Case Study Discharge MP-1)**

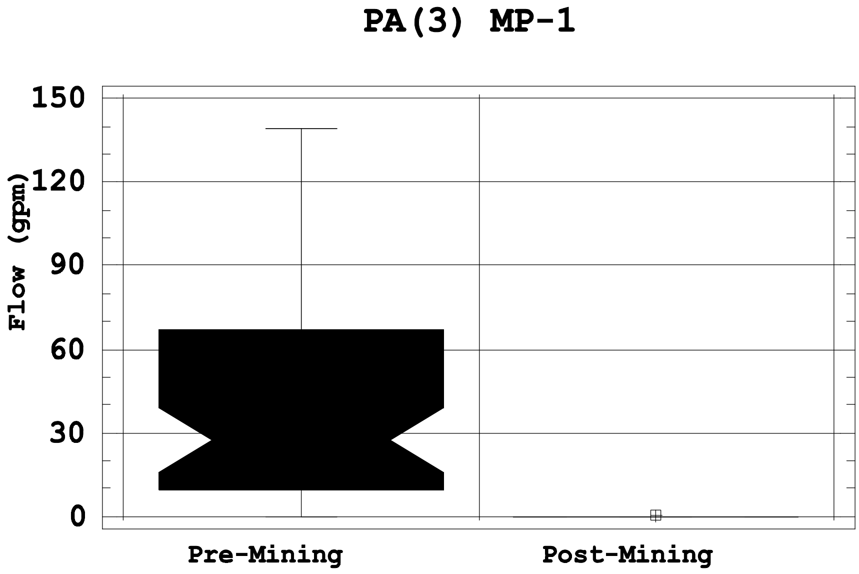
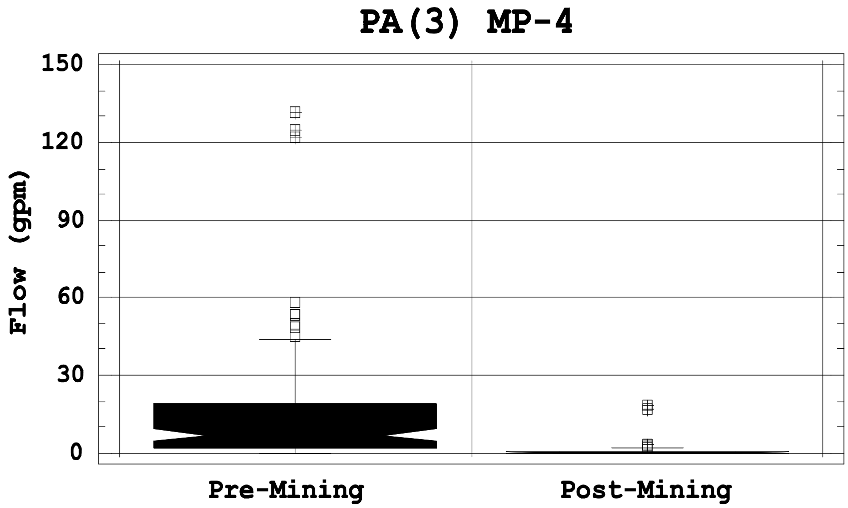
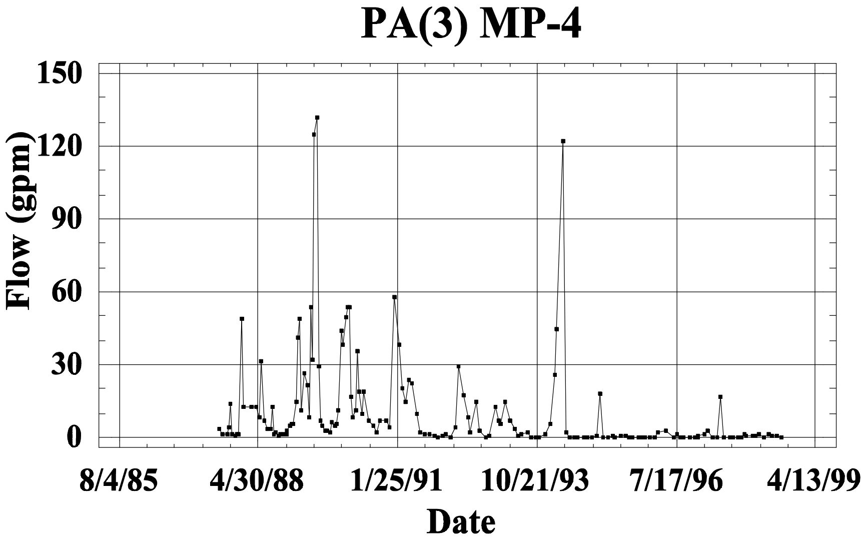


Figure 1.2.3b: **Change in Flow Over Time (Case Study Discharge MP-4)**



These analyses indicate that a flow reduction was observed even prior to complete backfilling (Figure 1.2.3c). MP-1 and MP-4 are directly down-gradient from the first areas to be mined and reclaimed, and down-gradient of limited-sized recharge areas. Therefore, it should be expected that these points would exhibit the greatest change during remining operations.

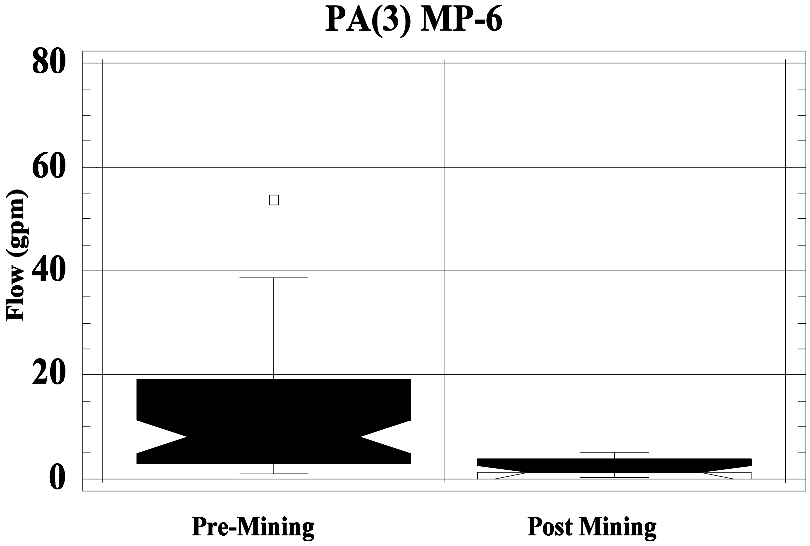
Figure 1.2.3c: Flow Rate Reduction, Pre- and Post-Remining Periods (Case Study Discharge MP-4)



Pre- and post-remining comparisons (discharge points MP-2, MP-3, MP-5, MP-6, and MP-D) exhibited no apparent change in flow. However, flows for MP-A and MP-B appear to have decreased slightly, although not significantly. Although MP-C shows a slight, but significant, increase in median flow (from 0.5 to 2.9 gpm) from before to after November of 1994 , the actual change in flow is relatively low by comparison to flow rate for most of other discharges.

Analysis of the post-mining data is, at this stage, preliminary. Only data for the first two months after remining were submitted for four of the discharges (MP-4, MP-5, MP-C, and MP-D), and these discharges have been excluded from the evaluation of pre- versus post-mining water quality. Four of the remaining discharges (MP-1, MP-6, MP-A, and MP-B) exhibited a post-remining median significantly below the background data at a 95 percent confidence interval. This improvement in water quality is illustrated in Figure 1.2.3d. Three of the discharges (MP-1, MP-A, and MP-B) have been nearly or completely eliminated. The two remaining discharges (MP-2 and MP-3) exhibited a median flow rate reduction that was not statistically significant.

Figure 1.2.3d: Flow Rate Reduction, Pre- and Post-Remining Periods (Case Study Discharge MP-6)



The results discussed above should be tempered with the knowledge that precipitation for the 32 month baseline period was near average (i.e., a mean of +0.05 inches per month), while the brief post-remining period (6 months) was significantly below the average (i.e. a mean of -0.50 inches per month). Post-remining monitoring should be continued until the precipitation has returned to near average for several months (preferably 6 to 12 months) and the water table has been fully re-established. Precipitation data were compiled from the Pittsburgh International Airport, approximately 37 miles west of this mine site.

Case Study 2 (Appendix A, EPA Remining Database, 1999, VA(7))

This site is located in Wise County, Virginia. The coal seams being remined are the Imboden Marker, Lower Kelly, Upper Kelly, Kelly Rider, Lower Standiford, Upper Standiford, Taggard Marker, Bottom Taggart, Top Taggart, Owl, and Cedar Grove.

The permitted acreage is 1,140, with 149 acres to be regraded, 158 to be reclaimed, and a total of 498 acres to be disturbed. Daylighting will occur on previous augering of the Standiford seams. Abandoned mine workings will be daylighted on the Upper Standiford. It is also probable the abandoned mine workings on the Upper and Lower Kelly seams will be intersected and partially daylighted.

There are three discharge points (SB-5, SB-6, and SB-7) that were identified as pre-existing mine discharges. Although this site was still active as of January 1999, it is worth evaluating because it illustrates the type of remining occurring in Virginia and because a substantial amount of daylighting and sealing of abandoned mines and auger holes is being performed.

Preliminary analysis of flow data yielded mixed results, but indicates an overall flow decrease. A comparison of baseline flow rates to flow rate during mining indicates that two of the three discharges (SB-6 an SB-7) have a reduced median flow.

The reduced flow was significant at a 95 percent confidence level for SB-7. SB-5 exhibited an insignificant increase in median flow for the same time periods. The sum of the median flows for baseline was 97 gpm compared to a median 53.5 gpm during remining, yielding a possible flow reduction of 45 percent. Evaluation of these results should acknowledge that climatic (e.g., precipitation) conditions were not considered during the analysis. Long term post-remining monitoring with determinations of precipitation during the same period, as well as that for the background period, will yield a true assessment of the impact of remining on the pollution load.

1.2.4 Discussion

The BMPs discussed in this chapter, when properly employed under the right conditions, will successfully reduce the lateral infiltration of ground water into the backfill and should subsequently reduce the discharge rates. However, these BMPs cannot be viewed as a panacea for all of the pre-existing problems at a site. There are limits to what can be physically achieved and/or economically attempted. The two lists below (Benefits and Limitations) include, but are not limited to, what should and should not be expected of these BMPs.

Benefits

- Pollution loading from abandoned mine land is reduced.
- An alternate, improved hydrologic balance at the site is establish ed.
- Surface subsidence features (e.g., sinkholes, disappearing streams, etc.) are eliminated.
- Highwall drains can be installed at the observed infiltration points.
- Control of the location of post-mining discharge points in case treatment is required.
- Daylighting often results in little profit, however, it is implemented as an integral part of the mining operation.
- Special handling of acid-forming materials is performed.
- Oxygen flow to the subsurface is reduced.

Limitations

- Current implementation of these BMPs lacks comprehensive evaluation of effectiveness for pollution prevention.
- Previous use of some of these BMPs (pit floor and highwall drains, highwall sealing, and diversion wells) has been limited, therefore the true extent of their effectiveness has not been adequately determined.

- The true effectiveness of mine seals, drains, and grout curtains installation cannot be determined prior to reclamation and establishment of the post-mining hydrologic regime.
- Given the highly heterogeneous and anisotrophic nature of surface mine spoil, the present state of predictability of the post-mining ground-water flow system is limited. It is doubtful that an extremely high degree of predictability of the efficiency of highwall and pit floor drains is possible.
- Complete exclusion of laterally-infiltrating ground waters is not likely, therefore there needs to be a realization that the discharges will likely not be entirely eliminated.
- Diversion wells are costly and even the best planning may not provide an effective BMP system, if the hydrologic system is poorly understood.
- Success of daylighting can be dependent on the geochemistry of overburden material and special handling of acid-forming materials.

Efficiency

Analysis of completed remining sites in Pennsylvania (Section 6, BMP Efficiencies) indicated that at least 90 percent of discharges impacted by ground-water control BMPs will either exhibit a significant improvement, no change in the pollution load, or be completely eliminated (in the case of manganese, 89.5% of the affected discharges were improved, eliminated, or unchanged).

For a total of 164 discharges with elevated acidity levels from remining operations in the state of Pennsylvania (Appendix B, PA Remining Site Study), slightly over 43 percent were improved or eliminated, over 56 percent were unchanged, and less than one percent were significantly worse from daylighting.

Of the 156 discharges with elevated iron, nearly 40 percent were improved or eliminated, about 55 percent were unchanged, and over 4 percent were significantly degraded from daylighting. Similar results were yielded by analysis of aluminum and manganese loads. With regard to iron, acidity, manganese, and aluminum, the percent of discharges that were degraded during daylighting was never greater than 6.5.

Analysis of the implementation of special water handling facilities, tabulated in Appendix B, yielded similar results. However, this category includes both surface- and ground-water handling facilities. Fifty percent of the 22 affected discharges exhibited an improvement or elimination for acidity loading with the remainder showing no significant change. Almost 48 percent of 23 discharges exhibited an improvement or elimination with an additional 48 percent showing no significant change for iron loading. Slightly over 4 percent were significantly degraded in regards to iron loads. Manganese loadings showed that 47 percent of the 20 affected discharges were improved or eliminated, and 42 percent were unchanged. The analysis indicated that slightly over 10 percent of the discharges had been degraded in regards to manganese loadings. Aluminum loads exhibited similar results with the bulk of the discharges (73 percent) being unchanged and none showing degradation.

Overall, the analyses of acidity, iron, manganese, and aluminum loading data from these completed remining sites indicates that between 90 and 100 percent of the discharges will show no degradation from daylighting or special water handling. Additionally, between 27 and 50 percent of the discharges will be improved or completely eliminated. These efficiency numbers can be improved with the specific tailoring of the BMPs to reduce or exclude lateral ground-water movement.

1.2.5 Summary

Previous studies have shown that the extent of pollution reduction from remining is largely dependent on reducing the discharge rate, which in turn is dependent on controlling the infiltration of ground water into the backfill. The commonly observed positive correlation between flow and loading rates illustrates this close relationship. BMPs designed and implemented to prevent ground-water infiltration from adjacent areas will be successful in reducing the pollution load and in some cases may completely eliminate the discharge.

Case Studies 1 and 2 illustrate that underground mine daylighting, entry and highwall sealing, and other ground water-controlling BMPs can yield mixed results, unless differences in precipitation rates are taken into account and the post-remining monitoring period is of sufficient length to accurately reflect site conditions. However, it is well known that these BMPs, when properly implemented, will reduce the contaminant load from remining operations.

1.3 Sediment Control and Revegetation

Erosion and sediment deposition caused by weathering and precipitation are natural processes that can be accelerated in disturbed watersheds. Disturbances such as surface coal mining involve the removal of vegetation, soil, and rock. Spoil or highwall surfaces create conditions highly vulnerable to erosion and result in adverse sediment deposition that can clog streams, increase the risk of flooding, damage irrigation systems, and destroy aquatic habitats. Sediment deposition in downslope areas can have adverse environmental impacts on watershed soil and vegetation. Abandoned surface mine land, spoil refuse, and gob piles often have exposed surfaces that are vulnerable to erosion or conducive to high rates of storm water runoff, resulting in increased sedimentation problems in receiving streams. Re-exposing these abandoned sites during remining operations, without concern for sediment control, can cause serious solids loading and hydrologic imbalance. Successful implementation of erosion and sediment control BMPs are critical for ultimate landscape stability and protection of receiving streams.

Theory

The implementation of the BMPs discussed in this section for management of surface water and ground water at remining operations also can form the basis for sediment control. If implemented properly, site hydrologic controls can serve to prevent erosion, solids loading into receiving waters, and unchecked sediment deposition. Likewise, if hydrologic controls are implemented without consideration for potential sedimentation, conditions leading to discharge of solids and sediment can rapidly increase and result in severe environmental degradation.

Remining and reclamation of abandoned mine lands typically require techniques that involve regrading to approximate original contour, replacing topsoil, applying vegetation amendments, and constructing erosion-control structures. The resulting reclamation often is aesthetically pleasing, but can result in an artificial drainage system that can be problematic and accelerate erosion as natural drainage systems are re-established. If reclamation techniques fail to consider natural drainage patterns and surface water flow characteristics, conditions can become worse than those that existed prior to implementation of these techniques. Sedimentation and erosion problems can be alleviated by proper implementation of some or all of the BMPs discussed in this section.

Site Assessment

Prior to implementation of BMPs to control erosion and suspended solids loading, sites should be assessed to determine existing drainage patterns and topography, to quantify effects of storm runoff and the yield of coarse- and fine-grained sediment, and to determine morphologic evolution of gullies. Natural drainage patterns can be determined using before and after maps and profiles, aerial photography, site mining history information and water quality data. Determinations should also consider precipitation frequency, duration, and intensity. This information can be used to indicate locations where the implementation of sediment control BMPs will be most effective.

In addition to determining sedimentation patterns, it is important to determine the quantity of sedimentation that can be expected. An estimate of sediment erosion and deposition can be derived over time using water samples, sediment traps, or sediment accumulation markers. Empirical equations also can be used to estimate the potential for and expected rate of erosion. The Universal Soil Loss Equation (USLE) was developed as a means to predict sediment loss from watersheds and can be used to estimate sediment yield produced by rill or sheet erosion in field areas. A Revised Universal Soil Loss Equation (RUSLE) was developed to estimate quantities of soil that can be lost due to erosion in larger, steeply sloped areas. Predicted soil loss is calculated using the following equation (OSMRE, 1998, PA DEP, 1999, Renard and others, 1997):

$$A = RKLSCP$$

Where:

A = Computed Soil Loss (Annual Soil Loss as tons/acre/year)

R = Climatic Erosivity or Rainfall erosion index - a measure of the erosive force and intensity of a specific rainfall or the normal yearly rainfall for specific climatic regions

K = Soil Erodibility Factor - Ability of soils to resist erosive energy of rain. A measure of the erosion potential for a specific soil type based on inherent physical properties (particle size, organic matter, aggregate stability, permeability). Soils with a K value of 0.17 or less are considered slightly erodible, and those with a K value of 0.45 or higher are highly erodible. Soils in disturbed areas can be more easily eroded regardless of the listed K value for the soil type because the structure has been changed.

LS = Steepness Factor - Combination factor for slope length and gradient

C = Cover and Management Factor - Type of vegetation and cover. The ratio of soil loss from a field with specific cropping relative to that from the fallow condition on which the factor K is evaluated.

P = Support Practice - Erosion control practice factor, the ratio of soil loss under specified management practices.

RUSLE can be used to predict soil loss from areas that have been subjected to a full spectrum of land manipulation and reclamation activities. RUSLE has been designed to accommodate undisturbed soil, spoil, and soil-substitute material, percent rock cover, random surface roughness, mulches, vegetation types, and mechanical equipment effects on soil roughness, hillslope shape, and surface manipulation including contour furrows, terraces, and strips of close-growing vegetation and buffers. It is important to note that RUSLE estimates soil loss caused by raindrop impact and overland flow in addition to rill erosion, but does not estimate gully or stream-channel erosion.

To establish successful vegetation, the soil loss rate should be minimized. Keeping the soil loss rate below 15 tons/acre for the first year after reclamation should, if surface water controls are included, allow the establishment of successful vegetation (PA DEP, 1999). For successful establishment of vegetative cover on abandoned mine land or redisturbed surfaces, the addition of soil amendments (e.g., soil substitutes, biosolids, etc.) may be necessary. Following regrading, final texture samples should be taken at a rate appropriate for site representation and analyzed for: pH, acid-base account, and fertility ratings for phosphorous, potassium, nitrogen, and magnesium. The necessity of amendments such as limestone, nitrogen, available phosphorous (P_2O_5), and potash (K_2O) can be determined from these analytical results. Additional analyses that can be performed for further determination of site characteristics include: percent sand, silt and clay, textural classification, and water-holding capacity. This information can be used to assist in the determination of the extent of final grading, cover preparation, and soil water retention amendments that should be implemented or added.

1.3.1 Implementation Guidelines

The intention of BMPs for control of sedimentation is to minimize erosion caused by wind and water. A remining sediment control plan should demonstrate that all exposed or disturbed areas are stabilized to the greatest extent possible. Operational BMP measures that can be implemented with this intent include:

C Disturbing the smallest practicable area at any one time during the remining operation,
C Implementing progressive backfilling, grading, and prompt revegetation,
C Stabilizing all exposed surface areas,
C Stabilizing backfill material to control the rate and volume of runoff,
C Diverting runoff from undisturbed lands away from or through disturbed areas using protected channels or pipes, and
C Using terraces, check dams, dugout ponds, straw dikes, rip rap, mulch, and other measures to control overland flow velocity and volume, trap sediment in runoff or protect the disturbed land surface from erosion (e.g., silt fences and vegetative sediment filters).

Construction of terraces, diversion ditches, and other grading/drainage control measures can be utilized to help prevent erosion and ensure slope stability. It is recommended that drainage ditches, spillways or channels be designed to be non-erodible, to carry sustained flows, or, if sustained flows are not expected, to be earth or grass-lined and designed to carry short-term, periodic flows at non-erosive velocities. Design should demonstrate that erosion will be controlled, deepening or enlargement of stream channels will be prevented, and disturbance of the hydrologic balance will be minimal. All slopes and exposed highwalls should be stable and protected against surface erosion. Slopes and highwall faces should be vegetated, rip rapped, or otherwise stabilized. Hydrologic diversions and flow controls should be free of sod, large roots, frozen soil and acid- or toxic-forming coal processing waste, and should be compacted properly according to applicable regulatory standards. Additional contributions of sediment to streamflow and runoff outside the permit area should be prevented to the greatest extent possible.

Certain sediment control BMPs already are an integral part of mining operations and do not require additional engineering designs or construction. These BMPs are recommended for implementation during pre-, active and post-remining activities, and often are incorporated into remining BMP implementation plans (Appendix A, EPA Remining Database, 1999). Recommendations for these BMPs include:

- Streams, channels, checks dams, diversion ditches, and drains should be inspected regularly and accumulated sediment removed. Channels and ditches should be seeded and mulched immediately after completion, if completion corresponds to regional growing seasons.

- Backfilling and regrading should be concurrent with coal removal and should follow removal as soon as is technically feasible. Final grading should be performed during normal seeding seasons to eliminate spoil piles and depressions at a time expeditious for prompt establishment of vegetation.

- Exposed and rounded surfaces should be mulched and vegetated immediately following final grading. It is recommended that mulch be anchored in the topsoil and that vegetation be planted immediately after topsoil grading.

- Areas should be reclaimed to an appropriate grade (slopes should not exceed the angle of repose or the slope necessary to achieve minimum long-term stability and prevent slides) to prevent surface-water impounding and promote drainage and stability. All final grading should be completed along the contour. Terrace-type backfilling and grading works to prevent slides and sedimentation while promoting slope stability (this also maximizes coal recovery and eliminates exposed highwalls and spoil piles).

- Unstable abandoned spoil and highwalls should be eliminated to the greatest extent possible. Care should be taken if the remining operation requires disturbance of existing benches and highwalls that have well-established vegetation and drainage patterns. Re-affecting abandoned mine lands that are well-vegetated and stabilized should be avoided to the greatest extent possible.

- Overburden and topsoil stockpiles that are not being used for topsoil or the establishment of vegetation should be located to minimize exposure and should be seeded with annual plants when needed to prevent excessive erosion.

- Topsoil material should be redistributed on graded areas in a manner which protects the material from wind and water erosion before it is seeded and planted. Compaction of surface topsoil materials should be such as to minimize erosion and surface water infiltration, yet promote establishment of vegetation.

- Streams and runoff should be directed away from spoil, refuse and overburden piles, exposed surfaces, and unstable slopes.

Site Stabilization

Minimization of the amount of disturbance during remining operations will decrease the amount of soil and sediment eroding from the site, and can decrease the amount of additional controls or BMPs that will be required. Operations should only disturb portions of the site necessary for coal recovery. Operations also can be staged to ensure that only a small portion of the site is disturbed at any given time. If possible, portions should be remined, regraded, and seeded prior to disturbance of the next area.

Preserving existing vegetation or revegetating disturbed soil as soon as possible after disturbance is the most effective way to control erosion (EPA, 1992). Vegetative and other site stabilization practices can be either temporary or permanent. Temporary controls provide a cover for exposed or disturbed areas for short periods of time or until permanent erosion controls are established.

Erosion and sedimentation can be minimized by removing as little overburden or topsoil as possible during remining operations, and by having sediment controls in place before operations begin. Any possible preservation of natural vegetation should be planned before site disturbance begins. The advantages of such preservation include the capacity for natural vegetation to handle higher quantities of surface water runoff.

Revegetation

Revegetation can be one of the most effective BMPs for achieving erosion control. By functioning to shield surfaces from precipitation, attenuating surface water runoff velocity, holding soil particles in place, and maintaining the soil’s capacity to absorb water while preventing deeper infiltration, the establishment of vegetation can stabilize disturbed areas with respect to erosion and surface water infiltration and attenuate AMD formation. Implementation of revegetation consists of seedbed preparation, fertilizing, liming, seeding, mulching, and maintenance.

Biosolids are a low-cost alternative to the use of commercially available lime and fertilizers. The biosolids typically used on remining sites are sewage treatment sludge. However, other biosolids can be obtained from paper mill waste and from other industries. Biosolids are available in various forms, but the most common is anaerobically digested materials that require an additional lime amendment.

Abandoned mine lands frequently have large areas with little or no topsoil, devoid of organic matter and microorganisms. Biosolids use is beneficial in terms of creating a soil substitute and improving revegetation, but also in developing soil structure through the addition of organic matter, which will foster a microbial community needed for the decomposition of biomass and other biochemical activities that take place in soil.

Vegetative cover can be grass, trees, or shrubs, but grasses are the most frequently used because they grow quickly, providing erosion protection sometimes within days. Permanent seeding and planting are appropriate for any graded or cleared area where long-lived plant cover is desired, and are especially effective in areas where soils may be unstable because of soil texture and structure, a high water table, high winds, or steep slopes.

Typical implementation and maintenance of revegetation operations at 51 mining sites in Alabama, Kentucky, Pennsylvania, Tennessee, Virginia, and West Virginia, are summarized in Table 1.3.1a.

Table 1.3.1a: Revegetation Practices and Maintenance (Appendix A, EPA Remining Database, 1999)

Revegetation Plan	
-	Systematic sample collection and analysis of topsoil, subsoil, and overburden materials to determine the type and amount of soil amendments necessary to maintain vegetative growth.
-	Topsoil placement and seeding occur no later than the first period of favorable planting after backfilling and grading. Disturbed areas are seeded/planted as contemporaneously as practicable with completion of backfilling and grading. Backfilled areas prepared for seeding during adverse climatic conditions are seeded with an appropriate temporary cover until permanent cover is established (cover of small grain, grasses, or legumes can be installed until a permanent cover is established).
-	Disturbed areas are seeded in such a manner as to stabilize erosion and establish a diverse, effective and permanent vegetative cover, preferably of a native seasonal variety or species that supports the approved post-mining land use.
-	Regraded areas are disced prior to application of fertilizer, lime and seed mixture. Fertilizer mixture is applied as determined necessary by soil sample analyses. Treatment to neutralize soil acidity is performed by adding agricultural grade lime at a rate determined by soil tests. Neutralizers are applied immediately after regrading. A minimum pH of 5.5 is maintained.
-	Mulch is applied to promote germination, control erosion, increase moisture retention, insulate against solar heat, and supply additional organic matter. Straw, hay, or wood fiber mulch are applied at approximately 1.0 to 2.5 tons/acre. Small cereal grains have been used in lieu of mulch (small grains absorb moisture and act as a soil stabilizer and protective cover until a suitable growing season).
-	Conventional equipment is used: broadcast spreader, hay blower, hydroseeder, discs, cyclone spreaders, grain drills, or hand broadcasting. Excess compaction is prevented by using only tracked equipment. Rubber tired vehicles are kept off reconstructed seedbeds.
Maintenance	
-	Vegetative cover is inspected regularly. Areas are checked and maintained until permanent cover is satisfactory. Bare spots are reseeded, and nutrients are added to improve growth and coverage. Areas that are damaged due to abnormal weather conditions, disease, or pests are repaired.
-	Unwanted rills and gullies are repaired with soil material. If necessary, the area is scarified and (in severe cases) back-bladed before reseeding and mulching.
-	Revegetation success is determined by systematic sampling, typically at a minimum of 1 percent of the area. Aerial photography can be used to determine success (typically at the 1 percent level - or higher if necessary). Standard of Success (SOS) for revegetation is based on percent of existing ground cover or achievement of vegetation adequate to control erosion.

Maintenance (cont.)	
-	Periodic mowing is performed to allow grasses and legumes a greater chance of growth and survival. Plants are not grazed or harvested until well-established.
-	Previously seeded areas are reseeded as necessary, on an annual basis until covered with an adequate vegetal cover to prevent accelerated erosion. Areas where herbaceous cover is bare or sparsely covered after 6-12 months are re-limed and/or re-fertilized as necessary to promote vegetative growth, then reseeded and mulched.

The amount of runoff generated from well vegetated areas is considerably reduced and is of better quality than from unvegetated areas. However, it is not possible, based on data currently available, to quantify the water quality benefits of the vegetative coverings as a BMP (EPA, 1996).

Direct Revegetation

Direct revegetation is an alternative to reclamation techniques that are designed to resculpture the existing topography. During direct revegetation, grading is avoided to prevent exposure of deeper, unweathered acid-forming materials and emphasis is placed on preservation of the weathered surficial materials and the network of natural drainage. Direct revegetation is generally low-cost, and it eliminates the acidity and potential acidity remaining in exposed surface layers by treatment with limestone or other alkaline materials. Once the surficial acidity is removed, natural processes that are aided and accelerated by application of fertilizer, mulch, and other organic amendments, can be relied upon to establish permanent vegetative cover (Nawrot and others, 1988). Work may be required for several (typically three) successive growing seasons, in order to ensure the establishment of vegetation across the entire area to be reclaimed (Olyphant, 1995).

Direct revegetation commonly requires the addition of lime and fertilizers to mine spoil or coal refuse piles that are devoid of vegetation. Biosolids can be easily employed in cases of direct revegetation. The material can be spread by use of a hydroseeder or farm equipment. Areas requiring direct revegetation are often poorly accessible due to steep and unstable slopes.

Therefore, the ability to spread biosolids from a secure distance makes it ideal for direct revegetation application. Biosolids, in many cases, form the basis of soil material or augment what little soil exists on the site.

Biosolids were used at numerous remining sites in Pennsylvania where little soil existed prior to remining or where, if soil did exist, it was lost due to burial or erosion from pre-SMCRA mining. Increases in plant growth and density can be dramatically improved using biosolids.

Channel, Ditch and Gully Stabilization

Stabilization of channels, ditches, and gullies at remining sites, whether they were constructed for surface water and erosion control or were formed naturally and are unwanted, is imperative for controlling sedimentation. In general, formation of unwanted gullies should be avoided. These BMPs are recommended when vegetative stabilization practices are not practical and where stream banks are subject to heavy erosion from increased flows or disturbances. If unwanted or naturally formed gullies are well- established, stabilization may prove more effective than removal. Gullies that are deeper than nine inches may form in regraded areas and should be filled, graded, and reseeded. Rills or gullies of lesser size may have a disruptive effect on post-mining land use or may add to erosion and sedimentation and should be filled, graded, and seeded (Appendix A, EPA Remining Database, 1999 VA(2)).

It is recommended that permanent channels and gullies be designed and constructed based on 100 year, 24 hour storm event. Channels and gullies can be stabilized and protected from eroding forces by the implementation of linings and/or check dams. Linings can be constructed of grass, rock, rip rap, or concrete. Check dams can be constructed with staked straw bales, wood, or rock. Although channel linings and check dams can trap small amounts of sediment, their primary purpose is to reduce the velocity of storm water flow, thus abating additional erosion.

Channel Linings

Erosion is a serious problem associated with channels and other water control structures. Sediment loads from eroded channels can cause numerous sediment and hydraulic problems and decrease the effectiveness of other sediment control measures. Depending on flow velocities, channel linings may be required to prevent channel erosion (MD DNR, 1989).

Due to the ease of construction and low cost, a vegetated channel lining is one of the most cost-effective ways of reducing channel erosion and is frequently used on diversion ditches. A well-established grass can protect the channel from erosive flow velocities of up to 6 feet per second (fps). Shorter meadow-type grasses with short, flexible blades can withstand a maximum permissible velocity of 5 fps. Bunch grasses or sparse cover provides only marginally better erosion protection than a well constructed earthen channel. For prevention of erosion, the Commonwealth of Kentucky (Kentucky, 1996) recommends that channels having a peak discharge design velocity of less than 5 fps be lined with grass species that are effective against erosion (e.g., Tall Fescue, Reed Canarygrass, Bermudagrass, and Kentucky Bluegrass). Channels having discharge velocities of 5 fps or greater should be lined with rip rap or other non-erodible, non-degradable materials unless the ditch is located in solid rock. Pennsylvania DEP (PA DEP, 1999) recommends a maximum velocity of 3 fps if only sparse cover can be established or maintained (because of shale, soils, or climate); a velocity of 3 to 4 fps if the vegetation is established by seeding (under normal conditions); and a velocity of 4 to 5 fps only in areas where a dense, vigorous sod is obtained quickly or if runoff can be diverted out of the waterway while vegetation is being established.

Vegetative linings typically begin eroding the base of channels, and once started, will continue until an erosion resistant layer is encountered. If it becomes evident that erosion of a channel bottom is occurring, rock or stone rip rap lining should be placed in the eroded areas. Rip rap lining should be durable and should be free of acid-forming materials. Generally, rip rap composed of varying sizes of stones is preferred over rip rap that is uniform, not only because it is less expensive, but because the varying stone size promotes natural settling and grading to form a better seal. In addition, rectangularly shaped stone is preferred for its durability. Smooth or rounded stones should not be used (MD DNR, 1989). A good recommendation is the use of a well-graded mixture down to the one-inch particle size, such that 50 percent of the mixture by weight is no larger than the median stone size. Rip rap layers should have a minimum thickness of 1.5 times the maximum stone diameter or no less than six inches, whichever is the lesser value. Channel banks should be protected to a height equal to the maximum depth of flow (Kentucky, 1996). Rip rap used in diversion ditches and pond spillways should consist of durable sandstone or limestone exhibiting a Slake-Durability Index of 85 or greater. The rip rap should be well-graded with the maximum stone size D(100) equal to the blanket thickness and the median stone size DD(50) equal to one half the blanket thickness (Appendix A, EPA Remining Database, 1999 VA(7)).

Check Dams

The purpose of check dams is to reduce the velocity of concentrated surface-water flow until diversion ditches or gullies are properly vegetated. Check dams can be constructed of straw bales, logs, rocks (Figure 1.3.1a), or other readily available materials, and should be designed so that water crosses only through a weir or other outlet and never flows along the top or the outside of the dam (Kentucky, 1996). The distance between check dams varies depending on the slope, with a closer spacing when slopes are steeper. Materials used should be relatively impermeable and of appropriate size, angularity, and density. They should be contained in anchored wire mesh or gabions, or staked to prevent flowing water from transporting them (Figure 1.3.1b).

The material used depends on the size and type of flow that is expected. Straw bale check dams generally are suitable for sediment control where concentrated flows do not develop. The efficiency of straw bale dams is limited by slope length and gradient. Straw or hay bales should be secured with stakes. Log check dams can be used in channels and generally are more effective and stable than straw bale barriers. It is recommended that logs be four to six inches in diameter, driven sufficiently beneath the channel floor, and stand perpendicular to the plane of the channel cross section, with no space between logs (Kentucky, 1996). It also is recommended that rip rap or shorter, wider logs on the downstream side be installed for stability. Rock check dams and straw bales allow water to pass through, controlling sediment movement through filtration and flow control. The size of the stone used in a rock check dam varies, with rock size increasing as flow velocity and discharge volume increase. For most rock check dams, the National Crushed Stone Association no. R-4 stone (3 to 12 inches, 6 inch average) is a suitable stone size (PA DEP, 1999). Filter stone applied to the upstream face of check dams can improve sediment trapping efficiency. Regular removal of sediment that accumulates behind the check dam is imperative for maintenance of efficiency, control of surface water flow, and avoidance of worsening conditions. Check dams also can be built in series, as necessary.

Figure 1.3.1a: Example of a Rock Check Dam (Kentucky, 1996)

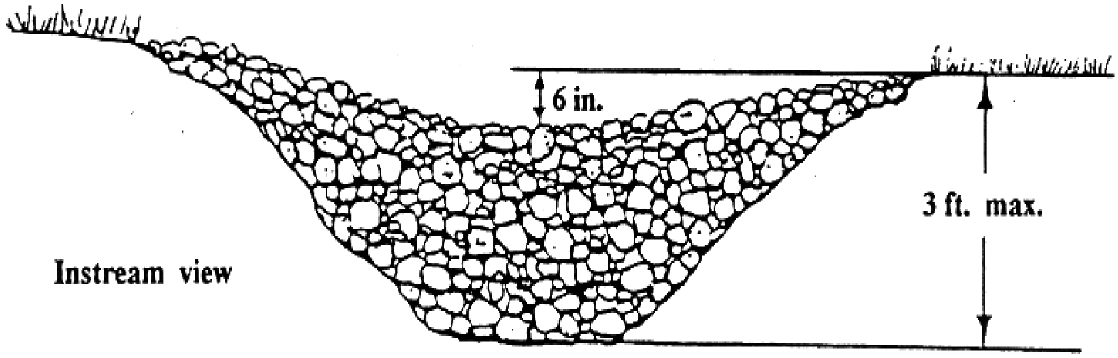
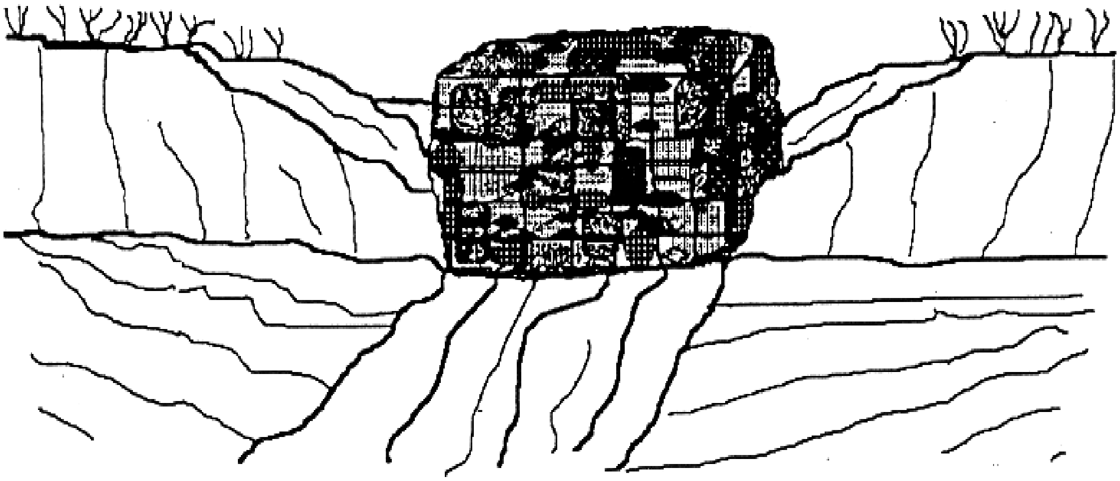


Figure 1.3.1b: Example of a Gabion Check Dam (Kentucky, 1996)



Silt Fences

Silt fences are used as temporary sediment barriers and are commonly constructed of burlap or synthetic materials stretched between and attached to supporting posts. The purpose of silt fencing is to detain sediment-laden, overland (sheet) flow long enough to allow the larger size particles to settle out and to filter out silt-sized particles. Because the screen sizes of synthetic screen fences will vary according to the manufacturer, these fences usually do not have the strength to support impounded water and are limited to control of overland runoff. Common problems associated with silt or filter fabric fences usually result from inappropriate installation, such as placement in areas of concentrated flows or steep slopes and placement down rather than along contours. These fences work best when placed on areas with zero slope. Because this often is not possible, flow should be otherwise reduced by the downslope emplacement of hay bales, mulching, or breaking the length of installation into separate sections that will not allow significant flow volumes. Silt fencing is appropriate for sediment control immediately upstream of the point(s) of runoff discharge, before a flow becomes concentrated, or below disturbed areas where runoff may occur in the form of overland flow.

Gradient Terraces

Gradient terraces can be used to control slope lengths, minimize sediment movement, and, on a site-specific basis, to address particular erosion problem spots according to need. Terraces are typically earth embankments or ridge-and-channels constructed along the face of a slope at regular intervals and at a positive grade. These BMPs often help stabilize steeply sloped areas until vegetation can be established and reduce erosion damage by capturing surface runoff and directing it to a stable outlet at a speed necessary to minimize erosion. Terrace locations and spacing can be determined following general grading and location of problem areas. It is recommended that terraces constructed on slopes not be excessive in width and have outer slopes no greater than 50 percent.

Design Criteria

General

C Design should approximate natural drainage as closely as possible.
C Sediment-control structures should be chosen according to review of existing topography, flow direction and volume, outlet location, and feasibility of construction.
C Sediment control structures should be constructed on stable ground.
C Use of costly earth-moving equipment should be minimized.
C Weathered, vegetated, and highly established portions of landscape should be preserved to the greatest extent possible.

Revegetation

C Volunteer, natural vegetation should be encouraged, and where possible, left undisturbed.

Channel, Ditch, and Gully Stabilization

C Liner materials should not contain acid-forming materials.

- Stabilization should be supported properly. Potential for stream bottom and sides to erode should be considered.
- Vegetation-lined ditches should be limited to velocities of 4 to 5 fps, unless documentation is provided that runoff will be diverted elsewhere while vegetation is being established.
- Permanent structures should be designed to handle expected flood conditions.

Check Dams

- Should be used only in small open channels which will not be overtopped by flow once the dams are constructed.
- Check dams should be anchored to prevent failure.
- Dams should be sized according to projected flows.
- The center of the dam should be lower than the edges.
- Straws bale barriers should be placed at zero percent grade, with the ends extended up the side slopes so that all runoff above the barrier is contained in the barrier.
- Stones should be placed by hand or using appropriate machinery and should not be dumped in place.

Silt Fences

- Support posts should be strong and durable.
- Filter material should be able to retain at least 75 percent of the sediment.
- Fences should be installed in undisturbed ground, and stability should be reinforced with rope or rip rap.
- Adjoining sections of filter fabric should be overlapped and folded.
- Bottom edge should be tied or anchored into the ground to prevent underflow.
- Maintenance should be performed as needed, and material should be replaced when bulges or tears develop.

Terraces

- Terraces, in general, should not be excessive in width or have outer slopes greater than 50 percent.
- Utilize diversion ditches as necessary, while a vegetative cover is being established.
- Terraces should be designed with adequate outlets, such as a grassed waterway or vegetated area, to direct runoff to a point not causing additional erosion.

1.3.2 Verification of Success or Failure

Implementation Checklist

Revegetation

- Vegetation should be maintained through cutting, fertilizing, and reseeding if needed.
- Vegetative success should be determined by a systematic sampling and plant count, and if necessary, aerial photography. Success should be measured on the basis of adequate vegetative cover which shall be defined as a vegetative cover capable of self-regeneration and plant succession, and sufficient to control soil erosion.
- Established vegetation should be inspected periodically for scouring. Scoured areas should be reseeded immediately.

Channel, Ditch, and Gully Stabilization

- Inspect regularly and after each major storm event for: sediment buildup, scouring, blockage, and lining damage or movement.
- If excessive scouring or erosion occurs in ditches or channels, they should be lined with rock rip rap or netting immediately.
- Sediment build up usually occurs in areas of low-flow velocities allowing particles to settle. Grade should be checked in these areas since low-flow velocities may mean the channel is undersized.

- Rip rap stones that have moved should be replaced and the rip rap fortified if undercutting has occurred.

Check Dams

- Inspect check dams regularly and after significant precipitation events for damage and sediment accumulation.
- Accumulated sediment should be removed from behind the dams and erosive damage restored after each storm or when half the original dam height is reached.
- The length of straw bale barriers should be inspected on a periodic basis to look for problem areas. Eroded areas should be regraded, accumulated sediment removed, and the barrier repaired to maintain effectiveness.
- Stone should be replaced as necessary to maintain correct dam height.

Silt Fences

- Silt fences should be inspected daily during periods of prolonged rainfall, immediately after each rainfall event, and weekly during periods of no rainfall.
- Required repairs should be made immediately.
- Sediment should be removed once it reaches one-third to one-half the height of the filter fence.
- Filter fences should not be removed until the upslope area has been permanently stabilized. Sediment deposits remaining after the filter fence has been removed should be graded, prepared and seeded.

Terraces

- Terraces should be inspected regularly at least once a year and after major storms.
- Proper vegetation and stabilization practices should be implemented during construction.

1.3.3 Literature Review / Case Studies

Case Study 1 (Harper and Olyphant, 1993; Olyphant and Harper, 1995; Carlson and Olyphant, 1996)

Direct Revegetation

Coal refuse is often an acid-forming material containing high concentrations of pyrite (> 0.50 percent total sulfur). If present, the oxidation of pyrite causes acidification of the soil, and acidification in turn, greatly inhibits vegetation. Substantial erosion and sedimentation occur due to poor or complete lack of vegetation on abandoned surface mine lands and coal refuse piles. Erosion is further accelerated by steep slopes common to some abandoned mine sites. Olyphant and Harper (1995) observed that direct revegetation of abandoned pyritic coal refuse piles can successfully reduce the sediment load, as well as improve the water quality of the runoff effluent from abandoned mine lands.

Direct revegetation was conducted on abandoned pre-SMCRA coal refuse piles located in Sullivan County, Indiana (Harper and Olyphant, 1993; Olyphant and Harper, 1995; and Carlson and Olyphant, 1996). Prior to revegetation, these piles were characterized by “severe and rapid erosion” and high pyritic content (up to 4.4 percent by weight). The colluvial material “derived from gully side slopes” built up through the winter months. This material was washed out during the spring followed by “erosional downcutting” through the summer and fall. Yearly backcutting of the gullies ranged from 2.5 to 4.6 centimeters with an interfluve lowering of 0.4 centimeters. The volume of sediment yielded by these gullies was approximately four fold that of the watershed as a whole and about 10 times that of adjacent interfluve areas. Yearly sedimentation yield was over 10 kg/m^2 (Olyphant and Harper, 1995).

In order to treat the acidity of the surficial refuse and allow plant growth, limestone was directly disced into the refuse without regrading the existing surface. Fertilizer was also broadcast over portions of the site to promote the vegetative cover. Additionally, small rip rap check dams and water bars were installed to prevent erosion and promote infiltration of precipitation. From 1990 to 1992, 100 to 210 tons per acre of agricultural limestone was disced to a depth of 6 inches into the refuse. Fertilizer was applied in the spring of 1991 and 1992 at rates of 100 lbs per acre of N_2, 150 lbs per acre of P_2O_2, and 350 lbs per acre of K_2O. The refuse was initially planted with a rye-nurse crop. Additionally, a permanent cover of Kentucky 31 fescue, bristly locust, and black locust was highly successful. Direct vegetation of weathered, undisturbed refuse with a pH less than 3.8 and pyrite concentrations less than 0.84 percent resulted in successful stabilization (Harper and Olyphant, 1993). Within 18 months, the site had a diverse dense growth of planted and volunteer vegetation (Olyphant and Harper, 1995).

The rip rap check dams were installed by “end-dumping” between 5 and 185 tons of rock directly into the upper parts of erosion gullies. Erosion netting and water bars were also used to control erosion on steep-slope areas, where additional time and effort is required to achieve sufficient vegetative cover to inhibit erosion.

The remedial work (direct planting, check dams, and water bars) resulted in increased precipitation infiltration (decreased runoff), reduced erosion, and sedimentation, and an improvement in the runoff-water quality. Runoff decreased by 56.7 percent, from 30 to 13 percent of the precipitation. The increased infiltration resulted in a higher moisture content in the root zone, especially during dry periods. Coarse sediment yield prior to vegetation and the implementation of sediment controls comprised more that 50 percent of the total sediment. Afterward, coarse-grained sediments were virtually nonexistent. Fine-grained sediments declined from 4.5 kg/m^2 to 0.3 kg/m^2, or 93.3 percent. The acidity of the runoff improved from being occasionally over 700 mg/L to an average alkalinity of 75 mg/L (Olyphant and Harper, 1995). However, no alkalinity was observed in the refuse pore water below a depth of 1.7 feet (Harper and Olyphant, 1993).

<u>**Case Study 2**</u> **-** Keel Branch, VA (Zipper and others, 1992)

The study area was an abandoned surface and underground coal mining site in Dickenson County, Virginia. The surface mining occurred between 1955 and 1958. “Shoot and shove” mining operations of that period produced a terrain consisting of exposed highwalls, more or less level benches, and steep spoiled outslopes. Abandoned mine land areas included approximately 170 acres and 8,000 linear feet of outslope-bench-highwall terrain. Highwalls from 50 to 100 feet high remained easily visible with evidence of some sloughing of highwall materials. Vegetative cover of the benches varied from dense to barren. The barren areas are associated with “burn out” from acidic coal fines. The outslopes were the main source of major environmental problems, with surface inclinations commonly exceeding 30E and extremely sloped areas nearing 40E. Adverse environmental impacts on watershed soil and vegetation was verified by the deterioration of natural forest areas directly below outslopes, caused by sediment movement from higher elevations downward toward the stream. A mining company was interested in remining coal from abandoned deep mine pillars and solid-coal sections that had not been surface mined, but was concerned about environmental liabilities (Zipper and others, 1992).

The goal of the study was to identify and compare the environmental effects of four remining and reclamation options. The objective was to estimate the reduction in soil loss and sediment yield likely to be achieved by various remining and reclamation strategies, relative to existing conditions using a modified Universal Soil Loss Equation model in a Geographic Information System (GIS) environment. The study evaluated three remining options and one AML-funded reclamation option and compared them to a “do-nothing” strategy. The remining options considered were:

<u>Remnant Recovery</u>: a technique frequently used to mine the remaining coal reserves from abandoned bench-highwall-outslope terrain in southwestern Virginia, eastern Kentucky and southern West Virginia. The mine operator employs conventional second-cut remining, taking an additional cut from the highwall to extract coal from the most profitable areas. Spoil from the second-cut is used to reclaim the exposed highwall segment to the maximum extent technically

practical. The reclaimed site is characterized as a steeply sloped highwall backfill, which may be adjacent to exposed highwalls remaining from unreclaimed pre-SMCRA operations. Existing spoil in the outslope areas is not re-affected (Zipper and others, 1992).

<u>Conventional Second-Cut Contour</u>: is also commonly used in steeply-sloped Appalachian areas and similar to remnant recovery, except rather than mining only the most profitable areas, additional cuts are taken from a relatively long, continuous portion of the highwall. This method also allows for reclamation of all exposed highwall to steeply sloped backfill contours. As with remnant recovery, outslope spoils are avoided to the greatest extent possible (Zipper and others, 1992).

<u>Innovative Remining</u>: designed to maximize reclamation effectiveness as allowed by the scope of the remaining minable coal reserves. The key to this plan is to apply virgin cuts to a coal seam at the base of the spoil slope as well as additional cuts into the existing highwall of a higher coal seam. In the process of reclamation, the spoil on the outslope will be eliminated. Critical to this plan is that the highest portions of the upper highwall do not have to be completely reclaimed. This is important because such reclamation can be cost prohibitive for remining operations. Much of the temporary sediment controls are placed down gradient in or near the headwaters of the adjacent streams. The main benefit of this methodology is that the problems caused by the spoil outslopes are eliminated (Zipper and others, 1992).

<u>AML Reclamation</u>: an option in which no additional coal is mined, the outslope area is regraded and the spoil is replaced into the existing open pit. Complete highwall elimination is unlikely, because the amount of spoil on the outslope is insufficient. However, the exposed strip bench is covered. Actual AML reclamation is unlikely at the study site because is has been assigned the lowest AML Fund priority number (3) (Zipper and others, 1992).

Roughly 40 percent of the abandoned mined areas of the site (mainly the steep outslopes) presently yield 95 percent of the sediment. Most of the study area (77 percent) has estimated soil losses of “stable conditions,” which are 0 to 1 ton per year. Approximately 8 percent of the AML area has soil loss potentials of between 20 and 50 tons per year. Soil losses exceeding 50 tons per year were determined for 2.6 percent of the AML area. Of the total soil loss, 60 percent was redeposited on the land surface, while the remaining 40 percent caused siltation of the streams. Remnant recovery and conventional second-cut contour were determined to be the least effective reclamation techniques in terms of controlling erosion and sedimentation. Remnant recovery showed a soil loss reduction of 8 to 23 percent depending on the amount of vegetative cover of 60 and 95 percent respectively. Conventional second-cut contour faired slightly higher with soil loss reductions of 19 to 39 percent. The two reclamation methods that eliminate the outslope spoil performed the best. Innovative remining has predicted soil loss reductions ranging from 38 to 86 percent, while AML reclamation would yield soil loss reductions from 52 to 75 percent. Regardless of the reclamation technique analyzed the effectiveness improved with increasing ground cover (Zipper and others, 1992).

Critical to innovative reclamation is procurement of a variance to the complete highwall elimination requirement. With this type of reclamation, sedimentation is greatly reduced, a coal resource is utilized, and substantial reclamation is achieved.

1.3.4 Discussion

Typical sedimentation control BMPs entail slope regrading, revegetation, sediment trapping, and control of runoff. Successful control of erosion and sedimentation from remining operations may require innovative practices and controls in addition to those normally implemented. Existing unreclaimed conditions create distinct problems, especially in terms of erosion and sedimentation on steeply sloped spoil. Innovative techniques for remining and reclamation can be employed to mitigate erosion and sedimentation problems.

Benefits

- Implementation can require minimal labor. Sediment control BMPs are typically low cost and use conventional farming equipment.

- These BMPs can subsequently reduce availability or reactivity of acid-forming materials.
- These BMPs can subsequently be implemented to control site surface-water hydrology.
- Hydraulic and sediment control BMPs are often already permit requirements.
- Biosolids can provide nutrients and organic mater on sites with poor or nonexistent soils, thus enhancing plant growth.
- These BMPs often improve site aesthetics and can provide wildlife habitats.

Limitations

- If not designed, implemented, and maintained properly, severe and rapid erosion can occur as natural drainage networks are re-established.
- Steeply sloped areas may require intensive physical labor (not machine accessible).
- Establishment of vegetative covering should be coordinated with climatic conditions for proper establishment.
- Biosolids application rates may be limited by metals concentrations.
- BMP success is often dependent on climate and weather.

1.3.5 Summary

There are remining situations where the primary water quality concern is not necessarily the dissolved contaminant component or pH, but is instead suspended solids and the subsequent deposition of sediment into receiving streams. Surface mining prior to SMCRA commonly left unreclaimed spoil piles and open pits. Pre-SMCRA mining operations in steeply sloped areas tended to spoil the overburden downslope of the operation. Abandoned spoil piles and exposed surfaces have been weathering for decades and through natural processes, typically have been partially to completely revegetated. Whether or not these spoil piles are reaffected, considerable erosion and sedimentation may result during remining operations. Therefore, erosion and sedimentation control BMPs frequently require additional measures in addition to the standard controls.

Slope stabilization through control of precipitation runoff is a critical component of these BMP practices. If erosion can be prevented, sedimentation will be controlled. Runoff and associated erosion is controlled through the integration of engineered slopes (e.g., terraces), revegetation, surface-water diversion through or away from spoil areas, sediment traps (e.g., silt fences, check dams, rip rap, dugout ponds), minimizing the amount of unreclaimed land at any given time, concurrent reclamation, and elimination of existing unstable spoil areas. Although significant sedimentation associated with remining is somewhat regional and is more prominent in steep slope areas, the problem is an important one. The BMPs discussed in this section have been successfully applied throughout the eastern coalfields.

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Section 2.0 Geochemical Best Management Practices

Introduction

The previous section discussed how hydrologic best management practices (BMPs) can reduce pollution load from remining sites. This section will discuss BMPs that use geochemical approaches to reduce pollution load. Effective use of geochemical BMPs requires at least a rudimentary understanding of the acid-producing and acid-neutralizing chemical processes.

Acid mine drainage results from the oxidation of pyrite (FeS_2). The following summary equation shows the reactants and products:

$$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_{3(s)} + 2\ SO_4^{2-} + 4\ H^+ \qquad \text{(Equation 1)}$$

Pyrite in the presence of oxygen and water will oxidize to form "yellowboy" [$Fe(OH)_{3(s)}$], sulfate (SO_4^{2-}) and acidity (H^+). Equation 1 is a summary equation. The following reactions are important intermediate steps:

$$FeS_2 + 3.5\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad \text{(Equation 2)}$$

$$Fe^{2+} + 0.25\ O_2 + H^+ \rightarrow Fe^{3+} + 0.5\ H_2O \qquad \text{(Equation 3)}$$

A product of Equations 2 and 3 is ferric iron (Fe^{3+}). Ferric iron can oxidize pyrite in the absence of oxygen:

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \qquad \text{(Equation 4)}$$

The oxidation of pyrite by ferric iron can become cyclical and self-feeding (Stumm and Morgan, 1996). Chemical reactions represented by Equations 1 through 4 occur "naturally," but the rate of reaction can be enhanced by orders of magnitude by the catalytic influence of bacteria, primarily *Thiobacillus ferrooxidans*. The bacteria obtain energy for their metabolism from the above reactions.

Equally important to any of the above acid-producing reactions is the ability of certain minerals to neutralize acid. This is illustrated by the dissolution of calcite:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad \text{(Equation 5)}$$

$$CaCO_3 + 2\ H^+ \rightarrow Ca^{2+} + CO_2 + H_2O \qquad \text{(Equation 6)}$$

In Equation 5, acidity (H^+) is neutralized and alkalinity (HCO_3^-) is produced. In Equation 6 acidity is neutralized, but no alkalinity is generated. Whether Equation 5 or 6 dominates depends on how open or closed the system is to the atmosphere (Guo and Cravotta, 1996). In a more closed system Equation 5 will dominate.

Two overall reactions can be written to describe pyrite oxidation (acid production) and carbonate dissolution (acid neutralization) in a closed (Equation 7) and open (Equation 8) system:

$$FeS_2 + 4\ CaCO_3 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 4\ Ca^{2+} + 4\ HCO_3^- \qquad \text{(Equation 7)}$$

$$FeS_2 + 2\ CaCO_3 + 3.75\ O_2 + 1.5\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 2\ Ca^{2+} + 2\ CO_2 \qquad \text{(Equation 8)}$$

Chemical BMPs attempt to counter the acid-generating chemical reactions in one or more ways. Approaches include the following:

- Preventing pyrite from being oxidized
- Keeping water away from pyrite
- Neutralization of acid by dissolution of calcareous materials
- Inhibition of the bacterial catalysis

The chemical BMPs examined in this section are alkaline addition, induced alkaline recharge, special handling of acid-forming materials, and bactericides. Alkaline addition can positively affect mine drainage in several ways. It can neutralize acid generated from pyrite oxidation, it can elevate pH, which can have an inhibitory effect on bacteria, and it can facilitate precipitation of ferric iron (Fe^{3+}), thus reducing its role in pyrite oxidation. Induced alkaline recharge is a hybrid of geochemical and hydrologic controls. The geochemical aspect is largely neutralization of acid. Special handling can be used to keep water or oxygen away from pyrite. Bactericides are used specifically for stopping the influence of bacteria on the acid mine drainage (AMD)-generating process.

2.1 Sampling

Introduction

Proper planning for implementation of geochemical BMPs requires an adequate understanding of overburden characterization and sampling. This discussion on sampling is primarily taken from Tarantino and Shaffer (1998), and supplemented by data from Sames and others (in preparation). Sames and others surveyed all Appalachian coal mining states to determine sampling protocol and interpretative techniques used by the various states.

The results of overburden analyses are generally used in two ways: 1) as a permitting decision-making tool (determining whether the permit is issuable), and 2) as a management tool (using the information to design best management practices for avoidance or remediation of pollution).

This section will concentrate on using overburden sampling for providing insights into the design of best management practices. Representative overburden sampling is used to:

- Determine overall acid or alkaline-producing potential of a proposed mine;
- Calculate alkaline addition rates;
- Determine the distribution of pyritic zones that may require special handling or avoidance;
- Identify alkaline zones which can be incorporated into a mining plan to prevent acidic Drainage (i.e., alkaline redistribution); and,
- Determine the economic feasibility of mining without unacceptable environmental impacts.

Acid-Base Accounting

Overburden analysis (OBA) refers to determination of the acidity or alkalinity producing potential of the rocks that will be disturbed by mining. OBA methods fall into two broad categories: static and kinetic. Static tests are "whole rock analyses" that determine the concentration of elements or minerals. Kinetic tests are simulated weathering procedures that attempt to reproduce weathering. In short, static tests measure what is in the rock, and kinetic tests measure what comes out of the rock. By far the most commonly used overburden analysis method in the Appalachian region is static "acid-base accounting" (ABA).

Components of ABA

ABA is based on the premise that the propensity for a site to produce acid mine drainage can be predicted by quantitatively determining the total amount of acidity and alkalinity contained in samples representative of site overburden. The maximum potential acidity (expressed as a negative concentration of $CaCO_3$) and total potential alkalinity (termed neutralization potential and expressed as concentration of $CaCO_3$) are summed. If the result is positive, the site should produce alkaline water. If it is negative, the site should produce acidic water. The maximum potential acidity (MPA) is stoichiometrically calculated from the percent sulfur (S) in the overburden. Sobek and others (1978), noting that 3.125 g of $CaCO_3$ is theoretically capable of neutralizing the acid produced from 1 g of S (in the form of FeS_2), suggested that the amount of potential acidity in 1000 tons of overburden could be calculated by multiplying the percent S times 31.25. This factor is derived from the stoichiometric relationships in Equation 9 and carries the assumption that the CO_2 exsolves as a gas.

$$FeS_2 + 2\ CaCO_3 + 3.75\ O_2 + 1.5\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 2\ Ca^{2+} + CO_2(g) \qquad \text{(Equation 9)}$$

Cravotta and others, (1990) suggested that, in backfills where CO_2 cannot readily exsolve, the CO_2 dissolves and reacts with water to form carbonic acid and that the maximum potential acidity in 1000 tons of overburden should be derived by multiplying the percent S times 62.50. In short, however, it can be said that interpretation of ABA data is far more complicated than simply summing the MPA and neutralization potential (NP) values. In addition to the percent sulfur and NP determinations, two other measured parameters in an ABA overburden analysis are paste pH and "fizz."

Paste pH

Paste pH has its origin in soil science, where weathered material (soil) is analyzed. A portion of prepared sample is mixed with deionized water, and then tested with a pH probe after one hour. The paste pH test indicates the number of free hydrogen ions in the prepared sample. However, since pyrite oxidation reactions are time dependent, the paste pH results provide little indication of the propensity of a sample to produce acid mine drainage. In fact, the paste pH of a unweathered, high-sulfur sample is likely to be near that of deionized water, while a weathered sample with relatively low percent sulfur (but which includes a small amount of residual weathering products) may have a significantly depressed paste pH. Thus, paste pH is of limited use when dealing with unweathered rock.

Percent Sulfur

Since acid mine drainage results from weathering of sulfide minerals, the amount of sulfur in a sample, or in an overburden column, is obviously an important component of ABA.

Sulfur determinations for ABA are often performed for total sulfur only, however, determinations for forms of sulfur are sometimes included. Sulfur generally occurs in one of three forms in the rock strata associated with coals in Appalachia: sulfide sulfur, organic sulfur, and sulfate sulfur.

Sulfide sulfur is sulfur that reacts with oxygen and water to form acid mine drainage. The sulfide minerals most commonly associated with coal in Appalachia are pyrite and marcasite, both of which have the formula FeS_2.

Organic sulfur is sulfur which occurs in carbon-based molecules in coal and other rocks with significant carbon content. Since organic sulfur is tied up in compounds that are stable under surface conditions, it is generally not considered a contributor to AMD. Organic sulfur is only a small percentage of total sulfur for most rock types, but can be significant in coal.

Sulfate sulfur, in humid climates, is generally found in relatively small concentrations due to its association with high-solubility minerals. However, when present in Appalachia, sulfate sulfur often occurs in partially weathered samples as a reaction by-product of sulfide-mineral oxidation. When solubilized, these by-products are the source of the contaminants found in acid mine drainage. For that reason, when determinations for forms of sulfur are performed, sulfate sulfur should be considered in the calculation of MPA. Alkaline earth sulfate minerals such as gypsum ($CaSO_4$) can also contribute to the sulfate sulfur fraction, but generally are not abundant in coal-bearing rocks in Appalachia. Where they are present, the alkaline earth-sulfate minerals do not contribute to acidity and should not be counted in the calculation of MPA (Brady and others, 1998).

A review of the methods for sulfur determinations described in Noll and others, (1988) reveals that the methods for total sulfur determinations have a relatively high degree of precision with few notable interferences and precautions, while methods for determination of the forms of sulfur had lesser degrees of precision and more numerous potential interferences. Stanton and Renton (1981) examined the nitric acid dissolution procedure, which is the cornerstone of the most frequently used methods for determining pyritic sulfur, including American Society for Testing and Materials (ASTM) D2492. They found that the procedure frequently does not succeed in digesting all the pyrite, and thus underestimates the pyritic fraction of the sulfur. Brady and others (1990) compared total sulfur and forms of sulfur determinations performed by various laboratories. Their findings include:

- While the results generated by each laboratory were internally consistent in terms of the ratio of pyritic sulfur to total sulfur, there were significant differences between laboratories in the median percent pyritic sulfur/total sulfur. Where the same samples were analyzed by different laboratories, differences were noted in the pyritic determinations, but total sulfur determinations were comparable.
- There was no significant difference in the percent pyritic sulfur/total sulfur between rock types (excluding coal). This contradicts one of the primary reasons for determining forms of sulfur: that some rock types contain significant percentages of organic sulfur.
- With one exception, all laboratories used high temperature combustion for determining weight percent total sulfur. The high temperature combustion results compared well on duplicate samples, while the pyritic results on the same samples did not.
- Standards are available from the National Institute of Standards and Technology for total sulfur but not for pyritic sulfur.
- A wide range of methods for determining pyritic sulfur were in use and individual laboratories had their own variations of the methods.
- According to ASTM Committee D-5 on Coal and Coke, the most commonly used method of pyritic sulfur determination, ASTM D2492, was developed for use on coal and is probably not appropriate for determinations on rock overburden.

The above findings can be summarized as:

- Total sulfur determinations are typically simple to perform, are reproducible, and can be calibrated and verified using available standards;

- Pyritic sulfur is determined using a variety of methods (the most common of which is considered inappropriate for rock samples),
- Pyritic sulfur methods produce results which are often not reproducible between laboratories, and cannot be calibrated and verified using available standards.

Given these considerations, and that pyritic sulfur is the most abundant form in coal overburden (but not necessarily in the coal), total sulfur determinations currently provide the best basis for calculating MPA.

Fizz Rating

The fizz test is a subjective test measured visually and rated according to the amount of effervescence when one to two drops of 25 percent HC1 is added to a small amount of finely-ground sample (Sobek and others, 1978). Fizz ratings range from strong effervescence to none. The fizz test serves two functions:

- As a check on the NP determination, since there should be a qualitative correlation between the two. Calcareous rocks with high NP should show a strong fizz, whereas non-calcareous rocks should not; and
- More importantly, the fizz rating determines the volume and the strength of the acid that is used to digest samples for NP determinations.

Neutralization Potential

The first step of the NP test is to conduct a qualitative fizz test on a small amount of the prepared sample as described above. Based on the fizz test results, an appropriate volume and normality of HCl is selected then added to 2.0 grams of prepared sample (Noll and others, 1988; Sobek and others, 1978). The strength of the acid is chosen to assure complete digestion of acid-neutralizing minerals. The neutralization potential is calculated by determining the amount of acid that has been neutralized by the rock.

Carbonate minerals, such as calcite and dolomite, are known to be major contributors to groundwater alkalinity in the coal regions of the Appalachians. The acid-digestion step of the NP test is suspected of dissolving various silicate minerals, which results in a NP determination that overstates the amount of carbonate minerals in a sample. Lapakko (1993) noted that since this dissolution will only take place at low pH values, it is unlikely to help maintain a drainage pH of acceptable quality.

Siderite ($FeCO_3$) is common in Appalachian coal overburdens, and has long been suspected of interfering with the accuracy of NP determinations and of complicating the interpretation of the data (Skousen and others, 1997). If iron from siderite is not completely oxidized when the titration is terminated, the calculated NP value will be overstated. Skousen and others (1997) found that the addition of hydrogen peroxide (H_2O_2) following sample digestion can expedite oxidation and precipitation of iron. Samples exposed to H_2O_2 digestion produced results similar to those of samples containing little pyrite or siderite. The additional H_2O_2 digestion step provided the lowest NP values for samples with significant siderite content and the best reproducibility between laboratories.

Net Neutralization Potential

Neutralization potential and maximum potential acidity are both expressed in units of tons $CaCO_3$ equivalent per 1000 tons of material (e.g., parts per thousand $CaCO_3$). Net neutralization potential (NNP) is neutralization potential minus maximum potential acidity. Thus, if the NNP is positive, there is an excess of neutralizers. If the NNP is negative, there is a deficiency of neutralizers.

Studies comparing ABA with post-mining water quality have consistently shown that although NP and MPA have the same units of tons $CaCO_3$ per thousand tons of material, and in theory should be "equal," their relative importance is not equal. It takes an excess of NP to assure that post-mining water will be alkaline (diPretoro, 1986; Erickson and Hedin, 1988; Brady and others, 1994; Perry, 1998). Post-mining water quality predictions should not be based on ABA alone, but should employ an array of prediction techniques. The best decisions involve consideration of as much data as is available (Kania, 1998b).

Information Needed to Conduct an Overburden Analysis

The site-specific data needed to properly plan an overburden analysis (OBA) include:

- Mining limits:
  - -Boundaries of the proposed area to be affected by coal removal;
  - -Proposed maximum highwall heights;
  - -Type of mining (e.g., contour/block cut or hill top removal); and
  - -Accessibility to drilling locations.
- Geologic considerations such as coal-seam identification, depth of weathering, and stratigraphic variation.
- Information available in state mining office permit files, such as water quality data from previous permits or applications covering the same or adjacent areas.
- Overburden analyses from the same or adjacent areas.
- Publications of state geologic surveys, the US Geologic Survey (USGS), the former US Bureau of Mines (USBM), US Army Corps of Engineers, and miscellaneous other state specific publications (e.g., the Pennsylvania “Operation Scarlift” reports from the late 1960s and early 1970s). These publications can include information such as:

  -Coal-bed outcrop maps,
  -Generalized stratigraphic sections,
  -Coal seam thickness maps,
  -Structure contour maps.

Old and current deep mine maps are available from the Office of Surface Mining, Appalachian Region Coordination Center, at 3 Parkway Center, Pittsburgh, PA, 15220, and various state agencies. These agencies have map repositories containing prints, originals, and microfilm, and copies can be readily obtained. These repositories include the Works Progress Administration (WPA) deep mine maps prepared in the 1930s, which cover an area that is 1/9 of a 15 minute quadrangle. In addition to showing mining limits, deep mine maps frequently show structure contours. This information can be very helpful in planning OBA drilling.

Other considerations in developing an OBA drilling plan include:

- Exploration equipment. It is important to understand the limitations that are inherent with different types of drilling equipment. These limitations can have an impact on the ability to obtain unbiased, representative samples. The choice of exploration equipment can influence costs.
- The type of overburden analysis to be performed. This is important in determining how much sample and what size fraction is required for the specific type of testing to be employed.
- Time constraints. Air rotary drilling is normally faster than coring.
- Economic constraints. Air rotary drilling is generally less expensive than coring.

Preparing for Overburden Analysis Sampling

The obvious questions that need to be asked when planning an OBA drilling plan are:

- How many OBA holes are needed ?
- Where should the drill holes be located ?

Once these details have been worked out, preliminary work can start. The first step in the development of an OBA proposal is to plan for the drilling. While there may appear to be savings associated with performing the drilling for the overburden analysis as part of the initial exploration drilling, it is generally preferable to perform exploratory drilling throughout the entire site before OBA drilling is initiated. This preliminary drilling enables the determination of depth to coal and the lateral extent of strata. This information can then be used to locate overburden holes best suited to represent the lithologic variation and degree of weathering within the site. If research and exploration are done prior to drilling the OBA holes, it is less likely that there will be a need to drill additional OBA holes later during the permitting process.

Areal Sampling - A Survey of State Practices

Sames and others (in preparation) surveyed Appalachian coal states to determine rules-of-thumb for areal sample coverage. According to Sames and others (in preparation) "all the states interviewed, except Virginia, have some minimum spatial distribution requirements for overburden analysis that should be supplemented upon request from the reviewing professional(s)." Table 2.1a shows the minimum drill hole spacing requirements by state.

Table 2.1a: Minimum Overburden Analysis Drill Hole Spacing Requirements by State (Sames and others, in preparation)

State	Minimum Requirement	Comments
AL	Two drill holes on small permit properties (<10 acres). One drill hole per 160 acres, or one per property quarter on larger permits.	-
KY	Eastern KY: Drill holes should be distributed on a staggered, one-quarter mile grid pattern. Western KY: Drill holes should be distributed on a staggered, one-half mile grid pattern.	-
MD	One drill hole per site regardless of size	-
PA	Two drill holes per site regardless of size. However, a rule-of-thumb of two drill holes per site plus one drill hole per 100 acres is usually requested.	On average, most applications contain one overburden analysis hole for every 20 permit acres.

State	Minimum Requirement	Comments
TN	One drill hole per 60 to 100 acres for permits to mine coal beds considered a high risk for AMD, based on past experience. One sample point per one-quarter mile in coal beds considered a low risk for AMD.	-
VA	-	In general, accepts any information submitted by the applicant, considers the quantity, quality, and consistency of the OBA for the permit area, and decides whether a reasonable characterization of the site is possible based on the spatial distribution provided.
WV	One drill hole in low cover and one in high cover. Otherwise, regulatory agency geologists to utilize Best Professional Judgement when determining the number of drill holes required for a permit.	In general, accepts any information submitted by the applicant, considers the quantity, quality, and consistency of the OBA for the permit area, and decides whether a reasonable characterization of the site is possible based on the spatial distribution provided.

Areal Sampling Experience: Pennsylvania

Pennsylvania has grappled with the issue of drill hole distribution since the advent of overburden sampling. A rule of thumb developed in Pennsylvania in the 1980s to determine a suggested minimum number of overburden holes was:

$$\frac{\text{Number of acres to be mined}}{\text{100 Acres}} + 2 = \text{Number of Overburden Holes}$$

If the first part of the equation resulted in a fraction, it was rounded to the closest whole number. For example:

$$\frac{\text{143 acres}}{\text{100 acres}} + 2 = \text{3 Overburden Holes}$$

$$\frac{49.99 \text{ acres}}{100 \text{ acres}} + 2 = 2 \text{ Overburden Holes}$$

$$\frac{179 \text{ acres}}{100 \text{ acres}} + 2 = 4 \text{ Overburden Holes}$$

This equation assumes that, for mines where OBA was requested, at least two holes are needed to determine whether the drilling was representative. This two-hole minimum is still in use. More recent data show that the actual sampling density for acid base accounting drill holes is greater than the "rule of thumb." A recent survey of overburden hole coverage for 38 sites in Pennsylvania revealed that on average, there is one OBA hole for every 15.5 acres of coal removal (Table 2.1b).

Table 2.1b: Number of Acres per Overburden Analysis Hole (Brady and others, 1994)

n = 38	**Coal Acreage**	**Acres per OBA Hole**
Mean	43.5	15.5
Median	30.3	11.9
Minimum	5.0	2.3
Maximum	172.5	44.9
Std. Deviation	38.0	10.6

A similar survey of 31 Small Operator Assistance Program (SOAP) applications received in Pennsylvania during the 1993 calendar year revealed that on average, there was one hole for each 18.8 acres of coal removal (Table 2.1c).

Table 2.1c: Number of Acres per Overburden Analysis Hole Based on SOAP Applications Received in 1993 (Tarantino and Shaffer, 1998)

n = 31	Coal Acres	Acres per OBA Hole
Average	72.6	18.8
Median	55.0	15.7
Minimum	6.0	3.0
Maximum	220.0	53.5
Std. Deviation	54.6	12.3

The above tables give an idea of the range of overburden analysis sampling intensity used in Pennsylvania. The ranges in the data are due to a multitude of factors including stratigraphic complexity of the site, shape of the site, and availability of other prediction tools. Approximately 30 to 40 percent of applications in Pennsylvania do not require submittal of overburden analysis because of the availability of equivalent prediction data. The data included in these tables apply only to permit applications that included overburden analysis data.

Operational Considerations

The overburden analysis drilling program should accurately represent the overburden that will be encountered during mining operations. Therefore, the overburden holes should be located within the limits of the proposed mining area. Some holes should be located at maximum highwall conditions (maximum overburden cover to be mined), and the holes should represent all of the strata that will be encountered. Additional holes should be located under both low and average cover conditions to provide representative sampling of the overburden where stratigraphic units may be missing or the strata may have been chemically altered due to surface weathering.

Stratigraphic Variation

It is important to provide enough drill holes to adequately represent the site, including any spatial lithologic variation. One of the first references to the minimum overburden hole spacing is contained in the West Virginia Surface Mine Drainage Task Force's "Suggested Guidelines for Surface Mining in Potentially Acid-Producing Areas" (1978), which recommended that all surface mining in potentially acid-producing areas be within approximately 3300 feet of a sampled overburden analysis hole or highwall.

Donaldson and Renton (1984) and Donaldson and Eble (1991) indicated that although drill cores spaced up to two miles apart in the Pittsburgh coal seam were adequate to reflect major thickness and sulfur trends for the coal seam, this spacing was not adequate for mine operation design. They felt that sampling at intervals on the order of 1200 to 1400 feet for the Pittsburgh coal and sampling at intervals of less than 500 feet for the Waynesburg coal would be necessary to determine small-scale sulfur content trends within the coal seams.

Representative Samples

Each OBA bore hole contains sample intervals representing various unit thicknesses of each lithologic unit encountered. Vertical sample interval thicknesses are typically three feet. The maximum thickness of each lithologic unit to be represented by one vertical sample interval will be discussed under "Compositing and Laboratory Preparation." It is also discussed on pages 29 to 30 of Part 1 "Collection and Preparation of Sample" in the "Overburden Sampling and Testing Manual" (Noll and others, 1988).

Noll and others (1988) do not, however, discuss the complexity of ensuring that accurate, non-biased, representative samples are collected. They do stress that it is critical that 100 percent of the sample volume of each sample interval be included for compositing purposes, because of possible geochemical variations within the 3-foot interval. The ultimate sample size used in

ABA is 1 gram for total percent sulfur and 2 grams for the neutralization potential (NP) test. Assuming no loss or contamination of the zone being sampled, only 1 gram to 2 grams are tested out of a 25,550 gram sample (based upon a 4.5 inch diameter drill bit and using an average rock density of 170 lbs/ft^3). Fortunately, sample preparation procedures have been developed to obtain representative, small sample aliquots. These procedures are discussed below in "Preparation of Samples."

Extensive literature has been published, and a complete science has been developed to integrate geology and statistics for spatial sampling and the determination of optimal sampling patterns for estimating the mean value of spatially distributed geologic variables. Textbooks on the subject include Journel and Huijbregts (1981), Webster and Burgress (1984), J.C. Davis (1986) and Koch and Link (1970).

The geologic systems responsible for the deposition and alteration of sediments and their chemical quality do not operate in a completely random fashion at the cubic centimeter level and, thus, do not produce overburden samples that are statistically independent. Although there are exceptions, most stratigraphic systems, especially those which produce calcareous material, operate over large areas with some degree of order, and deposit laterally pervasive units (Caruccio and others, 1980). Lateral continuity has also been observed in high-sulfur strata. Abrupt lateral changes in stratigraphy can occur such as where channel sandstones cut out and replace other strata. Surface weathering also causes changes to the percent total sulfur and NP over short distances. Therefore, it is imperative to know the areal extent of any alkaline or acidic material, and adequate exploratory drilling is essential for a representative overburden sampling plan.

Sample collection and handling

Sample Collection

Overburden sampling is accomplished by drilling or direct collection of the sample from an open surface such as a highwall. Sample methods used to obtain overburden samples include air rotary (normal circulation), air rotary (reverse circulation), diamond core, augering, and highwall sampling.

Air rotary (normal circulation) - This type of drill is the method most commonly used for the collection of overburden samples in Pennsylvania. Drilling in this manner uses air to blow rock chips (cuttings) to the surface for collection. The most common disadvantage of normal circulation air rotary drilling is that individual samples of stratum can be contaminated by an overlying sample zone as the rock chips are blown up the annular space of the drill hole. Rock chips traveling in this space can dislodge loose particles from an overlying source. Care should be taken to stop the downward progression of the drill stem after each interval has been sampled and allow any upper loose particles to blow out prior to continuing downward.

Contamination of the sample can also occur at the surface from the pile of ejected material that forms near the drill hole. These piled materials, if not removed during drilling, can slough back into the open hole and the chip stream. This can be avoided by shoveling the materials away from the hole during the period when drilling is stopped to blow out the hole. Another option is to add a short length of casing to the top of the hole after the upper few feet or first sample interval has been collected.

Samples are collected by placing a shovel under the chip stream. Care should be taken to clean the shovel of any accumulated materials from previous usage or sampling. This is particularly important when sampling wet test holes where the ejected materials consist primarily of mud. Before drilling the overburden hole, the dust collector hood should be cleaned to remove any accumulated materials that may dislodge and contaminate the samples being collected.

Air rotary (reverse circulation) **-** This type of drill rig is less commonly used for the collection of overburden samples, primarily because of availability. A reverse circulation rig uses a double-walled drill stem. Water or air is forced down the outer section of the drill stem and the cuttings/chips are forced up the inner section of the drill stem. The cuttings and water or air are brought into a separator and dropped near the rig where the samples can be collected. The samples are isolated from contact with overlying strata, offering a much cleaner and quicker means of obtaining overburden samples, without requiring that the drilling be stopped to blow out the hole. If water is employed in the drilling process, the materials are also washed free of the fine dust coating that can accumulate on the chips during drilling with air. This allows for much easier rock type identification and logging.

Diamond core **-** Diamond core barrels can be used on both types of rotary drilling platforms. Coring provides a continuous record of the lithology and provides more information than can be obtained through the collection of rock chips. Cores can provide a better overall view of the lithology by providing information necessary to judge rock color, gross mineralogy, grain size/texture, fossil content, and relative hardness. This type of information is not always readily available from rock chips. Although a core provides an uncontaminated and better source of reliable lithologic data, coring is very time consuming and costly, especially if the entire overburden section is to be sampled. Diamond cores can be used as a secondary means of data collection to target previously identified problem zones, or as a primary sampling tool in the coal area (i.e., the interval 5 feet above and below the coal horizon). The entire sample interval from the core should be collected and processed for analysis to ensure representative sampling, as opposed to only collecting and analyzing a portion of the sample interval.

A problem that can occur with coring is “core loss.” The problems of core loss can be reduced by regulating the drilling speed (i.e., rotational speed of the bit, and down pressure), diameter and type of core bit, and amount of water; by minimizing the overbearing weight in the core barrel through emptying it prior to drilling the coal; and by keeping the equipment in good condition. Knowing what drilling adjustments to make can prevent blocking of the core barrel.

Successful coring is dependent primarily upon the experience of the on-site geologist, project engineer, or driller. Factors that are important include total years of core drilling experience, experience with the drill being used, and previous drilling experience in the same region, including exposure to the same rock formations and weathering characteristics. Having as much geologic data as possible (e.g., approximate depth to the coal, extent of weathering) prior to drilling is also particularly useful. It is especially useful to have air rotary pilot holes to evaluate the site prior to the core drilling. These pilot holes allow particularly troublesome formations to be identified and avoided. Particularly troublesome conditions include highly fractured rocks, joints, or intersections of joints or fractures.

Mine voids, solution cavities, unconsolidated soil and rocks, and the transition through weathered rock into competent rock are the zones most subject to core loss. Core recovery on the order of only 50 to 60 percent or less in these situations is not unusual. When drilling is performed in unweathered rock, core recovery approaching 100 percent is the norm rather than the exception.

When coring into the coal, it is advisable to use a core barrel long enough to core the entire thickness of the coal. The core barrel should be no more than 20 percent full when the coal is first encountered. It is preferable to have a nearly empty core barrel containing 6 to 12 inches of overburden before drilling into the coal. The small amount of overburden aids in determining if the entire coal section has been sampled (i.e., knowing the starting point of the coal) and helps protect the coal from being crushed by the “ram” when extracting the coal from the core barrel.

In addition to actual core sample loss, drilling data can be lost due to improper handling of the cores. Data loss causes include placing cores in the core boxes in the wrong order or upside down or damage caused to the core during handling and shipping.

<u>Augering</u> **-** Auger drilling is not recommended for general overburden sampling. The materials lifted by the auger screw are in constant contact with the overlying stratum, thus providing for

intermixing and contamination. Augering is typically used for unconsolidated or highly weathered sections.

Highwall sampling - Direct collection of samples from an open source, such as a highwall, can be used for overburden analysis, provided several caveats are understood. First, samples may be weathered to such a degree that the strata to be mined is not accurately represented. Second, there is limited availability and accessibility of highwalls. Care should be taken to collect only unweathered samples in close proximity to and representative of the proposed mining. It is recommended that open source (e.g., outcrop, highwall, etc.) samples be used primarily to supplement drilled overburden samples.

Sample Description (Log)

For each sample or composite of sample intervals collected, an accurate description of the gross lithology should be determined. This lithologic description should include the rock type (e.g., shale, sandstone, etc.), rock color (as determined by comparison with the Munsell Rock Color Chart), texture/grain size, moisture conditions, and relative degree of weathering. Where applicable, a description of the gross mineralogy should be included with particular emphasis on the presence of any calcite ($CaCO_3$), siderite ($FeCO_3$), or pyrite (FeS_2). In addition, fossils should be noted to provide insights into coal seam correlations and depositional environment interpretations. The sample description should include the relative degree of fizz (effervescence) when doused with a 10 percent solution of hydrochloric acid (HCl). A field fizz based on a scale of " none, slight, moderate, or strong" should be used. A dilute (10 percent) HCl solution is widely used by field geologists to differentiate calcium carbonate ($CaCO_3$) from other carbonate rocks. Fizz determinations are highly subjective and should be made by the same individual for every sample on every hole for a particular site. Extreme care should be exercised to be sure that the displacement of trapped air is not mistaken for CO_2 evolution. It is also important to identify whether the fizz is from the matrix or from the cementing material. It is recommended that logging of test holes, including sample descriptions, be performed by a qualified geologist.

Sample Preparation and Compositing

Proper sample preparation techniques are essential for maintaining sample integrity. Preparation is divided into steps that occur in the field and steps that occur in the laboratory. Field preparation of samples is discussed in Tarantino and Shaffer (1998), Noll and others (1988), and Sobek and others (1978). Procedures discussed in these publications include the use of proper containers, labeling, preservation, and field logs. Field sample preparation will not be discussed further in this section.

Sample compositing and laboratory preparation techniques are just as important to the integrity of a sample. The purpose of compositing overburden samples is to reduce the cost of overburden analysis by minimizing the volume and number of samples to be tested, without sacrificing the accuracy and precision needed to predict post-mining water quality. Sobek and others (1978), in the first generally accepted “manual” on overburden sampling, recommend that most rock types should not be combined into composites representing more than three feet. They suggest that sandstone can be composited into 5-foot increments. Experience in some regions, such as Pennsylvania, has indicated that it is often prudent to sample sandstone at the same resolution as other rock types (Tarantino and Shaffer, 1998). As with any well-intended cost-saving procedure, if not done properly, the real long-term costs might far outweigh the small cost saving.

Table 2.1d lists vertical sampling practices of Appalachian coal-producing states.

Table 2.1d: Overburden Interval Sampling Requirements (Sames and others, in preparation).

STATE	INTERVAL SAMPLING REQUIREMENTS
AL	One sample every five feet or at a significant lithologic change, whichever comes first. Sample compositing is not allowed. Regulatory agency reserves the right to request core drilling in permit areas where there are known acid-forming lithologic units.
KY	Same treatment required for samples from eastern and western region. One sample for suspected acid-producing strata and coal seams less than one foot thick; smaller strata and seams may be grouped with the next lower unit. One sample within the lithologic unit for strata one to five feet thick. Two samples for strata ranging from five to ten feet thick. One sample every five feet for strata more than ten feet thick.
MD	For rotary drill cuttings, one sample every one foot or at a significant lithologic change; for core samples, 3-foot composite samples or at a significant lithologic change.
PA	One sample per three vertical feet or at a lithologic change plus one foot above and below the coal bed. Rotary drill samples should be collected in 1-foot increments that then can be composited up to three feet. Core sample composites also limited to 3-foot increments regardless of the unit thickness; an equal portion of the entire core length should also be crushed and split for analysis.
TN	One sample every three feet or at a significant lithologic change, whichever comes first.
VA	Sobek and others (1978) protocol: One sample every five feet for sandstone units. One sample every three feet for other lithologies.
WV	One sample every five feet or at a significant lithologic change, whichever comes first. Sample compositing is not allowed. Sobek and others (1978) followed as the official guide. Permit geologists also refer to NPDES, DMR discharge data, and other historical data from adjacent operations in the same seam.

Some sandstones, such as portions with significant coal inclusions, may need to be sampled at a greater resolution. Till, when from separate glaciations, should be sampled separately. The reason for the one-foot sample intervals above and below the coal (Pennsylvania) is that these are frequently the highest sulfur strata present. Mixing of these strata with overlying strata can result in dilution and a falsely low-percent sulfur, or make a thicker zone (e.g., three feet) resemble a high sulfur zone. The coal seam may also require greater sample resolution than the suggested three feet, if a portion of the coal will be left in the pit as pit cleanings or unmarketable coal. The coal that remains behind should be sampled separately.

As can be seen from Table 2.1e, if too many 1-foot intervals are composited or too large a vertical sampling interval is chosen, a high total sulfur, potentially acid-producing zone can be masked by dilution with adjacent low sulfur strata. The net effect is an underestimation of the potential for a site to produce acid mine drainage. Compositing one foot of 2.34 percent sulfur black shale with an overlying four feet of low-sulfur sandstone results in a 0.48 percent total sulfur for the composited 5-foot zone. If, for example, 0.5 percent sulfur is the "threshold" above which a unit is considered acid producing and thus targeted for special handling. This dilution effect would underestimate the acid-producing potential of the black shale and result in the strata not being specially handled.

Table 2.1e: Compositing of Too Many One-foot Intervals Can Underestimate Acid Producing Potential (Tarantino and Schafer, 1998)

Thickness (feet)	Lithology	Total % S	Average % S of Interval			
1	sandstone	0.01				0.48
1	sandstone	0.01			0.59	
1	sandstone	0.01		0.79		
1	sandstone	0.01	1.18			
1	black shale	2.34				

Sobek and others (1978) suggested that for core samples, a 5-inch section of the core could be extracted from the middle of a 1-foot interval to represent the entire 1-foot interval. The best way to ensure representativeness of an interval is to sample the entire interval. In order to avoid bias, one of the following two methods is recommended:

1) The entire core interval whether it be a 1-, 2-, or 3-foot interval, should be entirely crushed and reduced in size via a riffle or rotating sectorial splitter until a suitable amount of sample remains for analysis.

2) The entire core length should be bisected longitudinally using a core-splitter or saw. One half of the core is retained for historical records and possible additional testing. The entire other half of the core is crushed for the entire sampling interval. After crushing, the sample is divided and reduced in volume via a riffle or rotating sectorial splitter.

There are three reasons for splitting and crushing samples:

1) To reduce the bulk (amount) of a geological sample.
2) To provide an unbiased, statistically representative sample of small quantity, which can be analyzed to evaluate percent sulfur and NP for acid base accounting.
3) To reduce samples to a small size fraction that maximizes surface area and minimizes the analytical time.

2.2 Alkaline Addition

It is widely recognized that mine sites with an abundance of naturally occurring limestone or alkaline strata produce alkaline water, even in the presence of high sulfur. However, many sites contain little or no alkaline material and, as a consequence, often produce acidic drainage even when sulfur contents are relatively low. One approach to improving alkaline deficient sites is to import alkaline material to amend the spoil in order to obtain alkaline drainage.

Before implementing an alkaline addition BMP, the following factors should be considered: How much material should be added, and how and where should it be applied to the backfill? When is additional alkaline material needed? What are the prospects of obtaining alkaline drainage for a given application rate, and how much risk of acidic drainage is acceptable? Ultimately, whether alkaline addition is a feasible alternative is driven by the economics of the operation. Therefore, it is important that an alkaline addition project be carefully evaluated and designed before it is implemented. This section reviews theoretical and practical aspects of alkaline addition and summarizes the current state-of-the-art in the use of alkaline addition to prevent acid mine drainage.

Theory

AMD is formed when pyrite and other iron disulfide minerals present in coal and overburden are exposed to oxygen and water by mining. The oxidation of pyrite releases dissolved iron, hydrogen ions (acidity), and sulfate (Equation 1). Although this process occurs very slowly in undisturbed natural conditions, it can be greatly accelerated by both surface and underground mining.

Pyrite oxidation is further accelerated by the iron-oxidizing bacterium *Thiobacillus ferrooxidans,* which thrives in a low-pH environment and oxidizes ferrous iron to ferric iron (Kleinmann and others, 1980). Under low pH conditions, ferric iron remains in solution and can directly oxidize pyrite. Thus, once AMD formation gets started, the reaction is further accelerated by bacteria and the production of ferric iron. The result can be severe acid mine drainage.

Acidity produced by acid mine drainage can be neutralized in the presence of sufficient carbonate minerals. This reaction is shown by Equation 6, for which it is assumed that CO_2 will be produced and will exsolve from solution. Using this equation, it takes 31.25 tons of $CaCO_3$ to neutralize 1000 tons of material with 1 percent sulfur. This is the traditional method used for acid-base accounting calculations. The main shortcoming of this equation is that there is no "alkalinity" (bicarbonate or HCO_3^-) produced. Under normal conditions, not all CO_2 escapes to the atmosphere. Some CO_2 dissolves in water, producing acidity. If the reaction product is HCO_3^- alkalinity (Equation 5), twice as much carbonate will be required to neutralize the same amount of material (Cravotta and others, 1990). Whether it is the process in Equation 5 or Equation 6 that is dominant depends on the extent of how open or closed the mine is to the atmosphere.

Where neutralization occurs, the pH can remain near neutral, inhibiting bacterial catalysis of iron oxidation and keeping ferric iron relatively insoluble. Thus, the quality of drainage produced by a given mine is largely dependent not only on the presence or absence of pyritic sulfur, but also on the availability of calcium carbonate or other neutralizing agents in the coal and overburden.

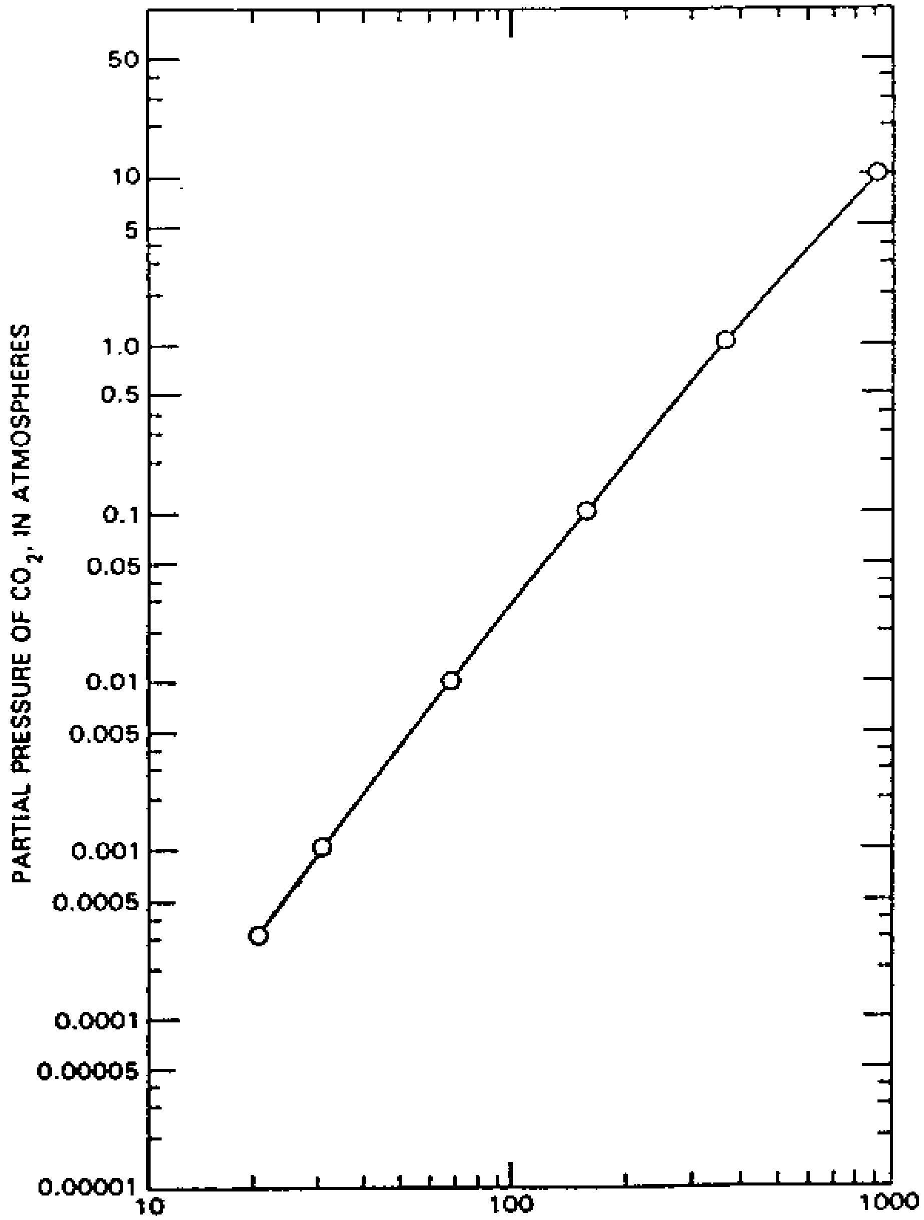
Brady and others (1994) and diPretoro and Rauch (1988) found a strong relationship between the neutralization potential of surface coal mine overburden and the alkalinity or neutrality of post-mining drainage. Sites with more than 3 percent naturally occurring carbonates produced alkaline drainage. Sites with less than 1 percent carbonate generally produced acidic drainage. Perry and Brady (1995) attribute this effect not only to neutralization but also to near-neutral conditions limiting bacterial catalysis of ferrous iron oxidation and oxidation of pyrite by ferric iron.

NP was found to be a much better predictor of whether a mine would produce alkaline or acidic water than was the maximum potential acidity, calculated from the overburden sulfur content, thus demonstrating the importance of carbonates on mine drainage quality (diPretoro, 1986; Brady and Hornberger, 1990; Brady and others, 1994; Perry and Brady 1995). For mines which are naturally deficient in carbonates, and therefore likely producers of acidic drainage, the implication is obvious. If sufficient alkaline material is imported from off-site to make up the deficiency in NP, the site will produce alkaline rather than acidic drainage.

The solubility of calcium carbonate also plays an important role in whether a site can generate sufficient neutralization to prevent acidic drainage. Calcite ($CaCO_3$) solubility is dependent on the partial pressure of CO_2 (Figure 2.2a). At atmospheric conditions, the solubility of calcite is limited to approximately 20 mg/L Ca (50 mg/L as $CaCO_3$ or 61 mg/L as HCO_3^- alkalinity) assuming a CO_2 content of the pore gases of only 0.03 percent. At 20 percent CO_2 content, which has been measured in some backfill environments (Cravotta and others, 1994a), calcite solubility exceeds 200 mg/L Ca (500 mg/L as $CaCO_3$ or 610 mg/L as HCO_3^- alkalinity). Guo and Cravotta (1996) note that CO_2 partial pressures vary from mine site to mine site depending on rock type and backfill configuration. Shallow backfills on steep slopes with blocky overburden and thin soil cover, for example, tend to "breathe," thereby reducing CO_2 partial pressures (Pco_2). Deeply buried backfills or sites with restricted airflow or thick soil covers would tend to have higher CO_2 levels, enhancing calcite dissolution. At these sites, Pco_2 tends to increase with depth. The Pco_2 has implications for the placement of alkaline materials within the backfill. Near-surface placement of alkaline material, where CO_2 partial pressures approach atmospheric conditions, may not be as desirable as distribution deeper within the backfill.

In theory, almost any acid-prone site could be transformed into an alkaline site, if enough carbonate material is imported. For this to be achieved, however, it is necessary to determine: 1) how much alkaline material should be applied to ensure a successful result; and 2) the optimum place within the backfill where the alkaline material should be applied.

Figure 2.2a: Solubility of Calcium Carbonate (Calcite) in Water at 25°C as a Function of Partial Pressure of CO_2 (Hem, 1985)



2.2.1 Implementation Guidelines

Fifteen years of research has shown that alkaline addition can improve water quality and prevent AMD production, but failures are common, especially where alkaline addition rates are too low. Based on these studies, any alkaline addition project should consider:

- How much and what type of alkaline material should be applied,
- How the alkaline material should be emplaced in the backfill, and
- When alkaline addition is appropriate.

Seventeen of 61 mining site data packages submitted by Appalachian coal mining states (Appendix A, EPA Remining Database, 1999) had alkaline addition listed as a BMP. Alkaline addition, like any other BMP, is seldom used alone. Table 2.2.1a lists additional significant BMPs that were used in conjunction with alkaline addition at these sites. In a Pennsylvania study of closed remining sites (Appendix B, PA Remining Site Study), alkaline addition was always used in conjunction with some other BMP. Other BMPs included daylighting of deep mines, special handling of acidic materials, surface regrading, ground-water handling, and surface revegetation.

Table 2.2.1a: Distribution, Type, and Amount of Alkaline Materials Used (Appendix A, EPA Remining Database, 1999)

Mine ID, Mine Type	Placement	Type of Alkaline Material	Other Major BMPs
PA(1) ^{S}	30 tons/acre applied to pit floor	Crushed limestone (>95% $CaCO_3$)	Daylighting
PA(2) ^{R*}	Alternate refuse & coal ash. 1,650,000 tons of reject refuse, 1,350,000 tons ash	Power plant coal ash. 5.8% $CaCO_3$	Removal of acid-forming materials, Revegetation
PA(7) ^{S}	10 ft thick layer in backfill. Compacted/set as cement, above post-mining water table	Coal ash	Daylighting, Regrading Revegetation, Special handling
PA(8) ^{S*}	360 tons/acre applied to pit floor. 240 tons/acre in blast holes; dispersed throughout spoil	Limestone screenings	Daylighting, Special handling
PA(10) ^{S}	Ripping of calcareous pit floor material	Pit floor rock is 15 to 20% $CaCO_3$	Bactericide, Special handling, Regrading
PA(11) ^{S*}	50 tons/acre applied to pit floor	Agricultural lime	Regrading, Revegetation
PA(12) ^{S*}	Within spoil. Compacted to 90% maximum dry density	Coal ash	Daylighting, Regrading, Revegetation
PA(14) ^{A*}	In abandoned strip pit. Five million yds^3 compacted to min. 90% dry density	Coal ash	Revegetation
PA(18) ^{A*}		Coal ash, pH 11	Daylighting, Regrading, Revegetation
PA(19) ^{S*}	100 tons/acre applied to surface and pit floor. Approx. 800 tons/acre in spoil	Lime processing flue dust	Regrading Revegetation
TN(3) ^{S}		Limestone	
TN(4) ^{S*}	"Spoil side" of dragline bench	Limestone	Special handling, Chimney drains, Regrading, Backfill inundation
WV(3) ^{S*}	2 ft lifts through overburden	Coal ash	
WV(5) ^{S*}	2 ft applied to surface. Mixed through overburden	Coal ash	Anoxic limestone drains
WV(6) ^{S*}	12 to 18 inches applied to pit floor. 2 ft applied to surface	Coal ash, pH 10.5 to 12	
WV(8) ^{S*}	Min. 1 ft thick, 30 ft wide channel		Regrading
AL(10) ^{S}	20 tons/acre applied to pit floor		Regrading

* Mine is still active ^{S} Surface
^{A} Anthracite ^{R} Refuse reprocessing

Alkaline Materials

A variety of alkaline materials are available as alkaline additives. Traditionally alkaline addition projects use crushed limestone or limestone-based waste products. Limestone-based waste products include crusher waste, kiln dust, partially burnt lime, and "off-spec" lime products. More recently alkaline waste products from other sources have been considered. Chief among these is fluidized-bed combustion fly ash and bottom ash. An examination of Table 2.2.1b shows the range of products being used and the current trend in using coal combustion ash.

Table 2.2.1b: Example Analyses of Coal Ash. (Units are percentages) (Scheetz and others, 1997)

Oxide	Coal Ash with < 10% CaO [a]	Coal Ash with > 20% CaO [b]	High BTU Coal [c]	Anthracite Culm [c]	Bituminous Refuse [c]
SiO_2	52.5 ± 9.6	36.9 ± 4.7	24	58	34
Al_2O_3	22.8 ± 5.4	17.6 ± 2.7	6.05	20.4	2.15
Fe_2O_3	7.5 ± 4.3	6.2 ± 1.1	2.05	5.74	5.98
CaO	4.9 ± 2.9	25.2 ± 2.8	42	4.11	30
MgO	1.3 ± 0.7	5.1 ± 1.0	0.045	0.62	0.62
Na_2O	1.0 ± 1.0	1.7 ± 1.2	0.07	0.59	0.11
K_2O	1.3 ± 0.8	0.6 ± 0.6	0.51	2.56	1.49
SO_3	0.6 ± 0.5	2.9 ± 1.8	20.8	1.1	13.0
Moisture	0.11± 0.14	0.06 ± 0.06	+ 0.25	+ 0.49	3.70
LOI[d]	2.6 ± 2.4	0.33 ± 0.35	2.03	3.31	10.0

[a] Characteristics of eastern bituminous and anthracite coal

[b] Characteristics of western lignitic and sub-bituminous coals

[c] Ash resulting from burning coal, culm, and refuse with limestone

[d] LOI = Loss on ignition

Limestone and Limestone-Based Products

The chemical principles of neutralization by limestone are presented above in the section "Theory of Alkaline Addition," and the neutralization reactions are shown in Equations 5 and 6. Limestone, which is composed mainly of the mineral calcite ($CaCO_3$), occurs naturally on many mine sites. An advantage of limestone is that it dissolves more slowly than quick lime or hydrated lime, thus lasting longer. A disadvantage is that its solubility is limited, such that alkalinity higher than ~400 mg/L as $CaCO_3$ is rarely achieved. At atmospheric pressures of CO_2, calcite will produce an alkalinity of <100 mg/L $CaCO_3$ (Hornberger and Brady, 1998). Another mineral that has neutralizing properties and occurs naturally in coal overburden is dolomite [$CaMg(CO_3)_2$]. Neutralization by dolomite is similar to that shown in Equations 5 and 6, but the reaction rate is slower than with limestone.

"Quick lime" (calcium oxide, CaO) and "hydrated lime" [calcium hydroxide, $Ca(OH)_2$] are produced by heating limestone and driving off CO_2. These are more soluble than calcite and can produce a pH as high as 11 or 12. The advantage of quick lime or hydrated lime is its high solubility and ability to generate high pH. The disadvantage is that, because of its high solubility, it may be consumed quickly. The neutralization processes are represented by Equations 6 and 7 (Cravotta and others, 1990).

$$Ca(OH)_2 + 2\,H^+ \rightarrow Ca^{2+} + 2H_2O \qquad \text{(Equation 9)}$$

$$CaO + 2\,H^+ \rightarrow Ca^{2+} + H_2O \qquad \text{(Equation 10)}$$

The neutralization of acid generated from pyrite oxidation by hydrated lime is represented by Equation 11 (Cravotta and others, 1990):

$$FeS_2 + 2\,Ca(OH)_2 + 3.75\,O_2 \rightarrow Fe(OH)_3 + 2\,SO_4^{2-} + 2\,Ca^{2+} + 0.5\,H_2O \qquad \text{(Equation 11)}$$

The purity of limestone or other alkaline additives is an important factor. Many rocks with the potential to generate alkaline water are not limestones, but calcareous shales or other rock. If a rock that is not nearly pure calcite is used, alkaline addition rates should be adjusted to compensate for the lack of purity. For example, if the material that is proposed for alkaline addition has a NP of 500 tons $CaCO_3$/1000 tons of material (50 percent purity), twice as much material would be required to provide the necessary amount of $CaCO_3$. Regardless of the alkaline material to be used, the application rate should be adjusted to reflect the material's neutralization potential as calcium carbonate equivalent.

Coal Ash

Coal ash has been used in a variety of ways for abatement of mine drainage pollution, including the following:

- Injection into underground mines with the intention of abating acid mine drainage by sealing (Aljoe, 1999; Canty and Everett, 1999; and Rafalko and Petzrick, 1999),
- As an additive to help create a suitable soil substitute out of acidic spoil (Stehouwer and others, 1999),
- As an impermeable cap for reduction of infiltration into acidic surface mine spoil (Hellier, 1998). Ash has been mixed with reprocessed coal refuse for AMD abatement (Foster Wheeler Corp., 1998; Panther Creek Energy Facility, n.d.),
- As a grout to isolate acidic material in surface mine spoil (Schueck and others, 1994),
- As fill material for abandoned surface mines and anthracite region "crop falls" (Scheetz and others, 1997), and
- As an alkaline additive to neutralize acidic mine spoil.

The use of coal ash as an alkaline additive will be discussed in this section. The use of ash for low-permeability caps and seals is discussed in Section 1.1 and its use for grout curtains is discussed in Section 1.2.

The popularity of using coal ash as an alkaline additive is demonstrated by the fact that it is being practiced by eight of the 17 mines listed in Table 2.2.1a. The alkalinity generating properties of coal ash vary depending on the type of power plant producing the ash. Most alkaline ashes are generated by fluidized bed combustion (FBC) power plants. These plants burn high-sulfur coal or coal reject material as fuel. Limestone is used to absorb the sulfur, and the limestone calcines leaving calcium oxide. According to Skousen and others (1997), about one-half of the CaO reacts with sulfur dioxide to form gypsum, and the rest remains unreacted. The ash can be 10 to 20 percent calcium carbonate equivalent. The amount of limestone used can be substantial. For example, the Colver, Pennsylvania, power plant burns 600,000 tons of "gob" (coal refuse) annually, requiring 120,000 tons of limestone to remove the sulfur (Foster Wheeler Corp., 1998). Table 2.2.1b shows the neutralizing properties of various coal ashes. As can be seen, not all coal ash is alkaline. In fact, some ash has to have alkaline material added for proper disposal.

One problem with using coal ash as an alkaline additive is that it can exhibit cementitious behavior. The cementitious behavior is activated by alkali materials. The making of cement from ash (volcanic ash) dates back to the time of the Romans. Many of these structures are still standing today (Scheetz and others, 1993), which is testimony to its durability. Cementitious behavior is an advantage if one is proposing ash as a grout or an impermeable cap. Scheetz and others (1993) list the following "advantages" for the use of coal ash for cementitious material:

- Low cost of raw materials
- Grouts can be formulated to gain strength rapidly
- Grouts have low heats of hydration
- Grouts are less soluble than portland cement-based materials
- Grouts can be less permeable than portland cement-based materials
- Grouts can be activated with alkali chlorides and sulfates.

Many of these same properties that are advantageous for impermeable grouts and caps are a disadvantage for their use as an alkaline additive. For example, low solubility and low permeability are not properties that are desirable for an alkaline additive. Pulverized coal combustion fly ash exhibits a pozzolonic reactivity "that is directly correlated to the calcium content of the ash" (Scheetz and others, 1997). In other words, the lime portion of the ash is an activator that can make the ash into cement.

Coal combustion ash, if it is to be used as an alkaline additive, should be evaluated for its calcium carbonate equivalency and its cementitious properties. It should be spread and mixed with spoil so as to maximize its surface area. If not adequately mixed, the ash may set up as large blocks of cement with minimal surface area for reactivity, thus resulting in an ineffective alkaline additive.

Coal ash, even with pozzolonic properties, has potential as an effective "seal" on acidic pit floors. This application would also provide an alkaline substrate for spoil waters.

Other Alkaline Additives

Information on other alkaline sources is scarce. Skousen and others (1997) briefly discuss the use of steel slags and states that these slags often have neutralization potentials from 45 to 90 percent, but warn that slags "are produced by a number of processes so care is needed to ensure candidate slags will not leach metal ions such as Cr, Mn, Ni, or Pb." Phosphate rock has been proposed for use as an alkaline additive, but no full-scale field projects have been commenced and the cost is high (Skousen and others, 1997). Phosphate rock can contain significant quantities of calcium carbonate. Thus, it may be difficult to determine the relative effectiveness of the phosphate relative to the carbonate.

Other alkaline additives or alkaline-producing additives mentioned by Skousen and others (1997) are AMD sludge and organic wastes. AMD sludge is the waste product from mine drainage treatment. Lime-treated flocs can contain up to 50 percent unreacted lime. Field results are limited. Organic waste is different from the other alkaline generating processes in that it does not directly impart alkalinity. Several species of bacteria can obtain metabolic energy by reacting sulfate with simple organic compounds. In the process, sulfate is reduced and bicarbonate is created (i.e., alkalinity). Stalker and others (1996) performed laboratory studies on a variety of organic materials. The rates of sulfate reduction for cellulose materials (sawdust, pulped newspaper and mushroom compost) were slow, but for milk products (cheese whey and lactate) the rates were more rapid.

Application Rates

Published studies on alkaline addition primarily examine mines in the northern Appalachian. The transferability of this research to the southern Appalachians is not fully known. The overburden in the southern Appalachians is typically lower in sulfur than overburden in the northern Appalachians. Field studies of alkaline addition in the northern Appalachians appear to be converging on required application rates. The amount needed to produce alkaline drainage is approximately 1.5 to 3 percent $CaCO_3$ equivalent for sites with low to moderate pyrite content. This application rate appears deceptively low. One percent $CaCO_3$ equates to approximately 37 tons of $CaCO_3$ for each acre-foot of overburden. A 100-acre surface mine with an average overburden thickness of 50 feet needing 1 percent additional $CaCO_3$ would require 183,500 tons of added alkaline material or 1,835 tons/acre. Thus, the feasibility of an alkaline addition project usually becomes a matter of economics as well as science. The challenge is to determine the minimum alkaline addition rate which will still be effective in preventing acidic drainage.

Using data from Brady and others (1994) and Perry and Brady (1995), Tables 2.2.1c - 2.2.1f show overall neutralization potential (NP) and net NP (NPP) requirements in order to produce alkaline drainage using acid-base accounting data. In all cases, NP and NNP calculations are made using the method described by Smith and Brady (1990). Total weights of overburden, NP, and maximum potential acidity (MPA) are determined for each drill hole interval, based on an approximation of the areal extent of that interval and unit weights for overburden materials. The total weights of the coal intervals are multiplied by a pit loss factor of 0.1, assuming that approximately 10 percent of the coal will be lost in the pit and not removed. A higher or lower pit loss factor can be used if warranted by site-specific conditions. The uppermost 0.5 feet of strata underlying the bottom coal seam is also included in the calculation. These quantities are summed to determine the total tonnage of overburden, NP, MPA and to represent the overall NP, MPA and NNP in parts per thousand as $CaCO_3$ for the site. Multiple overburden holes are combined by considering an area of influence of each hole using the Theissen polygon method (Smith and Brady, 1990).

Table 2.2.1c: Percentage of Sites Producing Net Alkaline Drainage by Net Neutralization Potential without Thresholds

Net NP (ppt $CaCO_3$)	Number of Sites (n)	% with Net Alkaline Drainage
< -10	1	0.0
-10 to 0	11	18.2
0 to 12	17	58.8
>12	10	100.0

Table 2.2.1d: Percentage of Sites Producing Net Alkaline Drainage by Total NP without Thresholds

Total NP (ppt $CaCO_3$)	Number of Sites (n)	% with Net Alkaline Drainage
<5	3	0.0
5 to 10	9	33.3
10 to 18	10	50.0
18 to 22	7	71.4
>22	10	100.0

Table 2.2.1e: Percentage of Sites Producing Net Alkaline Drainage by Net NP with Thresholds

Net NP (ppt $CaCO_3$)	Number of Sites (n)	% with Net Alkaline Drainage
< -2	14	28.6
-2 to 6	14	57.1
>6	11	100.0

Table 2.2.1f: Percentage of Sites Producing Net Alkaline Drainage by Total NP with Thresholds

Total NP (ppt $CaCO_3$)	Number of Sites (n)	% with Net Alkaline Drainage
<2	12	16.7
2 to 9	12	50.0
>9	15	100.0

When all acid base accounting (ABA) data are considered (i.e., there are no significance thresholds), an overall NNP greater than 12 ppt $CaCO_3$, or a NP greater than 22 ppt $CaCO_3$ is very likely to assure alkaline drainage. Based on these data, a conservative approach to determining alkaline addition rates would require application of alkaline material at a rate equal to the difference between an overall NNP of 12 ppt $CaCO_3$ or a NP of 22 ppt $CaCO_3$ and the actual pre-mining overall NP or NNP. A site having a NNP of 2 ppt $CaCO_3$, for example, would require the application of an additional 1 percent $CaCO_3$ (10 ppt). An example calculation is shown below:

Tons of overburden: 1,000,000 tons
Acres of mining: 20 acres
Average Net NP: 2 ppt $CaCO_3$
Deficiency: (12 - 2) ppt $CaCO_3$ = 10 ppt $CaCO_3$ = 1%

Tons additional NP required for Net NP of 12: 1% x 1,000,000 tons overburden = 10,000 tons
Tons per acre required: 10,000 tons / 20 acres = 500 ton/acre
Adjusted for alkaline material with 80% $CaCO_3$ equivalent: 500 tons/acre / 80% = 625 ton/acre

Similarly, where significance thresholds are used to analyze ABA data, a "safe" alkaline addition rate would bring the overall NP value above 9 ppt $CaCO_3$ or the NNP above 6 ppt $CaCO_3$.

Traditionally, the Commonwealth of Pennsylvania has required most alkaline addition sites to produce an overall NNP of 0 ppt $CaCO_3$ with thresholds. The success rate for sites with this application rate is risky at best, with only 59 percent of sites in this class producing alkaline drainage (Smith and Brady, 1990). To a great extent, the selection of the appropriate alkaline addition rate is determined by the risk of failure that can be tolerated, as well as by the availability and cost of alkaline additives.

As more data are compiled, the ability to accurately determine minimum alkaline addition rates needed to obtain alkaline drainage should improve. Also, based on the limited experience to date, most alkaline addition projects using more than 500 tons/acre as $CaCO_3$ have been successful. Except for sites with very low sulfur, alkaline addition rates less than 500 tons/acre have consistently failed to produce alkaline drainage. This is based on a small population of alkaline addition sites (about five), none of which contained the worst possible overburden. It would be premature to conclude that alkaline addition of more than 500 tons/acre will ensure success on all sites or that lower addition rates guarantee failure.

Materials Handling and Placement

Most successful alkaline addition sites have employed thorough mixing of alkaline material throughout the backfill. This can be done using various methods. One innovative and effective approach is to use the alkaline material as blast hole stemming (Smith and Dodge, 1995). Depending on the material being used and how well it packs, it may also result in more effectively directing the blast energy at breaking overburden. Alternately, alkaline material can be placed on the surface of the overburden where it will be subsequently redistributed following excavation and placement.

Another method of alkaline addition is to place the material on the surface of regraded spoil and disk it into the upper portion of the spoil. This approach usually is used either in combination with mixing in the backfill or as a remedial measure after the site has already been backfilled. Although it was originally thought that this method would take advantage of the added alkalinity in the most active zone of AMD production and create an alkaline environment, inhibiting AMD formation, most projects employing only surface application have not been successful. There are at least three possible explanations:

13) Dissolution of $CaCO_3$ and the production of alkalinity at near surface conditions is limited by the partial pressure of CO_2. Typically, the maximum alkalinity which can be achieved under thin soil cover is approximately 75 to 150 mg/L, (Rose and Cravotta, 1998). This greatly limits the effectiveness of near-surface alkaline material and usually does not produce enough alkalinity to neutralize acidity generated elsewhere in the backfill;

14) Mine spoils do not transmit water as a uniform wetting front (Caruccio and Geidel, 1989). Rather, surface waters tend to preferentially infiltrate the spoils at the most conductive areas, effectively bypassing much of the near-surface alkaline material; and

15) Contact of limestone with acid-producing materials is very limited in the surface environment.

The earliest alkaline addition projects involved spreading all of the alkaline material on the pit floor, prior to backfilling. The assumption was that this portion of backfill was the most likely to be saturated, allowing the alkaline material to neutralize all of the acidity produced. These sites tended to produce alkaline drainage initially, which soon changed to acidic drainage. This is presumably because the pit floor environment was not anoxic, and the alkaline material became ineffective due to armoring with ferric hydroxide precipitate. Alkaline addition to the pit floor still has utility, however, when there is a need to neutralize a high-sulfur pit floor. If the pit floor is saturated, and iron remains ferrous, calcite on the pit floor should function as an anoxic drain neutralizing acidity. Putting most of the material on the pit floor fails to take advantage of the inhibitory effect of maintaining a near-neutral pH within the spoil environment. There probably is little utility in application rates of more than 100 tons/acre to the pit floor, although at least 20 tons/acre should be applied to provide complete coverage. Again, the key appears to be getting the alkaline material mixed throughout the spoil, especially throughout the more pyritic material.

Alkaline addition is frequently implemented in conjunction with special handling of high-sulfur zones, where high sulfur material is placed in pods and isolated from percolating ground water.

Alkaline material can be mixed with the high-sulfur material to prevent AMD formation within the pod and to help maintain an alkaline environment near the pod. Alkaline material can be placed in conjunction with a cap to enhance hydraulic isolation. Observations at the Kauffman project suggest that lime kiln dust may actually cement the material, inhibiting ground-water flow (Rose and others, 1995).

The use of alkaline addition as part of special materials handling has not yet been fully evaluated although some demonstration projects are underway. Recommended procedures for handling imported alkaline materials have undergone continuous modification as more is learned about AMD prevention and the interaction between acid-forming materials and neutralizing agents. Currently, the recommended procedure is to first ensure that enough alkaline material is thoroughly mixed within the backfill. In addition, smaller amounts of imported alkaline material should be applied to the surface of the regraded backfill. Applications to the pit floor should be limited to conditions requiring isolation or neutralization of a high-sulfur pavement, and to no more than is needed to provide sufficient coverage. Unless the remaining spoil is clearly alkaline, sufficient alkaline material also should be retained for distribution throughout the backfill.

Alkaline Redistribution

A practice similar to alkaline addition is the redistribution of alkaline materials to alkaline-deficient areas from areas of the same or adjacent mine sites which have more than ample alkaline strata. This procedure is practical where sufficient quantities of alkaline material are present, but distribution is so uneven that some portions of the backfill do not contain enough neutralizers to prevent or neutralize AMD. Alkaline redistribution then becomes largely an exercise in materials handling. Alkaline stratigraphic units should be clearly identified, segregated, transported to the alkaline-deficient area, and incorporated into the backfill. Depending on the quantity and characteristics of the alkaline material available, it may also be necessary to crush the material prior to redistribution. The obvious advantage to redistribution, if it can be done, is the ready availability of the material and the low or zero cost of transportation.

Michaud (1995) developed a mining plan for a proposed surface mine where alkaline redistribution was fully integrated into the operation, minimizing the need for stockpiling and rehandling of alkaline overburden. Through the implementation of a complex series of selective sequencing of cuts and multiple benches, the handling plan provided for redistribution of alkaline strata, which existed only in limited areas and stratigraphic intervals throughout the site. Through this approach, thorough mixing of alkaline material could be achieved while avoiding the need to identify, segregate, and redistribute specific geologic units, usually the most difficult part of a spoil redistribution plan.

Alkaline redistribution has been successfully employed on several surface mining sites that are currently producing alkaline drainage. The Bridgeview "Morrison" site in Township, Fayette County, Pennsylvania, had abundant calcareous rock over most of the site with NPs as high as 700 ppt $CaCO_3$, but more typically in the 100 to 300 ppt $CaCO_3$ range. The site included two areas of about five acres each, containing shallow overburden and lacking calcareous rock due to erosion and weathering. Alkaline material from the high cover area was transported to these low cover areas. The resulting post-mining water quality from the areas was alkaline.

The Amerikohl "Schott" site in Westmoreland County, Pennsylvania, had calcareous rock on only about eight acres of the 38 acre site. Originally four acid-base accounting holes were drilled. These were supplemented by additional holes drilled to determine the lateral distribution of the calcareous rock. The calcareous rock was removed during mining operations and incorporated into the spoil on all portions of the mine. Waste limestone was also placed on the pit floor at the rate of 100 tons/acre. Four years of post-mining water quality monitoring data shows the water to be net alkaline with alkalinity ranging from 10 ppt to 138 ppt $CaCO_3$.

Alkaline Addition as a Best Management Practice on Shallow Overburden

In many cases, relatively low (less than 300 tons/acre) alkaline addition rates have been employed on mine sites that indicated a relatively minor potential to produce acid mine drainage, but were lacking in significant calcareous strata. Although these sites commonly have low sulfur contents, they frequently produce mildly acidic drainage due the lack of any significant NP. In other cases, alkaline addition was used as an added safety factor to assure alkaline drainage. Alkaline addition has proven to be an effective "best management practice" for these types of sites.

Often, mine sites with shallow overburden (less than 40 feet) have had calcareous minerals and pyrite leached out by weathering (Brady and others, 1988). Since easily weatherable minerals have been removed, water flowing through the overburden material picks up very little dissolved solids and emerges essentially with the characteristics of rain water. In Pennsylvania, precipitation typically has a pH less than 6.0. Thus, post-mining water from weathered overburden may also have a pH of 6.0 or less. The addition of alkaline material is needed to ensure alkaline post-mining drainage. An example of this implementation is described in Case Study 1, Section 2.2.3.

2.2.2 Verification of Success or Failure

A critical step in successful alkaline addition is to ensure that the alkaline addition plan is properly implemented. Both the amount of material to be applied and its distribution throughout the site should be appropriate. Because of the large quantities of materials involved, careful record keeping of each shipment of alkaline material and calculation of the quantities of material distributed is required. Depending on the method of mining, quantities of alkaline material to be applied or distributed should be tabulated for each individual cut or phase of the operation. It is necessary also to periodically retest the neutralization potential of the alkaline material being used, with a frequency determined by the variability of the material.

Inspections by the regulatory agency of sites with alkaline addition as a BMP should be frequent and detailed enough to document compliance with the mining plan. An inspection checklist identifying key aspects of the plan will be useful in many cases.

Implementation Checklist

Recommended items to be considered during the permit review process include:

- Site-specific overburden data should be available for determination of the amount of alkaline material.
- The site-specific overburden data should be representative of the mine overburden. This will typically require multiple holes and appropriate vertical sampling.
- Plans should be clearly designed with appropriate maps, cross-sections and narrative.
- The plan should be feasible in the field, not just on paper.
- The plan should be enforceable.

Recommended items to consider in an alkaline addition implementation inspection checklist include:

- Does what is being done in the field correspond with the plan that is specified in the permit plans, as shown on maps, cross-sections, and in the narrative?
- Is the appropriate equipment available?
- Is the alkaline material being placed where specified?
- Is the alkaline material being brought to the site the material that was specified in the permit plan?
- Are weigh slips or other records available to verify the amount of materials being imported? Are they up to date? Do these records match what can be observed on the site, in terms of material stored and applied?
- Is water-monitoring data being submitted?

2.2.3 Literature Review and Case Studies

There has been an extensive body of literature published on alkaline addition. This literature is discussed below along with selected case studies. An early published report regarding the use of imported alkaline material as a method of preventing the formation of acidic drainage was in the West Virginia Surface Mine Drainage Task Force's *Suggested Guidelines for Method of Operation in Surface Mining of Areas With Potentially Acid-Producing Materials* (1979). The Guidelines recommend that alkaline material be added to the backfill at the rate of one third of any net deficiency in neutralization potential as determined by acid-base accounting. Why this rate was selected is uncertain. Many sites with alkaline application rates based on this recommendation have subsequently failed and are producing acidic drainage.

Waddell and others (1986) used alkaline addition to abate acidic drainage resulting from the construction of Interstate 80 in north central Pennsylvania. The Waddell study involved surface application of limestone crusher waste and lime flue dust at the rate of 267 tons/acre. It improved pH values from 3.9 to 4.4. Sulfate concentrations were also reduced, indicating that the alkaline addition not only neutralized acid mine drainage (AMD) but slowed its production.

Geidel and Caruccio (1984) examined the selective placement of high-sulfur material in combination with the application of limestone to a pit floor at the rate of 39 tons/acre. Although the treated site initially produced alkaline drainage, the drainage soon became acidic. An untreated control site produced acidic drainage throughout the same period.

Attempting to abate acidic drainage from a Clarion County, Pennsylvania, mine site, Lusardi and Erickson (1985) applied high-calcium crushed limestone at the rate of 120 tons/acre. Although net neutralization potential (NNP) deficiencies at the site ranged from 25 to 590 tons/acre, they assumed that most acid production occurred near the surface and that it was necessary to add only enough limestone to balance the NP deficiency in the upper two meters of spoil. The limestone was disced into the upper 1.0 feet of the spoil surface. One year after application, no substantial neutralization or inhibition of acid formation was noted.

O'Hagan and Caruccio (1986) used leaching columns to examine the effect of varying rates of limestone application on alkaline and non-alkaline shales. A sulfur-bearing (1.07 percent) noncalcareous shale produced acidic drainage when no limestone was added, mixed neutral/ slightly acidic drainage when 1 to 2 percent limestone was added, and alkaline drainage when 3 percent or greater limestone was added. Following longer periods of leaching, the shale with 1 to 2 percent limestone produced consistently acidic drainage. The alkaline shale produced alkaline drainage regardless of whether or not any limestone was added.

By 1990, there were enough well-documented surface mining operations that had employed alkaline addition to allow an extensive review of the effectiveness of alkaline addition in preventing or ameliorating acid mine drainage. Brady and others (1990) examined 10 Pennsylvania mine sites. Of these 10 sites, eight employed alkaline addition as a means of preventing postmining AMD. Six of the eight alkaline-addition plans failed to prevent AMD. The sites which were successful in preventing or at least ameliorating AMD had several things in common: 1) alkaline addition rates were among the highest (500 to 648 tons/acre) and exceeded permit requirements, 2) pyritic materials were specially handled, 3) backfilling was performed in a timely manner, and 4) some potentially acid-forming materials were removed from the mine site. The study concluded that most unsuccessful attempts at alkaline addition were too conservative in terms of the application rate, particularly the practice of applying one-third the calculated deficiency. Further, alkaline addition is most effective when it is incorporated into the backfill concurrently with mining and reclamation and when implemented in conjunction with other best management practices.

A study of the use of acid-base accounting for predicting surface coal mine drainage quality (Brady and others, 1994) showed a strong relationship between the presence of neutralizing minerals in the overburden (generally carbonates) and the alkalinity of post-mining discharges. Critical values of NP and NNP were identified. Mines with NP values greater than about 15 ppt and NNP greater than 10 ppt $CaCO_3$ had net alkaline drainage. Sulfur content alone was not a reliable predictor of post-mining water quality, except where calcareous strata were absent. The implication for alkaline addition is clear. If it is assumed that imported alkaline material behaves no differently than native alkaline strata, the application of alkaline material at a rate that simulates a naturally alkaline site should assure alkaline post-mining water quality.

Skousen and Larew (1995) studied an alkaline addition project that imported alkaline shale from a nearby mining operation to an operation that was deficient in neutralizers. Although the deficiency calculated from ABA data was equivalent to a one-foot thick layer of the alkaline shale, 3 to 4 feet of shale were actually imported. Significantly, for this discussion, the alkaline addition project successfully prevented AMD.

Perry and Brady (1995) found that overall NP values in excess of 21 ppt $CaCO_3$, and NNP values greater than 12 ppt $CaCO_3$ would produce net alkaline water. Overall NP and NNP values less than 10 ppt $CaCO_3$ and 0 ppt $CaCO_3$, respectively, produced net acidic water. Variable water quality was found for NP and NNP levels between these limits. The same water quality data were examined using significance thresholds. Sulfur contents less than 0.5 percent and NP values less than 30 ppt $CaCO_3$ for individual strata were considered to be insignificant producers of acidity or alkalinity; hence, values which did not exceed these thresholds were assigned a value of zero for the NP and NNP calculations. Applying significance thresholds, overall (the entire volume of overburden to be mined) NP and NNP values greater than 10 ppt and 5 ppt $CaCO_3$ produced consistently alkaline water. Neutralization potential and NNP values less than 1 ppt and -5 ppt $CaCO_3$ produced consistently acidic drainage. Noting decreased sulfate concentrations with increasing NP, they concluded that the presence of carbonate minerals in amounts as low as 1 to 3 percent (10 to 30 ppt of NP) inhibit pyrite oxidation. Moreover, maintenance of the alkaline conditions created by carbonate dissolution is not conducive to bacterial catalysis or ferrous iron oxidation and greatly limits the activity of dissolved ferric iron, thus interrupting the self-propagating acid cycle.

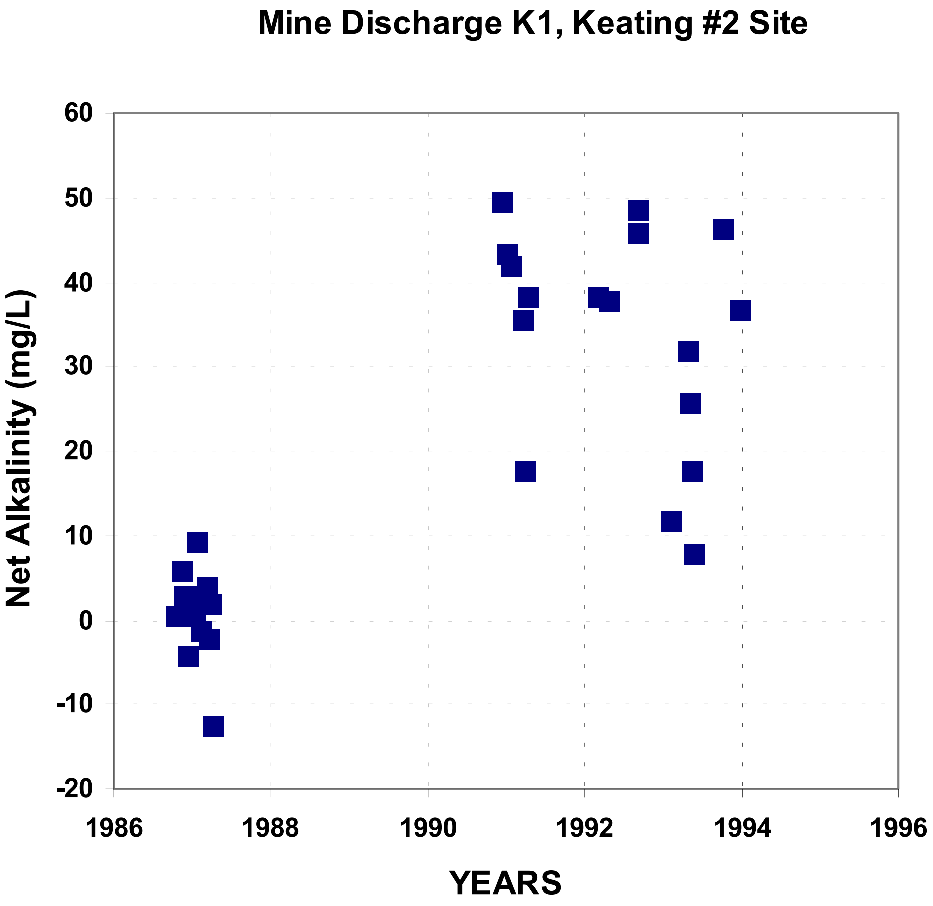
Case Study 1 (West Keating Township, Clinton County, Pennsylvania)

Unfortunately, actual mine sites having adequate acid-base accounting data, water quality monitoring, and records of mining practices (including alkaline addition rates and placement of materials) are difficult to find. One such site is located in West Keating Township, Clinton County, Pennsylvania. The area had been previously mined on a rider seam 10 feet above the main bench of the middle Kittanning (MK) coal, and had not been reclaimed. The recent operation mined the remaining MK coal and reclaimed the previously mined area. The total area affected by MK coal removal was 11.5 acre and the maximum highwall height, including old spoil, was about 20 feet. Overburden analysis was performed on five drill holes, but only sulfur was determined. The deepest hole was 18 feet to the bottom of the coal and seam and the shallowest was 5 feet. Rock between the rider coal and the MK was described as "soft brown shale," indicating weathering. The coal had the highest sulfur of any of the strata encountered, ranging from 0.28 to 0.50 percent. Sulfur in the rest of the overburden was 0.13 percent or less. No NP was determined, however, based on experience with other sites with shallow overburden in the same region, it can be assumed that no significant carbonates were present.

Mining began in January 1988, and the site was backfilled by the end of March 1988. Some alkaline material was added during mining, but the precise amount is not clear. The operation permit required 10 tons/acre of limestone to be added to the pit floor, and there would have been another 5 to 10 tons/acre of limestone added to the reclaimed surface for revegetation purposes. It is suspected that these alkaline addition amounts are minimums, and the actual amount added was probably several times greater.

A down-gradient discharge from an unreclaimed pit (K1) was monitored before and after mining. Following mining, the location of the discharge moved down hill to a lower seam that also had been mined. It is unclear why this point was not monitored during mining, although it may have gone dry. Figure 2.2.3a shows water quality over time for net alkalinity and sulfate. Water quality improved following mining. Because the overburden contained virtually no source of alkalinity, the increase in alkalinity would not have been possible without the importation of limestone. The added material was adequate to maintain net alkaline conditions from 1990 through sometime in 1994. The sulfate concentrations, mostly less than 40 mg/L, confirm that there was little pyrite available for oxidation. These concentrations are typical of pre-mining sulfate within the Appalachian Plateau (Brady and others, 1996). Comparatively small amounts (perhaps around 40 tons/acre) of alkaline addition may have been sufficient because of the small amount and highly weathered nature of overburden present at this site.

Figure 2.2.3a: Water Quality Before and After Mining at the Keating #2 Site, Clinton, PA

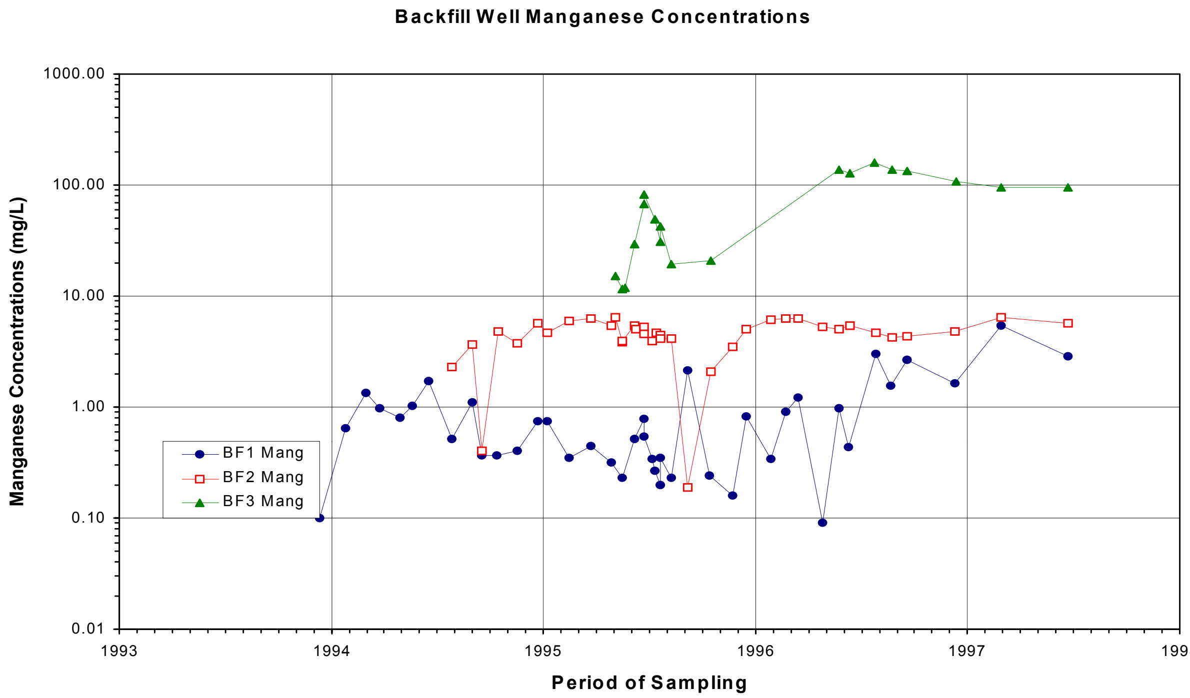


The Case Study 1 site illustrates that a surface mine with weathered overburden that lacks pyrite can produce alkaline drainage with a minimal quantity of alkaline material added as a safety factor. Without the addition of alkaline material, there would have been little or no alkalinity produced.

Case Study 2 (Boggs Township, Clearfield County, PA)

This study site is just to the south of the PA(19) site (Appendix A, EPA Remining Database, 1999). The alkaline addition measures used on PA(19) were partly derived from experience gained from this site. Rose and others (1995) reported results from an ongoing alkaline addition demonstration project in Clearfield County, Pennsylvania, that indicated positive but preliminary results. More recent data from monitoring wells in the backfill show mixed results. Baghouse lime, a lime production waste product, was applied at rates ranging from 150 to 1,080 tons/acre, adjusted to 100 percent $CaCO_3$ content, based on ABA calculations using significance thresholds and correcting for deficiencies in NP. Areas with the highest alkaline addition rate (and the most acidic overburden) were successful in producing alkaline drainage with low concentrations of dissolved iron and manganese (Figure 2.2.3b). Backfill wells in areas which received lower alkaline addition rates showed both alkaline and acidic water and relatively high levels of dissolved iron and manganese. Post-reclamation sulfate levels of 300 to 800 ppt in all of the monitoring wells indicate that AMD is being produced but neutralized.

Figure 2.2.3b: Water Quality Before and After Mining at the Case Study 2 Site



Based on the experience from this demonstration project, it is probably unrealistic to adjust alkaline addition rates based on minor overburden quality variations between drill holes. Unless there is a corresponding change in stratigraphy, alkaline addition rates should reflect aggregate (average) overburden quality.

Evans and Rose (1995) also reported the results of alkaline addition to large test cells constructed solely of high-sulfur overburden from this site. Cells were constructed of 2 percent pyritic sulfur mixed with different amounts of alkaline material. Although alkaline addition reduced the generation of acidity by as much as 96 percent, even the highest alkaline addition amount, equivalent to 3.4 percent $CaCO_3$, was insufficient to prevent AMD formation. Two important considerations resulted from this study. First, the high-sulfur overburden was exposed to weathering for a considerable time period before cell construction and application of alkaline material. Test cells remained exposed without a soil cover for an extended time period thereafter. More rapid application of alkaline material and timely covering may have reduced the likelihood of AMD formation. In other words, once AMD generation starts, it is much more difficult to slow its formation than to keep it controlled in the first place. Second, because complete mixing of alkaline material may be difficult or impossible to achieve, microenvironments within the spoil can still allow acid production and bacterial activity. AMD formation in very high-sulfur mine sites or areas of concentrated high-sulfur refuse, represented by the concentration of highly pyritic material in the cells, may be impossible to ameliorate using alkaline addition rates which have otherwise been successful in mines with more typical sulfur values.

Case Study 3 (Appendix A, EPA Remining Database, 1999 (PA (8))

Smith and Dodge (1995) reported on an alkaline addition site in Lycoming County, Pennsylvania, which was part of the original Brady and others (1990) study. Alkaline addition rates of 600 tons/acre and daylighting of an underground mine resulted in dramatic improvements in water quality from the underground mine discharge (Figure 2.3.3c). Pre-mining net acidity values exceeded 100 mg/L. After remining, the discharge was predominately alkaline.

Increased sulfate concentrations indicated that the improvement in water quality could be attributed to neutralization by imported alkaline material rather than daylighting. No naturally occurring alkaline material was present. This operation is one of the oldest successful alkaline addition sites. It has exhibited improved water quality since the onset of large-scale alkaline addition in 1986 and produced predominately alkaline water since 1989, suggesting that the impact of alkaline addition will be long-term or permanent.

Figure 2.2.3c: Water Quality at the Case Study 3 Site

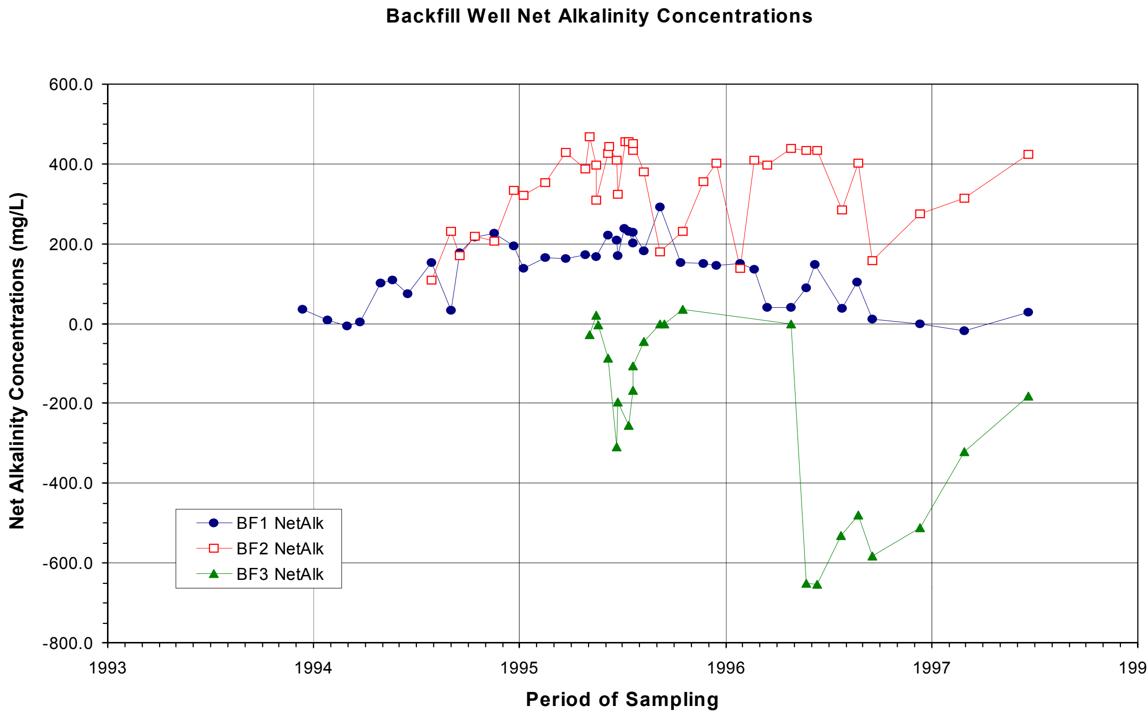
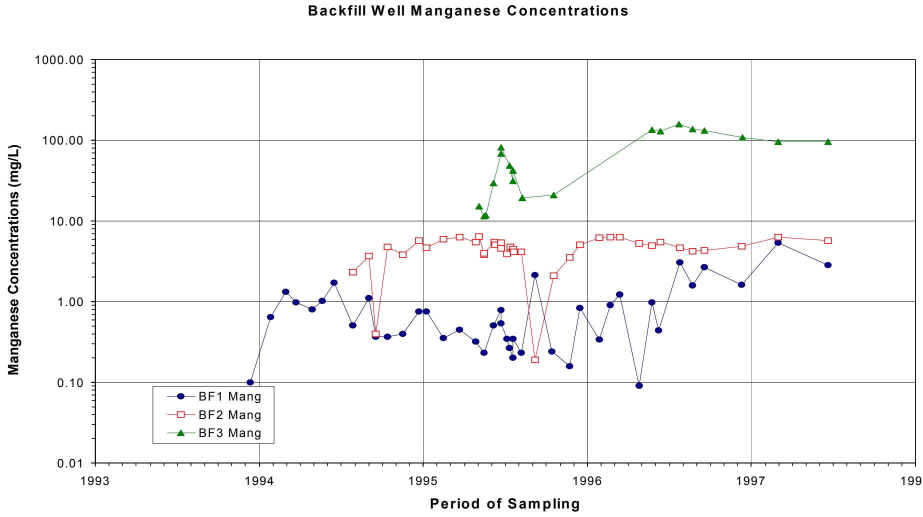


Figure 2.2.3c: Water Quality at the Case Study 3 Site (continued)



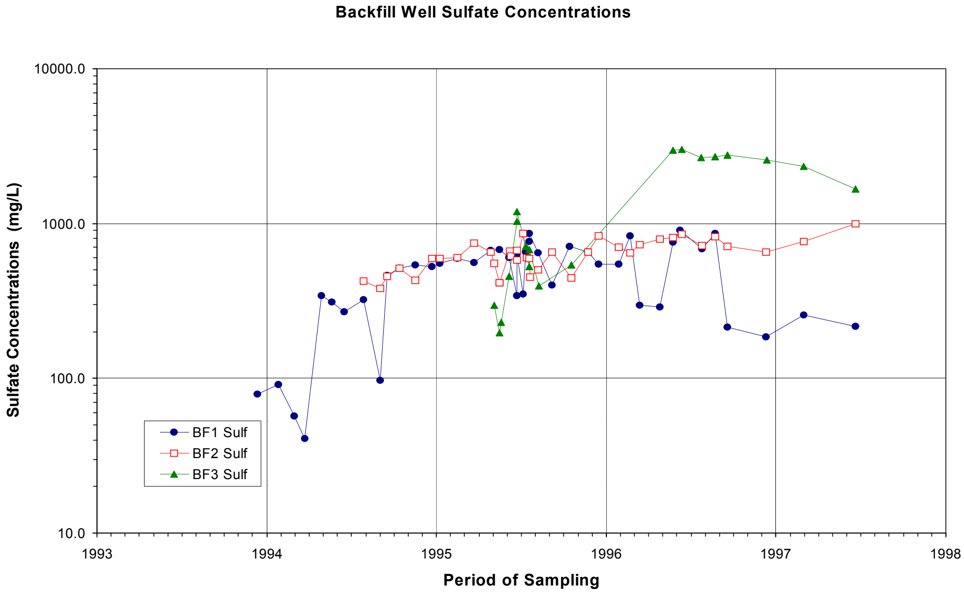
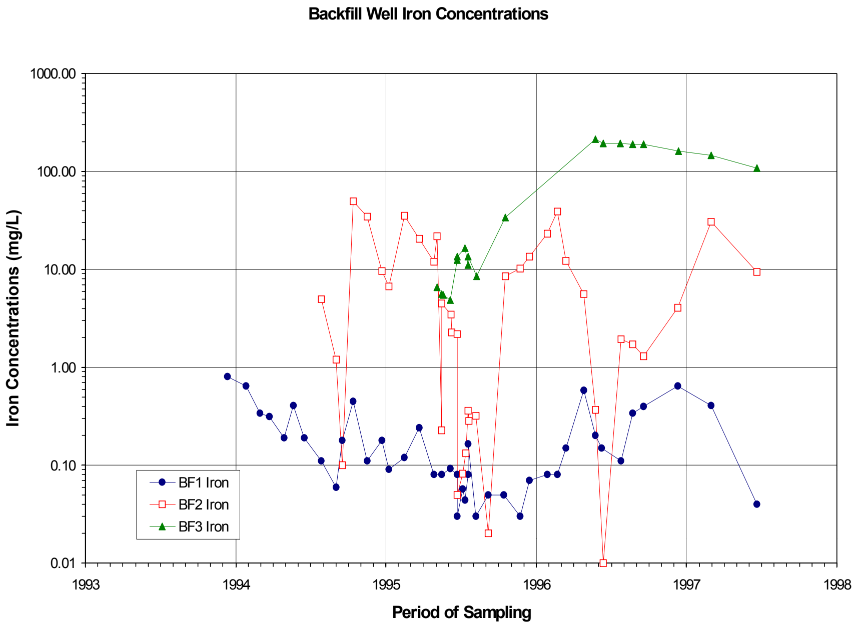


Figure 2.2.3c: Water Quality at the Case Study 3 Site (continued)



Case Study 4 (Sequatchie County, Tennessee)

Most of the published research in alkaline addition has taken place in northern Appalachian states. An exception is the work done by Wiram and Naumann (1996) on an AMD-producing surface mine in Sequatchie County, Tennessee. This site is adjacent to the TN(4) site (Appendix A, EPA Remining Database, 1999), and the pollution prevention measures used on TN(4) were first applied at this study site. Alkaline addition was implemented as the principal component of a toxic materials handling plan that also included selective overburden placement and the construction of chimney drains and alkaline recharge basins. Alkaline addition rates were determined for individual stratigraphic intervals having a NNP less than -5, however, a modified NP test was used in order to exclude the apparent NP contribution from siderite ($FeCO_3$).

Previous overburden analysis results erroneously predicted alkaline drainage due to the presence of siderite that falsely indicated the presence of significant alkaline strata. The role that siderite plays in mine drainage and acid-base accounting are explained by Skousen and others (1997). Limestone application rates for each of these intervals were summed to determine the application rate for the area around each bore hole. Net neutral zones were not factored into the alkaline addition calculations.

Results of the Wiram and Naumann study were favorable. Monitoring wells on the site in the backfill spoil area that had alkaline addition have higher alkalinities than wells into areas that did not have alkaline addition.

2.2.4 Discussion

It has long been known that mines with sufficient naturally occurring calcareous strata produce alkaline mine drainage. It is a logical next step that sites without sufficient naturally occurring alkaline strata can be made to produce alkalinity by importing the appropriate amount of alkaline material. The questions are: how much alkaline material should be added, and where should it be placed? Another question that can be of equal importance, especially in sensitive watersheds, is how much risk of failure can be tolerated. The literature and the case studies cited above provide some insights into these questions and identify benefits and limitations of the methods.

Benefits

- Alkaline materials are an effective means of neutralizing and preventing AMD.
- Alkaline materials are generally readily available, and in some cases available as waste products that would otherwise be landfilled.
- Alkaline addition is probably the best understood "chemical" BMP, and there are natural analogues (i.e., calcareous mines) for comparison.
- The amount of material required to assure alkaline drainage for low to moderate sulfur sites is well understood.

- The chemistry of the alkalinity generating processes of carbonate minerals is well understood.
- Site-specific data can be obtained to determine the amount of alkaline material that needs to be added.

Limitations

- Alkaline addition is not generally effective at fixing a problem once it has been created.
- Alkalinity from carbonate dissolution is limited and may not be adequate for high sulfur mines and coal refuse materials.
- Alkaline materials can armor with iron precipitates and become ineffective. Proper placement of alkaline materials to avoid high iron water is a way to prevent this problem.
- Ensuring that a site produces alkaline water does not guarantee that effluent limitations for metals will be met.
- Siderite can produce overburden analyses that falsely predict alkaline drainage. A modified method for determination of neutralization potential can greatly reduce this risk.

Efficiency

- Alkaline addition has proven to be an effective mine drainage prevention technique for mines with low to moderate sulfur content.
- Studies show that mines with net neutralization potentials greater than 12 produce alkaline drainage.
- For sites with moderate sulfur, alkaline addition rates below 500 tons/acre typically have not produced alkaline drainage.
- Alkaline addition rates at less than 500 tons/acre can be effective for low sulfur sites that would not otherwise produce alkaline water because of a lack of naturally occurring carbonates.
- More work needs to occur in the southern Appalachians to determine appropriate addition rates for those geologic conditions.

2.2.5 Summary

The addition of alkaline material to surface mine backfill can be an effective method of compensating for overburden that is naturally deficient in neutralizers and thus, reduce the potential for acid mine drainage. Two categories of alkaline additives currently are being used on Appalachian mine sites, limestone (and its derivatives), and coal ash. Coal ash addition was proposed for eight of the 17 alkaline addition sites in the BMP-site data packages.

To successfully prevent the formation of acid mine drainage, a sufficient quantity of alkaline material should be added to the backfill. Most successful alkaline addition sites to date have used substantial application rates, exceeding 500 tons/acre. Lower rates have proven to be effective only for low-cover overburden with very low sulfur content. Alkaline material is best applied by distributing and thoroughly mixing it throughout the backfill. It also may be useful to place up to 100 ton/acre on the pit floor. Surficial applications of alkaline material are less effective due to low solubility of calcite and limited contact with acid-producing materials deeper in the backfill. Most failed alkaline addition sites either had used application rates that were too low or employed ineffective placement of the alkaline material.

2.3 Induced Alkaline Recharge

Constructed recharge infiltration pathways composed of limestone within mine backfill have been used to increase alkalinity in mine spoil and to increase oxygen availability within spoil. These pathways can be near surface features (trenches) or deeper structures that extend from the surface to the base of the spoil (funnels). Surface runoff is directed into these pathways where it contacts the limestone and generates alkalinity. The pathway is positioned such that infiltrating water would not contact potentially acid-generating rock. As originally envisioned, the goal is net alkaline water in the mine spoil. A second goal at some sites is to induce oxygen into the backfill with the purpose of precipitating iron from solution. The principal studies on this subject have been conducted by Caruccio and Geidel (1984, 1985, 1989, and 1996) and Wiram and Naumann (1996).

Theory

Pyrite oxidation can result in significant quantities of soluble, acid-producing oxidation products. In fact, mine drainage acidities in the hundreds or even thousands of milligrams per liter are not uncommon. Calcite dissolution, on the other hand, is much more limited in terms of alkalinity generation. At surface conditions the maximum alkalinity is less than 100 mg/L. Carbonates are more soluble at elevated partial pressures of carbon dioxide and under high Pco_2 they can produce alkalinity as high as 500 mg/L, a condition that can occur in mine spoil. Alkalinity and acidity are both reported in the same units of calcium carbonate equivalent and, for example, 100 mg/L of alkalinity will neutralize the acid from 100 mg/L of acidity. A good discussion on the chemistry of pyrite oxidation and carbonate dissolution at coal mines is in Rose and Cravotta (1998).

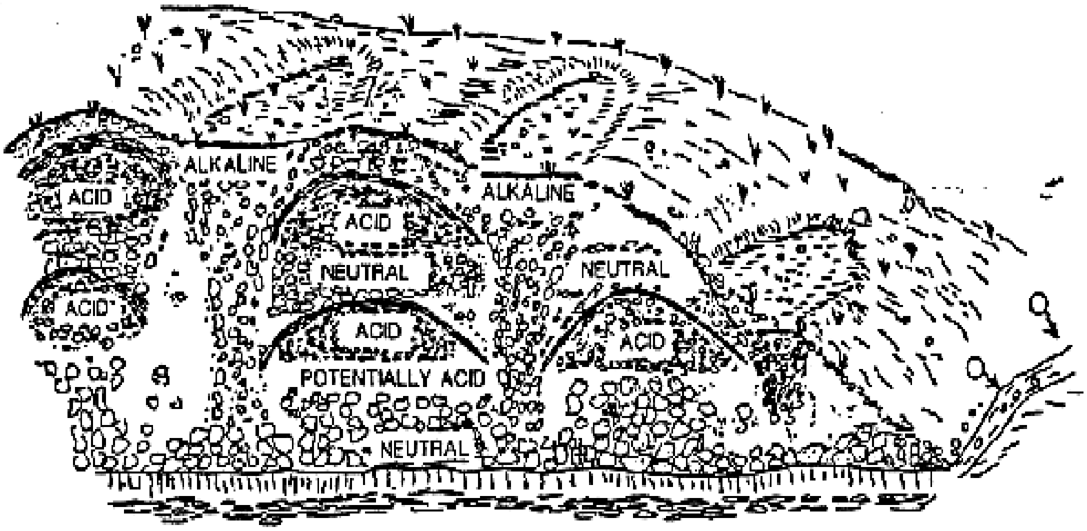
It has been proposed that one way to offset the frequently unequal generation of acidity in comparison to alkalinity was to increase the load of alkalinity. Load is calculated as concentration times flow and is reported in units of mass per time period (e.g., pounds per day). The proposed method was to divert surface runoff into trenches and/or funnels filled with limestone. This water would contact and dissolve some of the limestone. Thus, the water flowing from these structures into the spoil would be higher in alkalinity. It was hoped that the increase in the volume of water, even with limited alkalinity, would result in a large enough alkalinity load to offset the spoil water's acid load. It has been estimated that it would require three to eight times more water in contact with the calcareous material than the water in contact with the acidic material. This concept was developed by Caruccio and Geidel (1984) based on laboratory work by Geidel (1979).

A second purpose for recharge pathways is to promote the inflow of oxygen into the spoil. Oxygen could enter the spoil in three ways, dissolved in the infiltrating water, entrapped in the infiltrating water, and with air directly entering the recharge structure. This would be used where waters are already alkaline or only slightly acidic and where the water is iron-rich. Reduced iron (Fe^{2+}) precipitation is very slow even at neutral pH, however, oxidized iron (Fe^{3+}) precipitates rapidly under alkaline conditions. The additional oxygen would help to enhance oxidation and precipitation of iron within the backfill.

2.3.1 Implementation Guidelines

Caruccio and Geidel (1984) suggest a refinement to the concept above which would incorporate special handling and capping of acidic material. Acid-producing material is placed in pods and capped with clay. Alkaline recharge channels are located such that infiltrating water enters "neutral" or alkaline spoil located between the pods of acidic material. This concept is depicted in Figure 2.3.1a. The purpose is to minimize the amount of acidic water and maximize the amount of alkaline water that reaches the water table in the spoil.

Figure 2.3.1a: **Alkaline Recharge Channels and Capped Acid-producing Material Pods (Caruccio and Geidel, 1984)**



If recharge trenches are installed for the purpose of inducing oxygen into the backfill the limestone (or other rock) should be of sufficient size and sorting to be easily permeable to air.

2.3.2 Verification of Success or Failure

- The BMP should be constructed as designed and the on-site construction plan should be documented. Means of documentation include:
  - Engineer's certification of construction.
  - Photographs of the structure as it is being constructed.
  - Locations of the recharge structures accurately located by survey or global positioning system.
  - Verification of the amount of imported alkaline material by weigh slips or another accounting method. Weigh slips would be submitted to the regulatory authority at specified intervals. A copy should also be available for inspection at the mine site by the mine inspector.

- Increased inspection frequency may be needed to verify that a BMP is being constructed as designed. Inspections can include examination of limestone weigh slips and verification of the size and type of imported material.
- Photographs of the construction process can be taken by the mine inspector, company engineer or other qualified person. Copies would be placed in the state permit file. A narrative, including date and location, should accompany each photograph.
- Water quality monitoring should include both concentration and flow at discharge points. This is especially critical for remining sites where the intent and purpose is to reduce loads of constituents. Because alkaline recharge structures increase flow into the ground-water system, being able to determine load is critical.

Monitoring for concentration and flow, as well as other accurate documentation of construction, will allow for future improvements in design and determination of the efficiency of alkaline recharge structures.

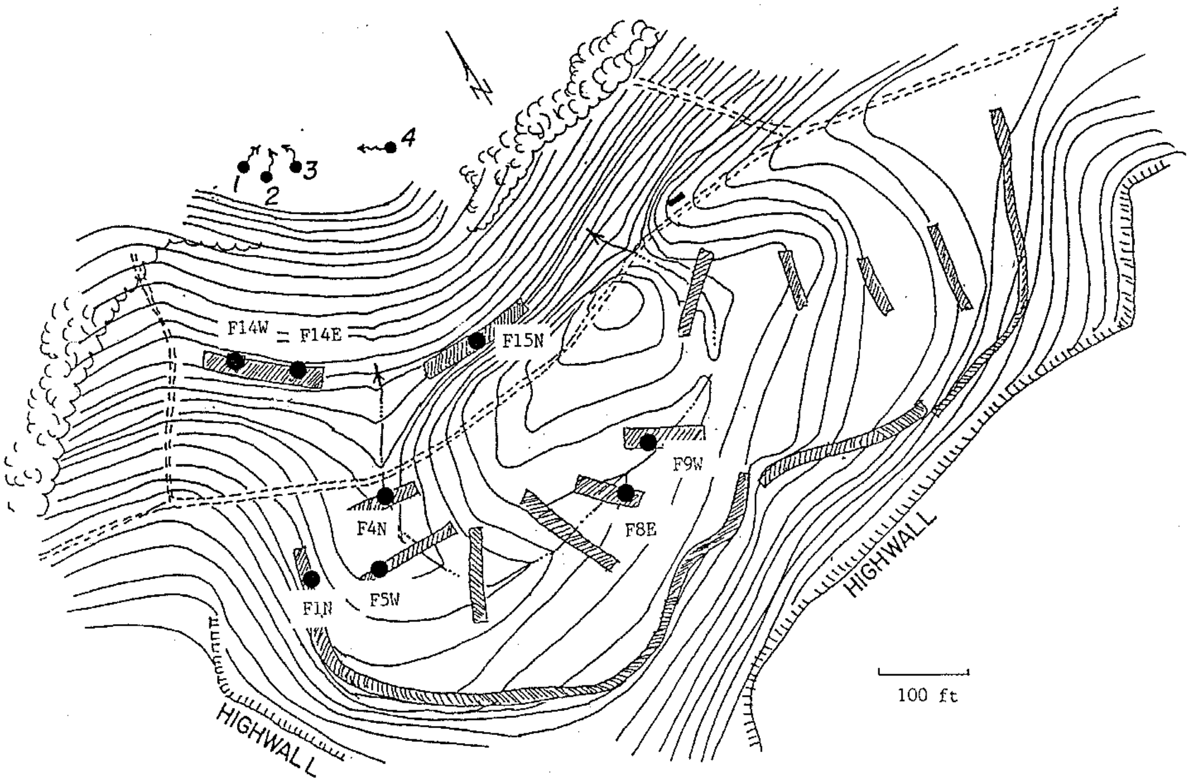
2.3.3 Case Studies

The case studies discussed below are examples of sites where the alkaline recharge concept has been applied.

Case Study 1 (Caruccio and Geidel, 1984, 1985, and 1996)

A site in Upshur County, West Virgnia, is approximately 20 acres and was mined in the early 1970s. Acidic discharges developed following reclamation. Four post-mining discharges from the toe-of-spoil had acidities between 400 and 600 mg/L. Caruccio and Geidel have attempted, over the course of more than a decade, various means of reducing the acidity, most of which involved alkaline recharge structures. Figure 2.3.3a shows the topography, location of recharge trenches and funnels, and locations of the seeps at the site.

Figure 2.3.3a: **Topography, Location of Recharge Trenches and Funnels, and Locations of Seeps (Case Study 1, Upshur County, WV) (Caruccio and Geidel, 1984).**

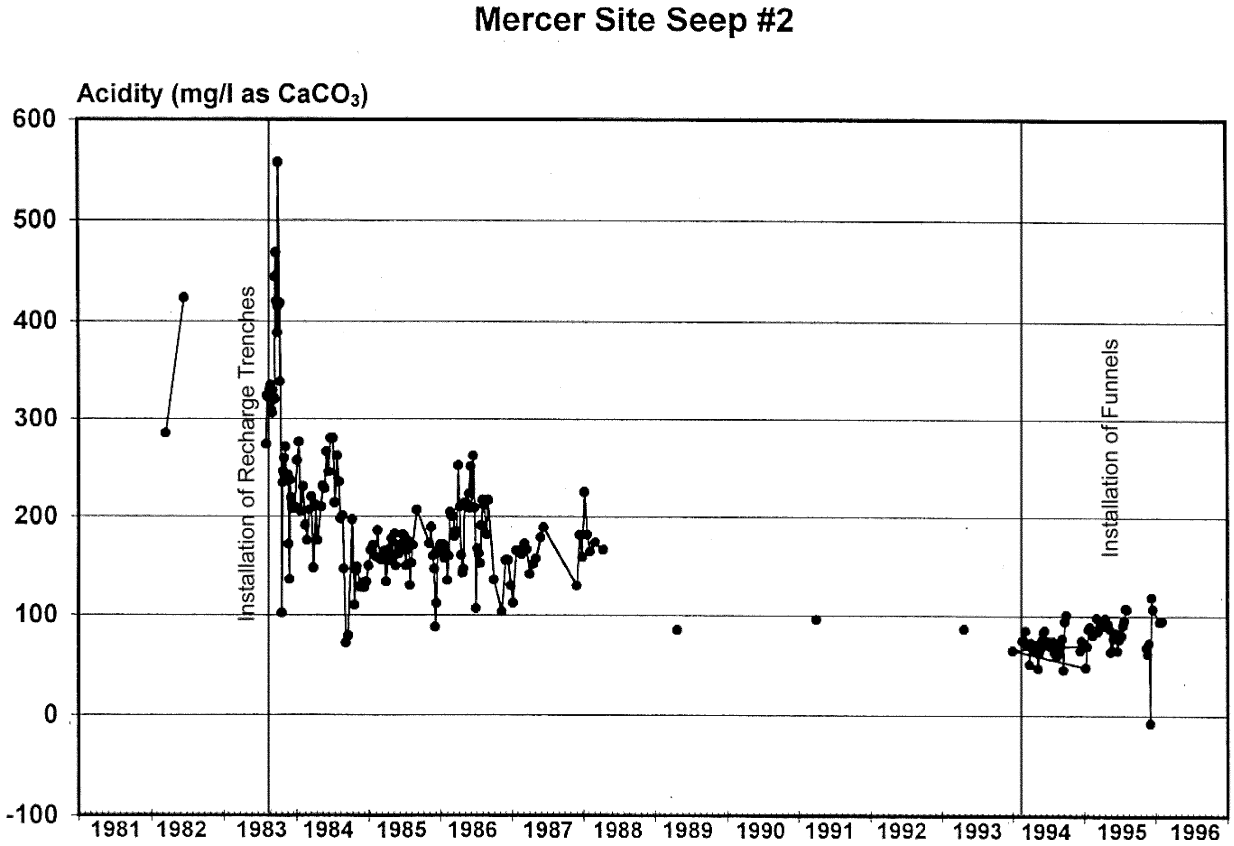


Fifteen alkaline recharge trenches were installed to divert surface water into the ground-water system in the summer of 1983. The trenches averaged 10 feet wide, 3 feet deep, and 75 to 725 feet long. Trench floors were capped with sodium carbonate briquettes (0.5 lbs/ft^2) and covered with two feet of limestone reject. Halogen tracers (KI and KBr) were placed at the base of the trenches to serve as tracers for infiltrating water. Eight months after installation, the tracers appeared at the seeps. At this time, the acidity decreased to a range of 75 to 125 mg/L. Because the water was still acidic, fine limestone (up to ½ inch) was broadcast over the site at a rate of 100 tons/acre in 1984. The acidity continued to hover at around 100 mg/L.

In February 1994, eight funnels were installed adjacent to or within the trenches. These funnels were excavations of approximately 4 feet x 7 feet x 8 feet, and were filled with a total of 60 to 80 tons of coarse limestone having a $CaCO_3$ equivalent of ~70 percent. The purpose of the funnels was to transmit water directly from the surface to the water table. Following funnel installation acidity was 50 to 100 mg/L.

Figure 2.3.3b shows acidity concentrations for Seep #2, and the time lines show when the alkaline recharge trenches and funnels were installed. The data indicate a decrease in acidity concentration following the installation of each BMP. Flow was not measured, thus load could not be calculated. Without flow information, it can not be determined how much of the decrease in acidity was due to dilution from infiltrating precipitation and how much was due to neutralization. Water quality data for the seeps following funnel installation shows alkalinity is occasionally at measurable concentrations, and in a few instances is greater than acidity. This measured alkalinity indicates that, at least occasionally, alkalinity is being generated by the trenches/funnels and sometimes is enough to neutralize all of the acid.

Figure 2.3.3b: Plot of Acidity versus Time for Seep #2 at Case Study 1 Mine (Vertical lines indicate when recharge trenches and funnels were installed.)



There are four possible interpretations of the observed decrease in acidity concentration:

1) Trenches and funnels provided alkalinity to the ground water and thereby neutralized existing acidity.
2) The trenches and funnels increased rain water infiltration into the ground water system, thus diluting the ground water and lowering concentration.
3) Some natural attenuation occurred through time. A control area with similar overburden would have to be monitored to account for the effects of this factor.
4) The decrease in acidity concentration is the result of two or three of the above factors.

If the decreased concentrations are due simply to dilution, increased infiltration could result in an increased acid load and exacerbate the problem. For example if:

> Before construction of funnels:
> Average flow is 10 gpm and concentration is 250 mg/L
> 10 gpm x 250 mg/L x 0.012 = 30 lbs/day acidity
>
> After construction of funnels:
> Average flow is 30 gpm and concentration is 150 mg/L
> 30 gpm x 150 mg/L x 0.012 = 54 lbs/day acidity

An evaluation of whether this BMP was effective requires a knowledge of both flow and concentration.

Case Study 2 (Wiram and Naumann, 1996; Wiram, 1996).

This site is located in Sequatchie County, Tennessee. Mining began in September 1987 and mining used loaders and trucks. Once the initial box cut was in place a dragline was used. Cast-blasting was later employed along with the dragline operation.

In mid-1990, pollution seepage began to enter a receiving stream. The mine discharge water had pH from 3.4 to 7.5, alkalinity from 0 to 121 mg/L, iron from 4.8 to 48.6 mg/L, manganese from 2.3 to 34 mg/L, and sulfate from 8 to 812 mg/L. The coal company embarked on an extensive investigation to determine the source of the problem and effective methods for resolving the problem. Alkaline recharge structures were just one of several BMPs that were ultimately used. Other BMPs included special handling of overburden and alkaline addition in the backfill. Although special handling and alkaline addition will be touched on in this discussion, the focus is on the alkaline recharge structures.

The alkaline recharge structures were approximately 150 x 50 feet, with a depth of 12 feet, and were often placed over chimney drains which had been constructed in the backfill. The recharge structures were filled with four feet of "crusher-run" limestone (0 to 1.25 inches) overlain by four feet of limestone gravel (2 to 2.25 inches). The remaining four feet were for "free storage." The purpose of these recharge drains was different from that of Case Study 1. In this case, the drains were installed to enhance "the alkaline/oxygen loading" of the backfill ground water. The key objective was to induce metal precipitation within the backfill.

This site can be divided into two areas in terms of BMPs. Most of the site (the southern seven-eighths) was mined conventionally without incorporation of special BMPs to prevent water quality problems. The northern one-fifth was mined using special handling and alkaline addition. Both areas had alkaline recharge structures installed. A map of the site showing the location of alkaline recharge structures, monitoring wells, and the area where alkaline addition and special handling were part of the mining plan are shown in Figure 2.3.3c. Monitoring wells OW-2, OW-5, and OW-8 were placed down-gradient from recharge trenches. Table 2.3.3a shows the range of water quality in terms of pH, alkalinity, iron, and manganese for these wells, as well as water quality for wells OW-7 and OW-10.

Figure 2.3.3c: Map of Case Study 2 Site

Table 2.3.3a: Water Quality for Wells at the Case Study 2 Site (data interpreted from graphs by Wiram, 1996)

Well	**OW-2**		**OW-5**		**OW-7**		**OW-8**		**OW-10**	
Date	10/90 to 4/93	1995	7/92 to 4/93	1995	7/92 to 4/93	1995	11/92 to 4/93	1995	11/92 to 4/93	1995
pH	6.0	6.0	6.0	6.0	6.5	6.4	6.5	6.3	6.0	6.0
Alk. mg/L	100-175	125-150	~100	150-200	~450	~450	50-500	400-450	150-200	100-200
Fe mg/L	15-30	<1-15	<10	10-20	<1-7	<1-6	<1-5	<1-4	15-30	40-90
Mn mg/L	10-20	8-18	~10	~10	5-8	2-8	2-4	3-8	~10	10-20

Water quality data from the monitoring wells prior to construction of the alkaline recharge structures do not exist. Thus pre- and post-construction data cannot be compared. For purposes of evaluation the data in Table 2.3.3a has been divided into early monitoring data (April 1993 and earlier) and late monitoring data (1995). Overall, the differences between early and late monitoring data are not significant. The biggest differences in water quality are observed when the wells drilled into the area without special handling and alkaline addition are compared to the wells located near the area of alkaline addition and special handling. Wells OW-2 and OW-5 were not influenced by special handling and alkaline addition, whereas there were indications that OW-7 and OW-8 were influenced. The water in OW-7 and OW-8 was more alkaline than in the other wells, and in general had lower metal concentrations than wells OW-2, OW-5 and OW-10. Well OW-10 was up-gradient from any BMPs and served as a "control." The water in OW-10 had higher metal concentrations than the other wells. If OW-10 is representative of mine spoil water in the absence of BMPs, then the BMPs appear to have resulted in water quality improvement.

<u>Case Study 3</u> (Appendix A, EPA Remining Database, 1999, TN(4))

This site was submitted as one of the 61 state data packages. It is located in Sequatchie County, Tennessee and is immediately to the east of the Case Study 2 site. The same company is mining both sites and experience gained at the Case Study 2 site was incorporated at the Case Study 3 site. This site incorporated numerous BMPs in addition to alkaline recharge structures, including alkaline addition, special handling, compaction of spoil, backfill hydrology routing, backfill water inundation, and stream buffer zone expansions. Only the induced alkaline recharge structures will be discussed here. The surface feature is a depression that is about 150 feet long by 75 feet wide and 12 feet deep. The area filled with limestone is somewhat smaller, and the depth of limestone is about eight feet. As with the Case Study 2 site, one of the goals is to promote the flow of oxygen into the spoil for *in situ* precipitation of metals. The effectiveness of the measures used at this site can not be evaluated because the site is still active.

2.3.4 Discussion

The theory of increasing alkaline load by increasing the amount of water that is in contact with calcareous materials is a valid concept, although it is not without potential problems and is not applicable to all mine sites. The benefits and limitations of implementation of this BMP are highlighted below. Most of the potential problems have not been discussed in previous literature.

Benefits

- Surface water is preferentially directed to calcareous material that can produce alkalinity. The water will flow through the limestone in the recharge structure and avoid contact with acidic material.
- Water flowing into the structures will be surface runoff (i.e., essentially rainwater) that is low in dissolved solids, and more importantly, has low metals concentration. Water

containing high concentrations of metals, such as mine drainage, can coat (armor) limestone and other calcareous materials rendering them ineffective.

- Limestone recharge structures are passive and require little, if any, maintenance.
- Recharge structures can introduce oxygen into the backfill to facilitate oxidation and, if the water is sufficiently alkaline, metals will precipitate in the backfill rather than at a surface water discharge point.

Limitations

- Limestone only dissolves when in contact with water, thus only during precipitation events.
- Permeable trenches can increase the flow of air into and out of spoil. This could increase oxygen availability and decrease carbon dioxide within the spoil. Increases in oxygen can be desirable (as in Case Studies 2 and 3 where the goal was/is to precipitate iron in the backfill), or undesirable (if the spoil is highly pyritic). Retention of carbon dioxide (CO_2) in spoil can be important if calcareous minerals are present, because carbonates are more soluble when CO_2 is elevated, a condition that often exists in surface coal mines (for examples of mine sites where elevated CO_2 has been measured see Guo and Cravotta, 1996, Lusardi and Erickson, 1985, and Jaynes and others, 1983). This is the reason that many mine waters have alkalinities greater than 200 mg/L (for examples, see Hornberger and Brady, 1998; and Brady and others, 1998; Table 8.2).
- The increased flow into spoil could potentially increase load of undesirable constituents such as acidity, metals and sulfate, especially if the water entering the spoil flushes oxidation products that have built up between precipitation events.
- To reach saturation with respect to alkalinity, water should be in contact with calcareous minerals for a sufficient length of time. If contact time is not enough, sufficient alkalinity may not be generated.

- Intentional diversion of surface water into the ground water system can result in a fluctuating water table. This could adversely affect water quality if pyrite oxidation products, which can build up between flushing cycles, are flushed during this fluctuation.

The effects of induced alkaline recharge structures have been studied at few sites. Thus there are unanswered questions regarding the effectiveness of this BMP. Although concentrations decreased at the Case Study 1 site, flow data was not evaluated, and BMP effects on acid load can not be assessed. The Case Study 2 site lacked pre-installation ground water monitoring data, but contained a single well in an area that was not affected by the BMPs. This control well has higher metal concentrations than wells below the recharge trenches. The recharge structures may have been effective at in-situ metal removal. Water in all the wells in Case Study 2 was alkaline. An evaluation of the effectiveness of alkaline recharge structures at the Case Study 3 site cannot be made at this time because the site is still active.

Efficiency

Until efficiency can be further demonstrated, it would be prudent to restrict the use of alkaline recharge structures as a BMP to the following scenarios:

- Sites where the overburden contains very little acid-producing material and there is a lack of calcareous rocks. In other words, this BMP should be implemented on "marginal" sites that would not create severe acid mine drainage in the absence of alkaline recharge structures, but likewise would not produce alkaline drainage. In cases where this technology is implemented and where selective handling of acidic materials has occurred, the acid material should be placed above the highest water table anticipated to occur during a recharge event. Otherwise the acidic material may be in a zone of water table fluctuation.
- This BMP has potential use at sites with alkaline or near-alkaline ground water with elevated metals. The purpose at these sites is to enhance the amount of oxygen that will reach the ground water and this in turn will promote in-situ precipitation of metals.

2.3.5 Summary

Although alkaline recharge structures have the potential to induce alkalinity in mine spoil, experience is limited, and there are possible drawbacks that have not been evaluated, such as the potential for increasing the load of undesirable chemical constituents. The Case Study 1 site had several acid seeps which had resulted from mining. Following installation of recharge trenches and funnels there were decreases in acidity concentration. Flow data, however, were not available so whether acidity load decreased cannot be determined. The mine spoil monitoring wells at the Case Study 2 site lack pre-installation data. A single control well in an area where BMPs were not applied is of poorer quality than wells in areas with induced alkaline recharge trenches. At this site, the primary problem was the discharge of metals offsite. The recharge trenches were constructed with the intent of causing precipitation of metals in the backfill by increasing alkalinity and oxygen availability. If a comparison between the control well and the other wells is valid, this could indicate that the efforts at the Case Study 2 site did result in better water quality. The Case Study 3 mine incorporated most of the measures adopted at the adjacent Case Study 2 site including using the recharge structures to enhance the flow of oxygen into the backfill. The Case Study 3 mine is still active, and it is too early to evaluate BMP effectiveness.

The number of sites where alkaline recharge structures have been constructed as a BMP are few and many questions remain as to their effectiveness. Some implementation considerations can be suggested, the most important being that it should be certain that an increase in surface infiltration will not also result in an increase in acid load. The methodology will probably be most effective on sites with minimal amounts of pyrite and a lack of naturally occurring calcareous rocks. Recharge structures may also be effective where the goal is increased oxygen in the backfill, so as to precipitate metals within the backfill.

Measures should be taken to ensure that plans were carried out as designed, including increased inspection frequency and engineer certification of on-site design. Monitoring of ground water discharges should include flow as well as concentration so that load can be determined.

2.4 Special Handling

Special handling at surface mines encompasses the selection, handling, and controlled placement of acid-producing and/or calcareous rock. The primary purpose of special handling is to place acidic or alkaline strata in such a way as to minimize acid production and transport, and to maximize the alkalinity generation within the mine spoil water.

Special handling is often used in conjunction with other acid mine drainage prevention techniques such as alkaline addition, water management (e.g., pit floor drains), and surface reclamation (e.g., slope grading to promote runoff) to improve the water quality. For example, special handling, in the absence of calcareous material, cannot by itself produce alkaline drainage. Thus, where calcareous strata are absent, offsite calcareous material can be imported to offset these natural deficiencies in acid-neutralizing rocks. Pit floor drains can be used to engineer where the post-mining water table will be re-established within the spoil, thus assuring that special handled material will remain above the water table.

Special handling is a common practice, occurring on at least 35 of the 61 mines included in the EPA Remining Database (Appendix A and Table 2.4a). It affected at least 78 of 231 discharges in Pennsylvania (Appendix B, Pennsylvania Remining Site Study). An examination of both databases shows that special handling is not a “stand-alone” BMP. It is always used in conjunction with other BMPs.

Table 2.4a: EPA Remining Database (Appendix A), Special Handling of Toxic/Acid Forming Materials

ID	Type of Mine	Mine Closure Date	Cover Material	Placement	Blending of Overburden	Other Major BMPs	Comments
AL (2)	Surface	3/90				Regrading Revegetation Terraces	
AL (7)	Surface	5/92	4' Non-toxic			Regrading Revegetation	
AL (10)	Surface Auger	12/95			Yes	Regrading Revegetation Temporary diversions	
AL (11)	Surface	No mining taking place.	Yes	On pit floor		Old washer fines to be relocated. Alkaline addition	Reclamation will occur through a party other than the mining company
AL (14)	Surface Coal Refuse Disposal	10/89	4' clay over fines 4' over rest			Regrading Revegetation	
KY (1)	Surface Coal Refuse Reproc.	Active	4' Non-toxic	On pit floor		Regrading Revegetation	
KY (2)	Surface Auger	Active	4'	Against highwall		Regrading Revegetation Daylighting	
KY (3)	Surface Auger Refuse Storage	Shut down - 11/98	4' Non-toxic			Regrading Revegetation	Shut down due to low coal demand. Will be reopened.
KY (4)	Surface Auger	Active	4' Non-toxic			Regrading Revegetation Seals	Acid material minimal
PA (1)	Surface	10/98	5' Non-toxic	10' above pit floor; 10' from highwall		Revegetation Daylighting Alk. Addition Clay Seals	Alternating layers of 2 ft "toxic", 2 ft clean spoil
PA (3)	Surface	6/98	4' Non-toxic	10' above pit floor		Regrading Revegetation Daylighting Clay Seals	Alternating layers of 2 ft "toxic", 2 ft clean spoil

ID	Type of Mine	Mine Closure Date	Cover Material	Placement	Blending of Overburden	Other Major BMPs	Comments
PA (5)	Surface	4/98	4' Non-toxic	20' above ground water; 10' from highwall	Yes	Regrading Revegetation	Alternating layers of 2 ft "toxic", 2 ft clean spoil
PA (6)	Surface Auger	8/96				Regrading Revegetation Daylighting	
PA (7)	Surface Auger Coal Refuse	5/96	15' Neutral spoil; 2' Clay shield	15' above pit floor; 15' from highwall		Regrading Revegetation Daylighting Alk. Addition	
PA (8)	Surface	Active				Regrading Revegetation Daylighting Alk. Addition	
PA (9)	Surface Rock	Active				Regrading Revegetation Daylighting Alk. Addition Biosolids	
PA (10)	Surface	11/95	Yes	Above ground water		Regrading Revegetation Scarification Bactericide	
PA (11)	Surface Auger	Active	4' Clean fill	25' above pit floor		Regrading Revegetation Daylighting Alk. Addition	25 T/ac Lime added 24" Toxic 30" Clean
PA (13)	Surface Auger	1996		70' above ground water			
PA (19)	Surface	Active	10'	10'		Regrading Revegetation Alk. Addition	
TN (1)	Surface Auger	Active	Non-acid strata	On pit floor		Backfill Drains	
TN (4)	Surface Auger	Active				Alk. Addition Backfill Inun.	
VA (1)	Surface Auger	10/98			Yes	Regrading Revegetation Daylighting	Excess of NP
VA (2)	Surface Auger	12/93	4' Non-toxic			Regrading Revegetation Topsoil Repl.	
VA (3)	Surface Auger	4/92	4' Non-toxic			Regrading Revegetation	

ID	**Type of Mine**	**Mine Closure Date**	**Cover Material**	**Placement**	**Blending of Overburden**	**Other Major BMPs**	**Comments**
VA (4)	Surface	88/90	Yes			Regrading Revegetation Bactericide Underdrains	
VA (6)	Surface	Active	4' Non-toxic			Regrading Revegetation Underdrains Diversions Compaction	
VA (7)	Surface	Active	4' Non-toxic	4' above pit floor; 4' from highwall; not in bottom fills		Regrading Revegetation Daylighting Drainage	
WV (1)	Surface Deep	Active	6' Non-toxic			Regrading Revegetation Daylighting Alk. Addition	
WV (4)	Surface	11/95	Calcareous rock	On pit floor Against highwall	Surround with calcareous rock	Regrading Revegetation Sed. Ditches	
WV (5)	Surface Ash Disposal	Active			Blend with calcareous rock	Regrading Revegetation ALD Alk. Addition	
WV (6)	Surface	Active	1' non-toxic	On pit floor	Surround with calcareous rock	Regrading Revegetation Alk. Addition	
WV (7)	Surface	6/87	10'	12-15'		Regrading Revegetation	24" Acid
WV (8)	Surface Deep Ash Disposal	Active	4' Non-toxic	4' above pit floor		Regrading Revegetation Alk. Addition Underdrains	Add alkaline material
WV (9)	Surface	1/91	Yes	Yes	Mixed with calcareous	Regrading Revegetation	

Theory

There are essentially four methods of special handling:

- Blending: mixing of naturally occurring calcareous and acid-producing rocks.
- Dark and deep: placement of acidic materials consistently below the water table.
- High and dry: placement of acidic materials consistently above the water table.
- Alkaline redistribution: distributing alkaline material from areas with an excess to areas with a deficiency of neutralizing rock.

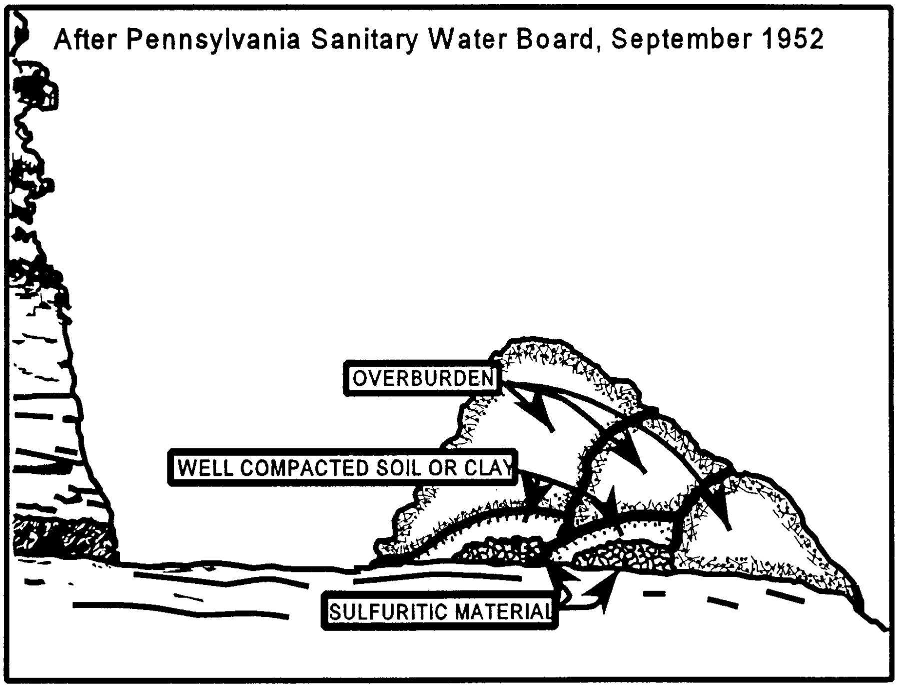
These four processes rely on different methods of avoiding acid production. Blending relies on the presence of a sufficient amount of calcareous rock throughout the overburden to produce enough alkalinity to offset acidity production from pyritic rocks. “Dark and deep,” or submergence, relies on the fact that water can contain only a small amount of dissolved oxygen (at most ~10 mg/L) and that water is therefore an effective barrier to atmospheric oxygen (Watzlaf, 1992). This lack of oxygen reduces the potential for the pyrite to oxidize and produce acid mine drainage. “High and dry” is based on the premise that ground water plays a role in the chemical reaction that takes place to form AMD and also acts as a transport medium. Placement above the water table cannot preclude the contact of water with pyritic material. Even in the unsaturated zone, there is gaseous water in the pore gases, and ground water can adhere to particle surfaces hydroscopically. Thus, the primary effect of high and dry is avoidance of the transport of pyrite weathering products. Alkaline redistribution takes advantage of naturally occurring alkaline strata where portions of the mine site lack sufficient neutralizers. This alkaline material is redistributed such that all parts of the site have sufficient alkaline material to prevent or neutralize AMD.

Blending is being used on at least five of the special handling sites listed in Table 6.4a. Blending takes advantage of naturally occurring calcareous strata. In its simplest form, mixing of the strata occurs in the coarse of overburden removal. Blending plans can be more intentional, with specific strata targeted to assure adequate mixing.

Typically, in the Appalachians, acidic material is placed above the post-mining water table to minimize water contact. Calcareous materials, on the other hand, are placed so that their dissolution will be maximized, which can mean placement below the ground-water table. Combinations of special handling, alkaline addition, water management, and surface reclamation can allow the mine operator some control over acid- and alkaline-generating processes.

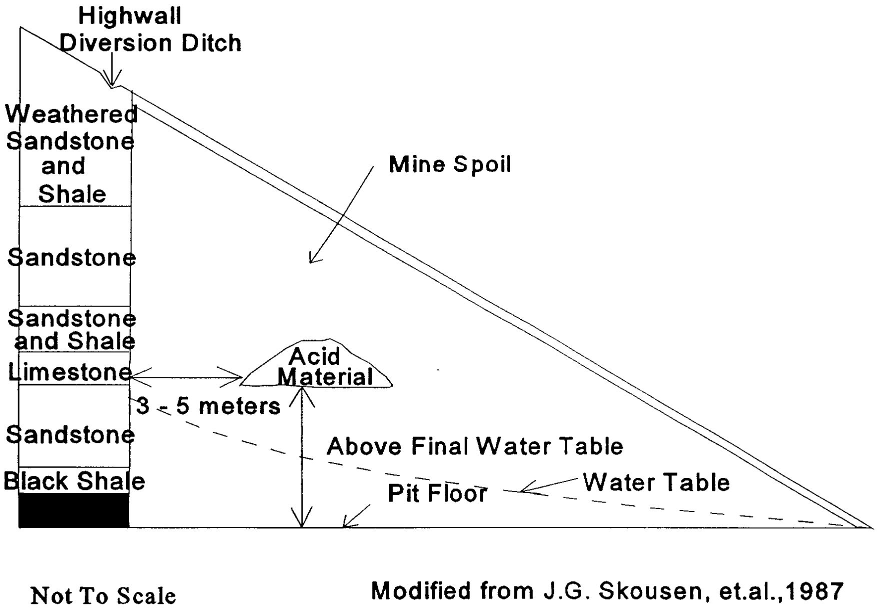
Probably the first special handling concept involved the recognition of black or very dark colored rocks and coal reject ("gob," "bone coal") as potential acid formers. Initially, it was proposed that the material be buried on the pit floor. Deep burial was thought to prevent contact with oxygen, and hence shut off acid production. This approach was discussed as early as 1952 by the Pennsylvania Sanitary Water Board and is shown in Figure 2.4a. The Sanitary Water Board also recommended highwall diversion ditches, pit floor drains, contemporaneous backfilling, and grading topography to limit water infiltration.

Figure 2.4a: **Early Recommendation of the Pennsylvania Sanitary Water Board for Handling Sulfuritic Material (suggested placement was on the pit floor under the unreclaimed spoil piles).**



Experience with deep burial of potential acid-forming materials in Pennsylvania showed that water quality problems were not always eliminated and sometimes were more severe. This is because of difficulties maintaining a sufficient water table to keep the material submerged. In most Appalachian states, special handling strategies began to evolve towards isolation of material above the post-mining water table with isolation from preferred ground-water flow paths. This remains the most common special handling technique used in the Appalachians and is illustrated conceptually in Figure 2.4b.

Figure 2.4b: **High and Dry Placement of Acidic Material (commonly used method of special handling in Appalachia).**



Sampling and Site Assessment

Special handling plans are site-specific and should include consideration of the following factors:

- **Geologic and Geochemical Conditions**: identifying acidity- and alkalinity-generating rocks in the overburden and determining the distribution, location, and volume of these rocks.
- **Hydrogeologic Conditions**: identifying ground- and surface-water conditions on the site. This would include examination of the geologic structure in relationship to the area to be mined; the occurrence, quantity, and quality of surface and ground water; and estimating the

highest post-mining ground-water elevation in the backfill based on projected spoil transmissive properties.

- **Operational Considerations**: determining an appropriate mining method(s), sequence of mining, area to be mined, equipment to be used, and placement and amount of acidic and alkaline materials.
- **Field Identification**: determination of whether the alkalinity- or acidity-producing rocks be identified in the field so that they can be properly handled.

Geologic and Geochemical Considerations

Development of a special handling plan requires knowledge of the stratigraphic position, aerial extent, and total volume of acidity- and alkalinity-generating rocks (See Section 2.1). Horizontal sampling should be sufficient to define the lateral distribution of calcareous or high-sulfur strata. Likewise, vertical sampling should be of adequate resolution to discriminate calcareous and high sulfur strata. Too large a sample interval can result in loss of resolution and an inability to determine acidic or alkaline rocks. Acid-base accounting (ABA) is the overburden analysis procedure most commonly used for these determinations, and is discussed in Section 2.1.

Hydrogeologic Conditions

Hydrologic conditions are an important consideration in the design of a special handling plan. The position of the post-mining water table has bearing on where materials are placed, and is an important consideration in whether materials should be submerged below the water table or placed above the water table. Whichever method is chosen, the goal is typically to keep the material out of the zone of water table fluctuation.

The information needed to predict the post-mining water table includes a determination of the type of ground-water system (regional, perched, unsaturated zone). Considerations include pre-mining ground-water levels, examination of ground-water conditions on nearby mined areas, relationship to adjacent streams, geologic structure, and water management designs in the mine plan and pit design. Overburden lithology and mining methods also play a role in the hydrologic characteristics of mine spoil, which ultimately impacts the post-mining water table.

Table 2.4b is a statistical summary of saturated thickness of ground water in spoil wells. The summary represents data from Kentucky, Ohio, West Virginia and Pennsylvania, with 5, 9, 27, and 83 wells, respectively. Data are from measurements made by Hawkins (1999). The data have been split into two categories, wells that were developed in spoil less than 15 meters thick, and wells in spoil greater than 15 meters thick. The median saturated thickness for the deeper wells is twice that for the shallower wells (4 and 2 meters). This difference is significant at the 95 percent confidence limit. The range, however, in both categories is extreme, ranging from a fraction of a meter to 8 and 11 meters, respectively. The significance for special handling is profound. The “dark and deep” method will not work where the saturated thickness is a fraction of a meter. Conversely, “high and dry” will not work where the overburden is less than 15 meters and the saturated thickness is 8 meters. With a water table, this high specially handled acidic material would be near the surface, thus exposing it to oxygen and placing it near or within the rooting zone. The values in Table 2.4b are a “snapshot” in time. They were a one-time sampling event and do not represent seasonal and climatic variations which would extend the range. These data, however, provide insights into the variability of saturated thickness in mine spoil.

Table 2.4b. Saturated Thickness in Meters for Wells Developed in Appalachian Mine Spoil (Hawkins, 1999).

	Saturated Thickness (meters)		
Summary Statistics	**All Wells**	**Spoil < 15 m Thick**	**Spoil > 15 m Thick**
Median	2.94	2.08	4.08
Minimum	0.18	0.26	0.18
Maximum	11.03	8.08	11.03
Lower Quartile	1.44	1.30	2.55
Upper Quartile	4.52	3.22	5.49
Number of Wells	124	69	55

It is also important to understand the sources of ground-water recharge. These sources include infiltrating precipitation, ground-water recharge through the final highwall or adjacent mined area, and upward flow through the pit floor. Monitoring wells, piezometers, and aquifer tests may be necessary to provide insight into ground-water conditions. However, one should be cognizant that ground-water flow in the coal fields of the Appalachians is largely fracture-controlled, and

that wells not located in fractures may underestimate the amount of water present and it's stratigraphic location. Another technique that can be used to estimate the amount of water present is the determination of flows from cropline springs. Insights can also be gained by looking at post-mining water conditions at nearby mines with similar geologic, hydrologic, and mining conditions.

Ground-water conditions are not "static" and vary seasonally and in response to recharge events. Monitoring should be sufficient to account for these variations. If, for example, the chosen placement technique is submergence below the ground-water table, and monitoring occurred only during the period of seasonally high water, there may be times of the year when the water table would be below the placement position, and the specially handled material would not be submerged. Alternatively, if the design is "high and dry" and monitoring only took place when the water table was low, there may be times of the year when the material is within or below the ground-water table.

Operational Considerations

Implementation of a special handling plan is also dependent on operational considerations. These considerations include: the size of the area to be mined, total overburden thickness, amount of material to be specially handled, sequence of mining, time needed to complete mining, the need for blasting, the mining method, and equipment. The equipment should be appropriate for the special handling plan and site conditions. For example, truck and loader operations are able to easily remove distinct portions of overburden and transport the overburden from one area of a mine to another. This type of segregation is not performed as easily with a dragline. Operational considerations will be discussed in more detail under Section 2.4.1.

2.4.1 Implementation Guidelines

Prior to developing a special handling plan the overburden should be sampled and acid- and alkaline-forming strata should be identified. Ground-water conditions should be well understood. The shape of the area to be mined should be considered. Only then can a plan be designed and the appropriate mining methods determined. Special handling plans should be clear, simple, and easily implemented by field personnel. Maps and cross-sections should show the positions of the materials to be specially handled and locations where these materials are to be placed. The materials should be readily identifiable in the field by color, position, or rock type. The plan should be logistically feasible and verifiable in the field.

Geologic and Geochemical Considerations

Stratigraphic position of the material is an important planning consideration. If the material lies immediately above or below the coal seam to be mined, segregation is usually not a problem. Segregating strata located in other positions above a coal seam may be more problematic.

Feasibility will require consideration of equipment and blasting plans, how readily identifiable the strata is in the field, and costs of implementing the plan. “Fizz tests” using dilute hydrochloric acid can be performed in the field to identify alkaline strata. Unfortunately there is no comparable filed test for acid-forming strata.

Hydrogeologic Conditions

In situations where the operator is attempting to special handle acid-forming material by submergence, the length of time required for the post-mining water table to re-establish is important. If the operator wishes to place this material above the post-mining water table timing of water table reestablishment is not important.

The contribution to the post-mining water table from infiltrating precipitation during the first few years following reclamation will be less than that for unmined areas. Jorgensen and Gardner (1987), Guebert and Gardner (1992), and Ritter and Gardner (1993) investigated infiltration and runoff on newly reclaimed surface mines in central Pennsylvania. They found that infiltration rates on newly reclaimed mine soils are an order of magnitude lower than adjacent, undisturbed soil. However, within four years after reclamation, infiltration rates on some mine surfaces approach pre-mined rates (8 cm/hr). During the topsoiling operation, the soil is compacted by the equipment. This compaction promotes runoff. During freeze/thaw and wet/dry cycles, macropores develop in the surface soils which promote infiltration. The re-establishment of soil structure and plants also promotes infiltration.

Re-establishment of a post-mining water table will probably occur most rapidly for those mines where the lowest seam mined lies beneath the regional water table. Once the pumps are shut off, the regional water table will typically re-establish itself in a relatively short period of time. It becomes somewhat more difficult to predict the configuration and rate of rebound of the post-mining water table for mines with aquifers perched above the regional water table.

Where the mine is situated above the regional ground-water table, the hydraulic characteristics of the pit floor will determine whether a post-mining water table will be intermittent or permanent.

If the pit floor material is a thick underclay, it will tend to serve as an aquitard and inhibit further downward migration. In other cases, the floor might be massive, fractured sandstone, which will allow the downward percolation of ground water. The post-mining, ground-water table is dependent on the structure of the lowest mined coal seam and the final highwall configuration. Where a down-dip highwall remains after mining and the pit floor retards vertical percolation, ground water may become impounded on the pit floor against the highwall, resulting in a higher post-mining water table than is typically the case with an up-dip highwall. In cases where a down-dip highwall remains after mining and conditions are present which promote impounding of the ground water against the highwall, the "rule of thumb" placement 10 to 20 feet above the pit floor may be inadequate. If the intention is to keep the ground-water table low, it may be desirable to change the orientation and/or location of the final highwall to avoid impounding water, or to incorporate underdrains to minimize ground-water buildup in the backfill.

Spoil hydrology plays a role in the configuration of the water table. Low-permeability spoil will tend to maintain a higher water table than high permeability spoil. However, most mine spoil is highly permeable compared to undisturbed strata.

Operational Considerations

The mining plan is often based on the configuration of the land that is to be mined rather than the optimum configuration for overburden and coal removal. The stratigraphic and areal distribution of the acid- and alkaline-forming materials, as they relate to the mining plan, are important in determining how these strata can be specially handled and how much is to be segregated. However, several pit orientations are often possible, and some may be more efficient than others for a particular handling plan.

Typically, when blasting, the total overburden column above the coal is broken up in one shot (lift). However, if the stratum to be segregated lies at some distance above the coal, it will probably be necessary to blast in multiple lifts. The first lift removes the overburden above the unit to be special handled, and the unit to be special handled is removed separately. The remaining overburden above the coal is then removed. This process can easily increase blasting costs by more than 50 percent, and may result in poor rock breakage at the top of the lift because of stemming requirements (Getto, 1998). Blast hole "stemming" refers to material that is placed in the shot hole above the explosive. Stemming confines the energy of the explosion to the area around the explosive.

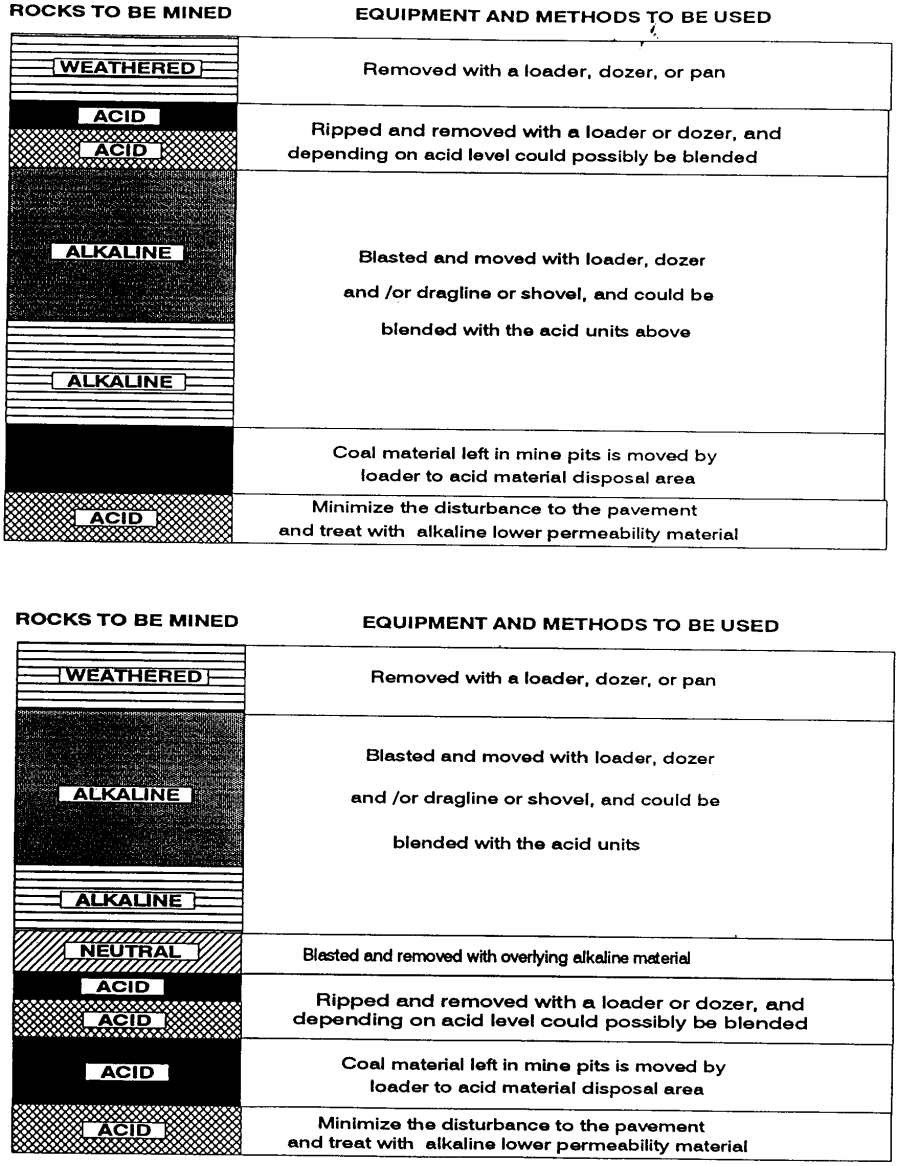
When potentially acid-forming strata are exposed, rapidly covering the strata helps prevent the onset of acid-forming reactions (Skousen and others, 1987). Perry and others (1997) examined seven sites with special handling and found timeliness of reclamation to have some influence on water quality. Extended exposure of unreclaimed spoil to infiltration and circulation of water and to oxygen apparently allows accelerated acid production.

In general, segregation of spoil material is more difficult when using a dragline. In many cases, dragline operators do not have visual contact with the spoil that is being loaded. Also, typically, for a dragline to remove material it has to be "shot," and this often results in random material mixing. Even without mixing, draglines are not good at separating discrete stratigraphic layers.

"Blending" of overburden is often appropriate where the alkaline and acidic overburden occur in proximity. Blending may not require anything out of the ordinary and may occur simply as a consequence of overburden removal and replacement.

Two overburden removal plans are shown in Figures 2.4.1a and 2.4.1b. In Figure 2.4.1a, acidic material is located in the upper part of the rock column and requires separate removal. In Figure 2.4.1b, acid material is located directly above the coal. In the later scenario, the entire overlying rock column can be blasted and removed in one lift, resulting in a blending of the alkaline- and acid-forming material.

Figures 2.4.1a and 2.4.1b: **Overburden Handling Procedures Depending on Stratigraphic Position of Acid-producing Materials (figures show the types of equipment that may be appropriate for handling the overburden).**



ROCKS TO BE MINED	EQUIPMENT AND METHODS TO BE USED
WEATHERED	Removed with a loader, dozer, or pan
ACID ACID	Ripped and removed with a loader or dozer, and depending on acid level could possibly be blended
ALKALINE ALKALINE	Blasted and moved with loader, dozer and /or dragline or shovel, and could be blended with the acid units above
	Coal material left in mine pits is moved by loader to acid material disposal area
ACID	Minimize the disturbance to the pavement and treat with alkaline lower permeability material

ROCKS TO BE MINED	EQUIPMENT AND METHODS TO BE USED
WEATHERED	Removed with a loader, dozer, or pan
ALKALINE ALKALINE	Blasted and moved with loader, dozer and /or dragline or shovel, and could be blended with the acid units
NEUTRAL	Blasted and removed with overlying alkaline material
ACID ACID	Ripped and removed with a loader or dozer, and depending on acid level could possibly be blended
ACID	Coal material left in mine pits is moved by loader to acid material disposal area
ACID	Minimize the disturbance to the pavement and treat with alkaline lower permeability material

Another operational constraint occurs when the alkaline material is located beneath the coal being mined. Ripping (disaggregating) the pit floor can be done to incorporate alkaline material into the mine backfill at sites where alkaline strata exist below the lowest coal seam to be mined. This method involves removing the coal and ripping the pit floor to expose the alkaline strata to ground water on the pit floor. It is a suitable practice if the pit floor or underclay is not acid-forming. The operator should have equipment capable of ripping the pit floor to the needed depth and sufficiently breaking up the alkaline zone. Typically, an average size dozer can rip to a depth of approximately 3 feet (1 m), while a D-11 dozer is capable of ripping to greater depths. If the alkaline material is at a depth greater than the depth accessible by ripping, the overlying material will need to be removed prior to ripping.

Limestone is generally a durable rock and is resistant to abrasion. When ripped, limestone tends to be of a much larger size than is normally associated with alkaline addition or redistribution, hence, increased surface area is limited. This method is adequate for mines where alkaline deficiencies are small, as it may have a limited effect on ground-water quality when compared to alkaline addition of fine-grained material or alkaline redistribution in the spoil. Section 2.4.4, Case Study 6 discusses a mine where the pit floor was ripped to expose alkaline material. This site is a rare case in which a Pennsylvania remining site resulted in degradation of water quality.

Special handling is an overburden management technique by which acidic and alkaline materials are selectively placed in the backfill. Special handling is rarely used alone and is typically used with other BMPs. Special handling techniques and associated BMPs include:

- Relocation of potentially acid-forming strata above the anticipated post-mining water table;
- Constructing "pods" of acid-forming materials;
- Capping the acid-forming material;
- Submergence or flooding;
- Blending including alkaline redistribution;
- Operational considerations; and
- Incorporation with other BMPs such as alkaline addition, daylighting and surface- and ground-water management.

Discussion of Theory

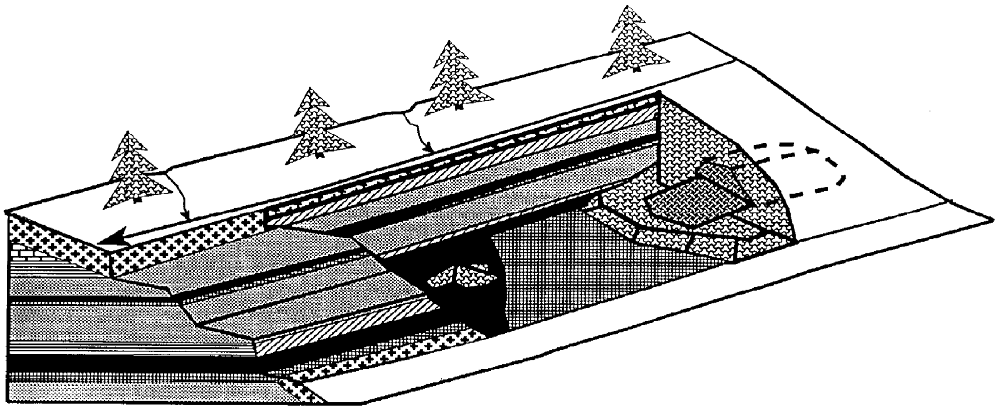
Placement above the water table and encapsulation

Placement of acidic materials above the water table using segregation, isolation, and encapsulation techniques minimizes contact between acid-forming material and ground water. Special placement usually occurs in "pods" or discrete piles that are located above the expected post-mining water table in the backfill; thus it is often referred to as the "high and dry" method.

A few mines have constructed liners and caps that are designed to prevent ground-water contact with the acid-forming materials. This method is encapsulation. Segregation and isolation from the ground-water system does not totally prevent pyrite oxidation. Oxygen, microbes, and water are still present in the pods. Segregation and isolation are directed at preventing massive downward leaching, or upward migration of oxidation products. The technique is illustrated and described in Figure 2.4.1c.

Construction of acid-forming material pods is one of the oldest techniques used to isolate potentially acidic strata. The purpose is to inhibit percolation or recharge of ground water through the potentially acid-forming strata. Pods are constructed in compacted layers, sometimes with potentially acid-forming material alternated with alkaline strata. Pods are placed above the highest anticipated ground-water elevation in the backfill, 10 feet from the surface, and usually at least 25 feet away from the final highwalls and lowwalls. Potentially acid-forming material needs to be rapidly excavated and covered to prevent prolonged exposure of the materials to oxygen and water.

Figure 2.4.1c: Three-dimensional Conceptual View of High and Dry Placement of Acid-forming Materials



SEGREGATION AND ISOLATION (HIGH AND DRY) TECHNIQUES

STEPS INVOLVED IN SPECIAL HANDLING ACID MATERIALS

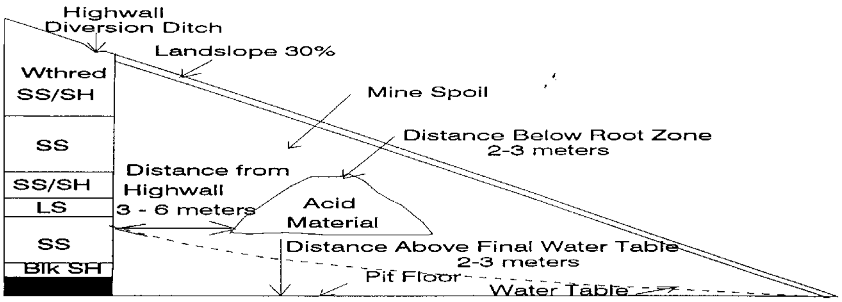
1) Conduct drilling and blasting to expose acid materials,
2) Remove acid materials with a loader or dozer,
3) Construct the disposal site in the backfill where:
   - at least 10-20 feet from the highwall,
   - above the final water table to be developed in the post mining backfill,
   - out of the root zone probably at least 10- feet below the surface
   - away from natural drains that would flow across the post mining backfill
4) Place the acid material either in on the constructed pad in the backfill or in a in a temporary storage for transport offsite or to another part of the permit
5) Add alkaline material to acid material to reduce acid generation, and
6) Complete the reclamation and revegetation as quickly as possibly

Cravotta and others (1994a and 1994b) compared the abilities of a dragline versus trucks and front-end loaders on two areas of the same mine to special handle acid-forming strata. Both handling methods tended to invert the original rock column. Where loaders were used, pyritic shale was selectively placed in pods near the final surface, and only low sulfur material was near the pit floor. On the area mined with a dragline, the overburden with the highest-sulfur content was placed near the surface, but the sulfur contents for the material at the bottom of the spoil were higher than they were for the area mined with loaders. A study of special handling in Montana with dragline mining also reported that the overburden profile was inverted (Dollhopf and others, 1977a, 1977b, 1978, and 1979). Both studies compared chemical and lithologic properties of drillholes in mine spoil to pre-mining conditions.

Improper construction of pods, especially the failure to construct an impervious cap over the top of the pod, can result in conditions favorable to the formation of AMD. High and dry burial places pyritic material closer to the surface where atmospheric oxygen is more abundant. This, in conjunction with percolating precipitation and the high concentrations of pyrite, creates an environment that can allow the bacteria *Thiobacillus ferrooxidans* to thrive. Schueck (1998) found severe AMD formation associated with segregated, but improperly isolated pyritic material. Subsequent drilling and ground-water sampling confirmed that the AMD associated with these improperly constructed pods was more severe than AMD generated elsewhere on the site. In many cases, the operator confirmed that the pods were segregated acid-forming materials, often pit cleanings, but that impervious caps were not constructed on top of the pods.

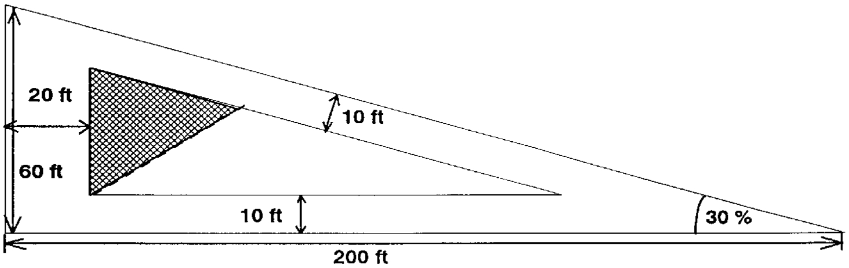
Placement of acidic material into a contour surface mine backfill should fall within a projected target zone (See Figure 2.4.1d). The bounds of this zone are established by the distance from the highwall, height above the pit floor, post-mining water table, the depth below the root zone, the distance from the outcrop, and the distance from re-established drainageways and various barrier areas. In Figure 2.4.1d, a simplistic approach is demonstrated to indicate the <u>maximum</u> amount of acid material that can be placed in the target zone.

Figure 2.4.1d: Projected Target Zone Determination for Placement of Acid Forming Material within the Backfill



Not To Scale

Modified from J.G. Skousen, et.al.,1987



Total Mined Area Triangle = 6000 sq ft

Acid Material Target Area Triangle = 1900 sq ft

32% of the Backfill is Available for Disposal

Reduction of the Target Zone Due to the Angle of Repose (Loader) Limitation:

27% of the Backfill is Available for Disposal

The values used for the Total Mined Area Triangle (TMAT) include:

Maximum Highwall Height	60 feet
Coal Thickness	4 feet
Stripping Ratio	15:1
Landslope	30%
Calculated Maximum Pit Floor Width	200 feet

The values for the Acid Material Target (Area Triangle TMAT) include:

Distance from the highwall	20 feet
Distance above the pit floor	10 feet
Depth below the root zone	10 feet
Distance above the post-mining water table	Variable
Away from re-established surface drains	Variable

The TMAT square footage value is 6000 ft^2 using the maximum pit floor width and highwall height. The maximum height of the TMAT to which the acid material could be placed (and still meet the segregation and isolation disposal conditions) is 34 feet on the side nearest the highwall. The maximum width of the TMAT is 112 feet. At most, only 32 percent (roughly one third) of the total mined area can be used for acid material placement. This value will change depending on highwall height, land slope, and placement constraints. As a general rule, as land slope increases, the size of the target area for acidic material will decrease.

Further reductions in the amount of acidic material placement result from the practicalities of handling and construction of the top portion of the TMAT. If the material is dumped at the angle of repose (assumed to be 30°) before being compacted, a portion of the TMAT would not be available for use during placement. This zone (cross-hatched area in Figure 2.4.4b) represents about 5 percent of the fill cross-section. Under these conditions, no more than approximately 27 percent of the total backfill is available for acidic material placement. This target triangle area for acidic material placement is not continuous around a hill (along the contour) because of the natural drainageways, which occur every few hundred feet in the Appalachian Plateau. Other obstacles such as gas wells, gas lines, power lines, and houses may further reduce available placement area, and further limit the lateral extent of placement. A high water table will often require placement more than 10 feet above the pit floor. Due to these constraints, the acid material should be less than 20 percent of the material to be backfilled.

Meek (1994) monitored acid production on surface mined areas with segregation and several different alkaline amendments. Acid load, on an area with segregation, was reduced about 50 percent compared to a control area with no segregation or alkaline addition.

Phelps and Saperstein (1982) suggested that pods should have a bulk density of 1.1 to 1.5 times the surrounding spoil to minimize infiltration. These investigators also observed that the highest spoil bulk densities occurred at 50 to 80 percent depth of spoil for most mining methods. They suggested that the high density spoil zones should be favorable locations for pods, if hydrologic requirements are satisfied.

Schueck and others (1996) reported on attempts to grout buried refuse with fluidized bed combustion ash as a method of isolating pods after the fact. This was done on a site where the lower Kittanning coal seam was mined and most of the overburden is apparently acid-forming. Grout was injected directly into the buried pods to fill the void spaces and directly coat the refuse. Grout caps were also constructed over several of the pods. Combined grouting affected only 5 percent of the site but resulted in a 50 to 60 percent decrease in acid concentration in down-gradient monitoring wells.

Short exposure time before burial and reclamation can reduce weathering and acid generation. As the acid-forming material remains exposed, rocks break down exposing more surface area, and weathering proceeds to produce acid products along with the subsequent buildup of soluble acid salts. In practice, potentially acid-forming materials are often stockpiled until enough material to start pod construction is accumulated. To reduce exposure, some mines in Pennsylvania construct temporary stockpiles covered with soil and vegetation, or cover the material with lime for neutralization.

When acid-forming material is handled from a cut, the construction of pods should be concurrent with mining and backfilling. This ensures that acid-forming material is rapidly buried. Rose and others (1995) reported on experimental test pods where the high-sulfur material was stockpiled for several months before construction of the pods. Some pods unexpectedly produced very acidic drainage even though they had been amended with alkaline materials. Delay in construction of the pods may have allowed significant acid generation to start even before the acid material was placed in pods.

Capping: A cap refers to an overlying low-permeability zone created through placement of compacted, fine-grained soil material (clay), combustion byproducts (fly ash, fluidized bed wastes), kiln dust, or synthetic (plastic or geotextile) fabric. The cap is significantly less permeable (at least two orders of magnitude difference) than the surrounding material. Caps inhibit or prevent the infiltration of water into acidic material from above.

The term liner is normally used in the context of an underlying low-permeability zone created through placement of an earthen or synthetic material which is at least two orders of magnitude less permeable than the surrounding units. However, materials used for liner construction can also be used as a cap over the specially handled pod. Liners restrict or prevent the adjacent and underlying ground water from encountering the acid-forming material. Caps and liners can also restrict diffusion of atmospheric oxygen, a key component of acid generation.

A detailed study of special handling at a Montana surface coal mine included the construction of a three-foot thick clay cap over special handled material (Dollhopf et al., 1977a, 1977b, 1978, and 1979). Construction of the cap required several pieces of equipment, including pans and bulldozers. Maintaining clay at optimum moisture content for maximum compaction was difficult; water sometimes had to be added to the clay material. The region in which the mine was located was semiarid. Cost of special handling with the clay cap was about 1.5 times "normal" operations, due in large part to idling the dragline at certain stages of cap construction. An experienced mining engineer was needed on-site to supervise operations and schedule equipment. Specially handled material was maintained in a dry state, and the investigators concluded that capping was successful.

Synthetic plastic and geotextile "liners" are a technology borrowed from the waste management industry. Thick, high-strength plastics of 20, 30, 40 or even 80 mm thickness can be used to isolate acid-forming materials from infiltrating precipitation and ground-water interflow. The liners are designed to be resistant to a wide range of leachate conditions. They are laid out in sheets with the seams stapled or welded by heat or solvent. Synthetic liners require a smooth, firm base to avoid puncture or stretching. A potential area of weakness is the seams which should be joined properly to avoid leakage or failure. The cost of synthetic liners is high in comparison to other capping methods. Refuse piles may be amenable to capping with liners due to their engineered structure and more controlled particle size distribution. Meek (1994) reported that a plastic cap reduced acid load by about 70 percent compared to no special handling and that a cap was one of the most effective treatment measures evaluated in that study.

Caruccio and Geidel (1983) used a 20 mm liner at a 40-acre site in West Virginia as an infiltration barrier. The acid load from two highly acidic seeps was reduced such that the liner would pay for itself in six years. Because of a steep outslope, the liner only covered the flatter, upper portion of the mined area. Recharge along the outslope area probably accounted for most of the remaining flow to the seeps.

Earthen materials can be placed and compacted to form relatively impervious-flow barriers. Cap thickness is frequently an issue, but a rule-of-thumb from the solid waste industry is a 2-foot minimum. Little information, directly applied to mining, is available to determine if two feet is adequate. Permeability of a cap is affected by grain size, mineralogy, and moisture content of the earthen material, the degree of compaction, and the thickness of the lifts (lifts of six inches are frequently required). Bowders and others (1994) tested mixtures of flyash, sand, and clay as candidate hydraulic barriers in mine spoil. They found that a mix of particle sizes and materials provided the highest packing density and lowest permeability, rather than flyash alone. Hydraulic conductivity varied about two orders of magnitude from 10^{-5} to 10^{-7} cm/sec over different mixes and moisture contents. Rubber-tired equipment or a sheepsfoot roller is required for good compaction efforts. Caps constructed of earthen material can shrink and crack if allowed to dry out. Caps can also be damaged by differential settlement of spoil, which commonly continues for over 10 years after backfilling.

Design geometry of the cap may enhance or reduce the volume of water passing through the cap. A dome shape tends to "shed" water, while flat caps could impound water.

Handling of Acid Materials Using the Submergence or "Dark and Deep" Technique

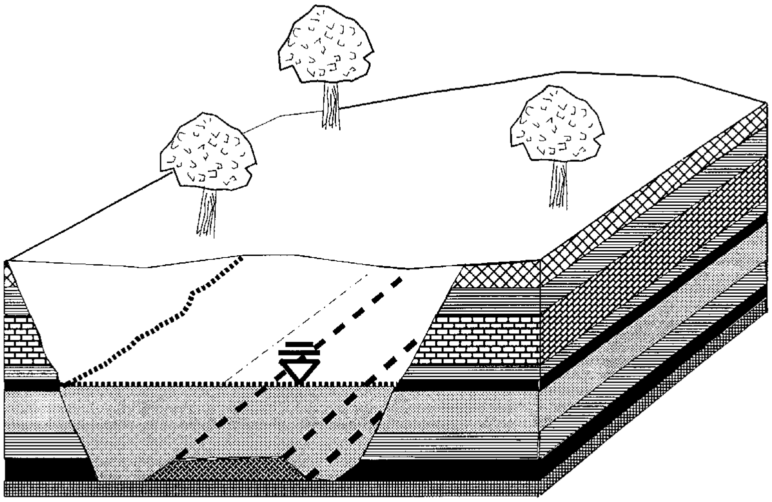
Submergence involves the placement of special handled material below the lowest level of the water table. This method is expected to exclude oxygen from pyrite and is similar in concept to sealing and flooding of underground mines to reduce acid generation. Watzlaff (1992) showed that complete submergence will virtually shut down pyrite oxidation, even with maximum dissolved oxygen. Submergence or "dark and deep" generally requires a relatively flat area with a thick saturated zone. A stationary water table helps to produce a near stagnant condition. The technique is not widely used in Appalachian states because of thin and seasonally variable saturated zones. It is used in Canada and elsewhere for tailings disposal at hard rock mines (Fraser and Robertson, 1994; Robertson and others, 1997) and in the Interior Coal Basin of the United States, where thick and stable saturated zones are more conducive to this method.

In Canada, tailings disposal in lakes usually involves water bodies with minimal circulation and anoxic conditions at depth. Tailings may also be buried on the lake floor by naturally accumulating sediment and organic debris, providing a further barrier to oxygen. In the US mid-continent, topographic relief is low, water tables tend to be near ground surface, and flow gradients are small. Surface mining is conducted mainly by area mining methods, and the final cut is often allowed to flood at reclamation, leaving a relatively deep narrow lake incised into the terrain.

Leach and Caruccio (1991) characterized backfill materials as consisting of three broad hydrologic zones. The first zone is the vadose (unsaturated) zone or zone of high oxygen concentration. Next is the zone of water-table fluctuation with alternately higher and lower oxygen concentration. The final zone is saturated, with very low oxygen concentration. Leaching experiments representing the three zones showed acid load under saturated conditions to be about five percent of that produced in the unsaturated zone. They recommended that acid-forming material should be in the saturated portion of the backfill to restrict oxidation.

Submergence has not been widely documented as a disposal technique in the Appalachian coal fields. Perry and others (1997) found that submergence of acid material buried on the pit floor produced very poor quality drainage at one Appalachian surface mine. In the Interior Coal Basin of the central United States, flooding of final pits and development of a thick saturated zone occurs on many sites. The water quality of most flooded last cut lakes is alkaline; some also have elevated concentrations of dissolved solids and sulfate (Gibb and Evans, 1978). The alkalinity is due to calcareous bedrock and till. A typical submergence scenario for the Interior Coal Basin is shown in Figure 2.4.1e.

Figure 2.4.1e: Schematic of Special Handling of Acid-forming Materials by the Submergence Technique



SUBMERGENCE (DARK AND DEEP) TECHNIQUES

STEPS INVOLVED IN SPECIAL HANDLING ACID MATERIALS

1) Conduct drilling and blasting to expose acid materials,
2) Remove acid materials with a loader or dozer,
3) Construct the disposal site in the backfill at a location:
   - on the mining pit floor,
   - below the final water table to be developed in the post mining backfill,
   - within a hydrologic "no flow" (very low) zone,
   - out of the root zone probably at least 10- feet below the surface
4) Add alkaline material to acid material to reduce acid generation, and
5) Complete the reclamation and revegetation as quickly as possible.

Submergence in the Appalachians entails some risk. If post-mining hydrology is not correctly anticipated, substantially more acid may be generated. Weathering products are leached or mobilized by flowing ground water. Therefore, it is imperative that the site hydrology be well understood. Information necessary to characterize the ground-water flow system includes:

- Estimates of ground-water recharge to ensure a permanent and sufficiently thick water table;
- Determination of how isolated the site is hydrologically from adjacent ground-water systems;

- Determination of whether the backfill can be constructed to produce a reservoir that will keep the acid-forming material continually submerged.

This type of disposal during the mining operation should involve handling the acid-forming material only one time before permanent placement (such as on the pit floor of a previously excavated pit).

A possible disadvantage of submergence is that pyrite oxidation may have already begun before the material is submerged, forming ferric sulfate salts. This can occur during storage and while the water table is rebounding. Upon dissolution, these salts release ferric iron that can oxidize pyrite and sustain acid generation in the absence of atmospheric oxygen. If material handling is unsuccessful (i.e., the water table is not stagnant or thick enough), resultant drainage problems can be large scale. This technique might require a relatively long lag time before success/failure can be determined and large areas can be impacted before the results are known.

Handling of Acid and Alkaline Materials Using Blending Techniques and Alkaline Redistribution

Blending is the mixing of rocks on a mine site to promote the generation of alkaline drainage. The term "blending" has been used widely in the past to refer to the mixing that occurs during the routine mining process. This technique has been recognized since at least the mid 1970s. Anecdotal information exists to suggest that it is an effective practice. It can be effective if sufficient carbonates are present and can maximize the contribution of carbonates by mixing them with acid-forming rock. This can inhibit oxidation of pyrite as well as neutralize acidity. In theory, it is possible to blend rocks from virtually any position in the overburden column, but the actual practice is dependent on the mining method and spoil handling equipment.

A spoil mixing experiment with dragline mining was conducted in Montana where saline or “toxic” overburden was present in varying amounts across a mined area (Dollhopf et al., 1977a, 1977b, 1978, and 1979). Pre-mining distribution and properties of the toxic material were determined from overburden analyses. Systematic drilling and sampling of the reclaimed spoil after mining showed:

- When the toxic material constituted about 5 percent or less of the overburden, the material was undetectable in the regraded spoil;
- When the toxic material constituted 5 to 15 percent of the overburden, partial to complete mixing occurred;
- At concentrations greater than 15 percent toxic material, partial mixing occurred.

Special handling and spoil mixing were conducted on this mine primarily to protect the root zone. It should be kept in mind that the potential problem was saline overburden, not pyritic overburden. Dilution is not always a solution when dealing with pyritic materials. Dilution of pyritic materials with inert materials frequently does not prevent the formation of AMD. Broadly disseminating a substantial amount of reactive, acid-forming rock throughout relatively inert material can allow for widespread generation of AMD.

<u>Alkaline redistribution</u> is a special handling strategy that is used when only a portion of a mine site contains and large portions are devoid of calcareous materials. Without redistribution or off-site importation of alkaline materials (alkaline addition), the portions of the site lacking calcareous materials will produce acidic mine drainage. Examples of sites where alkaline redistribution was used are given in Case Studies 2 and 5 in Section 2.4.4.

General considerations for use of alkaline redistribution include:

- Areal distribution of alkaline materials,
- Position of alkaline materials within the overburden section,
- Volume present at the mine site, and
- Calcium carbonate content of the material.

Location and available volume of alkaline material largely determine the feasibility and effectiveness of alkaline redistribution. If the material is present as a discrete identifiable unit, it can be moved as such. However, if the alkaline material is laterally discontinuous, or dispersed through the column, a plan to isolate and move this material will be difficult to implement.

Alkaline redistribution strategies can include:

- Determining the proportions of alkaline material to be placed on the pit floor, mixed into the spoil, and added to the spoil/soil interface,
- Determining the methods for incorporating the alkaline material into the backfill,
- Choosing the best pit orientation to minimize haulage of the alkaline material,
- Designing a multiple pit operation to facilitate redistribution of alkaline material, and
- Ripping the pit floor to expose alkaline material (when present) beneath the coal.

Actual implementation of alkaline redistribution generally requires the use of rock trucks, since the alkaline amendment is not an integral part of coal overburden removal. The amount of alkaline amendment per acre is calculated via overburden analysis and mass balance equations.

Operational Considerations

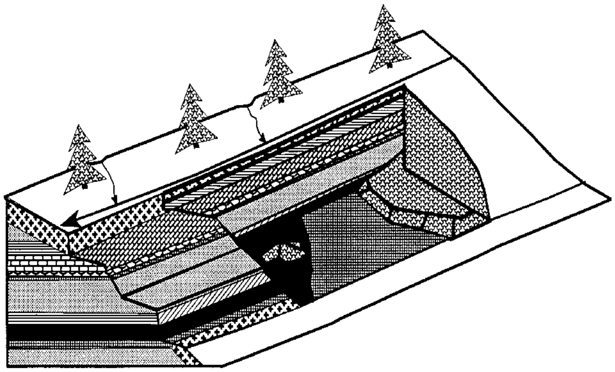
When special handling is part of the mine plan, keeping the pit clean (e.g., removing pit cleanings) and quickly covering acid-forming strata are simple and important activities to reduce the potential for acid production. Removing pit cleanings will ensure that any ground water that reaches the pit floor will encounter reduced amounts of potentially acid-forming material.

Equipment availability is an important consideration in the development of the special handling plan. If the proposal is to move discrete rock units, a truck-shovel operation may be necessary. In addition, if two pits are open at once, a truck-shovel operation facilitates the movement of overburden from one pit to another. However, if large sections of strata are to be removed, a skilled dragline operator may be required.

If an alkaline stratum lies adjacent to a potentially acid-forming stratum, the strata may become mixed without additional effort during the overburden removal operation, and separation of the potentially acid-forming strata may not be needed.

Generally an excess of neutralizers dispersed throughout the overburden profile is necessary to offset both acid production and imprecise mixing. A simple blending plan is shown in Figure 2.4.1f.

Figure 2.4.1f: Blending and Alkaline Redistribution Do Not Require the Isolation of Acid-forming Materials in Isolated Pods



BLENDING AND ALKALINE REDISTRIBUTION TECHNIQUES

STEPS INVOLVED IN SPECIAL HANDLING ACID AND ALKALINE MATERIALS

1) Conduct drilling and blasting to expose acid and alkaline materials,
2) Remove acid and alkaline materials with a loader or dozer,
3) Blend (mix thoroughly) the acid and alkaline materials, and
4) Complete the reclamation and revegetation as quickly as possible.

2.4.2 Verification of Success or Failure

A critical step in successful special handling is to ensure that the special handling plan is properly implemented. It may be necessary to periodically perform additional testing of the overburden to assure that the proper material is being handled.

Inspections by the regulatory agency, of sites with special handling as a BMP, should be frequent and detailed enough to document compliance with the mining plan. An inspection implementation checklist identifying key aspects of the plan will be useful.

Implementation Checklist

Recommended items to be considered during the permit review process are listed below:

- The overburden data should be sufficient enough to identify which strata will require handling.
- The overburden data should be sufficient enough to provide representative sampling for the mine. This will typically require multiple bore holes and appropriate vertical sampling.
- Plans should be clearly designed with appropriate maps, cross-sections, and narratives.
- Plans should be feasible in the field and not just on paper. For example, the strata to be special handled should be easily identifiable in the field.
- The plan should be enforceable.

Recommended items to consider in a special handling implementation inspection checklist are listed below:

- Field implementation should correspond with the plans in the permit application (e.g, agreement with the permit maps, cross-sections and narrative)
- The appropriate equipment should be available.
- The blasting method should be appropriate.

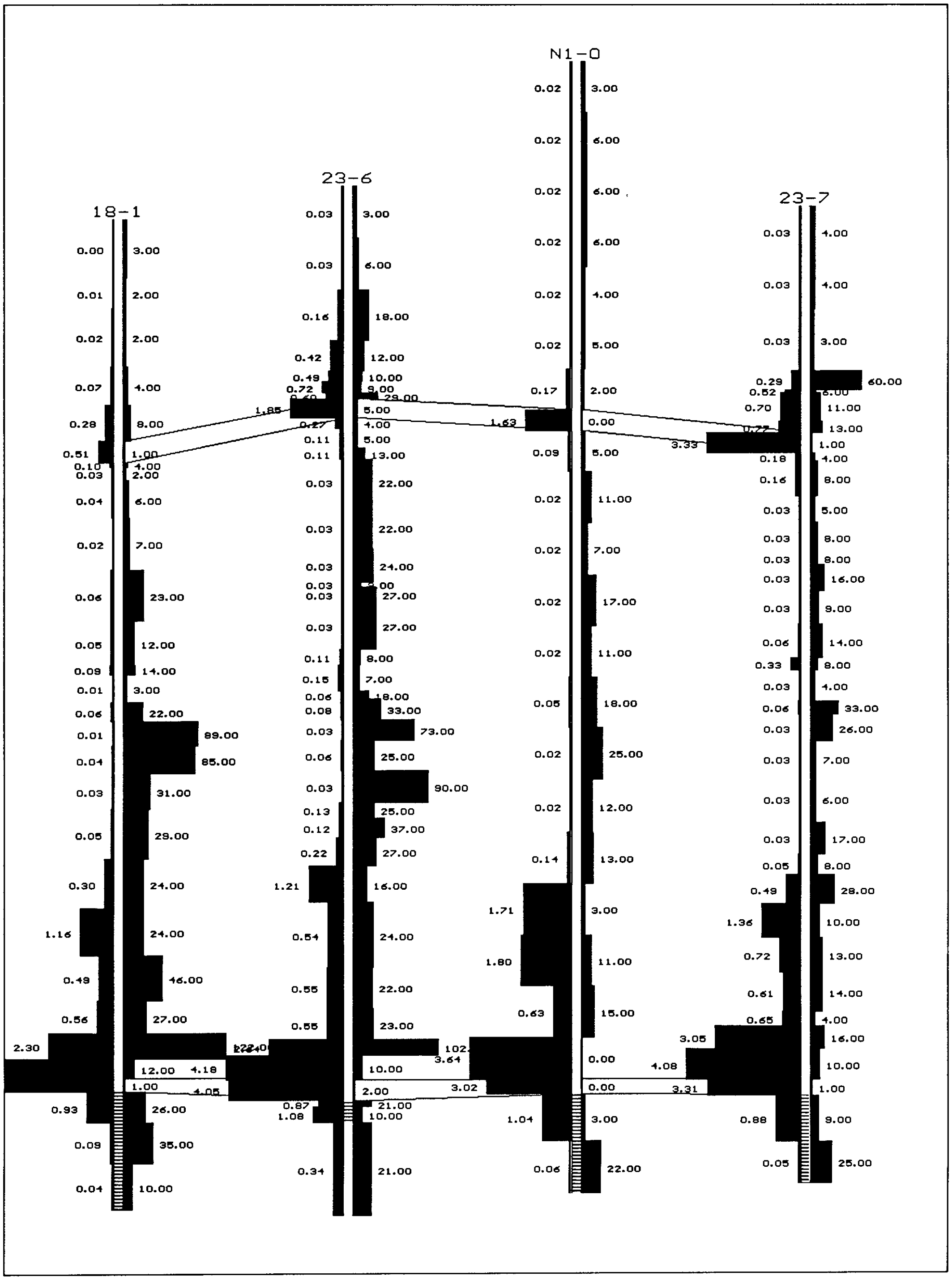
- The material to be special handled should be identifiable in the field by the equipment operators.
- The water monitoring data should be submitted.

2.4.3 Case Studies

Case Study 1

Cravotta and others (1994b) compared the distribution of sulfur and neutralization potential in undisturbed overburden strata (Figure 2.4.4a) with the post-mining redistribution of these parameters in the disaggregated mine spoil (Figures 2.4.4b and 2.4.4c) for two mining methods. The mine site studied was a reclaimed surface mine on two adjoining hilltops in Clarion County, Pennsylvania. The southern area was mined with a 45 yd^3 dragline. The northern area was mined with bulldozers and front-end loaders, which selectively handled the high-sulfur strata near the coal.

Figure 2.4.3a: Distribution of Sulfur and Neutralization Potential for Bedrock at the Special Handling Site in Clarion County, PA. (Drill logs are to scale. Most sample intervals for N1-0 are five feet.)



The original plan for the 16-acre northern area called for placing the high-sulfur rock in pods 10 feet above the pit floor, with low-sulfur material placed between the pods and the pit floor. Drill holes N2-0 and N2-2, located five feet apart, encountered one of the specially handled pods. The other drill logs show that mining, in general, inverted the high-sulfur (>0.5 percent) material and located it near the spoil surface. Most logs show low-sulfur (<0.15 percent) material near the pit floor. Maximum saturated thickness of spoil in the northern area was 18 feet and in the area of N2-0 the saturated thickness was ten feet. The spoil sulfur data and spoil water level data suggests that the high-sulfur spoil was successfully placed above the water table within the northern area. The permit specification for placement ten feet above the pit floor, however, would have been inadequate to keep the high-sulfur material above the spoil water table.

Spoil in the 34-acre southern area was also inverted, with the highest sulfur rock predominantly in the upper part of the spoil. The sulfur in the lower part of the spoil is typically between 0.25 and 0.4 percent, higher than typical on the northern area where the spoil was selectively handled. The highest saturated thickness in the spoil was about 20 feet. Thus the highest sulfur material in the southern area was also placed above the water table.

Spoil handled by bulldozers and loaders can be expected to have a more uniform particle-size distribution, exhibit similar or greater compaction, and exhibit lesser hydraulic conductivity than that handled by the dragline (Hawkins, 1998; Phelps and Saperstein, 1982; and Phelps, 1983). Air circulation commonly was lost in shallow spoil during air rotary drilling in the dragline-mined southern area. However, no air losses occurred in the bulldozer-mined northern area, suggesting greater compaction and more uniform particle size distribution from bulldozers and loaders than from a dragline. Nonetheless, hydraulic conductivities for saturated mine spoil were similar among the two areas. For saturated spoil, median hydraulic conductivities were $10^{-3.8}$ to $10^{-3.6}$ m/s in each area. The similarity in hydraulic conductivities could result from similar lithologies, and piping and settling processes (Hawkins, 1998, and Pionke and Rogowski, 1982) by which fines are transported downward and large voids fill or collapse. Mine spoil in the southern area is several years older than that in the northern area, so a longer time has elapsed for these processes to occur.

Figure 2.4.3b: **Distribution of Sulfur and Neutralization Potential for Spoil in the Northern Hilltop Where Bulldozers and Loaders Were Used (Note the "pod" of selectively handled high sulfur material in N2-0 and N2-2. Sample interals are five feet.)**

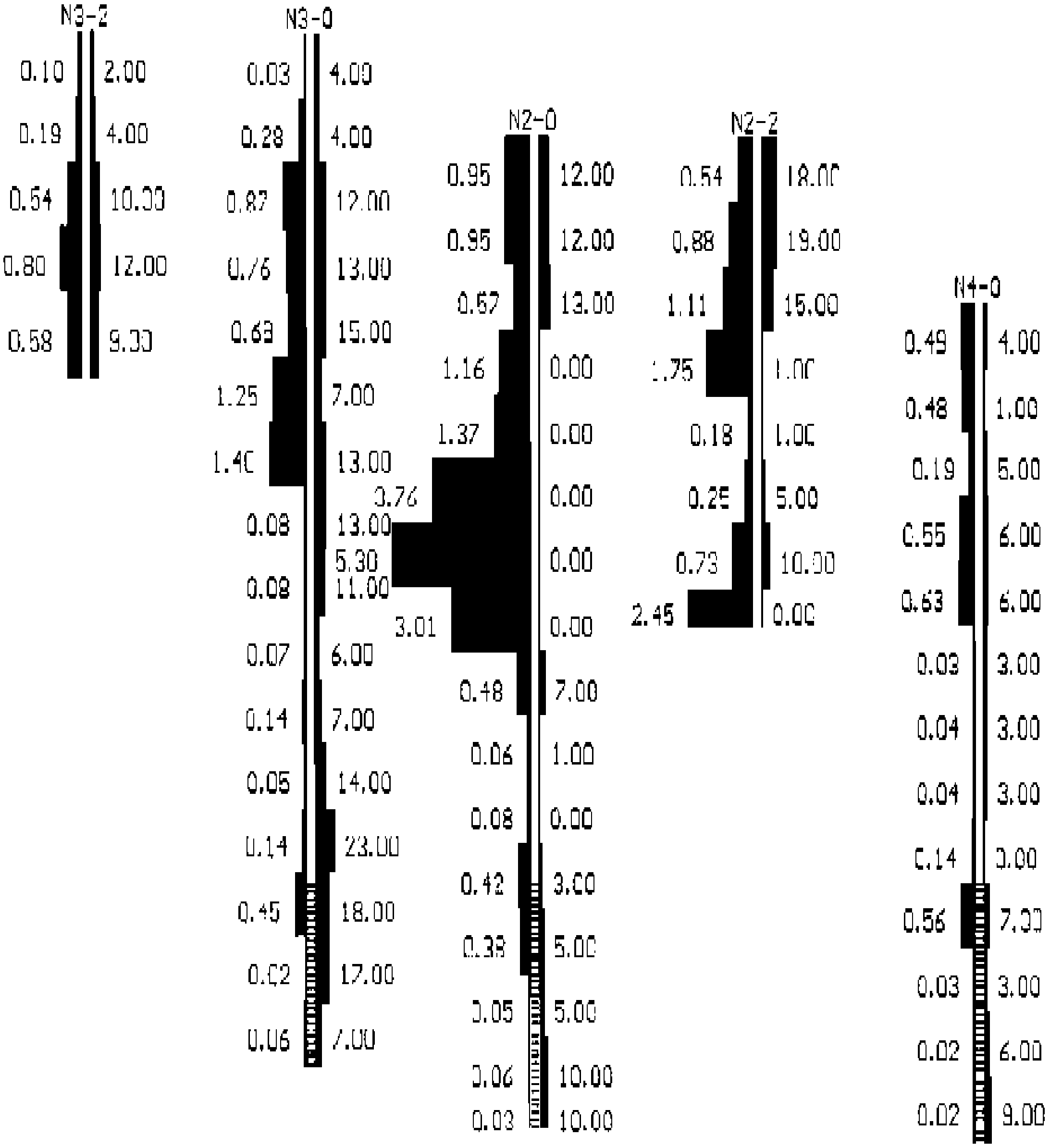
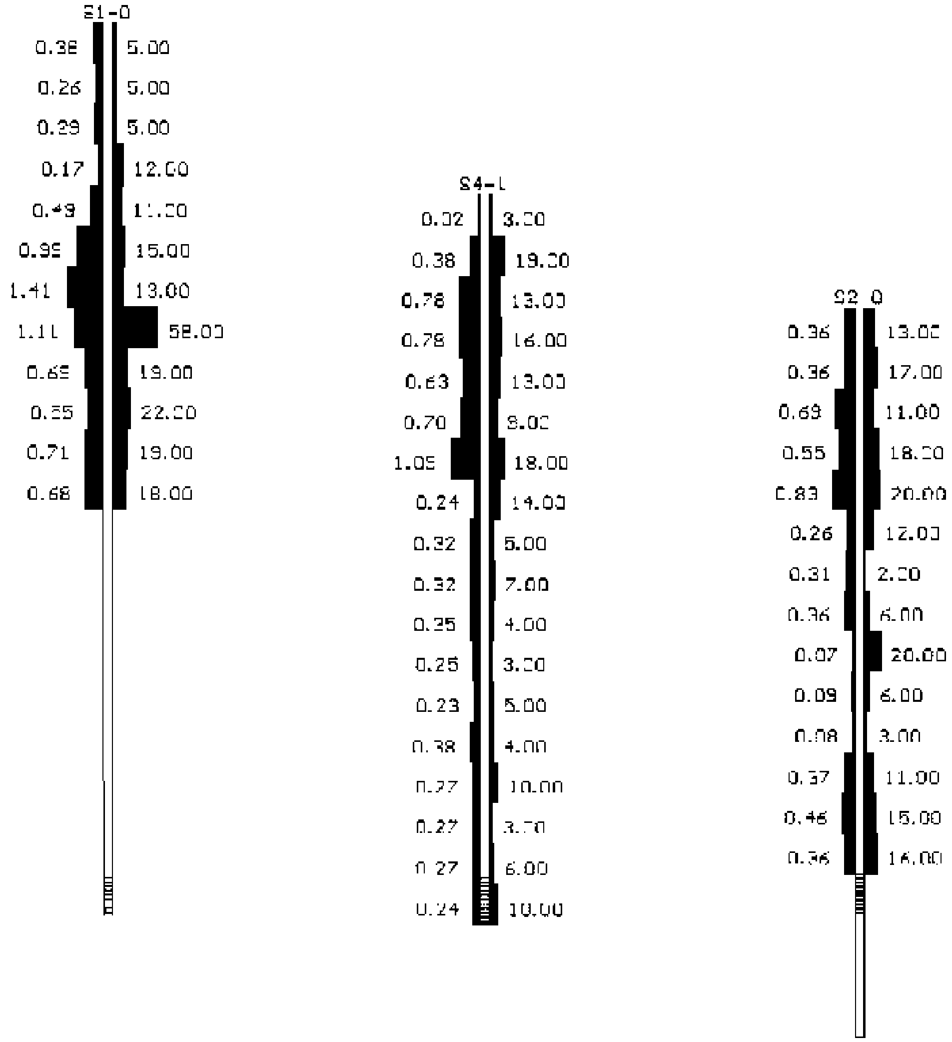


Figure 2.4.3c: Distribution of Sulfur and Neutralization Potential for Spoil in the Southern Hilltop Where a Dragline was Used (Sample intervals are five feet.)



Alkalinity, sulfate, iron, and manganese concentrations in the spoil ground water produced by the selective-handling method were similar to that in spoil produced by the dragline method. Median values for alkalinity of ground water in the saturated zone were between 100 and 400 mg/L. Sulfate ranged from 600 to over 1000 mg/L (Cravotta and others, 1994b).

Case Study 2 (West Virginia)

Skousen and Larew (1994) describe the redistribution of alkaline material from separate but adjacent mine sites. Calcareous rock was hauled from a mine extracting Bakerstown coal to a mine on the upper Freeport coal. Alkaline redistribution consisted of placement of about three feet of calcareous shale on the pit floor, partial backfilling, then placement of acidic material about 20 feet high in the spoil, followed by capping with more calcareous shale. A pre-existing, mildly acidic discharge (acidity about 75 mg/L $CaCO_3$) was ameliorated and made alkaline.

Case Study 3 (Clearfield Co., PA)

A cementitious cap constructed of fluidized bed combustion (FBC) ash mixed with waste lime has been placed on a 97 acre reclaimed mine site in Clearfield County, Pennsylvania. Hellier (1998) reports on the successful efforts of the operator. Surface mining on the lower and middle Kittanning coal seams began in the 1940s on this site. Upon completion of the mining in 1991, the operator was required to pump and treat an acidic post-mining discharge. Treatment costs threatened to bankrupt the operator. Most of the mining on the site predated special handling techniques. The operator removed the top three feet of material and spread a three-foot layer of FBC ash mixed with ten percent waste lime. Water was added to increase the moisture content. The ash/lime mixture hardened to form a low-strength cement. The top material was then replaced and revegetated. The cap served to inhibit infiltration, which was thought to be the primary source of water at this site. The cap would also inhibit oxygen from entering the backfill. At 80 percent completion, the operator no longer has to provide chemical treatment, pumps significantly less water, and the chemistry of the water remaining in the backfill has improved. A passive treatment system, which is in place, is adequate to mitigate the reduced flows of AMD.

Case Study 4 (Green County, PA)

A mine in Greene County, Pennsylvania, produced both alkaline and acid water on two segment phases (Perry and others, 1997). The two segments had similar geology and hydrology, and were mined by the same company. Alkaline drainage was produced on the segment where mining was completed without stoppage and where a special-handling plan was followed. Acidic drainage was produced from the Phase 2 segment where mining ceased for an extended period before the site was completely reclaimed. The poor quality drainage on the Phase 2 segment was attributed to weathering of partly reclaimed material during mining cessation and poor adherence to the special handling plan. Median water quality data for the two sites is summarized in Table 2.4.4a.

Table 2.4.3a: Summary Water Quality for Greene County Site Phases 1 and 2

Monitoring Point	pH	Net Alkalinity (mg/L CaCO3 Eq.)	Total Fe (mg/L)	Total Mn (mg/L)	Sulfate (mg/L)
Phase 1, Mining	6.5	176	0.3	6.5	606
Phase 2, Mining	3.6	- 488	71.4	105	2233
Phase 1, Post Mining	7.2	151	1.88	16.35	1197
Phase 2, Post Mining	4.0	- 128	18.7	62.7	1770

Case Study 5 (Westmoreland County, PA)

A mine in Westmoreland County, Pennsylvania, used alkaline redistribution to amend a portion of the site that was deficient in carbonate-bearing rocks. Acid-forming materials were laterally continuous and had 0.5 to over 2 percent total sulfur. A zone of calcareous materials, with carbonate content exceeding 20 percent, was present over a small area of the site. Special handling consisted of moving excess calcareous strata from the upper end of the mine and redistributing it in the alkaline deficient areas. Three pits were operated simultaneously. Operations were timed so that alkaline material would be available and cut and fill balances could be maintained. Material placement and backfilling included crushed limestone on the pit floor, "neutral" spoil backfill, placement of potentially acid material in lifts covered by more "neutral" spoil, and finally topsoil.

Wells and springs have been monitored for four years after reclamation at the alkaline redistribution site (Table 2.4.4b). In Well MW-6 (located down-gradient of the site), median sulfate concentration decreased by approximately 70 percent, and net alkalinity rose above zero after reclamation was completed. MP-10 (a spring located down-gradient of the mine) is representative of shallow ground-water conditions and contains negligible alkalinity. Overburden rocks in the recharge area for MP-10 and well MW-6 were likely acid forming. Post-mining water quality for MP-10 and MW-6 show a small but significant increase in net alkalinity. Sulfate concentrations indicate a lesser amount of oxidation and leaching is continuing within the spoil.

Table 2.4.3b: Summary of Water Quality Conditions, Alkaline Redistribution Site

Monitoring Point	**pH**	**Net Alkalinity (mg/L CaCO3 Eq.)**	**Specific Conductance (umhos/cm)**	**Sulfate (mg/L)**	**Total Fe (mg/L)**
MW-6, Mining	6.1	- 8	855	398	0.15
MW-6, Post Mining	6.1	24	404	115	1.5
MP-10, Mining	6.5	6	N/A	19.5	0.04
MP-10, Post Mining	7.1	20	280	90	0.09

Key factors influencing post-mining water quality are the redistribution of calcareous rock to alkaline-deficient areas, and rapid completion of mining and reclamation. Responses in water chemistry are attributed to placement of acid-forming materials above the water table to minimize leaching, while the calcareous rocks are dissolving and producing alkalinity.

Case Study 6 (EPA Remining Database, PA(10))

The PA(10) is also discussed in Section 1.1.4, Case Study 3. This site included the following BMPs: regrading of abandoned spoil, alkaline addition, hydrologic controls, revegetation and scarification of the calcareous pavement, and application of bactericides. The only calcareous stratum was the underclay beneath the lowest coal seam. There was a significant amount of high sulfur rock above the coal. To counter the lack of calcareous rock above the coal, the coal company proposed scarifying the pit floor (to expose the calcareous underclay) and a negligible alkaline addition rate of 3 tons/acre (applied to the spoil surface). Bactericide was added to prevent oxidation of pyrite through the retardation of the pyrite-oxidizing bacteria. Scarifying of the underclay is the form of special handling implemented at this site.

This site is one of only a handful of remining sites in Pennsylvania that have resulted in poorer post-mining water quality (see Section 1.1.4, Case Study 3). Several factors may have worked together to contribute to poor water quality. Failures have been observed at other, non-remining sites, where the bulk of the alkaline material was located on the pit floor (Smith and Brady, 1998). Scarifying may not have broken the rock sufficiently to allow for exposure of adequate surface area of the calcareous strata. Perhaps this plan would have been more successful if the calcareous material had been mixed through the spoil.

2.4.4 Discussion

Despite years of implementation, few studies of special handling and its effect on post-mining water quality have been performed. Special handling is almost always used in conjunction with other BMPs, thus separation of the effects of special handling alone is often not possible. For sites lacking calcareous strata, special handling alone will not create alkaline water. For this reason, special handling is often combined with alkaline addition. For a site to be a remining site, the area has to have been previously affected by mining. This previous mining and the type of associated remining is of three types: deep mining and subsequent daylighting, strip mining and subsequent regrading and revegetation, and coal refuse removal and subsequent regrading and revegetation. Thus remining sites with special handling do not occur without one of these additional BMPs.

Special handling methods fall into four categories: 1) blending, 2) high and dry, 3) dark and deep, and 4) alkaline redistribution. Blending is generally used where both calcareous and acid-producing rocks occur within the stratigraphic column. Mining is done in such a way as to blend the two materials together such that AMD should be prevented. "High and dry" and "dark and deep" are intended to limit the amount of water and oxygen in contact with the special handled material, respectively. Limitation of water will be most effectively accomplished if the surface of the special handled pod is sloped to achieve ground-water runoff, the pod is capped with a low permeability material, and the material is placed above the post-mining water table ("high and dry"). Limitation of oxygen can probably only realistically be achieved by submergence below the water table ("dark and deep"). Alkaline redistribution is used where calcareous materials occur on only part of a site. Excess alkaline material is redistributed to the portions of the site lacking alkaline materials.

Benefits

- Blending of calcareous material in the spoil has the advantage of being accomplished during the regular course of mining.
- Dark and deep (i.e., submergence below the water table) has the benefit of limiting oxygen available for pyrite oxidation.
- Alkaline redistribution results in calcareous rocks being distributed to parts of the mine where they did not occur naturally, thus providing the benefits inherent in calcareous rocks.
- High and dry, if material is capped and placed above the water table, should reduce the transport of pyrite-weathering products.

Limitations

- Blending is only effective if the calcareous material is can be adequately mixed in the spoil.
- Sites that can satisfy the requirements for "dark and deep" do not always exist in the Appalachians due to thin saturated zones and fluctuating water tables.
- High and dry technology has been inadequately studied and some of the studies are inconclusive. Without capping and proper placement it may be ineffective. The post-mining hydrology should be well understood.

Efficiency

Blending is the most common handling method, but is not strictly "special handling," because it does not require additional selective handling of materials and is accomplished as part of the routine mining process. The many sites in the Appalachians that have compliant post-mining water quality demonstrate its success. The key is to have sufficient calcareous strata present. The success of this method is probably reflected in the fact that mines that had regrading and revegetation as their only BMPs (Section 6.0, Table 6.3g) had 50 percent of discharges improve in acidity load, with the other 50 percent remaining unchanged. As discussed in Section 6, remining operations in the Pennsylvania Remining Site Study (Appendix B) that implemented these minimal BMPs probably contained better overburden quality than many of the sites that employed multiple BMPs.

The effectiveness of high and dry placement is not as clear. Studies that have been performed are few and some are inconclusive. High and dry is the most commonly used special handling method in Pennsylvania, and it can be assumed that most of the sites listing special handling as a BMP in the Pennsylvania Remining Site Study were using this method. Data from this study were used to predict the effectiveness of special handling for improving water quality during remining operations. Section 6.0, Table 6.3a shows that special handling can be predicted to result in slightly lower water quality improvement with regard to acidity loading than can be predicted if no BMPs are implemented. Section 6.0, Table 6.3g provides some different insight into the effectiveness of special handling. Special handling in conjunction with the minimal

BMPs of regrading and revegetation resulted in the same effectiveness rating as did the combination of regrading and revegetation alone. As other BMPs were added (regrading, revegetation, special handling, plus other BMPs), efficiency generally declined, with less discharges showing improvement in acidity load. This is probably due to the presence of greater amounts of acid-producing overburden and/or lesser amounts of calcareous overburden, with the additional BMPs added to offset the effects of the poorer overburden.

When deep mines are daylighted, there is often acidic material that requires special handling. This acidic material is typically unrecoverable coal and roof-rock. Section 6.0, Table 6.3m compares the implementation of daylighting alone to seven other BMP combinations. Four of these seven BMP combinations involve special handling. Three of the four resulted in a higher percentage of discharge water quality improvement than daylighting alone. Two of these three successful BMP combinations included the addition of alkaline materials. The fourth BMP group included a combination of five BMPs that routinely produced the poorest results. It is suspected that this is because additional BMPs were implemented in an attempt to counter poor quality overburden.

The dark and deep method of special handling has been shown to be a good means of AMD prevention. Its usefulness in the Appalachians, however, is often limited because of a thin saturated zone and a fluctuating water table that allows the acidic material to be exposed part of the year. The effectiveness of the dark and deep method cannot be evaluated using the Pennsylvania data, because it is used so seldom.

Alkaline redistribution has had a high degree of success. Evaluation of the Pennsylvania data (Section 6.0 and Appendix B) suggests that alkaline redistribution has been a very successful special handling practice. Section 6.0, Table 6.3a shows that the predicted odds for improvement of acidity load when alkaline redistribution is used is eight times greater than when no BMPs are implemented. The only other BMP that gave a greater odds of improving discharges was mining of alkaline strata (nearly 19 times greater than when no BMPs are implemented).

Special handling by itself may reduce acid production, but it can not produce alkalinity in the absence of calcareous materials. Special handling, in conjunction with alkaline addition or other means of incorporating alkaline strata, can result in better water quality than using special handling alone.

2.4.5 Summary

- Special handling practices used in the Appalachians include: blending of acid and alkaline materials, the segregation and isolation of acidic materials (high and dry), and alkaline redistribution.

- Special handling is often used in conjunction with other BMPs such as management of ground water and alkaline addition.

- Submergence (dark and deep) is seldom used in much of the Appalachians because the saturated thickness of the water table is generally thin and the water table can undergo large seasonal fluctuations.

- Special handling in the absence of alkaline materials cannot produce alkaline drainage.

- Special handling often involves <u>both</u> acid and alkaline materials and may also include clay materials for capping and lining pods of acidic materials.

- Special handling is most effective in conjunction with other BMPs such as alkaline addition and surface- and ground-water management techniques.

- Alkaline redistribution and mining of high-alkaline strata (which often involves special handling) have been very successful in improving post-remining water quality.

- The volume of the material to be special handled should generally be less than 20 percent of the mine backfill volume because of the need to keep acidic materials away from the surface, water table, highwalls, etc.

- Special handling is not necessary on all mine sites.

- Identification and segregation of acid material is extremely difficult if multiple zones exist in the stratigraphic section, unless these zones are persistent laterally and vertically, of uniform thickness, and distinctive in appearance.

- Special handling requires that the proper earth-moving equipment be used at the mine site.

- Monitoring during and after mining is necessary to evaluate special handling techniques.

2.5 Bactericides

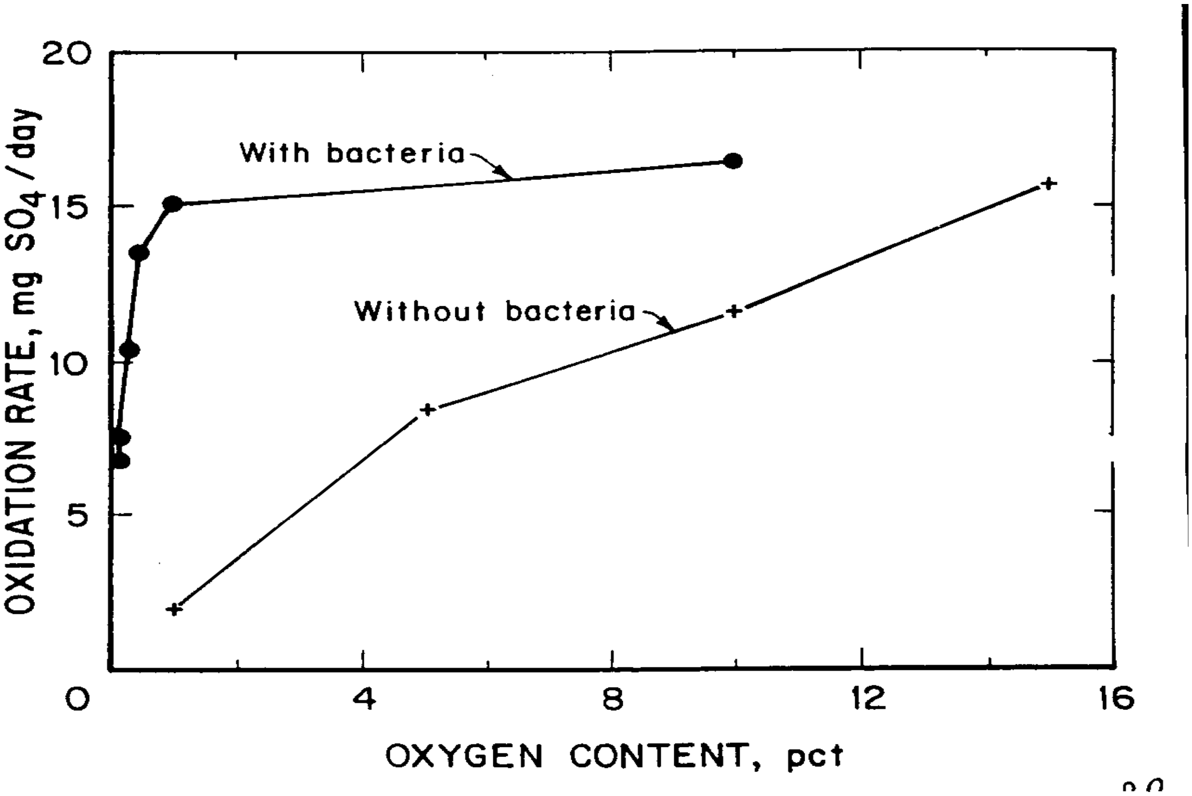
Introduction

Bacteria can play an important role in pyrite oxidation. They can cause pyrite to oxidize under low oxygen levels at a much faster rate than would occur in the absence of bacteria under the same conditions. Bactericides attempt to block the catalytic effects of certain bacteria on the pyrite oxidation process.

Theory

Pyrite-oxidizing bacteria, in particular *Thiobacillus ferrooxidans*, are responsible for the increased oxidation of pyrite over what would occur abiotically (Figure 2.5a), especially at low oxygen concentrations. Although numerous bactericides have been tested against pyrite-oxidizing bacteria, the bactericides of choice for mine sites have been anionic surfactants. These bactericides occur in household cleansers and soap products. At near-neutral pH these surfactants generally are considered to be poor bactericides, but they are markedly more inhibitory at low pH (Kleinmann, 1998). *T. ferrooxidans* has a near-neutral pH internally, but it can exist in low pH conditions (in fact, the conditions that it creates by oxidizing pyrite) because of a coating that protects the cell from the externally low pH environment. Anionic surfactants dissolve the protective coating, thus subjecting the bacteria cell to low pH conditions, conditions under which it can not survive unprotected.

Figure 2.5a: Rates of Pyrite Oxidation with and without Iron-oxidizing Bacteria (In small columns maintained at different oxygen partial pressures) (Hammack and Watzlaf, 1990).



The amount of oxygen present within the pore gas of mine spoil or coal refuse is an important factor when considering the use of bactericides. Figure 2.5a shows pyrite oxidation rates under biotic and abiotic conditions. At oxygen levels of approximately 14 percent, biotic and abiotic rates are about equal. Below oxygen levels of 14 percent, pyrite oxidation rates are considerably slower when bacteria are absent. In the presence of bacteria, pyrite oxidation can be significant even at oxygen concentrations as low as one percent. Thus bactericides are most advantageous where oxygen concentrations are low.

Bactericides have a limited period of effectiveness, and typically are only effective for up to four months. This limitation can be compensated for by repeated application or by application of time-release pellets.

Cations such as calcium and magnesium can cause water "hardness," which can reduce the effectiveness of surfactants in much the same way that hardness reduces the effectiveness of soap. Calcite and dolomite, which contain calcium and magnesium, are common minerals in coal overburden. Kleinmann (1999) felt that this surfactant inhibition would be greatest with highly-soluble neutralizers such as quick lime (CaO) and hydrated lime ($CaOH_2$). Something to keep in mind is that bactericides in-and-of-themselves do not produce alkalinity, and compounds that produce alkalinity frequently contain calcium and magnesium, which may inhibit the effectiveness of bactericides. That is, the minerals that result in acid neutralization can retard the effectiveness of bactericides.

Site Assessment

The initial site assessment for bactericides is similar to that for other geochemical BMPs. First, the acidity- and alkalinity-generating potential of the site should be determined by evaluating overburden and water-quality data. If the site has little or no potential to produce acidity, bactericides are not necessary.

Kleinmann (1998) points out that application rates of anionic surfactants are site-specific and heavily dependent on the adsorptive capacity of the material being treated. He suggests that pilot-scale field tests in plastic 55-gallon drums be used to determine the adsorptive properties of the surfactant. He cautions that small test piles may not accurately simulate larger sites because of higher oxygen concentrations in the small piles (Kleinmann, 1998). Determination of the amount of adsorption is important to assure that there will be adequate bactericide available to combat the bacteria on the surfaces where it is needed.

It is important to estimate the oxygen concentration in the mine spoil or coal refuse. For bactericides to be effective the oxygen concentration should be relatively low (<10 percent). Most experiments with bactericides have been done on compacted coal refuse. This material, because it is compacted (and often contains a high percentage of fine materials) can have low concentrations of oxygen. The use of bactericides at surface coal mines is potentially less effective because of likely higher concentrations of oxygen. If oxygen levels are high (>10 percent), there may be very little benefit from bactericides because abiotic pyrite oxidation is sufficient to create significant amounts of acid.

Spoil pore gas oxygen concentrations can be related to the type of rock that was mined, or disposed of (in the case of coal refuse). Some examples of oxygen levels in pore gas, which can serve as guidelines, are given below in the literature review/case study section.

Site evaluation should include assessment of:

- The acid-producing potential of the site;
- The adsorptive capacity of the overburden; and
- Prediction of the percent oxygen in spoil or coal refuse pore gas.

2.5.1 Implementation Guidelines

The following guidelines are recommended for application of bactericides:

- Surfactants should be targeted to treat unweathered acid-forming material, such as coal refuse, that can be quickly buried.
- They should be applied at a rate higher than the rate they are adsorbed by the rock.
- They should not be applied to soils if the intention is to treat spoil, because soils will adsorb the surfactant leaving little to act on the underlying spoil.
- They are probably only effective where oxygen content is low (< 10 percent), thus an estimation of pore gas oxygen should be made.
- Surfactant solutions can be applied to acid-producing materials prior to their disposal. Time release pellets can be mixed with the spoiled material. Both methods may be needed for long-term effectiveness. If used in solution form, the surfactant may need to be applied 3 to 4 times per year.

- Carbonate content may also be important. Kleinmann (personal communication, June 28, 1999) says that high calcium water can inhibit the effectiveness of some anionic surfactants. More soluble neutralizers such as hydrated lime and quick limes are most problematic. Essentially calcium can cause hard water and inhibit the effectiveness of the surfactant.

2.5.2 Verification of Success or Failure

As with all BMPs, bactericide application should be implemented as described in the plans. Means of documentation include:

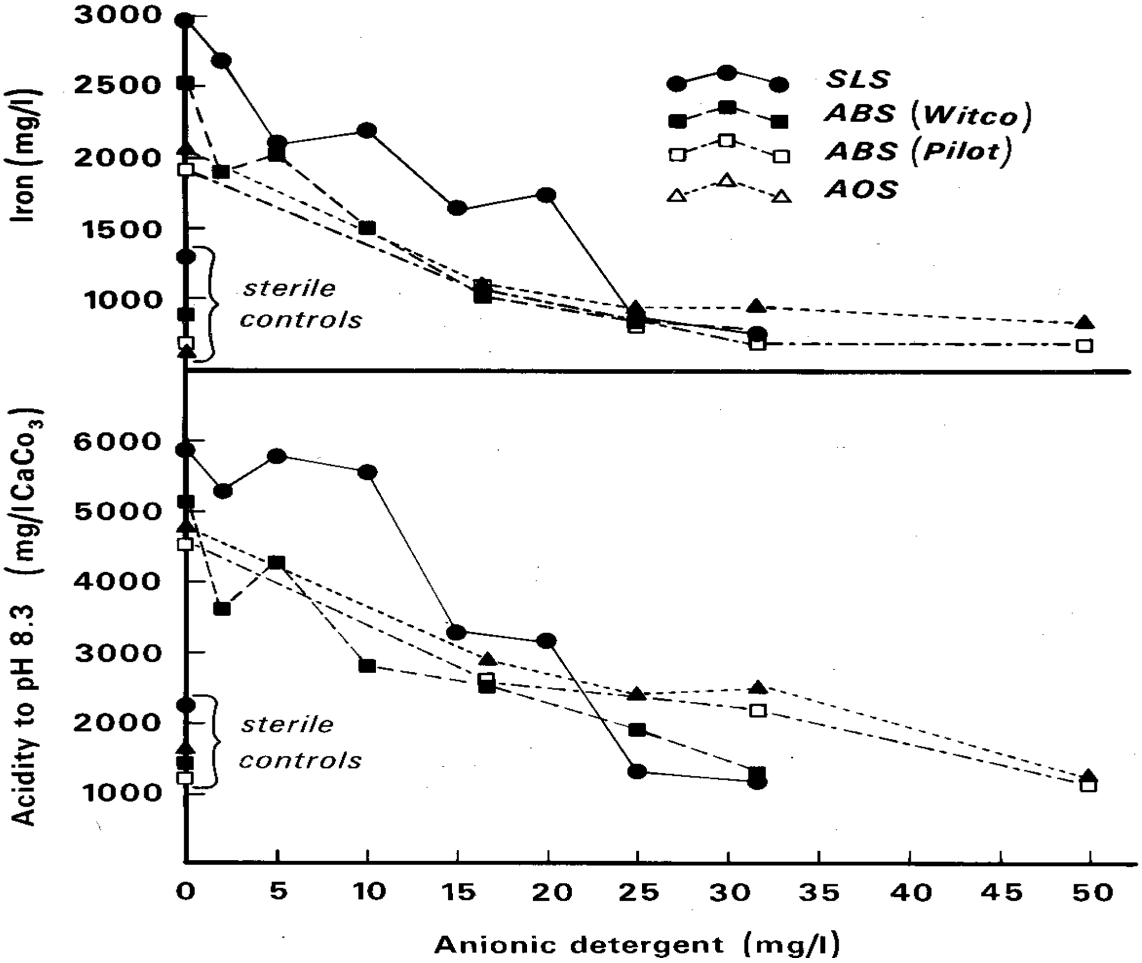
- Engineer's certification and increased inspection frequency to verify that the bactericide was implemented as planned
- Photographs of the bactericide application
- Locations of bactericide applications being accurately recorded through surveying or global positioning systems
- Verification of the amount of bactericide used by submittal of receipts.
- Laboratory analyses of the acid-forming materials to assure proper placement of bactericides
- Water-quality monitoring for flow and concentration of mine drainage parameters and bactericide.

Monitoring of water quality and flow, as well as accurate documentation of implemented plan, will allow for future improvements in design and determination of the efficiency of bactericides.

2.5.3 Literature Review/Case Studies

There are a variety of substances that can inhibit pyrite-oxidizing bacteria, but Kleinmann (1998) states that only anionic surfactants proved to be cost effective. Kleinmann tested, in the

Figure 2.5.3a: **Effect of Anionic Detergents on Acid Production from Pyritic Coal. (SLS = sodium lauryl sulfate, ABS = alkyl benzene sulfonate, AOS = alpha olefin sulfonate) (from Kleinmann, 1998).**



laboratory, the relative effectiveness of three anionic surfactants in preventing acid formation. He found sodium lauryl sulfate (SLS) to be the most effective (Figure 2.5.3a). Higher concentrations of the other surfactants were required to get the same effect.

As mentioned earlier, an important consideration as to the effectiveness of bactericides is pore gas concentration of oxygen. Oxygen concentrations in pore gas have been measured for refuse material and for surface mines. Guo and Cravotta (1996) reported oxygen concentrations with depth for two surface mines in Pennsylvania (Figure 2.5.3b). Mine 1 contained predominantly shale/siltstone overburden and Mine 4 contained predominantly sandstone overburden. Mine 1 shows significant decreases in oxygen with depth, with concentrations as low as 2 to 4 percent at 11 meters. By contrast, oxygen was never below 18 percent at Mine 4, even at depths of 17 meters. This is probably due to the blocky nature of the sandstone which allows more atmospheric exchange than the smaller-sized rubble resulting from shale/siltstone.

Figure 2.5.3b: **Measured Profiles of Oxygen in Unsaturated Spoil (after Guo and Cravotta, 1996) (At Mine 1 gas transport is by diffusion and at Mine 4 it is by convection. Mine 1 has shale/siltstone overburden and Mine 4 has sandstone overburden.)**

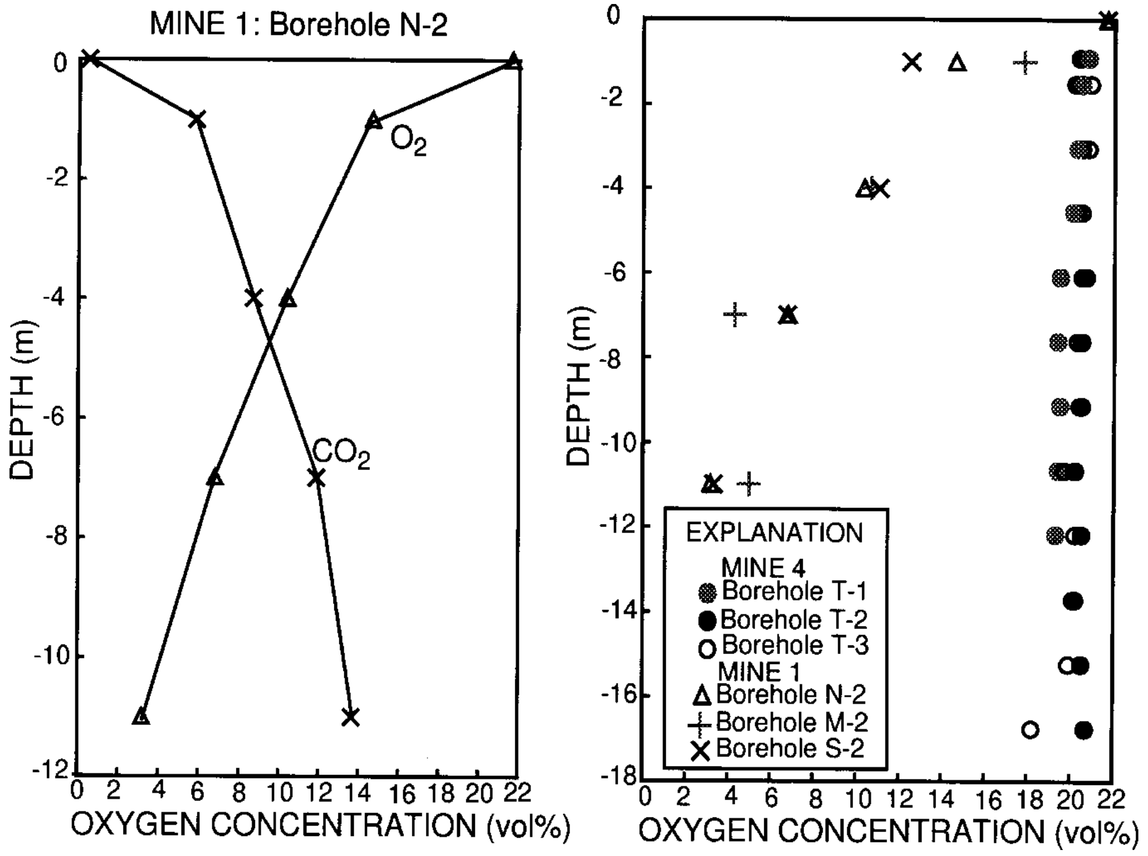
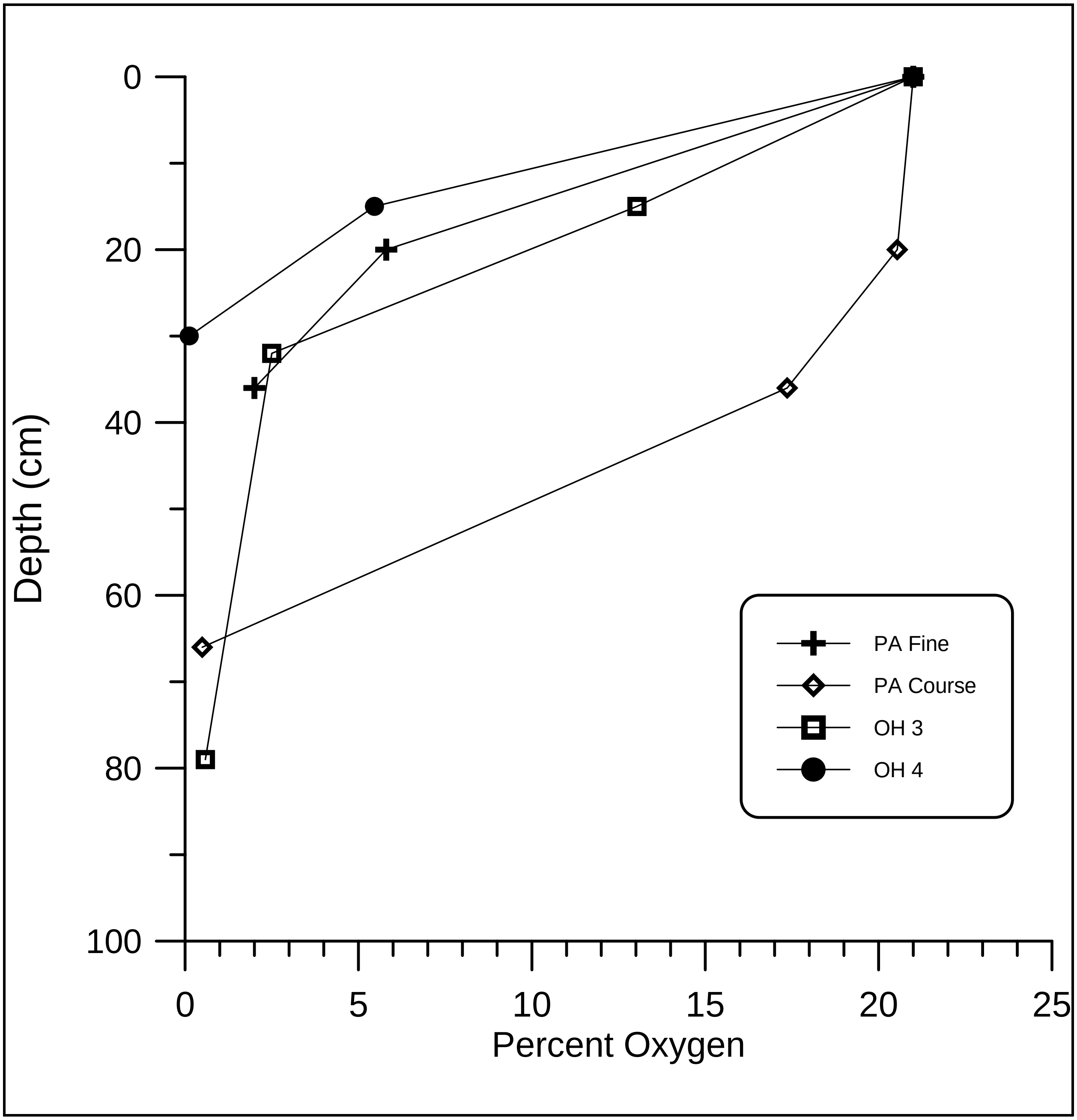


Figure 2.5.3c: **Oxygen Concentration with Depth in Coal Refuse in Pennsylvania and Ohio.**



Erickson and Campion (1982) report on oxygen concentrations with depth in coal refuse for sites in Pennsylvania and Ohio. The results of their measurements are shown in Figure 2.5.3c. All gas probes were installed at less than one meter deep. Three of the four plots show similar declines in oxygen concentration with depth (PA Fine, OH 3 and OH 4). The "PA Coarse" refuse had substantially higher oxygen concentrations at a depth of 36 cm than did the other refuse. The coarser nature of the refuse apparently allowed for greater exchange with the atmosphere.

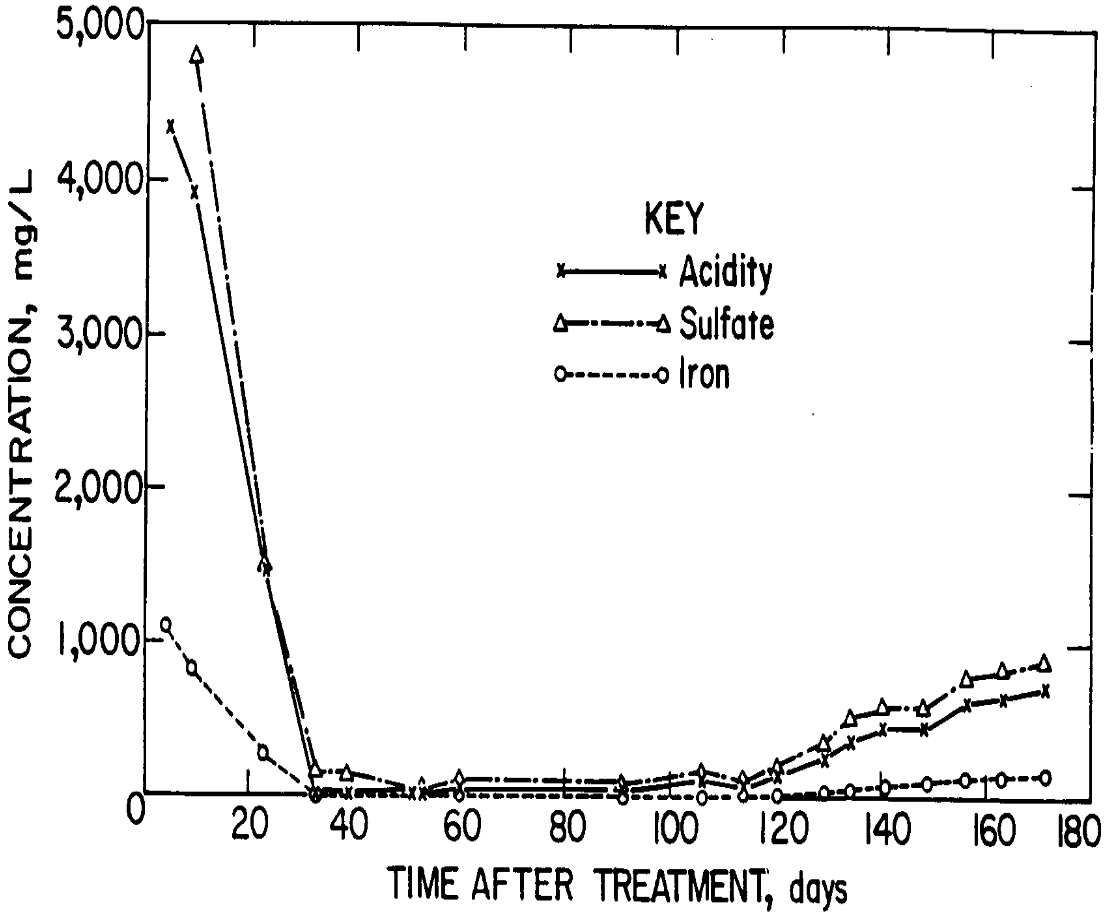
The coarse refuse had less than 1 percent oxygen at less than meter, whereas oxygen concentrations in surface mines had 12 percent and greater at one meter depth. At 7 meters, the surface mines had at least 4 percent oxygen, even where the overburden was shale (a rock that breaks into small sizes). There are a couple of explanations for these results. First, coal refuse is generally composed of highly pyritic material that will consume and deplete oxygen near the surface. Surface mine spoil, by comparison, is lower in sulfur and oxygen consumption is not as great. Second, coal refuse is typically finer-grained and more compacted than mine spoil. This permits less oxygen exchange between the pore gas and the atmosphere.

Case Study 1 (Preston Co., WV) (Kleinmann and Erickson, 1983)

This site was an 8-acre active coal refuse disposal area. Because the area lacked background water quality data, a pond was constructed to collect runoff for monitoring purposes. Adsorption tests indicated that an application rate of one 55-gallon drum of 30 percent SLS would be needed per acre. The bactericide was diluted with water by a factor of 50:1. A larger dilution factor would have been preferred, but good quality water was limited.

Water quality improved dramatically within a month of the SLS application. Acidity, sulfate and iron were reduced by 95 percent and remained low for approximately four months following application (Figure 2.5.3d). A complicating factor with this study was that coal refuse not treated with bactericide was added during the study period. It is thus impossible to separate out

Figure 2.5.3d: **Effect of Sodium Lauryl Sulfate on Runoff Water Quality at an 8-acre Active Coal Refuse Pile in Northern West Virginia (Application rate: 55 gal/ac of 30 percent solution, diluted 50:1 (Kleinmann and Erickson, 1983))**



whether the increases in acidity starting at 120 days was due to this untreated refuse or diminishing effects of SLS. Effluent concentrations of surfactant remained extremely low (consistently less than 0.1 mg/L) throughout application with none being detected in the receiving stream.

Case Study 2 Ohio (Kleinmann, 1998)

This site provides a long-term evaluation of bactericide application to a refuse pile. The initial field test was conducted in 1984 by the Ohio Department of Environmental Resources. A 2.5 acre area was treated with SLS, and an adjacent 2.2 acre area served as an untreated control. SLS was applied in solution at a rate of 200 lbs/acre and as pellets composed of a rubber matrix at a rate of 500 lbs/acre (containing 16 to 28 percent SLS). Both areas were covered with 6 to 8 inches of topsoil which was fertilized, limed, seeded and mulched.

Five years after reclamation, biomass production on the treated area was nine times greater than the untreated area. Acidity in the vadose zone in the treated area was 80 percent lower than in the untreated area. After 10 years, 35 to 40 percent of the control area was barren and eroding, whereas the treated area showed no significant erosion and the vegetative cover was dense.

Case Study 3 West Virginia (Skousen and others, 1997)

A 35-acre coal refuse pile was first regraded. Controlled release surfactant pellets were applied to the surface, which was then topsoiled, limed and revegetated. The treated area had a pH of 6.2 compared with a pH of 2.9 in a 1.2-acre untreated control area. Acidity was as low as 1 mg/L compared to 1680 mg/L, and reductions in iron and manganese were equally significant.

Case Study 4 Ohio (Skousen and others, 1997)

Bactericides were applied to an abandoned surface mine that was poorly vegetated. The application was in the form of slow-release pellets that were spread by a hydroseeder. The overburden was predominantly sandstone with abundant pyrite. Seeps with acidity of 1000 to 3000 mg/L have remained acidic, showing little sign of improvement.

Case Study 5 Appendix A, EPA Coal Remining Database (PA (10)), Somerset County, PA

Details on the specifics of this site are presented under Section 1.1, Case Study 3, with regard to Control of Infiltrating Surface Water. Multiple BMPs were implemented at this site including surface regrading, scarification of calcareous pavement (seat rock), alkaline addition, hydrologic controls, and bactericides. The bactericides were applied in the form of time release pellets on the spoil surface prior to spreading of topsoil.

Two of four seeps have had increases in acid and sulfate post-mining loads compared to baseline loads. The other two seeps show no significant statistical difference in load. In all cases the concentrations of acidity have increased.

Case Study 6 Remining Database VA (4), Wise County, VA

A blend of polymers and a bacteria inhibiting agent were formulated to retard acid soil formation. The bactericides were used as part of a plan to reduce the thickness of topsoil from four feet to one foot. In addition to bactericide use, the topsoil was limed, seeded, fertilized and hay mulched. Erosion control blankets were applied to reduce erosion and to protect the seed. Tree seedlings were planted on slope areas. Vegetation remains successful after more than a decade.

2.5.4 Discussion

The literature review and case studies suggest that bactericides have been successfully used on fresh (unweathered) coal refuse to inhibit pyrite oxidation (Case Studies 1, 2 and 3) and for revegetation purposes (Case Studies 2 and 6). Case Studies 4 and 5 concern application of bactericides at remining sites, and in both cases the water quality was not improved. This lack of improvement at remining sites containing abandoned surface mines may be due to the high oxygen concentrations present in spoil pore gas, the large volume of material that needs to be treated, and adsorption of much of the bactericide on non-acidic rock. An additional complication with surface mines is that calcareous strata or alkaline amendments may cause water hardness that can decrease the effectiveness of bactericides.

Bactericides are regulated under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Only bactericides registered under FIFRA can be legally used.

Benefits

- Can inhibit pyrite oxidation in low oxygen environments
- Can assist in revegetation efforts by acting as a wetting agent.

Limitations

- Limited to low oxygen environments, such as coal refuse disposal
- The bactericide will be adsorbed onto rock and soil, thus an excess should be applied
- Bactericides have a limited period of effectiveness and should continually be replenished
- Works best on fresh materials
- Limited by the presence of certain cations (Ca, Mg)

Efficiency

Not enough data regarding the application of bactericide is available for statistical analysis. However, review of the case studies cited above allows for some tentative efficiency statements to be made:

- Bactericides appear to have successfully reduced acidity at active refuse piles, where they can be applied directly to fresh refuse.
- Very few studies exist for surface coal mines. The two case studies cited above were not successful. This may be due to oxygen availability in surface mine spoil. Another complicating factor is "hard water," due to the high concentration of calcium and

magnesium. Much of the bactericide may be adsorbed on non-acid-producing rocks, thus diminishing its availability for acid-producing rocks.

- Bactericides can be effective for enhancement of revegetation efforts by acting as wetting agents.

2.5.5 Summary

As a remining BMP, the evidence to date does not support the use of bactericides for prevention of acid water on surface coal mines. It appears, however, that bactericides have assisted in enhancement of revegetation efforts and bactericides have successfully reduced acid production from active coal refuse piles.

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Section 3.0: Operational Best Management Practices

Introduction

Some remining Best Management Practices (BMP) are operational procedures that specifically should or should not be implemented during mining. Other operational BMPs pertain to how, where, and under what circumstances a certain procedure should be employed or to what areal extent it should be implemented. The BMPs discussed in this chapter deal with a broad range of mining practices such as: the rate of mining, the speed of reclamation, handling and disposal of pit and tipple cleanings, auger mining, on-site coal stockpiling, issuance of permits with acid-forming overburden, coal refuse reprocessing, and the scope of underground mine daylighting.

In certain mine sites, the proposed remining operation is within a “gray area” with regard to whether the pollution load will be reduced or increased. In these marginal situations, there are operational procedures that, if implemented, can improve the likelihood of pollution load reduction. These operational BMP procedures are generally sound environmental practices even when the site is not considered marginal.

Theory

The production of acid mine drainage (AMD) requires three basic components: a sulfide mineral (i.e., pyrite), oxygen, and water. If any one of these components is missing or controlled, AMD production will not occur. In the production of AMD, pyrite is oxidized to form hydrous iron sulfates (salts). Pyrite oxidation is catalyzed to a high degree by the iron-oxidizing bacteria *Thiobacillus ferrooxidans* (Erickson and others, 1985). These salts are subsequently dissolved in water and a hydrolysis reaction occurs yielding acidity (H^+), iron (Fe^{2+}), and sulfate (SO_4^{2-}). AMD production can be attenuated or prevented if:

- Pyrite is not present in significant quantities.
- The contact of oxygen with pyrite is limited or prevented.
- The proliferation of iron-oxidizing bacteria is prevented.
- The contact of ground water with pyritic materials is prevented.

The BMPs discussed in this chapter are based on limiting one or more of the basic components that cause the formation of AMD.

Site Assessment

The mining operation should be reviewed in terms of whether or not the concurrent reclamation is an viable option. Will the topography, type of surface mining, number of coal seams, mining equipment allow for concurrent reclamation? Are there other factors that may impact the speed of reclamation? If so, the question of how these factors be mitigated to ensure concurrent reclamation should be addressed.

As part of site assessment, the amount of tipple refuse material that the remining will produce should be determined. This determination will require lithologic logs and chemical analyses of the coal, partings, and enclosing strata. Information should be provided on how this material will be segregated and temporarily stored on-site. The type and location of an off-site disposal facility also should be given.

Information on the hydrogeologic properties of the site should be obtained. The location, direction, and depth of auger mining needs to be delineated on mine maps. Depth of the overlying cover also needs to be determined from drill holes. Using monitoring wells and boreholes, the stratigraphic location of aquifers can be determined. Aquifer tests (e.g., slug or constant-discharge tests) will yield information on the hydraulic properties (transmissivity and hydraulic conductivity) of the aquifers. Water levels in the monitoring wells should be measured at least monthly to determine seasonal variations and response to precipitation. A literature review of spoil testing and/or on-site testing of existing spoils, where present, will provide data on the projected hydrologic properties of the post-mining backfill. Analysis of the hydrogeologic data will yield insight into the potential post-mining water levels with respect to the auger holes.

Assessment of on-site coal stockpiling will require information on coal sulfur values, location and construction details of the stockpile pad, and determination of pad construction material (e.g., clay or other low-permeability substance). Engineering specifications on the pad material compactibility, permeability, and stability should be available. Available space to construct a treatment facility down gradient for any stockpile leachate should be demonstrated. If on-site stockpiling is deemed undesirable, an operational plan to haul off-site the coal as soon as it is excavated should be required.

Assessment of the additional overburden to be disturbed by remining requires that the overlying rocks be analyzed using standard overburden analysis techniques as described in Section 2.0, Geochemical BMPs. The drill holes need to be distributed in a manner to ensure that the entire site is characterized. The overburden analysis can be used to calculate alkaline addition rates, if needed.

Refuse piles commonly contain areas where burning has occurred in the past from spontaneous combustion or ignition by trash fires. If these areas are extensive, they can dramatically impact the economics of the operation. The refuse pile needs to be drilled to the extent that an accurate assessment of the amount of recoverable coal can be made. Once reprocessed, some type of cover material that will support vegetative growth is required. Availability of enough topsoil or a soil substitute to reclaim the site also needs to be determined. A survey of support areas surrounding the pile will yield information regarding the on-site availability of topsoil materials.

A pre-remining assessment of the amount of daylighting that will occur should be performed. This assessment is based on the amount of cover to be disturbed and, perhaps more importantly, on the amount of recoverable coal. Determination of the recoverable coal reserves needs to be accurate. This level of accuracy is achieved by an extensive drilling program. It is not uncommon for different sections of an underground mine to contain significantly different recoverable percentages. If these differences exist they need to be delineated. If the entries are relatively open, a borehole camera can also be used to visually inspect the remaining pillars. The amount of cover can likewise be determined by drilling.

3.1 Implementation Guidelines

Rapid Mining and Concurrent Reclamation

In recent years, many mine operators have come to the realization that expedient reclamation reduces the potential for AMD production. Concurrent reclamation thus, has become an integral part of mining operations. The speed at which mining and subsequent reclamation are conducted can have a substantial impact on the resulting post-mining water quality. Accelerated pyrite oxidation occurs when the overburden is broken up and exposed to atmospheric oxygen. The process of overburden removal during mining breaks the rocks into clay- to large boulder-sized particles, which increases the exposed surface area by several orders of magnitude. This greater exposed surface area in turn greatly increases the potential amount of pyrite that is freshly exposed to the atmosphere and is susceptible to oxidation. A certain amount of pyrite oxidation is expected and inevitable in the course of surface mining. However, when a mine spoil is permitted to remain exposed to the atmosphere for a protracted period of time prior to reclamation, accelerated and extraordinary oxidation of the pyrite-rich rocks (>0.5 percent total sulfur) in the overburden can occur.

The scale and scope of acid mine drainage formation from mining cessations depends on several factors, including but not limited to:

- Length of the cessation period;
- Amount and sizes of pyrite-rich rocks that are exposed;
- Concentration of the pyrite in the exposed rocks; and
- The form of the pyrite (e.g., massive versus widely disseminated).

Other geochemical factors also come into play in the protracted cessation scenario. The chemical reactions that create acid mine drainage are accelerated by protracted subaerial exposure. The chemical reactions that can prevent or ameliorate AMD are attenuated by this exposure. If present, alkaline materials (e.g., calcium carbonate-rich rocks) will yield alkalinity to water when exposed. At atmospheric carbon dioxide (CO_2) concentrations (mean 0.03 percent by volume or 0.0003 atmosphere), an approximate maximum of 61 mg/L as bicarbonate (HCO_3^-) alkalinity or 20 mg/L calcium can be released into water (Hem, 1989; Smith and Brady, 1998). When alkaline rocks are buried, they can yield substantially more alkalinity through calcium carbonate dissolution. The release of alkalinity is governed by several factors, including to a large extent the CO_2 concentration of the surrounding atmosphere. Figure 3.1a illustrates the relationship between the solubility of calcium carbonate in water at 25°C and the partial pressure of CO_2 (Pco_2) in the atmosphere. Lusardi and Erickson (1985) and Cravotta and others (1994) recorded CO_2 concentrations in mine backfills exceeding 20 percent by volume. A Pco_2 of 0.2 (20 percent) is capable of yielding calcium concentrations up to and exceeding 200 mg/L, which yield substantially higher bicarbonate alkalinities (610 mg/L) than produced at atmospheric CO_2 concentrations.

Unreclaimed spoil will likely produce much less alkalinity than the same spoil after reclamation has occurred and once the natural background levels of gases in the vadose zone are re-established. Carbon dioxide is produced in soils from plant root respiration and bacterial decay of organic matter. Concentrations of 1 to 2 percent in soil are common. However, higher concentrations can occur (Jennings, 1971). When spoil is unreclaimed there is no soil cover to aid CO_2 production and retard its escape. Exposed spoil is highly subject to advective forces driven by winds, temperature gradients, and other factors, which permit the flow of the surrounding atmosphere through the piles. With continual advection, near atmospheric levels of CO_2 are maintained within the spoil. Figure 3.1b illustrates advective impacts on unreclaimed mine spoil. The relatively low permeability of a soil cover slows the rate of gases released from the backfill, thus preventing the escape of CO_2 once it is introduced into the subsurface. Infiltration of atmospheric gases into the spoil is likewise impeded by the soil cover.

Figure 3.1a: Relationship Between the Solubility of Calcium Carbonate and the Partial Pressure of Carbon Dioxide at 25°C (modified after Hem (1989))

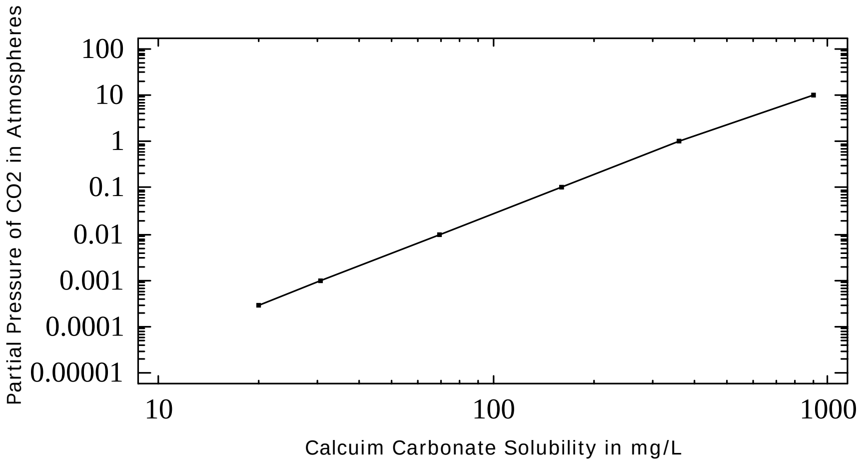
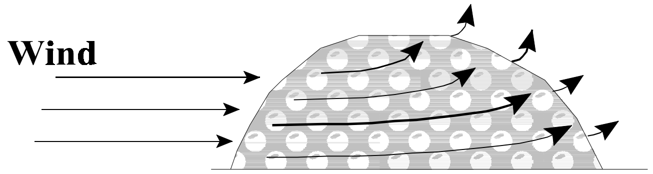


Figure 3.1b: Advective Impacts on Unreclaimed Mine Spoil



The reaction rate of sulfide (pyrite) oxidation and subsequent hydrolysis to form AMD is generally much faster than the dissolution of calcium carbonate to yield alkalinity under normal backfill conditions. With prolonged atmospheric exposure of spoil, this inequity of reaction rates is accentuated even more. The rate-determining step for AMD production at low pH is the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) which is facilitated (catalyzed) by certain iron oxidizing bacteria (Stumm and Morgan, 1996) that thrive under acidic conditions. Then, because the Fe^{3+} will oxidize pyrite much faster than O_2 (atmospheric oxygen) in a low pH environment (Rose and Cravotta, 1998), AMD production greatly increases once a low pH is established. Substantial pyrite oxidation from protracted mining cessation and associated spoil exposure can accelerate the progression to this higher phase of AMD production. With accelerated AMD production, any alkalinity that is released may be overwhelmed, resulting in a net acidic discharge. If the backfill is prevented from reaching this high rate of AMD production, alkalinity released from the spoil may be able to prevent or neutralize AMD.

Some possible exceptions to the necessity of this operational BMP include but may not be limited to those listed below.

- Situations where the pyritic content of the overburden material is extremely low, there are no disturbed rock units with any significant pyrite concentrations or most overburden samples are well below the threshold of concern (0.5 percent total sulfur). For example, overburden associated with many of the coals in the southern West Virginia coalfields fall into this category. Table 3.1a summarizes overburden analysis data from a surface mine located in Logan County, West Virginia. These data are indicative of the low-sulfur values common to these coalfields, but they are not necessarily representative of the quality of the entire coalfields.
- It is possible that the application of massive amounts of bactericides on the unreclaimed spoil may temporarily prevent the deleterious effects of a protracted cessation. Bactericides can, for a time, dramatically slow the rate of pyrite oxidation. However, the use of bactericides on surface mines in the past has been less than successful. Some success has been observed for the temporary stockpiling of coal refuse subsequent to

burial (Sobek and others, 1990). Additionally, because the use of bactericides is expensive, it may not be economically feasible for many remining operations.

Table 3.1a: Summary of Overburden Analysis Data from a Surface Mine Located in Logan County, West Virginia

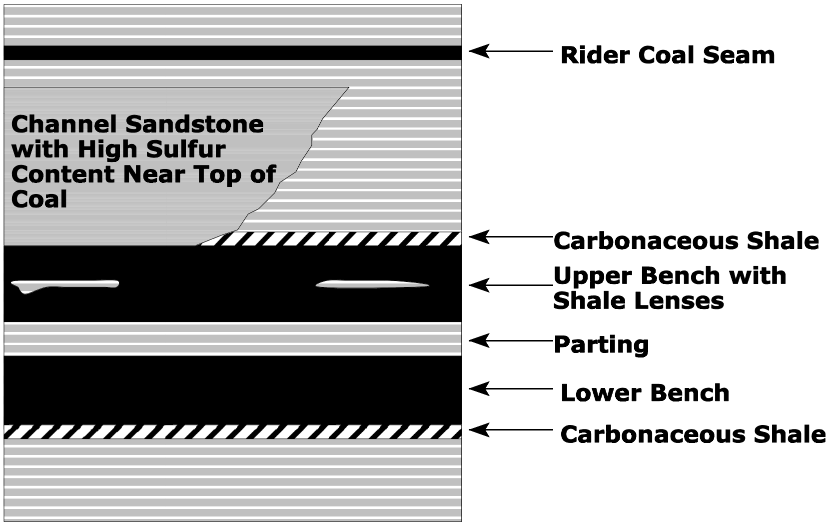
Coal Seam	Total Overburden Thickness (feet)	Sample Thickness Range (feet)	Highest Sulfur Value (percent)	Lowest Sulfur Value (percent)	Median Sulfur Value (percent)
Lower Stockton	44.70	1.30-15.00*	0.10	<0.01	<0.01
Lower Stockton Leader	14.95	0.95-3.65	0.09	0.02	0.04
Upper Stockton “A”	16.40	1.60-3.40	0.06	<0.01	0.03
Lower Stockton “B”	95.10	0.30-5.00	0.10	<0.01	<0.01
Coalburg	91.05	0.30-5.00	2.21**	<0.01	0.01

* The first 15 feet of soil and subsoil was grouped.
** This was a 1.45 foot thick unit and the only one to exceed 0.50 percent total sulfur.

Off-Site Disposal of Acid-Forming Materials

In the course of a remining operation, quantities of acid-forming rocks associated with the coal (e.g., pit and tipple cleanings) are removed and frequently stockpiled for later disposal within the spoil. These rocks include rocks immediately overlying the coal (commonly a black shale or pyritic sandstone), parting or binder (usually a carbonaceous black shale or bone coal), immediate seat rock (carbonaceous and/or pyritic shales or claystones) removed along with the coal, unsaleable rider or split seams, and other acid-forming materials separated from the coal during loading out of the pit or during the initial coal cleaning at the tipple/breaker. See Figure 3.1b for examples of sources for pit and tipple cleanings. Total sulfur concentrations of several percent are common in these rocks. Table 3.1c contains total sulfur values for stratigraphic sections surrounding the coal in an overburden analysis hole drilled on a remining site is located in Westmoreland County, Pennsylvania (Appendix A, EPA Remining Database, 1999, PA(3)).

Figure 3.1c: Potential Sources of Pit and Tipple Cleanings



Remining operations typically occur on abandoned mine sites that are already producing AMD from prior coal mining activities. Therefore, it is generally a sound practice to remove acid-forming materials from the remining site and dispose of them elsewhere. Disposal of materials that have been identified as acid-producers within backfill that is already producing AMD has the potential to accentuate or aggravate the existing problem.

Table 3.1b: Total Sulfur in Stratigraphic Sections Enclosing the Coal at a Remining Site in Westmoreland County, Pennsylvania (Appendix A, EPA Remining Database, PA(3))

Lithology	Interval Thickness (feet)	Total Sulfur (Percent)
medium gray claystone	1	0.80
black shale	1	1.86
coal	1	2.31
grayish black shale with coal layers	3	1.16
coal	6	1.01
medium dark gray calcareous fireclay	1	1.48

There are a few circumstances that would allow on-site disposal of acidic pit and tipple cleanings while limiting the potential to produce more acid. These conditions include, but may not be limited to:

- Sites where the overburden is composed to a great extent of calcareous (alkaline) material. Any potentially acidic material can be entirely encapsulated within this material. In these situations, the production of alkalinity will most likely either preclude acid production (iron oxidizing bacteria do not thrive in an alkaline **environment**) or overwhelm any acidity that is produced.
- Sites where the amount of pit and tipple cleanings are relatively small in volume and insignificant compared to the entire volume of the spoil. In these cases, the acidic material can be specially handled (e.g., strategically placed, capped, encapsulated, etc.) to prevent additional acid production. Care should be taken in these situations to ensure that the special handling technique is physically viable (See Section 2.4, Special Handling of Acid-Forming Materials). For example, if the special handling plan is to place the acid-forming materials above the water table, the backfill should be thick enough allow material placement well above the anticipated highest level of the post-mining water table.

Auger Mining

Similar to on-site disposal of pit and tipple cleanings, auger mining during a remining operation is generally not recommended. Auger holes, depending on the hydrologic system of the site and the sulfur content of the coal, have a high potential to create additional AMD. Because remining sites are usually already yielding AMD, it is generally not a good practice to permit auger mining.

Auger holes can create similar environmental conditions to those previously described for underground mine workings, substantially increasing exposed surface areas in potentially acidic strata. Ground water entering the auger holes contacts primarily coal and perhaps a minor amount of roof and seat rock. All three of these rock units are composed of potentially acid-forming materials as illustrated in Table 3.1c. At the final highwall, auger holes typically are sealed with a low-permeability material to a depth up to three times the diameter of the hole. The sealed holes are then covered with spoil. A large portion of the holes remains empty, allowing the exposure and possible oxidation of pyrite. Ground water entering auger holes will dissolve the salts created by the pyrite oxidation and subsequently hydrolyze, creating acid mine drainage.

The amount of increased surface area caused by auger holes can be considerable compared to exposure of the remaining coal at a final highwall. For example, a mine with a 1000-foot final highwall, no augering, and a four-foot coal seam would have 4000 ft^2 of coal exposed prior to reclamation. If the same site incurred augering, the exposed surface area would include the area defined by the auger holes plus the remaining coal exposed at the highwall. If the auger holes were 3.5 feet in diameter, spaced on eight-foot centers (leaving one foot between holes) and augered to a depth of 400 feet, the additional area is equal to 549,750 ft^2 or an increase in exposed surface area of over two orders of magnitude (137-fold).

In addition to the increased exposure of acid-forming materials, the hydrologic system of the auger holes is drastically different from spoil that is simply backfilled against a highwall. These differences in the hydrology can result in differences in the types of drainage produced. The nature of many surface mines may permit the auger holes to experience alternate dewatering and flooding, which allows oxidation of pyrite followed by flushing from the influx of ground water. Depending on the dip of the strata, overlying topography, aquifer characteristics, and other hydrogeologic factors, it is possible that the coal will be below the water table. If the water table levels are somewhat stable and the coal lies below water level, the coal seam will be essentially inert in terms of AMD production, because of the exclusion of atmospheric oxygen. Thus, depending on the hydrologic system, auger holes can become AMD generating systems.

There are circumstances where auger mining may be permissible at remining operations with little chance of increasing the pollution load. These include, but are not limited to:

- If the hydrologic system is such that the auger holes are likely to be flooded and remain so permanently, auger mining may be acceptable. Permanent flooding will preclude the introduction of atmospheric oxygen, thus the acid mine drainage production should cease. Watzlaf (1992) and Watzlaf and Hammack (1989) observed that subaqueous positioning of pyrite virtually stops the oxidation. Even if the ground water is saturated with dissolved oxygen (12.75 mg/L at 5°C (Hem, 1989)), pyrite oxidation is halted by submersion. Augering below the regional drainage system will likely allow for complete and permanent inundation the auger holes.
- Augering above regional drainage may be permissible if auger hole sealing can be achieved to a degree that precludes the infiltration of atmospheric oxygen and/or inhibits ground-water drainage from the holes. If the auger holes, once sealed, flood and the flooded conditions are maintained, AMD production should be prevented.

Stockpiling of Coal

Stockpiling of coal on-site for extended periods is not recommended. Coal is often the most acidic material encountered during mining and therefore can produce the worst water quality. Leaving a large stockpile of acidic material exposed to the atmosphere and precipitation will create extremely acidic, metal-laden water that can infiltrate into the backfill and foster additional AMD production.

Often the least saleable coal is the coal with the highest sulfur concentration. This lower quality coal is commonly held until it can be blended with a higher quality (lower sulfur) coal to promote sales. This coal is the most frequently stockpiled and held for extended periods of time, prior to sale. This coal also creates some of the worst water quality associated with coal mining.

Acidity concentrations in the thousands of milligrams per liter are not uncommon for water draining from these stockpiles. Concentrations exceeding even 10,000 mg/L have been recorded. Total iron concentrations frequently exceed 300 mg/L. If drainage of this quality enters the ground-water system, AMD production within the backfill can greatly accelerate. Thus, it is probable that more AMD will be produced under this scenario than would be produced if the two sources (stockpile and backfill areas) remained hydrologically separate. Additionally, if stockpile runoff infiltrates into the spoil, it may overwhelm any natural alkalinity in the backfill. The alkalinity in the backfill may be able to ameliorate acid production from the spoil, but not from the additional high-acid source. Exceptions to this BMP include, but are not limited to, sites where:

- The coal has an extremely low reactive sulfur (pyritic and sulfate) concentration (<0.5 percent).
- The stockpile and associated treatment facilities are underlain by a liner material to prevent infiltration and the runoff is treated to effluent standards prior to discharging. The liner material, commonly an on-site clay, should be nonacidic and have a sufficiently low permeability (e.g., less than 10^{-8} m/s).
- A bactericide is used to prevent or delay the oxidation of the pyrite. This is only a short-term solution, and the bactericide may have to be reapplied periodically.
- The stockpile is covered or otherwise sheltered to prevent the infiltration of precipitation.
- The amount of time the coal is permitted to stay on-site (e.g., one or two weeks) and perhaps the size of the stockpile are greatly limited.

Consideration of Overburden Quality

There are cases where hydrogeologic conditions inherent to specific sites will (with remining) cause the pollution load to be increased. Permits for these sites are not issuable. The potential for reclaiming abandoned mine lands should not override the potential to increase the pollution load. The decision of whether or not to issue a remining permit to some extent hinges on the quality of the overburden material. The associated strata for some coal seams in certain areas of the coalfields are going to produce AMD if disturbed by surface mining. When mining occurs on these sites, there is little that can be done to prevent AMD.

AMD emanating from abandoned and unreclaimed surface mines does not necessarily have to be caused by poor mining and reclamation practices in the past, such as improper handling of acid-forming materials, poor ground- and surface-water handling practices, open pits, exposed highwalls, unclaimed and unvegetated spoil piles, and protracted on-site coal stockpiling. The cause of the AMD can be due, in some cases, to the fact that the overburden quality is such that AMD production was almost inevitable. The overburden is simply net acidic.

A particular rock unit in a coal overburden is considered acidic if the net potential acidity, based on the total sulfur content, exceeds the net potential alkalinity, based on the neutralization potential. Both these values are given in terms of calcium carbonate equivalency. The threshold for significant acid-producing potential of a particular rock unit has been empirically derived as 0.5 percent total sulfur by weight (Brady and Hornberger, 1990). At or above this value, the rock unit has a good potential to produce acid mine drainage. The threshold for significant alkalinity generation has been empirically defined as a neutralization potential of 20 to 30 (tons per thousand tons calcium carbonate equivalent) with a noticeable “fizz” (Brady and Hornberger, 1990; Perry, 1998). A fizz is the effervescence that is released when a few drops of a 25 percent solution of hydrochloric acid is applied on sufficiently alkaline material (Kania, 1998). For a comprehensive and detailed discussion on overburden analysis and mine drainage prediction the reader is directed to “Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania” (1998), published by the Pennsylvania Department of Environmental Protection.

In situations where the overburden quality is such that additional AMD production is predicted, and BMPs will not effectively offset additional AMD production, remining should not take place. In some cases, where it is economically feasible, other BMPs can be increased to compensate for and prevent the increased acid-production. BMPs that can be used to offset the effects of acidic overburden include, but are not limited to:

- Alkaline addition based on the net acidity of the material. Alkaline addition rates above the net acidity for the spoil are recommended to provide a margin of safety and offset the inequity of the reaction rates (See Section 2.2, Alkaline Addition).
- Removal and off-site disposal of delineated acidic material (See Section 2.4, Special Handling of Acid-Forming Materials).
- Encapsulation of the acidic material within an alkaline or a low-permeability material (See Section 2.4, Special Handling of Acid-Forming Materials).
- Physical ground-water controls such that either the water will not contact the acidic spoil or the forecasted decrease in post-mining flow rates are more than sufficient to offset the projected increase in concentration (See Section 1.2, Exclusion of Infiltrating Ground Water).

If the proposed BMPs are sufficient to overcome the acid potential expressed by the overburden, remining without contributing to AMD production may be possible. This evaluation will have to be made on a case-by-case basis. A significant decrease in the flow rate may be able to more than compensate for a predicted increase in concentration. For example:

> An extensive daylighting operation is forecasted to decrease the discharge rate from a median of 300 gpm to a median of 80 gpm. The pre-mining median acidity concentration is 120 mg/L, which yields a median pollution load of 433 lbs/day of acidity. The overburden, which has been identified as potentially acidic, will be disturbed by the daylighting. This scenario could accommodate an increase in the median acidity concentration to 450 mg/L without a concomitant acidity load increase.

It is recommended that remining permits, where the contaminant concentrations are predicted to be increased, either be amended to include BMPs to prevent additional pollution or be reconsidered for issuance. However, the opportunity to gain significant reclamation without truly increasing the pollution load may bear heavily on the final permitting decision.

Coal Refuse Reprocessing or Cogeneration Usage

Remining operations where abandoned coal refuse piles are reprocessed to glean out the remaining coal or the entire pile is excavated and hauled to a electricity-producing cogeneration plant are almost without exception highly beneficial. These operations remove a significant portion of the acid-forming materials in addition to regrading and vegetating the remaining material to inhibit water infiltration. All reprocessing activities work to greatly reduce, if not eliminate, the pollution load.

Abandoned coal refuse piles are common in areas with historic mining. In the past, the coal cleaning process was not nearly as rigorous or technologically advanced as it is today and large piles of waste material were dumped at the surface. Older coal refuse piles tend to have commercially recoverable quantities of coal or enough burning ability for use in newer technology, such as electrical cogeneration.

These piles, even though some may be approaching 100 years old, are still producing AMD. The coal and true refuse material (e.g., carbonaceous black shales, some roof and seat rock) that comprise refuse piles usually have a significant sulfur content (>0.50 percent total sulfur) making acid generation almost inevitable. Acid production is additionally facilitated by the fact that coal refuse does not readily support vegetation. The acidic nature of the refuse inhibits plant growth, and the commonly dark color generates considerable heat in the summer causing heat toxicity. Without vegetation, the infiltration of atmospheric oxygen and surface water into the pile is virtually unimpeded, promoting continual acid generation within the pile. If the size of the piles and the amount of acid-forming material they contain can be reduced, and if the piles can be regraded, topsoiled, and vegetated, the volume of acid generation will be reduced. In the case of refuse used in cogeneration, the entire pile is commonly removed for burning, and ash from the cogeneration plant is frequently returned to the site. This ash, depending on the type of cogeneration plant and original sulfur content of the refuse, may be highly alkaline.

It is not uncommon for refuse piles located in the bituminous regions of western Pennsylvania, eastern Ohio, and northern West Virginia to have rates for recovery of coal from coal refuse piles exceeding 20 percent. Similar values are found elsewhere in the coalfields. Some positions within individual piles have reportedly had recoveries exceeding 50 percent. Much of this coal is economically recoverable using modern coal processing techniques, and many of these piles (anthracite and bituminous) have overall burning abilities of several thousand BTUs. This refuse is commonly burned in conjunction with oil, natural gas and other materials to produce heat or electricity. Because of the relatively high sulfur content, limestone is frequently burned with the refuse to aid in desulfurization of the smoke stack emissions. The ash created is commonly alkaline and can be returned to the site or used at other sites to add alkalinity.

The operation of reprocessing performs several functions that work toward reducing the pollution load. First, a significant portion of the pile, containing acid-forming materials, is removed. Second, the refuse material is crushed to a much finer particle size and, when replaced, the pore space percentage is dramatically reduced. Thus, water will move through the piles more slowly, and much less water will be stored. It will also be more difficult for water to infiltrate initially. These piles are regraded to promote surface water runoff and reduce infiltration. The piles are topsoiled and vegetated, which also reduces surface-water infiltration and inhibits the infiltration of oxygen into the pile. In other words, reprocessing has the ability to reduce the rate of acid generation, reduce the amount total amount of acidity generated, and reduce the discharge rate from the pile.

The use of refuse piles for cogeneration has the potential to completely eliminate acid generation from these piles. Complete removal removes the acid-generating source. Additionally, if alkaline coal combustion waste (CCW) is returned, the site may begin yielding alkaline waters, offsetting acid generation elsewhere in the basin from other piles where remining is not economical.

Very few limitations exist for coal refuse reprocessing or cogeneration use. However, the potential exists that if a relatively stable (physically and geochemically) pile is excavated, acid generation may be reactivated or accelerated. The sediment load could also be increased, albeit temporarily. In the case where CCW is returned to the site, care should be taken to ensure that higher amounts of trace metals will not be liberated from the ash. Testing of the CCW, for example by using the Toxicity Characteristic Leaching Procedure (TCLP), should performed to establish the potential for trace metals leaching.

Maximizing Daylighting

In general, daylighting as much area of an abandoned underground mine as possible yields positive results in terms of reducing pollution loads. Daylighting can work both physically and geochemically to effect a pollution load reduction.

First, and perhaps the most salient mechanism that works toward reducing pollutant loads, is the reduction of potential surface water infiltration zones. As previously discussed in Section 1.2, daylighting tends to eliminate large portions of subsided mine sections where considerable vertical ground-water infiltration into the mines occurs. The reduced infiltration rates in turn facilitate reduced loads. Surface-expressed subsidence features, such as exposed fractures and sinkholes, tend to collect surface and ground water and divert it directly into the mine. When surface mining eliminates these subsidence features, water infiltration into the mine is significantly reduced. Daylighting also eliminates substantial void spaces that serve as mine water storage areas, which tend to facilitate a more continuous source of lateral recharge to the adjacent reclaimed remining operation.

Daylighting dramatically changes the ground-water flow system from open conduit-type of underground mines to the double-porosity system exhibited by mine spoils (Hawkins, 1998). In underground mines, once ground water has entered the workings, it tends to contact only seat rock, roof rock, and coal. All of these units are commonly sulfur-rich, hence, potentially acid-producing (Table 3.1c). The data in Table 3.1c is from a mine in Donegal Township, Westmoreland County (Appendix A, EPA Remining Database, 1999 (PA(5)). The strata that the ground water will contact in this mine, based on this drillhole, have a total sulfur range of 0.574 to 1.637 percent. In short, everything the water contacts is potentially acidic (i.e. <0.50 percent). Once in the underground mine, ground water tends to follow the path of least resistance, which is through the open void areas. Therefore, the ground water continues to contact acidic rock units until it exits the mine via a discharge point or infiltrates into other ground-water systems (e.g., adjacent surface mine spoil or undisturbed strata).

Once surface mining and reclamation have occurred, the ground-water flow system changes dramatically, and the strata encountered are reflective of the entire overburden quality. Rather than only encountering acidic strata exposed in the underground mine, ground water will contact strata in the spoil that can be potentially alkaline or acidic or relatively inert. The amount of each type of rock intersected by the ground water is directly related to the volume of the material in the spoil, and to some degree, the mining and reclamation methods. Daylighting operations may need to have special conditions to require mining to a predetermined overburden thickness to ensure that a sufficient amount of alkaline strata are encountered and spoiled.

Table 3.1c: Coal and Enclosing Strata Sulfur Values (Appendix A, EPA Remining Database, 1999, PA(5) hole OB-5)

Interval	Lithology	Total Sulfur (percent)
95-97	light gray shale and interbedded sandstone	0.344
97-98	medium dark gray clay shale	0.574
98-101	coal -Lower Kittanning	1.637
101-104	light gray fireclay	1.201

Table 3.1d summarizes overburden analysis data from an acid-producing underground mine in Armstrong County, Pennsylvania, on the Upper Freeport Coal. The data illustrate that the coal itself is the acid-producing rock unit, with total sulfur ranging from 1.60 to 2.78 percent. Remining will remove most of the coal. As is common with most daylighting, some of the coal will be unrecoverable. On the other hand, the overburden itself exhibits relatively low total sulfur values (i.e., <0.50 percent). Total sulfur in the overburden ranges from 0 to 0.32 percent with the bulk of the strata being less than 0.10 percent. However, the overburden does exhibit several zones of significant alkaline material with neutralization potential (NP) of up to 209.7 tons of calcium carbonate equivalent per thousand tons. About 22 feet or 26 percent of the overburden exhibited NPs exceeding 30.

When the overburden is removed and then replaced, this material is highly broken up, increasing the exposed surface area, and it is mixed to some degree in the backfill. Ground water should contact each stratum to a degree similar to the volumetric content of that rock unit. Therefore, in the aforementioned site, roughly one fourth (26 percent) of the time during transit through the spoil the ground water should be contacting alkaline strata. Most of the remaining time, the material encountered by the ground water will be relatively inert in terms of acidity and/or alkalinity production. Thus, once mining has occurred at this site, the ground water will contact very little acid-producing materials. This illustrates how daylighting has the potential to greatly improve the quality of the material that the ground water will potentially contact.

Table 3.1d: Overburden Analysis from an Acid-producing Underground Mine in Armstrong County, PA (Appendix A, EPA Remining Database, 1999, PA(6) hole OB-4).

Interval	Lithology	Total Sulfur (percent)	Neutralization Potential (tons per 1000 tons of $CaCO_3$ equivalent)
0-1	soft light brown sandstone	0.02	0.47
1-5	medium light gray clay	0.02	3.15
5-10	dark yellowish brown sandstone	0.01	5.29
10-17	pale yellowish brown sandstone	0.04	9.63
17-20	dark to medium brown sandy shale	0.16	6.41
20-25	moderate brown shale	0.04	8.77
25-28	medium gray shale	0.14	3.73
28-31	pale red to grayish red shale	0.02	3.50
31-33	moderate yellowish brown shale	0.02	40.1
33-35	moderate yellowish brown shale	0.03	44.07
35-38	pale brown sandstone	0.00	29.85
38-40	pale brown sandstone	0.02	29.85
40-42	pale brown sandstone	0.02	209.70
42-45	dark yellowish brown shale	0.04	4.66
45-48	dark yellowish brown shale	0.00	7.00
48-51	dark yellowish brown shale	0.04	82.05
51-54	dark yellowish brown shale	0.00	125.82
54-56	dark yellowish brown shale	0.02	7.46
56-58	dark yellowish brown shale	0.02	5.60
58-61	medium light gray shale	0.18	3.96
61-64	medium light gray shale	0.14	16.90
64-67	medium light gray sandstone	0.10	16.21
67-69	medium light gray sandstone	0.06	8.74
69-71	medium light gray sandstone	0.06	11.31
71-74	brownish gray sandstone	0.04	77.19
74-77	medium light gray sandstone	0.06	31.61
77-80	medium light gray sandstone	0.02	44.37
80-82	medium gray sandy shale	0.14	12.82
82-84	medium gray sandy shale	0.11	3.38
84-85	medium gray sandy shale	0.32	9.09
85-88	coal	1.60	0.82
88-90	coal	2.78	0.12
90-91	medium gray clay	0.11	4.20
91-93	medium gray clay	0.10	10.73

If the entire mine is not daylighted, the remaining underground mine entries need to be adequately sealed to restrict or prevent ground-water movement between the underground mine and the backfill, and to preclude oxygen infiltration into the mine entries.

Daylighting underground mines does not always yield a decrease in the pollution load. The predicted decrease in flow rates and the change in the ground-water flow system, as described in Section 1.2, can be offset by the increased exposure of highly acidic overburden material to atmospheric oxidation and subsequent contact of ground water. This situation could in turn produce a higher pollution load (acidity and/or metals) than previously existed. Reed (1980) observed that daylighting of a underground mine in Tioga County, Pennsylvania, on the Bloss Coal seam, increased the acidity concentrations. In fact, he observed a direct relationship between the amount of daylighting and the acidity concentration. The overburden of the Bloss Coal was “mostly shale containing pyrite,” indicating the potential for acid production. However, this site is an exception, rather than the rule. In most cases, daylighting successfully decreases the pollution loads.

Implementation Checklist

The efficiency of these operational BMPs is related to a large degree to the restraint of certain activities, the promotion of others, and effective management operation activities. All have the specific goal of reducing the pollution load; however, these BMPs are somewhat diverse in regards to how this goal is achieved. The following list includes some recommended implementation guidelines for these BMPs.

Rapid Mining and Concurrent Reclamation

- The amount of time the spoil is sub-aerially exposed should be minimized.
- Regrading and revegetation should be performed as soon as possible after coal removal.

Off-Site Disposal of Acid-Forming Materials

- High-sulfur strata should be noted and segregated.

- Acid-forming materials should be stockpiled and hauled off-site.

Auger Mining

- Auger mining above the water table should be avoided.
- If augering is necessary for economic reasons, all holes should be properly sealed to preclude ground-water movement and oxygen infiltration.

Stockpiling of Coal

- Uncontrolled drainage should not be permitted.
- The stockpile should be covered or lined to prevent drainage.
- The maximum time allowed prior to removal should be set or stockpiling should be completely precluded.

Consideration of Overburden Quality

- The net acidity/alkalinity for the entire volume of overburden to be affected should be determined.
- If the overburden is acidic, other BMPs should be employed to compensate for the negative impacts of disturbance.

Coal Refuse Reprocessing or Cogeneration Use

- Regrading and vegetation should be performed to promote runoff and inhibit infiltration.
- Where possible alkaline coal combustion waste (CCW) should be returned to the site.

Maximizing Daylighting

- As many of the existing water-infiltration areas as possible should be eliminated.
- Contact between acid-forming materials and ground water should be removed or decreased.
- Mining should disturb as much alkaline overburden as possible.
- Unmined entries should be properly sealed.

3.2 Verification of Success or Failure

As with all BMPs, verification of proper implementation during remining operations is crucial to effective control or remediation of the discharge pollution loadings. The importance of field verification of all aspects of a BMP cannot be overstated. It is the role of the inspection staff to enforce the provisions outlined in the permit. The inspector generally does not need to be present at all times to assess the implementation of the BMPs in this chapter. However, some BMPs will require closer and more frequent field reviews than others. Monitoring of water quality and quantity will be the truest measure of BMP effectiveness.

During rapid mining and concurrent reclamation, the inspection staff needs to verify that the site is reclaimed shortly after the coal is removed. It is possible for permits to require notification by the operator of certain reclamation phases and/or require certification by an engineer or registered surveyor that the reclamation occurred within the predefined guidelines. An inspector should be able to visually assess that reclamation is occurring concurrently during each site visit.

The removal of pit and tipple cleanings can be verified using a lined stockpile area and review of weigh slips from the waste disposal facility. The refuse material may be stockpiled for short time periods, until it is hauled to the waste disposal site. Copies of the weigh slips from the waste disposal site and an estimate of the amount of material stockpiled should be submitted to the inspector, for comparison of the amount of material sent to the waste site to the amount previously stockpiled. The amount of material stockpiled can be estimated from the dimensions of the pile or from company-supplied records. The total amount of refuse to be removed from the site can be estimated from the overburden analysis and volumetric calculations, based on the strata thickness and the area mined. This estimated amount then can be compared to the total amount that was actually shipped off-site. The inspection staff should also observe the segregation of the acidic material during overburden removal.

Verification that no auger mining has taken place is relatively straight forward. If augering is permitted, affirmative proof should be submitted that all of the augering occurred below drainage and/or the holes were sealed as approved. The determination that augering is below drainage is initiated during the permitting stage. The operator should submit hydrologic data showing that the coal where the augering is proposed is below the regional drainage. Data needed for this determination include, but are not limited to:

- Pre-mining water levels
- Stratigraphic location of aquifers
- Transmissive properties of the aquifers
- Dip of the strata
- Projected post-mining water table
- Anticipated post-mining recharge rates
- The location of potential nearby dewatering sources
- The location and relative elevation of adjacent streams
- Specifics of the auger mining plan (e.g., location, direction, depth, etc.)

Once mining operations have begun, an inspector should make certain that the augering is conducted in the locations and in the manner indicated in the approved permit. Verification that the auger holes have been properly sealed is a difficult procedure and is discussed in detail in Section 1.2, Control of Infiltrating Ground Water. If it is deemed important to verify that the auger holes are below the water table and flooded after reclamation, monitoring wells can be installed in and adjacent to the holes to monitor the ground-water conditions.

Verification that coal is not being stockpiled is accomplished by a simple visual inspection. However, where stockpiles are allowed under limited circumstances, slightly more effort is required. Verification will be needed to ensure that a liner was installed, that the pile is usually covered, or that there is a limited on-site holding time.

The sulfur concentration (acid-producing potential) of coal can be determined from the analysis of the coal quality or the overburden analysis. An inspector will need to verify that a liner was constructed for the stockpile area, and stockpiling of the liner material will be required prior to placement. This determination can be performed on-site during construction or after installation, but before use. An inspector can also verify that the runoff is collected and routed to a treatment facility. If there is a discharge visible at the base of the pile, but it is not reaching the treatment facility, it is an indication that the leachate may be infiltrating into the ground and will eventually reach the water table. If no drainage is observed from the stockpile during or immediately following a wet period, it is also an indication that the liner is leaking, and steps will need to be taken to remedy the situation. Elimination of coal storage or reconstruction of the liner may be required.

Verification of the application of a bactericide can be performed by reviewing sales receipts or being present when the material is applied and reapplied. Stockpile covering is accomplished by visual inspection. The lack of any runoff from the pile is an indication that the cover is being used consistently and effectively. Verification of short-term stockpiling can be performed by comparing the amount of coal removed from the pit to the amount shipped to the buyer. The amount taken from the pit is a simple calculation:

Coal Thickness x Acreage x 1750 tons per acre/foot of Thickness = Coal Tonnage

Verification of the amount trucked off-site is available from dated weigh slips or sales receipts. The inspector can also observe the removal of coal from the stockpile while no coal is being actively excavated from the pit.

The delineation of acid-forming materials is verified by review of the overburden analysis submitted with the permit application and discussed in Section 2.0. However, it is recommended that the inspector periodically examine the exposed highwall, to ensure the lithology expressed by the overburden drill hole logs does not appreciably change across the site. Channel samples (a vertical series of overburden samples collected by hand, comprising the entire exposed strata) may need to be collected at the highwall and analyzed to verify that the overburden quality has not changed laterally from the nearest overburden hole.

Visual inspection will determine whether the amount of reprocessing, or refuse removal, taking place matches the original plan. The amount of CCW returned to the site can be determined from weigh slips and volumetric calculations. The quality of the CCW and potential to leach toxic trace metals can be determined from laboratory analysis. Adequate post-mining slopes and vegetation can be measured in the field and compared to those proposed in the permit.

To ensure that the maximum amount of daylighting is completed, certification from an engineer or registered surveyor may be needed. The inspector can visually estimate the daylighted acreage to a reasonable degree of accuracy. The operator may need to flag the site to define the limits of the daylighting on the surface.

Implementation Checklist

Monitoring and inspection of BMPs in order to verify appropriate conditions and implementation should be a requirement of any remining operation. Though BMP effectiveness is highly site-specific, it is recommended that implementation inspections of Operational BMPs include the following practices:

- Flow should be measured and sampling for contaminant concentrations should be performed before, during, and after mining .
- Monitoring should continue well beyond initial water table re-establishment period (e.g., about 2 years after backfilling).
- Hydrologically connected units and/or individual discharges should be assessed.
- Liner material weigh slips or receipts and/or marked stockpiles should be inspected.
- Any deviation from the approved implementation plan should be assessed.
- Salient phases of the BMP implementation should be inspected.
- Frequent inspection to determine reclamation concurrency should take place.

- Frequent observation of the handling of pit and tipple cleanings and stockpiled coal.
- Augering operations, if present, should be inspected.
- Coal recovery or refuse shipping records should be reviewed.
- The scope of daylighting should be monitored.

3.3 Literature Review / Case Studies

Perry and others (1997) discussed the impacts of operational cessations on post-mining discharge water quality for several surface mines in Pennsylvania and West Virginia. Their conclusions were that rapid mining without delays generally yielded improved post-mining water quality, compared to similar mines that experienced delays or cessations during mining. One site in particular (the Greene Mine) had two discrete mining phases. Mining and reclamation on Phase 1 proceeded without delays, while the mining on Phase 2 was interrupted by a two and a half year cessation of operations. The two phases were also hydrologically separate. Phase 1 was mined without any work stoppage. While Phase 2 was idle reclamation was incomplete and the acid-forming overburden material was exposed to atmospheric oxidation. The post-mining water quality of the two phases was distinctly different. The net alkalinity for Phase 1 was 151 mg/L, while that of Phase 2 was -128 mg/L (net acidic). Iron concentration for Phase 1 was 1.88 mg/L, while Phase 2 yielded 18.7 mg/L. Manganese concentration for Phase 1 was 16.4 mg/L, while the concentration for Phase 2 was 62.7 mg/L (Perry and others, 1997). Sulfate concentration, while not a regulated effluent parameter, is a viable and direct indicator of acid mine drainage production. The sulfate ion is released as part of the mine drainage reactions and, except under extreme conditions, sulfate remains in solution. The sulfate values for the two phases of the Greene Mine also differed significantly, indicating a difference in the volume and rate of mine drainage production. Phase 1 had a sulfate concentration of 1197 mg/L, while that of Phase 2 was 1770 mg/L or an increase of 48 percent. The lack of acid production at several other sites included in the study was attributed to the rapid mining followed by concurrent reclamation of the sites (Perry and others, 1997).

3.4 Discussion

The operational BMPs discussed in this section are recommended during remining for controlling the effects of the mining activities. Rapid and concurrent reclamation, appropriate location of auger mining (if allowed at all), off-site disposal of acid-forming materials, control of coal stockpiling, and thorough daylighting are operational procedures that should be implemented as part of the mining plan. Coal refuse reprocessing is a type of remining that should be encouraged. These BMPs do not preclude application of other BMPs discussed in this guidance document or required for environmental maintenance or improvement.

Benefits

- Rapid/concurrent reclamation reduces the risk of the operator falling behind which often results in incomplete reclamation and promotes AMD formation.
- Off-site disposal of pit and tipple cleanings may transform a remining site from producing additional acidity to producing less acidity.
- Appropriate implementation of auger mining can maximize the amount of coal recovered while reducing the risk of increased AMD production.
- Short-term or no coal stockpiling reduces the risk of accentuating AMD production.
- Reviewing the overburden quality and making a decision on permit issuance or denial based on this review will lessen the likelihood of making the pollution loads worse and the operator assuming treatment liability.
- Removal of significant amounts of acid-forming materials from refuse piles and introduction of alkaline material decreases acid and metal loads.
- Daylighting radically changes the geochemistry and hydrology of the site, reducing the amount of acidic material, increasing the potential for ground water to encounter alkaline material, and reducing the water infiltration volume.

Limitations

- Unscheduled or unforeseen circumstances may prevent maintenance of concurrent reclamation.
- Off-site disposal of pit and tipple cleanings may not be economically feasible.
- Without the approval to auger mine, some abandoned mines may not be economically viable to remine, because of the limited coal recovery.
- Auger mining above drainage areas may not be permissible.
- The coal market may dictate whether or not the coal may need to be stockpiled. Avoidance of stockpiling may induce coal sales at below anticipated prices, possibly compromising the economics of the operation.
- Redisturbance of a refuse pile may reactivate or accelerate acid production.
- In many cases, it may not be economically feasible to daylight large amounts of an underground mine. The low coal recovery rates and higher cover may make additional daylighting unprofitable.

Efficiency

Analysis of sites with Coal Refuse Removal or off-site disposal of pit and tipple cleanings showed that two thirds of the discharges were eliminated or significantly improved in terms of acidity loading (Appendix B, PA Remining Site Study). The remaining one third were unchanged. Almost 86 percent of the discharges exhibited either no change or a significant improvement in the iron loading with about 14 percent exhibiting some degradation. Most (83 percent) of the discharges were unchanged for manganese load with the remainder being significantly worse. No discharge was degraded in terms of aluminum load. All were unchanged or significantly better.

The success of Mining of Highly Alkaline Strata is directly related to the overburden quality. At sites where alkaline overburden existed, no discharges were made worse by remining, while over 67 percent were significantly improved or completely eliminated in regard to acidity load.

Twenty-three percent of the discharges exhibited significantly higher iron loads. Another 39 percent were unchanged and the remaining 38 percent were significantly better or eliminated. None of the discharges exhibited degradation in terms of manganese or aluminum loads.

Less than one percent of the 170 discharges analyzed for daylighting showed degradation due to acidity loading. Over 58 percent were unchanged, with the rest being eliminated or significantly better. Iron, manganese, and aluminum loads exhibited similar results with a slightly higher degradation rate (about 4 to 6.5 percent).

3.5 Summary

In general, operational BMPs are "rules-of-thumb" for good mining procedures. Research and experience has demonstrated that these BMPs will minimize the potential for additional AMD production and thus increase the likelihood of reduced pollution loads.

These recommendations are intended to prevent unchecked, large-scale pyrite oxidation within the spoil and adjacent areas. Once accelerated oxidation has occurred, abatement or treatment of the acidic drainage becomes increasingly difficult, if not impossible. In general:

- Rapid, concurrent reclamation is a good practice regardless of the overburden quality.
- Off-site disposal of pit and tipple cleanings reduces the probability of additional AMD production.
- Auger mining should only be permitted below drainage or where effective auger hole sealing will preclude AMD production.
- Unless the drainage is controlled, extended on-site coal stockpiling is discouraged.
- Overburden quality should be a consideration during permitting remining operations.
- There are very few, if any, problems associated with coal refuse pile utilization.
- The greater amount of daylighting during remining will produce the most positive reduction in pollution loads.

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Section 4.0 Passive Treatment Technologies

Introduction

Passive treatment encompasses a series of engineered treatment facilities that require very little to no maintenance once constructed and operational. Passive water treatment generally involves natural physical, biochemical, and geochemical actions and reactions, such as calcium carbonate dissolution, sulfate/iron reduction, bicarbonate alkalinity generation, metals oxidation and hydrolysis, and metals precipitation. The systems are commonly powered by existing water pressure created by differences in elevation between the discharge point and the treatment facilities.

Passive treatment does not meet the standard definition of a Best Management Practice (BMP). In general, BMPs consist of abatement, remediation, and/or prevention techniques that are conducted within the mining area (at the source) during active remining operations. Passive treatment, by its nature, is an end-of-the-pipe solution to acid mine drainage (AMD). These systems are frequently installed after reclamation to treat AMD. BMPs, on the other hand, are performed as part of the mining or reclamation process, generally not after the fact. If treatment, passive or conventional, is required for a discharge to meet effluent standards (BAT or some alternate standard), the operator is held liable and treatment continues, theoretically, until the discharges naturally meet the applicable effluent standards.

Regardless of whether passive treatment fits the definition of a BMP, it can be used as part of the overall abatement plan to reduce pollution loads discharging from remining sites. There are situations where passive treatment may be employed to improve water quality above what was accomplished by the BMPs. Therefore, a detailed discussion of the use of passive treatment technology to treat AMD in this manual is warranted.

Passive treatment includes, but is not limited to:

- Anoxic limestone drains (ALDs)
- Constructed wetlands
- Successive alkalinity-producing systems (SAPS)
- Open limestone channel (OLCs)
- Oxic limestone drains (OLDs)
- Pyrolusite® systems
- Alkalinity-Producing Diversion wells

Passive treatment technologies also can be incorporated into the reclamation plan along with more traditional BMPs. For example, anoxic limestone drains can be installed within the backfill as a type of pit floor drain. This has been done at a remining site on the Shaw Mines Complex in Somerset County, Pennsylvania, where an ALD 2,500 feet long, 30 feet wide, and 10 feet deep was installed within the backfill (Ziemkiewicz and Brant, 1997). Wetlands can be constructed where returning the site completely to the approximate original contour is not economical. Discharges can be routed through these wetlands for treatment. Open limestone channels can be used in the construction of diversion ditches or as pond outflow structures. Additionally, passive treatment can be employed on AMD-yielding discharges that would not otherwise be impacted by the operation or by integral BMPs. These discharges are hydrologically discrete from the operation.

Theory

Once installed, passive treatment systems require little maintenance through the projected life of the system. They are a low-cost method of treating mine water. However, these systems have a finite life and may require rebuilding or rejuvenation over the life of treatment. The period of treatment can be considerable; some mines have continually yielded AMD for well over a century. The power to run these systems is generated by changes in elevation that creates sufficient head and forces the water flow through them. The treatment is performed by natural, biological, geochemical, and physical actions.

Frequently, more than one type of passive treatment or an integrated system of passive treatment technologies is employed to treat mine drainage. These facilities, like conventional treatment facilities, are typically designed to raise the pH and remove metals (e.g., iron, manganese, and aluminum) of acid mine drainage.

Site Assessment

In order to determine the feasibility of integrating passive treatment into a remining operation BMP plan, there are several factors that need to be assessed. The most critical is the determination of the water quality and discharge rates. These data need to be collected and analyzed on a seasonal basis to completely characterize discharge(s). Sampling at least once per month, for a complete year, is recommended. Additional monitoring may be required, if the precipitation has been substantially above or below normal. These data directly relate to the sizing of passive systems.

The water quality characteristics of the discharge are of particular importance in selecting the type of passive treatment system(s). Dissolved oxygen (DO) concentration in the water as it emanates, speciation of the dissolved iron (i.e. ferrous and ferric) concentrations, dissolved aluminum concentration, net acidity or alkalinity, and pH are all important parameters. The concentrations of dissolved manganese and sulfate are of lesser importance and less problematic, but should also be determined.

Determination of the discharge flow rate is perhaps the most critical data for the sizing and selection of passive treatment technologies. Without accurate flow data, an improperly sized passive treatment system may either under treat the water or be much larger, and thus more expensive, than needed. Flow measurements should be determined at the time water samples are collected and should be performed using standard scientifically accepted means. A weir (e.g., v-notch) or flume (e.g., H-type), timed-volumetric (e.g., bucket and stopwatch), or flow meter and cross sectional area are acceptable and commonly used methods to determine flow. It is recommended that at least one extreme high flow and low flow be sampled during the monitoring period. If the flow is too low or too erratic, some types of passive treatment (e.g., wetlands, successive alkalinity-producing systems) may not be suitable.

Most passive treatment systems require a sufficient gradient to create the desired head to drive the water flow through the treatment systems. Therefore, implementation of these systems requires a large enough area for construction sufficiently down gradient of the discharge.

4.1 Implementation Guidelines

Anoxic Limestone Drains

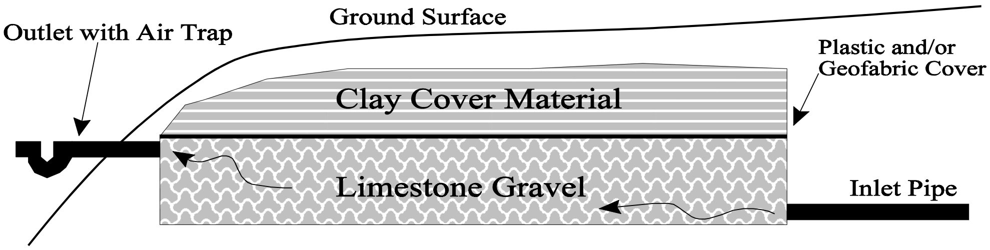
In general, attempts to use limestone to treat acidic ferruginous mine drainage at the ground surface commonly fail after a short time period. These failures are caused by the low dissolution rate of limestone at atmospheric levels of CO_2 and by iron (ferric) hydroxide ($FeOH_3$) armoring of the limestone. Limestone armoring virtually halts all bicarbonate alkalinity production from the dissolution of calcium carbonate. Once exposed to the atmosphere, the iron in mine drainage rapidly oxidizes from ferrous (Fe^{2+}) to the ferric state (Fe^{3+}). Once oxidized, the ferric iron will quickly precipitate out of solution, coating the limestone, and creating an iron hydroxide precipitate sludge known as “yellow boy”. However, if mine drainage is maintained in a low oxygen (anoxic) environment, the iron will remain in the ferrous state and will not readily precipitate from solution. Anoxic mine water passing through limestone drains allows for the production of alkalinity without iron armoring and precipitation. For these drains to function properly, the mine drainage dissolved oxygen content should be less than 1 mg/L (Kepler and McCleary, 1994). Cravotta (1998) states that dissolved oxygen in the water should be less than 0.3 mg/L to preclude iron oxidation.

Anoxic limestone drains are designed to generate alkalinity in acid mine drainage without atmospheric exposure. In addition to preventing iron hydroxide precipitation, the closed environment of an ALD fosters increased CO_2 concentrations, which in turn facilitates higher alkalinity production. Alkalinity production in ALDs is much greater than what can be expected at atmospheric CO_2 levels. CO_2 partial pressures ranging from 0.022 to 0.268 atmospheres were calculated for 21 ALDs (Hedin and Watzlaf, 1994). The production of 61 mg/L alkalinity under atmospheric conditions can quickly be increased to over 450 mg/L within an ALD (Hem, 1989; Hedin and Watzlaf, 1994). The mechanism for the increased alkalinity production from higher CO_2 concentrations is discussed in Section 2.0 and 3.0. Removal of acidity from mine water flowing through ALDs ranges from 0 to over 5900 mg/L. The higher levels of acidity removal are attributed to loss of mineral acidity from detention of ferric iron and aluminum within the drains. This detention of ferrous iron was observed at two sites using ALDs with detention times exceeding 25 hours (Hedin and Watzlaf, 1994). The lower acidity and higher alkalinity of the water once it leaves the drain cause the pH of the water to rise, which in turn significantly increases the precipitation rate of iron and other metals.

ALDs are often installed to aid the efficiency of constructed wetlands. These wetlands work more effectively to remove metals if the pH of the water is raised by ALD pretreatment. Most metals associated with AMD will precipitate more readily from solution in a high pH environment. Nairn and others (1991) stated that a pH of 6.0 (standard units) and net alkalinity allow passive treatment systems (constructed wetlands and settling ponds) to work much more effectively.

Design and construction of an ALD should be based on the required detention time for the maximum flow anticipated for the discharge over the effective life of the facility. The discharge water quality should also be considered. It is recommended that an environmental safety factor be employed in design to cover the worst case scenario. The discharges should be monitored for at least one year prior to system installation to determine the range of flows anticipated and the variability of water quality. Precipitation records during the monitoring period should be compared to average years to determine the representativeness of the flow and water quality data. Configuration and size of ALDs are based on the flow rate, projected life of the system, purity of the limestone, and desired water quality. The ALD should be able to treat the water to the desired levels under all flow conditions. Design details of ALDs can vary, but the general configuration is relatively consistent. Figure 4.1a illustrates the basic construction of an ALD.

Figure 4.1a: Typical Anoxic Limestone Drain Construction



Hedin and Watzlaf (1994) analyzed water quality and flow data from 21 completed ALDs treating AMD in Appalachia to determine their efficiency. They determined that an in-drain detention time of at least 15 hours and perhaps as high as 23 hours is required to produce the maximum alkalinity. ALD sizing criteria were developed based on the discharge rate, a minimum 15 hour detention time, the desired life of the drain, and physical and chemical properties of the limestone used. The equation derived is as follows:

$$M = \frac{Q p_b t_d}{V_v} + \frac{QCT}{x} \qquad \text{(Equation 1)}$$

Where: M = mass of the limestone
Q = discharge rate
p_b = bulk density of the limestone
t_d = the detention time
V_v = bulk void volume expressed as a decimal (20 percent voids is expressed as 0.20)
C = predicted concentration of alkalinity of drain effluent
T = designed life of drains in years
x = calcium carbonate content of the limestone in decimal form

An example calculation of drain size in metric tonnes (mt) is as follows. The calculation assumes a discharge rate of 30 L/min, limestone bulk density of 1600 kg/m^3, bulk void volume of 40 percent, a projected alkalinity of 300 mg/L, a limestone calcium carbonate content of 95 percent, and a life of 25 years.

$$M = \frac{(30\ \text{L / min x 60 min / hr}) \ (1600\ \text{kg / m}^3\ \text{x m}^3\ /\ 1000\text{L x mt / 1000 kg}) \ (15\ \text{hr})}{0.40}$$

$$+ \frac{(30\ \text{L / min x 60 min / hr}) \ (300\ \text{mg / L x mt / 109 mg}) \ (25\text{yr x 8766 hr / yr})}{0.95} = 232.6\text{mt}$$

ALDs are located down-gradient of the discharge point to allow for a free-flowing, gravity-driven system. A sufficiently wide and deep trench is dug to accommodate the amount of limestone needed to provide the desired detention time to yield the maximum alkalinity. Dimensions of ALDs commonly range from 2 to 9 feet wide and 150 to 1500 feet long; however, much larger drains have been constructed. Drain depth should be enough to hold a 2- to 6-foot thick layer of limestone with sufficient cover to preclude infiltration of oxygen (Nairn and others, 1991). Once excavated, the trench is filled with crushed limestone. Brodie and others (1991) recommended that the size of the limestone be 0.75 to 1.5 inches to give both the needed surface area and needed drain hydraulic conductivity. Purity of the limestone should be as high as possible to prolong the functional life. Use of a low-purity limestone would require the drain to be larger and more limestone material to be used.

Mine drainage is piped into the ALD directly from the source, before it has been exposed to the atmosphere. It is common to dig into the discharge point and install a buried collection and piping system. The drain inlet is usually at the base of the drain to maximize limestone contact. The limestone is covered with 10 to 20 mm (0.01 to 0.02 inches) thick sheet plastic followed by geosynthetic fabric to prevent puncturing of the plastic. The fabric is then covered with lightly compacted clay. The plastic and clay are emplaced to inhibit the infiltration of atmospheric oxygen. Clay is then covered with soil. The clay and soil should be at least two feet thick to effectively prevent oxygen infiltration. The surface should be crowned (mounded) to inhibit erosion and water infiltration and to accommodate long-term subsidence as the limestone dissolves. Brodie and others (1991) recommend that the drain should be rip rapped or vegetated with a plant species, such as Sericea or crown vetch, that will discourage tree growth. Tree roots could breach the drain seal and allow oxygen infiltration. The outflow pipe is installed at the top of the limestone trench opposite to the inflow point. The outflow pipe is equipped with an air trap to prevent oxygen migration into the drain. The elevation of the outflow pipe should be below the head elevation driving water through the drain. The inflow and outflow piping size should be large enough to permit unrestricted flow for the highest projected discharge rates.

Once the water exits the drain and is subaerially exposed, dissolved iron and most other dissolved metals in the water will rapidly oxidize and begin to precipitate out. It is recommended that the water be diverted to a settling basin or pond sized for this purpose. The settling basin will greatly extend the life of a constructed wetland or other subsequent treatment facility. Ideally, the alkalinity yielded by the drain will be high enough to neutralize the existing mine water acidity as it enters the drain, and to neutralize the mineral acidity created subsequently by the oxidation and hydrolysis of the iron and metals after the water exits the drain.

There are some restrictions to using anoxic limestone drains to treat AMD. Most are related to the mine water quality. If the dissolved iron in the discharge water has been oxidized to the ferric state prior to entering the drain, the drain will eventually fail. Ferric iron will readily precipitate in the drain once the pH of the water is sufficiently raised, armoring the limestone and clogging the void spaces. This precipitation decreases the drain efficiency and eventually causes failure in terms of limestone dissolution rate and/or water not flowing through the drain. The introduction of dissolved oxygen to the mine water will allow iron oxidation to the ferric state. Therefore, the available atmospheric oxygen should be restricted. These drains are not recommended to treat mine water with high concentrations of dissolved aluminum, because aluminum will also precipitate out in the drain once the pH is raised with or without oxidation. It is not recommended to use a dolomitic limestone, because the dissolution rate of dolomite ($CaMg(CO_3)_2$) is much slower than calcium carbonate. Therefore, the effectiveness of the drain would be diminished or the drain size would have to be increased to accommodate the lower reaction rates. If sulfate concentrations exceed 2000 mg/L, it is possible for gypsum ($CaSO_4$ + $2H_2O$) to precipitate within the drain once the pH is raised and calcium concentration is increased (Ziemkiewicz and others, 1994).

Constructed Wetlands

The possibility of using constructed wetlands to treat AMD was first indicated by observations made on the treatment of mine drainage by naturally existing wetlands. The flow of AMD through *Sphagnum* moss bogs illustrated that iron and acidity concentrations could be reduced without degrading the wetland. Studies on naturally formed wetlands treating mine drainage were initially conducted in Ohio and West Virginia. Both studies showed that iron and acidity were substantially decreased and the pH of the water was raised after flowing through the wetlands (Kleinmann, 1985).

Because of the beneficial effects observed at natural wetlands, numerous wetlands have been constructed in attempts to treat acid mine waters passively. *Sphagnum* moss was used initially, because it was observed to be successful in natural wetlands and preliminary studies showed that it can remove large quantities of iron (Kleinmann, 1985). Near-surface oxidation and sulfate reduction in deeper organic-rich zones also decrease the amount of iron in wetlands. Later, cattail (*Typha*) wetlands were constructed to treat mine drainage. This change in vegetation appears to be related to limited iron detention from cation exchange by *Sphagnum* moss and the high sensitivity of the moss to wetland water levels. Studies showed that most of the iron detention in constructed wetlands was due to binding to the organic matter and the direct precipitation of iron hydroxides (Wieder, 1988).

There are two ways that constructed wetlands treat AMD. First, aerobic reactions cause oxidation and hydrolysis of the metals forming metal hydroxide precipitates. This removal of metals has a tendency to release mineral acidity and lower the pH of the water. Aerobic wetlands work primarily with mine water flowing through at or very near the surface. The subaerial exposure permits oxidation of iron and other metals. However, in order for these wetlands to work most efficiently, the water needs to have a pH of 6.0 or higher and a net alkalinity. At a pH of 6.0 or higher, the rate of iron oxidation dramatically increases. At pH levels below 6.0, manganese oxidation virtually halts. As these metals oxidize and hydrolyze, mineral acidity is released and the pH will decrease. Therefore, the more efficient wetland systems will have an excess net alkalinity in the water prior to the precipitation of the metals, to buffer (the ability to hold the pH relatively steady with the addition of an acid or a base) the release of mineral acidity.

Second, anaerobic reactions that occur under anoxic conditions cause sulfate reduction. Under anaerobic conditions, metals are removed in reduced forms (metal sulfides), and bicarbonate alkalinity is created. Anaerobic wetlands, also called compost wetlands, support reducing conditions within the substrate. Sulfate reduction by sulfate-reducing bacteria (e.g., *Desulfovibrio* and *Desulfomaculatum*) is one of the primary anaerobic reactions (Smith, 1982). Sulfate-reducing bacteria thrive in anoxic environments, feed on organic material, and utilize sulfate in their respiration processes. The organic substrate acts as an oxygen sink in natural and constructed wetlands, creating suboxic or anoxic conditions from the bacterial decomposition of the organic matter. Oxygen in water flowing through the organic substrate is rapidly removed. With sulfate reduction, hydrogen sulfide gas (H_2S) is created and a variety of metal sulfides (e.g., pyrite (FeS_2), iron monosulfides (FeS)) are formed and deposited within the substrate. Wetland flow systems designed to force water through the organic substrate promote sulfate reduction on a larger scale. In the process of sulfate reduction, bacteria use organic carbon (CH_2O) and sulfate (SO_4^{2-}), producing hydrogen sulfide (H_2S) and bicarbonate alkalinity (HCO_3^-) (McIntire and Edenborn, 1990) as shown in Equation 2. The production of bicarbonate alkalinity neutralizes acidity and raises the pH of the water.

$$2CH_2O + SO_4^{2-} = H_2S + 2HCO_3^- \qquad \text{(Equation 2)}$$

There are a multitude of configurations for constructed wetlands. However, a few researchers have developed criteria for wetlands sizing and design to maximize AMD treatment. Kleinmann (1985) suggested that 200 ft^3 of wetland are required for each gallon per minute of discharge. Kleinmann indicated that constructed wetlands may be most applicable to discharges of no more than 10 gpm, with pH over 4.0 and iron concentration of 50 mg/L or less. Attempted uses of wetlands to treat discharges with water quality or quantity exceeding those criteria were mostly unsuccessful.

Hedin and Nairn (1990) determined that loading (mass/time) directly related to the wetland treatment area was a more appropriate criteria for wetland engineering. They developed a sizing formula based on iron grams per day per meter squared (Fe $g/day/m^2$ or gdm) of wetland area. The method also factored in pH, flow, and iron concentration. A sizing criterion of 10 gdm of iron was determined for water with a pH of 4.0. For water with a pH of 3.0, the efficiency drops to 4 gdm of iron.

Kepler (1990) observed that there may be other factors that also play a role in the efficiency of wetlands to treat mine water. He noted seasonal variations in the treatment effectiveness related to variations in influent iron loadings as well as treatment area and biological efficiency. An inverse relationship was observed between the iron load (ferrous and ferric iron ratio) and the efficiency of the wetland. This is related to the flow system through the wetland allowing time for aerobic and anaerobic reactions to occur. He indicated that the flow system may be as important as the surface area or vegetation types. For overall effectiveness, a value of 15 gdm was determined for year round treatment. A sizing safety factor of 1.25 was also recommended (Kepler, 1990).

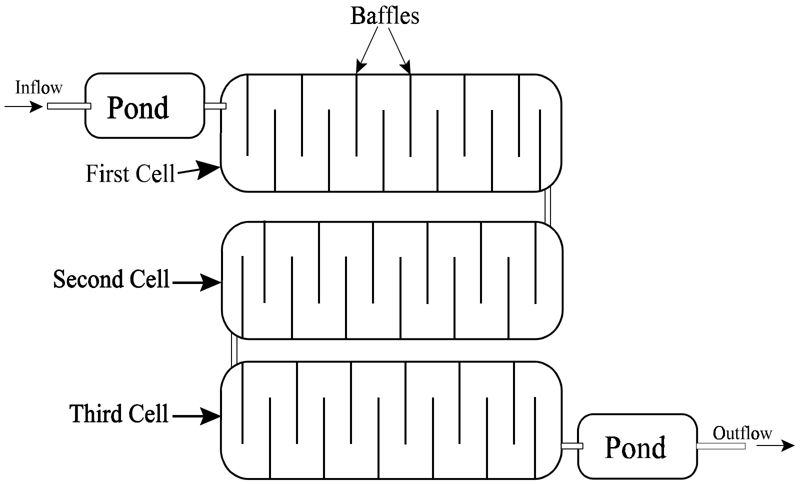
Stark and others (1990) in a study of a *Typha* wetland near Coshocton, Ohio, observed a consistent treatment efficiency at 10 gdm. However, the site averaged over 13.5 gdm. They likewise recommended that wetlands be sized to treat the maximum loads anticipated.

It is critical that accurate discharge flow and water quality background data are collected for at least one water year (October 1st through September 30th). Extreme care should be taken to ensure that flows are accurately measured. Wetlands should be sized for the maximum forecasted flow, concentration, and load, so extreme conditions can be successfully treated.

Although configuration of constructed wetlands can vary widely, there are some basic common components. Figure 4.1b is a schematic diagram of a typically constructed wetland system. In many instances, the mine discharge is initially diverted to a small settling pond. Depending on the pH and alkalinity of the water, some iron will precipitate within the pond, extending the working life of the wetland. The water then flows from the pond into a large wetland cell or series of cells. The water course is designed so the detention time is as long as possible to yield maximum treatment. This is usually accomplished by the inclusion of a series of baffles to divert the water along a circuitous path. The last wetland cell is followed by a final "polishing" pond to allow for precipitation of any appreciable remaining iron. After the final pond, the water, if it meets applicable effluent standards, is discharged to the receiving stream. If effluent standards are not being met, additional treatment may be required.

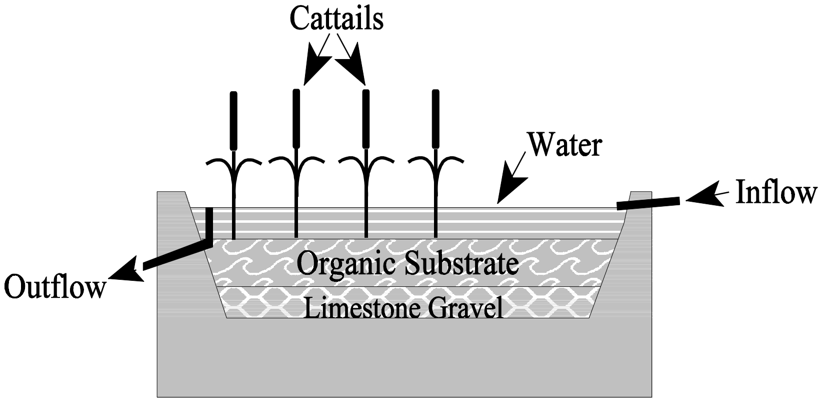
Construction design of individual wetland cells is directly dependent on the amount of flow and water chemistry. Brodie and others (1988a) based the size and number of cells on the projected flow from a 10-year, 24-hour storm event. The cell size is based on the area required to treat the flow for iron concentration, according to grams/day/m^2 of iron, as discussed above. Cell dimensions are based on the treatment area needed, maximization of the flow path, site topography, and configuration of the available space down gradient of the discharge.

Figure 4.1b: Commonly Constructed Wetland Diagram



Wetland cells are frequently lined with an initial thin layer of crushed limestone that is usually about six inches thick (Figure 4.1c). The limestone is covered with a thicker organic layer, usually 12 to 18 inches. Mushroom compost is the most common material used for the organic substrate. The cell is subsequently flooded with 6 to 12 inches (15 to 30 cm) of water and planted with vegetation. Cattails are by far the most commonly planted vegetation in constructed wetlands. Other plants used include, but are not limited to, cattail-rice cutgrass, sphagnum moss, rushes, and bulrushes (Brodie, 1990; Brodie and others, 1988b). Various types of blue-green algae (Cyanobacteria) have also been introduced into wetlands in attempts to improve efficiency for manganese reduction (Spratt and Wieder, 1988).

Figure 4.1c: Typical Wetland Cell Cross Section



There are limits to which wetlands can be used to treat mine water. One of the most salient problems is the amount of area required. A high-flowing, high-iron discharge requires a huge area for treatment. A low pH (<4.0) water will require more treatment sizing (4 gdm) than a higher pH (>4.0) water (10 gdm). Using the sizing criteria developed by Hedin and Nairn (1990), a mine discharge of 600 gpm, 75 mg/L of iron, and a pH greater than 4.0 would require a wetland area of at least 6.1 acres and an area of 15 acres for a pH under 4.0. However, Hedin and Nairn (1990) stated that for “highly contaminated drainage,” a larger wetland sizing criterion may be required. At a pH of 3.0, the wetland sizing may need to be increased by 300 percent.

The performance of aerobic wetlands is greatly hampered by low-pH water. Raising the pH prior to piping the water into the wetland will greatly improve iron removal. ALDs have been used successfully in conjunction with wetland treatment. The increased alkalinity buffers the decrease in pH caused by release of mineral acidity from iron hydrolysis. This buffering in turn improves the treatment ability of the wetland (Brodie and others, 1991).

By design, iron hydroxide will precipitate within constructed wetlands. This precipitation will eventually cause iron hydroxide sludge buildup in the cells, which will cause changes to the water levels. These changes will adversely impact the vegetation and decrease the wetland treatment ability. Also organic material will eventually be depleted through bacterial action, and require replacement. Depending on the flow system, the limestone may also need to be replenished as dissolution occurs. Therefore, over time, wetlands require periodic maintenance to remove the iron hydroxide sludge and replace substrate materials.

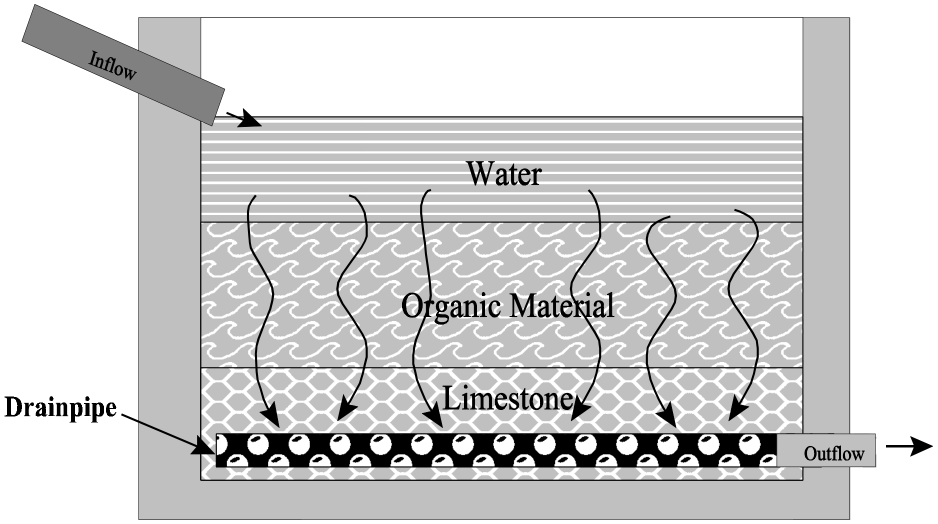
Successive Alkalinity-Producing Systems

Successive alkalinity-producing systems (SAPS) utilize the alkalinity production of anaerobic wetlands and ALDs to remove metals from mine water, while greatly increasing the alkalinity production over either of the two systems working singly. With SAPS, the ALD criteria for anoxic mine water and the requirement of ferrous iron does not apply. An oxygen sink is created by anaerobic sulfate reduction which will reduce any ferric iron (Fe^{3+}) to ferrous.

Construction of individual SAPS cells is similar to that of a constructed wetland cell, but the flow system differs and no vegetation is required. Because SAPS work on the concept of a series of steps that produce alkalinity, there are several configurations for the entire system. Kepler and McCleary (1994) suggested a configuration of an ALD followed by an aerobic wetland or settling pond, which is then followed by a SAPS cell that discharges into a second aerobic wetland or settling pond.

An individual SAPS cell is designed to accept water inflow at the surface and drain from the bottom. The basal layer in a SAPS cell is crushed limestone covering perforated underdrain pipes (Figure 4.1d). Skousen and others (1995) suggested that the underdrain pipes be covered with 12 to 24 inches of limestone. However, Kepler and McCleary (1994) indicate that the thickness of the limestone layer is based on the detention time required for maximum alkalinity production. A similar amount of detention time as that required for an ALD is recommended. Four SAPS constructed in Pennsylvania had limestone layers ranging in thickness from 18 to 24 inches (Kepler and McCleary, 1995). A layer of organic matter, usually mushroom compost, is placed over the limestone. The thickness of the organic layer, like the limestone layer, is based to a large extent on the required detention time. Kepler and McCleary (1995) observed four sites in Pennsylvania where the organic layers were 18 inches thick. Skousen and others (1995) recommended 12 to 18 inches of organic material. Overlying the organic layer is free-standing mine water. The depth of the water is dependent on the head (pressure) required to drive the water through the organic and limestone layers at a rate that to adequately achieve the required the biochemical and chemical reactions (discussed below). Kepler and McCleary (1995) indicated a depth range of 5.25 to 6.23 feet was adequate at the four study sites in Pennsylvania; whereas, Skousen and others (1995) suggested a water depth of 4 to 8 feet. Size of the SAPS is based on the required water detention time, which is related to the flow rate, more so than the water quality. The rate of atmospheric oxygen diffusion into a body of water is relatively constant and should be used in determining the areal size of the SAPS cell.

Figure 4.1d: Example of a Successive Alkalinity-Producing System Cell



SAPS function through a series of chemical and biochemical reactions to remove iron and other metals from the water, while increasing the alkalinity. When mine water is initially discharged into the SAPS cell, it does not matter if the water has been oxygenated or the iron has been oxidized to the ferric state. Some of these metals, especially iron, will oxidize in the shallower water and precipitate on top of the organic layer. Kepler and McCleary (1994) observed 2 inches (5 cm) of iron hydroxide deposited in a SAPS at a mine site in northwestern Pennsylvania.

Once in the cell, the water flows downward toward the organic layer and the water is rapidly stripped of dissolved oxygen by microbial decomposition of the organic material. Bacteria utilize the DO in the mine water to metabolize the organics. These reactions occur near the interface of the organic material and the water. Kepler and McCleary (1994) reported that water nearly saturated with dissolved oxygen (~10 mg/L) entering the cell was virtually anoxic (<0.2 mg/L) after passing through the system. Oxygen can only infiltrate several centimeters into the organic substrate (Kepler and McCleary, 1994). Once the dissolved oxygen is removed, anaerobic sulfate-reducing bacteria in the organic layer will chemically reduce the metals as well as the sulfate ions, yielding hydrogen sulfide (H_2S) gas and metal sulfides. The H_2S will be released into the atmosphere, where it subsequently oxidizes to form water and native sulfur (S) (Lehr and others, 1980). When these systems are working properly, considerable H_2S is yielded and the systems tend to have an offensive smell. H_2S smells similar to rotten eggs and is unpleasant even at very low concentrations (0.05 mg/L). Metal sulfides are deposited within the organic material, but some of the reduced metals will remain dissolved and pass through the organic layer.

This reduction process also yields bicarbonate alkalinity to the water as described in the preceding wetlands section. This process, in turn, will neutralize acidity, add alkalinity, and raise the pH of the water.

Once the water has passed through the organic layer, it enters the underlying limestone gravel. Because the oxygen has been stripped from the water, and any metals that are not precipitated are in a reduced state, the limestone layer functions as an ALD. Passage through the limestone adds additional alkalinity to the water through dissolution of the calcium carbonate, as described above under ALDs. If the SAPS are properly sized, the effluent should have a pH of 6.0 or higher (Skousen and others, 1995). Aluminum tends to pass through the organic layer and is precipitated in the limestone. Because aluminum precipitate does not armor the limestone, but instead remains as loose precipitate, it can eventually plug the limestone layer. Therefore, a piping system that will allow a periodic forced flushing of the limestone layer is needed to maintain the efficiency of the system (Kepler and McCleary, 1997).

The SAPS cell effluent is typically piped into a conventional aerobic wetland or settling pond. With the excess alkalinity yielded by the SAPS, much of the remaining metals (mainly iron) will quickly precipitate out of solution in the wetland or pond. The process of iron oxidation and hydrolysis will, as discussed earlier, yield acidity. However, the excess alkalinity in water from a well-designed SAPS should perform a buffering action and be sufficient to maintain a net alkalinity throughout this secondary precipitation process. If the alkalinity is insufficient to neutralize the acidity produced by the iron precipitation, the water can be piped through a second SAPS. This process can be repeated until the mine water meets the applicable effluent standards.

Limitations on SAPS construction, use, and maintenance are similar to those for wetlands and ALDs. Restrictions to the use of SAPS include, but are not limited to the following items:

- Engineering and sizing should be determined by the discharge flow rate. The highest anticipated flow rates should be used as an engineering guideline.
- Topography should be such that the system will function (flow) properly without the need for additional power.
- The organic material and limestone will eventually be exhausted and will need to be replaced.
- The water level needs to be deep enough that significant continued diffusion of dissolved oxygen at depth is prevented.
- There should be some mechanism to control the water level in the SAPS cell. This is important during extremely low flow periods, because the organic material could be

subaerially exposed and dry out, thus shutting down oxygen removal and sulfate reduction. At high flows, the system could be overwhelmed.

- Iron sludge can eventually fill the pre- and post-SAPS ponds and will require periodic cleaning. If the iron precipitation within the SAPS is substantial, this will also require a periodic cleaning.
- Calcium carbonate purity of the limestone should be the highest available to prolong the life and maximize alkalinity production.
- Aluminum tends to precipitate in the limestone layer just as with ALDs. Therefore, a system is required to permit periodic flushing of the aluminum floc from the limestone.

Open Limestone Channels

In contrast to treating AMD with limestone in an anoxic environment, more recent research has been conducted on this treatment in an environment open to the atmosphere (oxic). As previously stated, when dissolved iron is oxidized, it will precipitate, armoring limestone and creating an iron hydroxide sludge. In theory, limestone, even if completely armored with iron, will continue to yield some alkalinity. Ziemkiewicz and others (1994) indicated that $CaCO_3$ in fully armored limestone is 20 percent as soluble as that in unarmored limestone. However, Ziemkiewicz and others (1996) reported that armored limestone may exhibit 25 to 33 percent of the $CaCO_3$ solubility of unarmored limestone. They observed an acidity reduction of 0.029 to 1.77 percent per foot of open limestone channel (OLC). Though rapid neutralization of acidity by armored limestone is observed initially, it slows with time, and exhibits a logarithmic decay of the neutralization rate (Ziemkiewicz and others, 1996).

Limestone channels are sized based on a projected 90 percent acidity neutralization with one hour of contact time or 100 percent acidity neutralization with three hours of contact time. Construction criteria are determined from the flow rate, channel slope, and acidity concentration. This information will determine the mass of limestone, the cross-sectional area and length of the drain, and ultimately, the in-channel detention time. Channels are constructed with an initial dam-like structure at the upstream end to trap sediment and other debris and keep it from clogging the pore spaces between the limestone material throughout the remainder of the channel

(Ziemkiewicz and others, 1994). OLCs also require sufficient slope, to result in sufficient water velocity, to prevent clogging of the interstitial pore spaces with iron, manganese, and aluminum floc. If the pore spaces are substantially filled with metal floc, the water will flow over the top and be precluded from contacting the armored limestone, greatly attenuating, if not eliminating predicted dissolution rates.

Table 4.1 presents examples of limestone tonnage calculated to treat mine drainage with 1000 mg/L acidity, in an OLC with a cross section 3 feet deep by 10 feet wide. A mine discharge of 200 gpm and 1000 mg/L acidity would require a channel 3 feet deep, 10 feet wide, and 401 feet long filled with 5,085 tons of armored limestone to treat 100 percent of the acidity.

Table 4.1: OLC Sizing Calculations

	Channel Length in feet		Tons of Limestone Required			
			100% Dissolution		20% Dissolution	
Flow in gpm	1 hour contact time	3 hour contact time	1 hour, 90% Treatment	3 hour, 100% Treatment	1 hour, 90% Treatment	3 hour, 100% Treatment
100	67	201	169	508	847	2,542
200	134	401	339	1,017	1,695	5,085
500	334	1003	847	2,542	4,237	12,712
1000	669	2006	1,695	5,085	8,475	25,424

Modified after Ziemkiewicz and others (1994)

A recommended size of limestone gravel for use in these channels is greater than four inches in diameter (Ziemkiewicz and others, 1994). Optimal efficiency may be reached with limestone in the 6- to 12-inch diameter range. A channel grade exceeding 10 percent is also recommended to facilitate flushing of the metal floc from the drain, preventing a clogging of the pore spaces. Channels with less than a nine percent grade were shown to be much less effective than channels with steeper grades (Ziemkiewicz and others, 1996). Because these channels are designed to flush out the metal floc, settling ponds are often constructed at the outlet point. These ponds will allow the metal floc to be concentrated at one point and should permit discharging the compliance water to the receiving stream. However, ponds will require periodic cleaning to maintain efficiency.

Open limestone channels are relatively simple and inexpensive systems to construct. However, there are some limitations to their use. Neutralization ability of these channels is greatly limited by the dissolution rate of armored limestone, atmospheric CO_2 concentrations, and contact time. Additionally, the reported dissolution rates (Ziemkiewicz and others, 1994; 1996) may be greater than what is chemically possible. Acidity reduction of up to five percent may occur due the formation of the minerals swartzmanite and jarosite, which store acidity (H^+). Calcium concentrations indicate the limestone dissolves at a rate considerably below five percent (Rose, 1999). In order to treat relatively large discharges with considerable acidity concentrations, very long drains (> 3000 feet) with thousands of tons of limestone would be required. Therefore, these channels may not be applicable to space-limited mine sites. These channels require at least a 10 percent slope to prevent clogging, so they cannot be constructed in areas without the required topography or where the receiving stream is too near.

Oxic Limestone Drains

An oxic limestone drain (OLD), unlike an ALD, is designed to treat water containing appreciable dissolved oxygen and iron that has been oxidized (ferric). Like ALDs, OLDs are designed to promote higher limestone dissolution, hence alkalinity production, by concentrating the partial pressure of CO_2 (Pco_2). The Pco_2 is increased because the drain is covered, hampering its escape. The limestone dissolves rapidly enough to make the surface an unstable substrate for iron armoring, because the chemical reactions within the drain cause the dissolution of two moles of $CaCO_3$ for each mole of $Fe(OH)_3$ produced. The iron hydroxide ($Fe(OH)_3$) and aluminum hydroxide ($Al(OH)_3$) will precipitate to some extent within the drain. However, Cravotta (1998) observed that some of the metal flocs were “loosely bound” and were eventually carried down through the drain with water velocities 0.33 to 1.31 feet per minute and residence times $\leq$ 3.1 hours (Cravotta and Trahan, 1999). Additionally, the drains can be designed for periodic flushing to preclude buildup of these metal hydroxides.

There has been limited research on the use of OLDs to treat mine drainage. AMD with a moderate acidity concentration (< 90 mg/L), a pH of less than 4.0, and moderately low dissolved metal (iron, manganese, and aluminum) concentrations (1 to 5 mg/L) was treated using an OLD (Cravotta, 1998). The drains studied exhibited decreased iron and aluminum concentrations of up to 95 percent. Initially (first six months), manganese concentrations were unaffected by the drains. After the initial six months, the manganese concentrations were lowered by 50 percent, because of coprecipitation with the $Fe(OH)_3$ facilitated by higher pH (> 5.0) of the water. The higher pH was due to increased alkalinity production as the water flowed through the drain. The rate of alkalinity production was greatest initially and decreased as the water traveled through the drain (Cravotta, 1998). This observation was likely caused by the more aggressive nature of the water as acidity (H^+) is released with the formation of $Fe(OH)_3$.

Drain sizing criteria are based largely on the discharge rate and desired alkalinity production. The discharge rate relates to in-drain residence time, which in turn is related to treatment effectiveness. Cravotta (1998) recommends that a perforated-pipe under drain be installed to permit periodic flushing of the precipitated metal hydroxides.

Although the research and use of OLDs are limited at this time, these drains may be a low cost method of treating low-level mine drainage. These drains will likely fail to effectively treat if:

- The flow rates are too high for the required detention time.
- The acidity is higher than the limited reaction rates allowed by the drain .
- The metal concentrations of the inflowing water are well above those previously tested.
- Drain clogging cannot be prevented or abated.
- The Pco_2 cannot be maintained at a high level.

The Pyrolusite® Process

Manganese removal from AMD is extremely difficult and has been historically costly. Manganese does not precipitate as easily as iron, and certain manganese oxides are soluble in the presence of ferrous iron. For these reasons, many operators should raise the pH to above 10 in order to effectively precipitate it out of solution (Kleinmann and others, 1985). The elevated pH then becomes problematic, because it is out of compliance (6.0 to 9.0 standard units) and extremely costly in terms of reagents and facility sizing. The manganese effluent standards were originally established as a surrogate instead of establishing standards for a series of toxic metals at mine treatment facilities. This was due to some extent to the adverse impacts of manganese on stream quality and the best practicable control technology (BPT) of existing water treatment facilities (Kleinmann and Watzlaf, 1986). However, the toxicity of manganese on aquatic life has not been conclusively established. An effective and inexpensive passive method to treat manganese in AMD has been actively pursued for several years.

Vail and Riley (1997) reported on a biologically driven patented process to remove iron and especially manganese from mine drainage, while raising the alkalinity of the water. In this process, a bed of crushed limestone is inoculated with “cultured microorganisms” that oxidize iron and manganese in the water contacting the bed. These aerobic microorganisms produce relatively “insoluble metal oxides” while yielding alkalinity by “etching” the limestone hosting medium. The microorganisms are environmentally safe and are not biologically engineered (Vail and Riley, 1997). The metal oxides formed during this process are believed to be manganese dioxide or pyrolusite (MnO_2) and hematite (Fe_2O_3). Both metal oxides are relatively stable and insoluble in alkaline water.

The system is designed so that the water has a protracted contact with the limestone with a recommended minimum residence time of 2.5 to 3.0 days. The engineered treatment cell size should be based on a projected maximum peak flow. The purity of the limestone should be at 87 percent $CaCO_3$ or greater (Vail and Riley, 1997). The hydraulics of the cell should be managed to maximize water contact with the limestone substrate.

Results from a Pyrolusite® process cell monitored over a five-year period showed a dramatic reduction in metals and an increase in the pH. An average influent of 30 mg/L manganese was reduced to below 0.05 mg/L in the effluent. Inflowing iron ranged from near 1 to over 115 mg/L, while the effluent was consistently below 1 mg/L. The pH of the water was raised over two orders of magnitude from about 4.5 to over 7.0. The pH improvement is directly attributable to a dramatic increase in the alkalinity from about 10 mg/L or less to an average of nearly 80 mg/L (Vail and Riley, 1997).

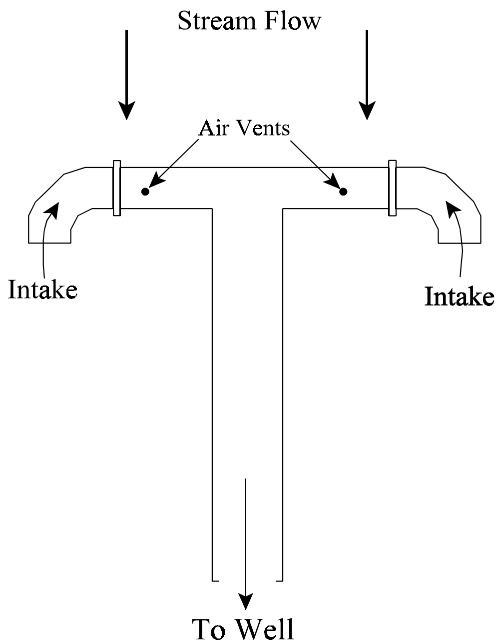
Restrictions on the use of Pyrolusite® cells stem to some extent from the limited knowledge of these systems and details on precisely how they function. The mineral created may in fact be todorokite (i.e., delatorreite), which is a more complex manganese oxide (Cravotta, 1999). The microorganisms that oxidize the metals may be inherent in nature. Therefore, culturing and inoculation procedures may not be necessary. There are size considerations in the construction of these systems due to the relatively long residence times recommended (2.5 to 3.0 days). A large flow rate would require a fairly large system for successful treatment. It is also uncertain how highly acidic ($pH < 4.0$) metal-laden water would affect the treatment process.

Alkalinity-Producing Diversion Wells

Alkalinity-producing diversion wells, a low maintenance method for treating acidic water, were developed in Norway and Sweden using a water pressure-driven, fluidized limestone bed. This technology has been modified for use in treating AMD and streams contaminated by AMD (Arnold, 1991).

Typically, these diversion wells are large cylinders (commonly 5 to 6 feet in diameter and 6 to 8 feet high) composed of reinforced concrete or other erosion resistant material (Figure 4.1e). Two manhole sections, one on top of the other, are frequently used. The bottom of the well should be equally strong and erosion resistant and is commonly formed from reinforced concrete. Water is piped into the center of the well with the end of the pipe just above the well bottom (2 to 3 inches). The outlet point can also be fitted with a metal collar with holes drilled in the sides.

Figure 4.1e: Typical Alkalinity-Producing Diversion Wells

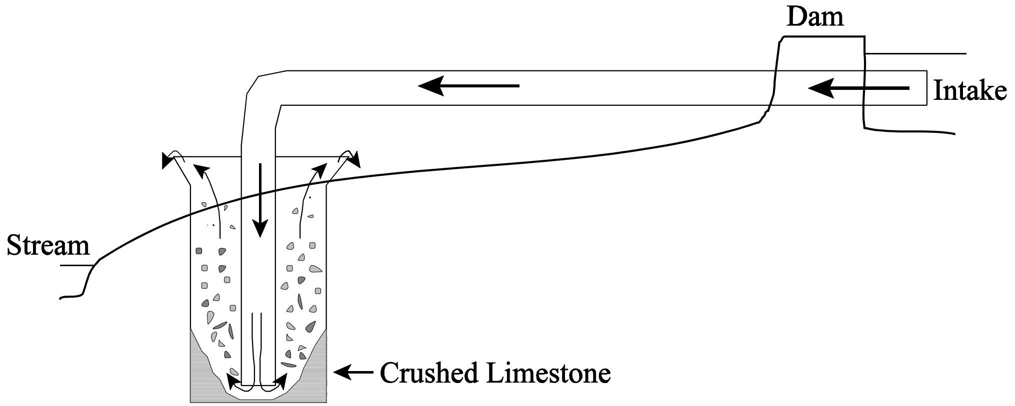


Modified after Arnold (1991).

This will direct the water sideways and appears to be more efficient than directing the water downward. An 8 or 10 inch pipe size is recommended to provide the required flow rate. The water is fed from a point up-gradient, where the water is dammed to yield a consistent 8 feet of head above the well surface (Arnold, 1991). A driving head of 10 to 12 feet was suggested by McClintock and others (1993). Only a portion of the stream flow is diverted, while the rest continues to flow normally down-gradient. The recommended flow rate should average about 2,244 gpm (Arnold, 1991); however, observations of working wells in eastern Pennsylvania indicate that a flow rate of 112 to 224 gpm may sufficiently operate diversion wells. McClintock and others (1993) stated that stream flows as low as 100 gpm can be treated with diversion wells. In low-flow streams, virtually all of the flow will be routed through the well. Crushed limestone is dumped into the well. The optimum size of the limestone is one-half to three-quarters of an inch. Smaller size particles tend to easily wash out and larger particle sizes require higher flow rates to maintain a fluidized bed. The rapid upward movement of the water through the well causes the limestone chips to roil creating a fluidized bed. The top of the well is flared to accommodate an energy reduction in the upward flow which inhibits limestone from washing out. The well is maintained to be consistently approximately half full of limestone (Arnold, 1991).

The water intake point needs to be constructed to inhibit the uptake of leaves, sticks, and other debris, which tend to clog the plumbing. Arnold (1991) recommends a tee with each side fitted with an elbow open toward downstream (Figure 4.1f). Air vents drilled into the tee are recommended to allow the bleeding off of entrained air from vortex action and from air entrained during low flow periods (Arnold, 1991).

Figure 4.1f: Example of a Water Intake Portion of an Alkalinity-Producing Diversion Well



Modified after Arnold (1991)

These wells yield alkalinity from acidic water that reacts directly with the limestone and by the churning action of the fluidized bed grinding the limestone into fine particles. The finer limestone particles will also react with the water in the well, imparting additional alkalinity, and are carried out of the well and to the stream to react with the remaining acidic water that is not piped through the well. The constant churning and surface abrasion of the limestone prevents armoring by dissolved iron in the mine drainage. Limestone consumption rates vary with flow rate, well size, limestone purity and hardness, and to a lesser extent water quality. However, these wells are generally designed to use approximately 0.92 yd^3 of limestone per week. Purer limestones are recommended, because highly dolomitic, very hard limestones tend to react too slowly (Arnold, 1991). It is important to note limestones that are too soft will break up too easily, rapidly wash out of the well, and require more frequent replenishment.

The turbulent action within the wells preclude *in situ* iron deposition. Any dissolved iron present, above 0.3 mg/L, will likely precipitate after leaving the well. It may be prudent to have a settling pond constructed between the well and the receiving stream to collect much of the precipitating iron and other metals.

Arnold (1991) recorded an increase of one to two pH units (orders of magnitude) of the water leaving the diversion well at 5 cfs. McClintock and others reported a pH increase of up to three orders of magnitude. Arnold anticipated a rise in alkalinity proportional to the pH increase, and which alkalinity was increased somewhat, but the concentrations remained relatively low. No detrimental impacts on the in-stream aquatic life were noted with the use of diversion wells (Arnold, 1991). The limited alkalinity production is due primarily to the low atmospheric levels of CO_2, which govern the rate of limestone dissolution. Watten and Schwartz (1996) proposed pretreating the mine water by injecting CO_2 under pressure (100 psi), which increases CO_2 saturation by 22,000 fold. This CO_2 saturation increases the potential alkalinity production to 1,000 mg/L (Watten and Schwartz, 1996). However, CO_2 injection is not passive in nature and would dramatically increase the cost and labor of the operation.

There are some restrictions in the use of diversion wells. These include, but are not limited to:

- Sufficient grade is required to maintain the 8 to 12 feet of head.
- Sufficient flow is required to keep the well functioning properly.
- Waters with high acidity concentrations will not be completely treated by one pass through a well. The water may need to be piped through a battery of wells to achieve complete neutralization.
- There is more maintenance required for these wells than is needed for other passive treatment systems. Recharging of the limestone may need to be performed on a weekly basis.
- If considerable dissolved iron is present, an additional settling pond may be required.
- Intake clogging may be a problem during certain times of the year. Keeping the intake clear and unclogging of the entire piping system are periodic maintenance requirements.

Design Criteria

Passive treatment systems are designed to inexpensively treat AMD with very little or no maintenance once constructed. These systems are engineered to raise the alkalinity and pH while facilitating the precipitation of metals. The mechanisms of AMD treatment rely on metals oxidation or reduction and the production of alkalinity by sulfate reduction or limestone dissolution. The design of these treatment systems varies according to the type, but there are some basic requirements that are common to all. The following list includes basic criteria of passive treatment systems:

- Data are required to determine anticipated flow rates and water quality.
- The size of the facility is based to a large extent on flow rates and detention time.
- The type of system to be employed is directly dependent on water quality (e.g., pH, ferrous vs ferric iron, dissolved oxygen content, net alkalinity, etc.).
- The highest $CaCO_3$ purity limestone is recommended.

- Considerable area is generally required to construct these systems.
- Sufficient grade is required to permit gravity-driven water flow through these systems.
- Flow through these systems needs to be consistent. An interruption of flow can cause the treatment efficacy to be compromised.
- ALDs require low levels of dissolved oxygen, dissolved iron to be virtually all ferrous, and low levels of dissolved aluminum.
- Aerobic wetlands work best when the pH is elevated and there is a net alkalinity.
- To maintain efficiency, SAPS, oxic limestone drains, and open limestone channels require periodic flushing to wash out the loose metal precipitates.

4.2 Verification of Success or Failure

As with all BMPs, verification of proper implementation is crucial to effective control or remediation of the discharge pollution loadings. Monitoring of the water quality and quantity will be the truest measure of the effectiveness of these BMPs. The importance of field verification of all aspects of a BMP cannot be overstated. It is the role of the inspection staff to enforce the provisions outlined in the permit. The inspector generally does not need to be present at all times to assess the implementation of the BMPs in this chapter. However, during installation, some passive BMPs will require closer and more frequent field reviews than others.

The truest test of the success of passive treatment is the water quality of the effluent compared to the influent. This assessment is determined through sampling and analysis of the water and measurement of the flow rate. A sampling and measurement port is needed to access the discharge prior to treatment. An assessment of influent verses effluent flow rates is also necessary. Greater outflow than inflow is indicative that the system is gaining unaccounted-for water within the system. If the outflow is less than the inflow, the system is likely leaking. If the treatment system is gaining or losing unaccounted-for water, it should be repaired. Topographic maps or surveying can be used to determine if sufficient grade exists to adequately drive the flow of these systems.

Implementation Checklist

There are several items that should be monitored to ensure these treatment systems are adequately engineered and installed. This list includes but is not limited to:

- Measurement of flow rate and analysis of the water quality of the discharge. Treatment system engineering is based on these data. Water should be especially analyzed for DO, ferrous and ferric iron, acidity, pH, alkalinity, dissolved aluminum, and dissolved manganese.
- Measurement of the flow rate and analysis of the water quality of the system effluent. Compare effluent quality to raw water for efficiency determinations.
- The amounts, size, and purity of any limestone used should be monitored. Limestone purity should be determined from laboratory analysis. Monitor the type and amount of organic materials. The amount of limestone can be determined from reviewing the weigh slips or estimated from the stockpile dimensions.
- Background data, especially flow, iron concentration, and acidity concentration, should be reviewed to determine the adequate sizing of the treatment systems.
- Crucial portions of the system installation should be monitored.
- Checks for unwanted water infiltration and/or leaks should be performed.
- Whether sufficient grade exists to create the head required to run these systems should be determined.

Many of the verification techniques are common to several passive treatment types, while others may be system-specific. The following list includes implementation verification techniques for passive treatment systems:

<u>Anoxic Limestone Drains</u>

- The size of the trench can be measured during excavation for comparison to the calculated amount of crushed limestone required for treatment. A cubic yard of crushed limestone (1.5 to 2.0 inch) weighs about 2,300 pounds (Nichols, 1976).

- Cover material (e.g., plastic and clays) can be inspected prior to use or can be viewed during installation. If there is a concern as to the adequacy of this material, certification of the strength, permeability, and other properties can be required.
- The dissolved oxygen (DO) concentration and/or iron oxidation state of the effluent can be analyzed to ascertain the ability of the drain to preclude atmospheric oxygen.
- A lack of drain outflow and/or the existence of unanticipated discharge points are indicative that the drain is clogged and/or cannot handle the amount of water piped into it.
- Drains should be sized to permit at least a 15-hour, preferably 23-hour, detention time.

Constructed Wetlands

- Sizing of wetlands can be directly measured and compared to the flow rate, to determine if they were sized adequately to properly treat the water. It is recommended to use a sizing factor of 10 gdm for water with a pH of greater than 4.0 and 4 gdm if the pH is less than 3.0 (Hedin and Nairn, 1990). However, a sizing factor of 15 gdm may provide reasonable results (Kepler, 1990).
- The optimal flow through the wetland can be determined from visual observation or by use of tracing dyes .
- Lack of vegetation may be an indication that the water level is too high or too low.

Successive Alkalinity-Producing Systems (SAPS)

- The size of the system can be measured during excavation for comparison to the calculated amount of crushed limestone required for treatment.
- Sizing of SAPS can be directly measured and compared to the flow rate, (using the above-referenced sizing criteria) to determine if it is adequate for proper treatment.
- Effluent water quality can be monitored to determine if the iron is being reduced and the DO is being removed.
- The water level should be monitored to ensure that the SAPS will not be dewatered or overflow. Either situation will impede the effectiveness of the system.
- SAPS should be sized to permit a detention time similar to ALDs (15 to 23 hours).

Open Limestone Channels

- The size of the trench can be measured during excavation and compared to the calculated amount of crushed limestone required for treatment.
- Sizing of channels can be directly measured and compared to the flow, using the above-referenced sizing criteria, to determine if it is adequate for proper treatment.
- Visual inspection or inadequate flow rate will indicate if the metal floc is clogging the pore spaces in the limestone.
- Flow-through rate and average detention time can be determined by use of dye tracing.
- Recommended detention time is at least three hours to effect 100 percent acidity neutralization.

Oxic Limestone Drains

- The size of the trench can be measured during excavation and compared to the calculated amount of crushed limestone required for treatment.
- Proper sizing of drains can be directly measured and compared to the flow, using the above-referenced sizing criteria, to determine if it is adequate for proper treatment.
- A lack of outflow and/or unanticipated discharge points are indicative that the drain is clogged and/or cannot handle the amount of water piped into it.
- Drain residence times of $\leq$ 3.1 hours and water velocities of 0.33 to 1.31 feet per minute are adequate to effect treatment and flush out the metal flocs.
- Flow-through rate and average detention time can be determined by use of dye tracing.

The Pyrolusite® Process

- The size of the trench can be measured during excavation and compared to the calculated amount of crushed limestone required for treatment.
- Sizing of beds can be directly measured and compared to the flow, using the above referenced sizing criteria, to determine if it is adequate for proper treatment.
- A minimum detention time of 2.5 to 3.0 days is recommended.

Alkalinity-Producing Diversion Wells

- The size of the well can be measured during excavation.
- Sizing of well can be directly measured and compared to the flow, using the above-referenced sizing criteria, to determine if it is adequate for proper treatment.
- The in-stream improvement and the quality of the well effluent are indicative of the efficiency of these systems.
- A head of 10 to 12 feet is required to run the system. Flow rates of 100 gpm to over 2,000 gpm can be treated.

4.3 Case Studies

Case Study 1 (Appendix A, EPA Remining Database, 1999 TN (5))

This site is located in Campbell County, Tennessee, approximately 4 miles north of Caryville. The operation was permitted for 201 acres adjacent to Interstate 75 with roughly 108 acres of coal removal. This was a conventional SMCRA permit, for non Rahall-type remining, and accessed the Coal Creek coal seam. Passive treatment was used effectively to treat the post-mining effluent. Problems arose at this site when operations were ceased, due to a fatal fly rock incident from blasting of the overburden. After approximately 80 percent of the mining had been completed, the operation was ceased and never reactivated. The performance bonds were eventually forfeited ,and a mine drainage problem developed from flooding of the pit, lack of proper handling of acid-forming materials, no contemporaneous reclamation, and other undesirable conditions.

In order to remediate the problem, the Tennessee Valley Authority (TVA), owner of the mineral rights, undertook the task of reclaiming the site and installed a series of passive treatment systems to treat the water. They elected to install an ALD followed by staged aerobic wetlands.

An underdrain was installed across the pit floor as part of the mining process. The outflow of the underdrain was intercepted and an ALD was tied into it. The ALD was designed for a 30-

year lifespan with almost 3,200 tons of limestone used. Prior to entering the drain, the discharge was slightly net alkaline (~50 mg/L), with around 40 mg/L dissolved ferrous iron, and an expected flow estimated at 160 gpm. The drain was designed to yield 250 mg/L alkalinity.

The discharge of the ALD was piped to the staged wetlands. The wetlands were designed to remove 20 gdm of iron and 0.5 gdm of manganese. Based on these removal rates, the wetlands were sized at 3.45 acres. Initially, the ALD effluent was piped to an oxidation pond for primary treatment (abiotic oxidation of metals, hydrolysis, and subsequent precipitation) and to prolong the effective life of the wetland. The pond was 0.77 acres with a detention time of about 24 hours. Following the pond, the mine water flowed into a 2.7 acre wetland. The wetland was divided into five cells with different water levels and vegetation. The first cell had an average of three feet of water and was planted with rice cutgrass, wool grass, and arrowhead. The area of the first cell was 1.02 acres. The second cell had an average of 18 inches of water over 0.59 acres and was planted with cattail, rice cutgrass, and bulrush. The third cell was 0.44 acres with an average water depth of 8 inches and was planted with wool grass, arrowhead, and burreed. The fourth cell was 0.35 acres with an average of 10 inches of water and planted with wool grass, arrowhead, bulrush, burreed, and sedge. The last cell was 0.3 acres with an average depth of 12 inches of water and was planted with cattails. Following the last wetland cell, the water was channeled to an existing basin for final polishing prior to discharging.

The water of the underdrain discharge prior to the ALD installation (given by the TVA) had a pH of 6.0, 40 mg/L iron, 7 mg/L manganese, 15 mg/L acidity, and 65 mg/L alkalinity. The flow was given as 160 gpm. These values were used for treatment system design criteria. Once the passive system was installed, the raw discharge water could no longer be sampled. Table 4.3a is a summary of the water quality at various points as it flows through the treatment system from November 1996 through August 1998.

Table 4.3: Summary of Water Quality Data at Various Points Along a Passive Treatment System

Sample Point	Median Flow (gpm)	Median pH (Standard Units)	Median Alkalinity Concentration (mg/L)	Median Iron Concentration (mg/L)	Median Manganese Concentration (mg/L)
ALD Effluent	186.5	6.2	196	59.50	24.8
Fourth Wetland Effluent	197.5	6.9	106	0.88	22.6
Last Settling Pond Effluent	197.0	7.0	100	0.82	11.1

It appears that initial flow estimates used in sizing the system were too low. The median flow through the system was about 23 percent above the pre-installation estimate. However, the system has effectively raised the alkalinity. The alkalinity after the ALD is over three times greater than the underdrain inflow value. The alkalinity is lowered as the water flows through the wetland by release of mineral acidity as iron and manganese are oxidized and hydrolyzed. The final effluent alkalinity remains over 50 percent above the levels exhibited by the underdrain. The final pH (~7.0) is significantly above the pH of the ALD influent (~6.0). Iron concentrations have been dramatically reduced from near 60 mg/L to well below BAT effluent standards (<1.0 mg/L). Manganese has been reduced by greater than 50 percent, but continues to be well above effluent standards. The continued manganese problem may be due to the apparent undersizing of the system. It is uncertain how the 160 gpm was determined for the discharge prior to sizing the treatment system. Analysis of the existing data indicates that the median flow prior to installation of the treatment system was nearly 190 gpm.

4.4 Discussion

The remining Best Management Practices discussed in this section relate to improvement of effluent by end-of-the-pipe treatment of mine water. Because these systems can be considered as treatment of mine water, they may not necessarily be categorized as true BMPs. There are exceptions where a passive treatment technology or system may qualify as an integral BMP. If an ALD is incorporated within the backfill as a pit floor drain, it can be considered a traditional BMP. If a passive treatment system is installed to treat a discharge that is adjacent to the remining operation and outside of the permit boundary, but is not hydrologically connected to the operation, this also could be considered a BMP. In other words, the operator installs passive treatment on an adjacent discharge, not legally associated with the remining site, to improve the overall watershed water quality.

Benefits

- Passive treatment systems are a low-maintenance method to reduce the pollution load of mine water.
- They are means of gaining additional water quality improvement on and above what is capable with traditional BMPs.
- Some systems are capable of yielding very high amounts of alkalinity and thus, additional buffering capacity, by maintaining elevated CO_2 concentrations.

Limitations

- Passive treatment systems generally require a substantial construction area for moderate to high-flow discharges.
- They require topography that provides sufficient gradient for gravimetric flow.
- They need to be refurbished periodically for cleaning out or replenishment of the reactive materials.

- Certain water quality parameters (e.g., ferric iron, aluminum, or low pH) can cause some systems to fail or to perform below peak efficiency.
- Metals removal and alkalinity are limited by detention times and chemical reaction rates.

Efficiency

Very few of completed remining sites in Pennsylvania (Appendix B: PA Remining Site Study, 1999) utilized passive treatment as an integral part of their BMP plan. In this study, two out of a total of 231 discharges were effected by passive treatment BMPs. However, only one discharge was treated with a passive treatment BMP for a manganese problem. A statistical evaluation of these data is not powerful, because of the extremely limited data. However, no discharge exhibited significantly degraded water quality for acidity, iron, manganese, or aluminum loadings. One discharge was significantly improved for acidity, iron, manganese, and aluminum loadings. The other discharge was unchanged for acidity, iron, and aluminum loadings.

Additional remining sites are required to conclusively evaluate the use of passive treatment BMPs in improving effluent pollution loads. However, the research into passive treatment indicates that in most cases a water quality improvement can be anticipated.

4.5 Summary

Passive treatment technology, although not generally a traditional BMP, can be used to improve pollution load reduction achieved by implementation of true BMPs. Passive treatment provides low cost and minimum labor methods to treat AMD for acidity and certain metals. Research into passive treatment illustrates that a variety of systems can be used to treat a broad range in water quality. The type of systems to be employed should be tailored specifically to the mine water quality.

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Section 5.0 Integration of Best Management Practices

As the preceding sections have illustrated, Best Management Practices (BMPs) are seldom employed singly. Furthermore, it is virtually impossible for some BMPs to be employed without the use of other integral and complementary BMPs. For example, if regrading of dead spoils is performed, corresponding revegetation would also be needed; partial underground mine daylighting requires sealing of undisturbed mine entries at the final highwall. Daylighting commonly entails the cleanup of acid-forming materials surrounding the remaining pillars, which in turn need to be specially handled. The efficiency of many BMPs can be augmented by employing others which complement them. The ability of regrading of dead spoils to preclude surface water infiltration can be improved when combined with diversion ditches, lined channels, stream sealing, or spoil capping. The efficacy of special handling of acid-forming materials can be aided by specialized water handling facilities and alkaline addition.

Past mining practices, prior to the initiation of the Surface Mining Control and Reclamation Act (SMCRA), dealt mainly with extracting coal as inexpensively as possible. Little attention was paid to the environmental impacts of the active operation, much less the condition of the site after mining was completed. The need for employing multiple BMPs is driven by site characteristics such as the condition and amount of prior land disturbance, acidity of overburden, and the extent of abandoned deep mines, and by requirements to prevent further degradation by taking additional countermeasures to pollution. These abandoned mines often require multiple BMPs to effect adequate reclamation and pollution mitigation.

There are two basic mechanisms by which BMPs work to decrease the contaminant load: 1) by physically decreasing the flow of the discharge, and 2) by geochemically improving the water quality (decrease the contaminant concentration). Some BMPs perform both functions to varying degrees simultaneously. Sealing of deep mine entries will inhibit the flow of ground water as well as prevent the infiltration of oxygen into the mine. Revegetation will inhibit water and oxygen infiltration into the backfill as well as impede erosion and sedimentation. It can also increase the amount of CO_2 available in spoil and therefore can positively influence carbonate dissolution. The choice of which BMPs are needed to decrease the pollutant loads is site-specific and cannot be determined using cookbook methodology. The experience and knowledge of permit preparers and reviewers are the major factors in the successful selection, design, and implementation of remining BMPs.

Some of the BMP combinations have been discussed in preceding sections. This section will discuss these combinations in more detail, as well as cover BMP combinations not previously discussed. This section was written to cover the benefits of combining BMPs. It is not the intention of this section to discuss the benefits of all possible BMP combinations, but rather to discuss the overall benefits of combining BMPs. It is likely that there are some beneficial combinations not specifically addressed.

Regrading and Revegetation

Regrading and revegetation work hand-in-hand to decrease pollution loadings both physically and geochemically. This BMP combination functions physically by reducing the amount of surface water introduced into the backfill and geochemically by altering spoil pore gas composition that impacts the weathering of carbonates and pyrite. Spoil regrading eliminates exposed, highly permeable material and closed contour depressions, both of which, when unchecked, facilitate direct infiltration into the spoil of surface water, and promote surface runoff.

The addition of soil and vegetative cover over regraded spoil also works to enhance the inhibition of surface water infiltration. Soils will allow some surface water infiltration, but a great deal of the infiltrating water will be held in the soil horizon until it is used by plants. The structure of soil cover is such that significant quantities of water are preferentially retained. The soil holds water near the ground surface which permits direct evaporation. The addition of vegetative cover further inhibits water infiltration into the underlying spoil. The plants, during the growing season, will take up the water in the soil and transpire it back into the atmosphere. Certain types of plants will promote additional runoff, especially during high intensity precipitation events. Use of biosolids can greatly enhance the vegetative growth and cover percentage, which in turn, will promote greater water use by the plants. However, biosolids should be applied with the provision that the nutrients that they provide may promote significant growth of iron-oxidizing bacteria, thus possibly increasing acid production. However, this effect may be transient and relatively insignificant (Cravotta, 1998). The application of biosolids in Pennsylvania's Remining Site Study appears to have resulted in a positive influence on water quality (Section 6, Table 6.3a).

The more stable regraded surfaces will also function geochemically by inhibiting the introduction of oxygen at depth and by retaining carbon dioxide. Regrading of several spoil piles into one large backfilled area results in less surface area and fewer slopes for atmospheric exchange. In addition, thicker spoil will make it more difficult for oxygen to penetrate at depth. Soil cover and plant growth tend to further preclude oxygen infiltration and retain carbon dioxide in the underlying spoil. In addition, the decay of organic matter in the soil utilizes oxygen, further suppressing deeper oxygen infiltration.

Combining implementation of diversion ditches and stream sealing above the mined area and/or across the surface of the backfill (typically implemented on sites with severely acidic overburden) can augment the efficiency of regrading and revegetation. Capping the site with a low permeability material can also reduce surface water and oxygen infiltration.

There are cases where regrading and revegetation alone are not adequate for pollution reduction. If the regraded spoil is determined to be inherently acidic and the acid-forming materials are widely disseminated, other BMPs such as alkaline addition, mining into alkaline strata (if present), or alkaline redistribution may be necessary. Another BMP that has been used in these circumstances is the installation of induced alkaline recharge structures.

Daylighting

There are several BMPs that can be implemented in conjunction with daylighting to enhance the impact on discharge pollution loadings. Daylighting commonly generates considerable acid-forming materials (waste coal, immediate roof rock, etc.) when the area around pillars is cleaned prior to the excavation of the coal. This acidic material generally requires special handling to further prevent AMD formation. If the amount of acid-forming materials removed from around the coal pillars is significant, this material may need to be removed from the site and disposed of off-site. Additionally, because of the fair amount of acid-forming material that is usually spoiled, alkaline addition may be needed to offset the acidity potential. The alkaline material may also require special handling. Depending on the situation, alkaline material may need to be placed either above the acidic material to prevent AMD formation, or below or within the acidic material to neutralize AMD already formed. Alternatively, mining may need to progress to a predefined overburden thickness to allow disturbance of significant quantities of naturally occurring alkaline rocks above the coal.

If the daylighting does not eliminate all of the abandoned underground mine, other BMPs may be used to aid pollution abatement. The mine entries will need to be sealed to exclude the lateral infiltration or discharge of ground water as described in Section 1.0. Mine entry seals also inhibit the infiltration of atmospheric oxygen to or from the underground mine. If considerable water is stored in and is flowing through the underground mine, a drain may need to be piped from behind the seals through the backfill, thus diverting the water away from the site.

Coal Refuse Removal

Coal refuse removal or reprocessing is a special case of remining. The acidic material is partially or completely removed from the site. In either coal refuse removal or reprocessing, the potential for AMD production is greatly reduced, because the sulfur source is diminished.

Other BMPs can also be employed to further the pollution abatement. In cases where the coal is reprocessed on-site and the waste rock is returned, bactericides may be an option to inhibit pyrite oxidation prior to covering and revegetating the pile. Bactericides can be applied as the waste material is transported via a conveyor belt. Sites involving coal refuse removal or reprocessing are also prime candidates for alkaline addition. Coal refuse seldom has any natural alkalinity-producing ability, therefore any alkaline material added should be beneficial in AMD prevention or neutralization.

Prior to remining, coal refuse piles commonly allow considerable water and oxygen infiltration. These piles are poorly vegetated and typically do not promote runoff. Regrading, soiling and revegetation of the waste material will prove beneficial in many respects, not the least of which is to promoting runoff and reducing water and oxygen infiltration. Surface water control structures (e.g., diversion ditches) and the capping of the refuse with a low permeability material can also aid the reduction of pollution loads.

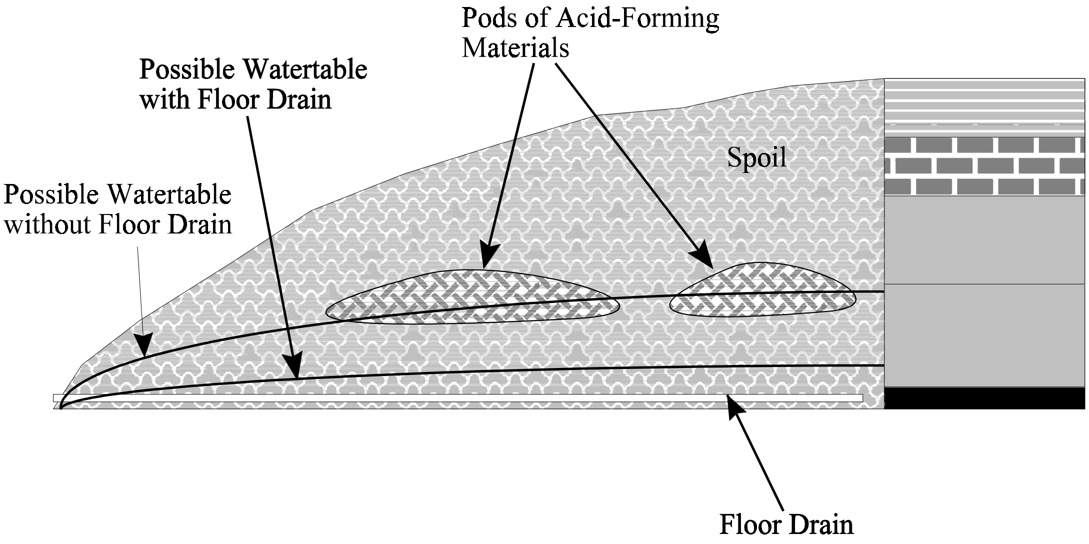
Remining operations involving complete removal of the coal refuse will nearly completely eliminate the AMD production. However, all of the refuse is seldom removed. Refuse is screened, and the fine material, which contains most of the coal, is sent to the power plant. The larger materials remain behind. There are usually minor amounts of refuse left in place. Other BMPs that can prove useful with these types of operations are alkaline addition, regrading and revegetation, and surface water control. Coal combustion waste (CCW), a byproduct of burning the refuse, is often returned to these sites. CCWs typically contain some alkaline material resulting from the addition of limestone during the burning process, thus providing some acid-neutralization potential.

Special Handling with Surface and Ground-Water Controls

A critical component of successful special handling of acidic and alkaline material is understanding the ground-water system. If the ground water can be controlled, special handling will more likely prove successful.

In cases where the acidic material is placed in the backfill in pods that are intended to be located above the fluctuating water table, ground-water control and, to some extent, surface water control can be used to suppress the water table and dampen water table fluctuations. Highwall drains and highwall diversion wells can be employed to intercept laterally infiltrating ground water, and floor drains can be used to collect and rapidly remove ground water. Both of these BMPs will work to suppress the water table (Figure 5.0a). Mine entry sealing and diversion (piping or channeling) of underground mine waters will also aid in this respect. The use of surface water diversion ditches, spoil capping, and/or stream sealing will aid in suppressing the water table through reduced vertical infiltration. Capping and revegetation may aid geochemically by inhibiting atmospheric oxygen infiltration into acidic pods, reducing pyrite oxidation, and reducing the amount of water available for transport of acid materials.

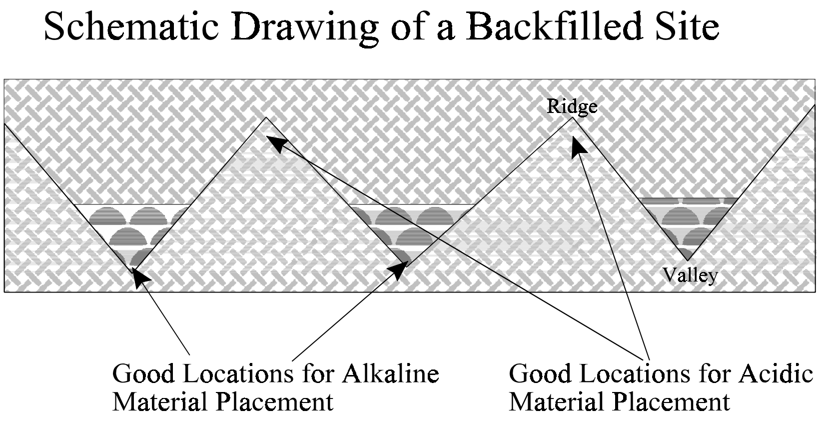
Figure 5.0a: Water Table Suppression in Conjunction with Special Handling of Acidic Material



Conversely, if alkaline material is specially handled within the backfill, it may be beneficial to divert extra water through these areas to generate additional alkalinity. This is similar to induced alkaline recharge (Section 2.3). In cases of special handling of alkaline materials, there are ground- and surface-water controls that can be employed to increase the amount of water that encounters the alkaline material. Chimney drains can be used to funnel water from the surface toward alkaline zones. Additionally, the drains themselves can be comprised of limestone or other alkaline rock. The surface of the reclaimed site can be configured to promote selective infiltration. Small impoundment areas can be created to allow surface water to collect and infiltrate in areas above alkaline-rich areas.

Alkaline material can be placed in areas that will be within the main ground-water flow paths. Ground water will flow primarily along the path of least resistance, which in mine spoil is commonly the buried spoil valleys. The larger spoil particles tend to roll off the sides and collect at the valleys between spoil piles. Thus, these valleys tend to be highly transmissive zones that facilitate significant ground-water flow (Hawkins, 1998). Placing alkaline material in these valleys, prior to reclamation, will likely enhance alkalinity production. Conversely, the acid-rich pods would be best placed in the center of the ridges as far away as possible, both vertically and horizontally, from the highly transmissive zones, but such that they will not be too near the surface. These optimal placement locations are illustrated in Figure 5.0b.

Figure 5.0b: Optimal Location for Special Handling of Acidic and Alkaline Materials



For selected sites where acidic material placement is below the water table, the use of water infiltration control BMPs can be beneficial. It is critical to keep this acidic material under saturated conditions and out of contact with atmospheric oxygen. Given the hydrogeologic conditions within the Appalachian Plateau, many surface mines are located above the regional water table and local water tables are relatively thin. Keeping acidic material under saturated conditions is extremely difficult. However, if large amounts of water can be induced to infiltrate into and held within spoil, it can help maintain a minimum water level in the backfill. Chimney drains and induced alkaline recharge structures can be used to promote infiltration. In addition, the surface of the reclaimed site can be configured to promote direct infiltration, and small impoundment areas can be created to allow surface water to collect and infiltrate into the spoil.

Engineered highwalls can also be created to aid infiltration. For example, bench slopes can be designed to induce infiltration by directing water back toward the highwall, permitting small impoundments or infiltration zones rather than promoting runoff. Once ground water has infiltrated the backfill, as much ground water as possible should be stored to maintain a high water table and saturated conditions. Surface mining below the regional ground-water flow system should allow acidic material submergence, because the water table will commonly re-establish itself and be maintained at a sufficient level. It is common in the Appalachian Plateau for undisturbed strata to have hydraulic conductivity values two orders of magnitude lower than the associated spoil (Hawkins, 1995). Therefore, if the final highwall is down-dip from the mining operations, substantial ground water should impound behind it. In these situations, acidic material should be placed against the highwall to maximize the potential for continual submergence. If the highwall is up-dip of the mining operations or the strata are nearly level, maintaining a high water table will be extremely difficult, because the ground water will tend to drain more freely at the toe of the spoil. Therefore, subaqueous placement of acidic materials will likely not be an option.

If hydrologic controls (e.g., low permeability zones) can be installed in the backfill to inhibit ground-water movement and subsequent discharge, subaqueous placement of acid-forming materials may be viable through maintenance of an elevated water table. A thorough knowledge of site hydrogeologic conditions is required to attempt a “dark and deep” placement or saturated condition of acid-forming materials. However, even with these ground-water controls, a protracted drought may cause the water table to drop below the level of the acidic material, which will likely make worsen the water qualitiy.

Alkaline addition also can be combined with the use of low permeability coal combustion waste (CCW). CCW, when used as a capping, entry seal, or grouting material, can be used with other BMPs to inhibit water movement and provide the ground water with some alkalinity. CCW also can be beneficial when applied to acidic pit floors by sealing the pit floor from ground water.

Miscellaneous BMP Combinations

The use of passive treatment systems can be beneficial to virtually all remining sites with continuing post-remining AMD discharges, regardless of the BMPs employed during mining. However, some types of passive treatment can be integrated into the reclamation plan. These passive treatment systems include installing an anoxic limestone drain as a pit floor underdrain through the backfill and configuring the regrading and revegetation to create a wetland.

Mining into enough cover to encounter alkaline strata can also be beneficial for special handling of acidic materials. Acidic materials, when strategically placed above the water table, commonly need to be well above the pit floor (e.g., >15 to 20 feet) and deep enough to be removed from the impacts of infiltrating atmospheric oxygen. Therefore, a substantially thick backfill is required to maintain the acid-forming materials within these narrow guidelines. Mining into additional cover may yield the necessary spoil thickness to properly handle acid-forming materials.

Capping of mine spoil with a low permeability material can aid the alkalinity production of inherent, redistributed, and added alkaline materials in the backfill. These caps can inhibit the exchange of gases from the backfill to the atmosphere and vice versa. Therefore, the caps will prevent CO_2 in the vadose zone from escaping, which will promote higher alkalinity production.

Summary

BMPs are seldom employed alone. Because of the frequently multifaceted nature of abandoned surface and underground mines, BMP combinations are required to enhance reclamation and to preclude the potential for greater pollution loadings due to remining. Some BMPs, when used in conjunction with others can enhance the pollution load reduction efficacy.

This section does not cover all potential BMP combinations, but does review some of the more common combinations being implemented during remining operations. BMP plans do not lend themselves to a pre-set methodology or cookbook formula. Each remining operation requires a

BMP plan that stems from site-specific conditions that are contingent on the background and experience of the remining permit and BMP plan preparer and reviewer. Factors such as the extent of previous mining, configuration of the abandoned site, geochemistry of the overburden, site hydrology, and topography all impact the formulation of an effective BMP plan.

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Section 6.0 Efficiencies of Best Management Practices

Determination of the efficiencies of Best Management Practices (BMP) is best performed using data that accurately represent water quality and pollution loading before, during, and after remining has occurred. Water quality and flow data that are used to determine baseline pollution loading for pre-existing discharges can be compared to data collected to monitor the same discharges after mining operations have been completed. Because the effects of both remining operations and associated BMPs are generally not immediate and can continue well beyond mine closure, it is important to consider water quality and flow conditions for a period of time (e.g., two years) following site closure.

Site-specific efficiency statements for BMPs have been included in each section of this Guidance Manual. The purpose of this section is to: 1) present observed results of the effects of the implementation of 12 BMPs at over 100 remining sites in Pennsylvania using existing data, and 2) analyze these data, using statistical methods, in order to predict BMP efficiencies at remining sites throughout the Appalachian coal region. Efficiencies are presented for the following BMPs, as implemented individually or in combination:

Regrading: the restoration of positive drainage to pre-Surface Mining Control and Reclamation Act (SMCRA) surface mined areas. Regrading can be to approximate original contour (if adequate spoil is available) or terraced (if existing spoil is inadequate or if terracing will result in a higher land use).

Revegetation: the establishment of a diverse and permanent vegetative cover on inadequately vegetated pre-SMCRA surface-mined areas that is adequate to control surface-water infiltration and erosion.

Daylighting: the exposure by surface mining of a deep-mined coal seam, with the purpose of removal of the remaining coal.

Special Handling of Acid-Producing Materials: the selective placement of acid-generating overburden rock at a position within the backfill that is advantageous for reducing the amount of acid that would otherwise be generated from that rock.

Alkaline Addition: the importation of off-site calcareous material to a mine site. Alkaline addition is used in a variety of circumstances, particularly where a mine lacks sufficient naturally occurring calcareous rock, but does contain a sufficient amount of pyritic material that could produce mine drainage pollution in the absence of neutralizers. Alkaline addition is measured as tons of $CaCO_3$ equivalent/acre.

Water Handling Systems: refers to any BMP that is specifically designed to: 1) reduce the amount of surface water that could infiltrate into the spoil and become ground water, or 2) channel ground water through spoil with the purpose of reducing water contact time with spoil and/or lowering the ground water table or preventing ground water from entering the spoil.

Passive Treatment: means of treating polluted mine drainage chemically and/or biologically such that metals concentrations are oxidized or reduced and acidity is neutralized. Compared with conventional chemical treatment (the typical alternative), passive methods generally require more surface area, but use less costly reagents, and require less operational attention, power, and maintenance.

Coal Refuse Removal: the elimination or reduction of abandoned coal waste piles. This material is typically sent to power plants for generation of electricity. In addition to the elimination or reduction of the size of the pile, the site of disturbance is regraded and revegetated.

Biosolids Addition: the application of nutrient-rich organic materials resulting from the treatment of sewage sludge (a solid, semi-solid or liquid residue generated during the treatment of domestic sewage in a treatment works) as a soil amendment for enhancement of plant growth on surface mines.

Mining of Highly Alkaline Strata: the encountering and mixing of naturally-occurring calcareous rock during the mining process. The mining plan may have to be adjusted to ensure that sufficient calcareous rock is encountered.

Alkaline Redistribution: the process of taking excess calcareous material from a portion of a mine and placing it in areas of the mine that lack calcareous materials. Typically, these areas lacking calcareous materials would not produce acceptable post-mining water quality without the addition of the calcareous material.

BMP efficiencies presented in this section are based on data provided by Pennsylvania Department of Environmental Protection (PA DEP) as a remining site study (PA Remining Site Study). The database from this study existed prior to the initiation of this evaluation, and includes summary water quality information and associated BMPs only. Therefore, factors that may have affected discharges in addition to the associated BMPs (such as compliance history) were not considered in this evaluation. The PA Remining Study was not specifically designed for the purposes of evaluating or determining the BMP efficiencies presented in this section. It is, however, the largest database available on completed remining sites and includes baseline data, post-mining data, and a record of BMPs used on 113 mine sites.

In spite of certain limitations of the data evaluated, these data include 231 discharges from 112 closed remining operations and are the most comprehensive compiled to date regarding the efficiency of remining. These data are considered highly suited for the determination of BMP efficiencies, and the BMP efficiencies that have been predicted using these data can be considered the best available at this time. The advantages of this data set include:

- Over 100 different remining sites and over 230 pre-existing discharges are represented.
- Baseline data include monthly samples, typically for one year.
- Post-mining data include at least one year of monthly sample results.
- Post-mining data represent conditions following reclamation of remining sites.
- BMPs implemented are identified for each discharge.
- Water quality data represent ground-water discharges that are hydrologically connected to the mine.

Limitations

It is important to note while reviewing this section that, although the data set used is the most extensive available on remining at this time, there are some limitations to its use for evaluating BMP efficiencies.

- The data are specific and exclusive to remining operations in the Pennsylvania bituminous coal regions. Although hydrologically and geologically very similar, remining in other parts of the Appalachian coalfields may exhibit slight differences.
- All permits were State-approved, Rahall remining permits. Sites have been reclaimed to at least Stage II bond release standards. During permit application review, for operations

thought to be potentially environmentally detrimental (i.e., resulting in increased pollution loadings), permits are either denied or amended to preclude degradation.

- This data set does not include non Rahall-type remining operations where pre-existing discharges are subject to statutory effluent limitations.
- No discharge data from mining on areas previously unmined, and no discharge data from areas unaffected by BMPs (i.e., control data) were included.
- All sites all had at least monthly water quality analysis and flow measurement requirements for determining baseline, as well as during-mining and post-mining monitoring data. However, no compensation has been applied for sampling through periods of abnormal precipitation (well above or below the average).
- At this time, only contaminant loading and flow data are available. Review of concentration data would permit a more rigorous determination of BMP efficiency. Determination of whether a change in flow or contaminant concentration effected the change in load would permit determinations as to whether a specific BMP made a physical (flow) and/or geochemical (concentration) difference. These data may be available in the near future and an in-depth analysis and discussion may follow.
- For mines reclaimed only recently, the post-mining data may not be fully representative of equilibrium conditions. During this early period (about two years), the water table is rebounding and discharge rates may be below those that will occur once the water table has reached equilibrium. Because the most recently collected 12 months of data (at the time of database compilation) was used in this study, most sites have been reclaimed for a number of years and the water table should have stabilized in the backfill.

6.1 Pennsylvania DEP - Remining Site Study

In 1998, Pennsylvania DEP evaluated water-quality and flow data for 248 pre-existing discharges from 112 remining sites that had been reclaimed to at least Stage II bond release standards (completely backfilled and revegetated). The remining sites were scattered throughout the bituminous coal region of the state and most heavily concentrated in the southwestern counties. The most recently available 12 months of pollution loading and flow data were compared against baseline loading and flow data (usually 12 months) for each pre-existing discharge. The same statistical test used to detect significant increases in pollution load (Tukey, 1976; PA DER, 1988) was used to determine whether there were significant decreases in pollution load. In addition, the current (or most recently available) median pollution load was calculated in order to quantify the actual increase or decrease in pollution load. This analysis was conducted for acidity, total iron, total manganese, and total aluminum loadings.

Results of the analysis for each individual discharge or discharges identified by and combined into hydrologically connected units were entered into a database. The database also identified the best management practices employed during remining operations that were expected to have an impact on the water quality of that discharge. A single surface mining permit, more often than not, includes several individual discharges or hydrologic units and implements multiple BMPs. Some or all of the employed BMPs may be applicable to each discharge or hydrologic unit. Therefore, analysis of BMP effect on discharges was performed at the discharge or hydrologic-unit level, not at the permit level.

Of the 248 discharges included in the database, some could not be used for BMP efficiency analyses due to missing or unavailable information or data. Six monitoring points did not have baseline water quality data for any parameter, most likely due to an absence of flow. Ten other discharges did not have any associated BMP information. Therefore, the total number of discharges used in the BMP efficiency analyses was 231, derived from 109 permits.

Sulfate loadings and flow rates were also analyzed in this section to yield insight as to which BMPs may have caused the observed loadings changes. Sulfate loading trends may indicate if changes in loading rates of acidity, iron, manganese, and/or aluminum are due to geochemical changes in acid mine drainage (AMD) production (increases or decreases in pyrite oxidation). Sulfate ions are a conservative indicator of AMD production. Flow rate data may indicate whether changes to contaminant loadings are due to changes in the flow rate. These two parameters can in turn indicate if an improvement in water quality is related to a particular geochemically based or physically based BMP.

6.2 Observed Results

The database was used to summarize the number of discharges which showed statistically significant increases, decreases, or no change in pollution load and to compare the aggregate (combined) median pollution load. Statistical significance is determined by comparing the baseline upper and lower confidence limits about the median pollution load against the upper and lower confidence limits about the post-mining median. BMP effects on discharges were rated as follows:

- No significant difference - If the baseline and post-mining confidence intervals overlap, then there is no statistically significant difference and the median pollutant loading of the discharge is considered unchanged.
- Significantly degraded - If the post-mining lower confidence limit exceeds the baseline upper confidence limit, then there is a significant increase in median load.
- Significantly improved - If the post-mining upper confidence limit is lower than the baseline lower confidence limit, there is a significant decrease in median load.
- Eliminated - If the post-mining upper confidence limit was zero, the pollution load was considered to have been eliminated. This does not necessarily mean that the discharge was physically eliminated, only that with 95 percent confidence, the median pollution loads were zero.

This analysis was performed for each discharge affected by any of the 12 specific BMPs listed earlier in this section. The results of the observed BMP effects on pre-existing discharges are summarized by BMP and parameter in Table 6.2a.

Most discharges (or hydrologic units) were affected by multiple BMPs. For that reason, BMP effects on a single discharge may be represented in Table 6.2a under several different BMPs. For example, surface regrading, revegetation, and daylighting may have been implemented in an area affecting a single discharge. In Table 6.2a, the water quality results for that discharge would be represented in the summary results for each of these BMPs separately. Therefore, changes in pollution-loading rates may not be attributed solely to that BMP, but may have been affected by a group of BMPs. Table 6.2b summarizes the observed effects of BMPs on discharges by BMP group and parameter.

Table 6.2a: Pennsylvania Remining Permits, Summary of Observed Water Quality Results by Individual BMP (Appendix B, Pennsylvania Remining Site Study)

Water Quality Results - Overall

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	43	19.1%
Significantly improved	57	25.3%
No significant difference	123	54.7%
Significantly degraded	2	0.9%
Total for parameter	225	

Iron		
Discharge eliminated	49	23.7%
Significantly improved	37	17.9%
No significant difference	110	53.1%
Significantly degraded	11	5.3%
Total for parameter	207	

Sulfate		
Discharge eliminated	43	18.7%
Significantly improved	47	20.4%
No significant difference	116	50.4%
Significantly degraded	24	10.4%
Total for parameter	230	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	32	20.6%
Significantly improved	31	20.0%
No significant difference	78	50.3%
Significantly degraded	14	9.0%
Total for parameter	155	

Aluminum		
Discharge eliminated	21	17.9%
Significantly improved	23	19.7%
No significant difference	69	59.0%
Significantly degraded	4	3.4%
Total for parameter	117	

Flow		
Discharge eliminated	42	18.2%
Significantly improved	54	23.4%
No significant difference	122	52.8%
Significantly degraded	13	5.6%
Total for parameter	231	

Water Quality Results by BMP - Alkaline Addition > 100 tons/acre

Acidity	# Discharges	Percent of Discharges	Manganese	# Discharges	Percent of Discharges
Discharge eliminated	4	36.4%	Discharge eliminated	1	16.7%
Significantly improved	3	27.3%	Significantly improved	0	0.0%
No significant difference	3	27.3%	No significant difference	3	50.0%
Significantly degraded	1	9.1%	Significantly degraded	2	33.3%
Total for parameter	11		Total for parameter	6	
Iron			Aluminum		
Discharge eliminated	5	45.5%	Discharge eliminated	0	0.0%
Significantly improved	1	9.1%	Significantly improved	0	0.0%
No significant difference	4	36.4%	No significant difference	1	100.0%
Significantly degraded	1	9.1%	Significantly degraded	0	0.0%
Total for parameter	11		Total for parameter	1	
Sulfate			Flow		
Discharge eliminated	5	45.5%	Discharge eliminated	4	36.4%
Significantly improved	1	9.1%	Significantly improved	3	27.3%
No significant difference	4	36.4%	No significant difference	3	27.3%
Significantly degraded	1	9.1%	Significantly degraded	1	9.1%
Total for parameter	11		Total for parameter	11	

Water Quality Results by BMP - Alkaline Addition < 100 tons/acre

Acidity	# Discharges	Percent of Discharges	Manganese	# Discharges	Percent of Discharges
Discharge eliminated	11	16.9%	Discharge eliminated	8	20.5%
Significantly improved	11	16.9%	Significantly improved	5	12.8%
No significant difference	43	66.2%	No significant difference	22	56.4%
Significantly degraded	0	0.0%	Significantly degraded	4	10.3%
Total for parameter	65		Total for parameter	39	
Iron			Aluminum		
Discharge eliminated	13	21.7%	Discharge eliminated	5	19.2%
Significantly improved	9	15.0%	Significantly improved	2	7.7%
No significant difference	37	61.7%	No significant difference	19	73.1%
Significantly degraded	1	1.7%	Significantly degraded	0	0.0%
Total for parameter	60		Total for parameter	26	
Sulfate			Flow		
Discharge eliminated	14	20.9%	Discharge eliminated	14	20.9%
Significantly improved	11	16.4%	Significantly improved	9	13.4%
No significant difference	36	53.7%	No significant difference	41	61.2%
Significantly degraded	6	9.0%	Significantly degraded	3	4.5%
Total for parameter	67		Total for parameter	67	

Water Quality Results by BMP - On-site Alkaline Redistribution

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	5	83.3%
Significantly improved	0	0.0%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	4	100.0%
Significantly improved	0	0.0%
No significant difference	0	0.0%
Significantly degraded	0	0.0%
Total for parameter	4	

Iron		
Discharge eliminated	2	66.7%
Significantly improved	0	0.0%
No significant difference	1	33.3%
Significantly degraded	0	0.0%
Total for parameter	3	

Aluminum		
Discharge eliminated	3	100.0%
Significantly improved	0	0.0%
No significant difference	0	0.0%
Significantly degraded	0	0.0%
Total for parameter	3	

Sulfate		
Discharge eliminated	4	66.7%
Significantly improved	1	16.7%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Flow		
Discharge eliminated	4	66.7%
Significantly improved	1	16.7%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Water Quality Results by BMP - Biosolids application

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	0	0.0%
Significantly improved	5	83.3%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	3	60.0%
Significantly improved	0	0.0%
No significant difference	2	40.0%
Significantly degraded	0	0.0%
Total for parameter	5	

Iron		
Discharge eliminated	3	50.0%
Significantly improved	1	16.7%
No significant difference	2	33.3%
Significantly degraded	0	0.0%
Total for parameter	6	

Aluminum		
Discharge eliminated	2	66.7%
Significantly improved	1	33.3%
No significant difference	0	0.0%
Significantly degraded	0	0.0%
Total for parameter	3	

Sulfate		
Discharge eliminated	2	33.3%
Significantly improved	3	50.0%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Flow		
Discharge eliminated	2	33.3%
Significantly improved	3	50.0%
No significant difference	1	16.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Water Quality Results by BMP - Coal Refuse Removal

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	2	22.2%
Significantly improved	4	44.4%
No significant difference	3	33.3%
Significantly degraded	0	0.0%
Total for parameter	9	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	0	0.0%
Significantly improved	0	0.0%
No significant difference	5	83.3%
Significantly degraded	1	16.7%
Total for parameter	6	

Iron		
Discharge eliminated	0	0.0%
Significantly improved	2	28.6%
No significant difference	4	57.1%
Significantly degraded	1	14.3%
Total for parameter	7	

Aluminum		
Discharge eliminated	0	0.0%
Significantly improved	2	33.3%
No significant difference	4	66.7%
Significantly degraded	0	0.0%
Total for parameter	6	

Sulfate		
Discharge eliminated	0	0.0%
Significantly improved	2	22.2%
No significant difference	7	77.8%
Significantly degraded	0	0.0%
Total for parameter	9	

Flow		
Discharge eliminated	0	0.0%
Significantly improved	1	11.1%
No significant difference	8	88.9%
Significantly degraded	0	0.0%
Total for parameter	9	

Water Quality Results by BMP - Construction of Special Water Handling Facilities

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	5	22.7%
Significantly improved	6	27.3%
No significant difference	11	50.0%
Significantly degraded	0	0.0%
Total for parameter	22	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	5	26.3%
Significantly improved	4	21.1%
No significant difference	8	42.1%
Significantly degraded	2	10.5%
Total for parameter	19	

Iron		
Discharge eliminated	7	30.4%
Significantly improved	4	17.4%
No significant difference	11	47.8%
Significantly degraded	1	4.3%
Total for parameter	23	

Aluminum		
Discharge eliminated	2	18.2%
Significantly improved	1	9.1%
No significant difference	8	72.7%
Significantly degraded	0	0.0%
Total for parameter	11	

Sulfate		
Discharge eliminated	6	26.1%
Significantly improved	4	17.4%
No significant difference	12	52.2%
Significantly degraded	1	4.3%
Total for parameter	23	

Flow		
Discharge eliminated	6	26.1%
Significantly improved	5	21.7%
No significant difference	10	43.5%
Significantly degraded	2	8.7%
Total for parameter	23	

Water Quality Results by BMP - Daylighting

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	28	17.1%
Significantly improved	39	23.8%
No significant difference	96	58.5%
Significantly degraded	1	0.6%
Total for parameter	164	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	21	19.4%
Significantly improved	23	21.3%
No significant difference	57	52.8%
Significantly degraded	7	6.5%
Total for parameter	108	

Iron		
Discharge eliminated	27	17.3%
Significantly improved	35	22.4%
No significant difference	87	55.8%
Significantly degraded	7	4.5%
Total for parameter	156	

Aluminum		
Discharge eliminated	17	18.5%
Significantly improved	13	14.1%
No significant difference	58	63.0%
Significantly degraded	4	4.3%
Total for parameter	92	

Sulfate		
Discharge eliminated	28	16.6%
Significantly improved	33	19.5%
No significant difference	87	51.5%
Significantly degraded	21	12.4%
Total for parameter	169	

Flow		
Discharge eliminated	28	16.5%
Significantly improved	35	20.6%
No significant difference	96	56.5%
Significantly degraded	11	6.5%
Total for parameter	170	

Water Quality Results by BMP - Mining of Highly Alkaline Strata

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	3	25.0%
Significantly improved	5	41.7%
No significant difference	4	33.3%
Significantly degraded	0	0.0%
Total for parameter	12	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	0	0.0%
Significantly improved	2	50.0%
No significant difference	2	50.0%
Significantly degraded	0	0.0%
Total for parameter	4	

Iron		
Discharge eliminated	3	23.1%
Significantly improved	2	15.4%
No significant difference	5	38.5%
Significantly degraded	3	23.1%
Total for parameter	13	

Aluminum		
Discharge eliminated	0	0.0%
Significantly improved	0	0.0%
No significant difference	3	100.0%
Significantly degraded	0	0.0%
Total for parameter	3	

Sulfate		
Discharge eliminated	2	15.4%
Significantly improved	4	30.8%
No significant difference	6	46.2%
Significantly degraded	1	7.7%
Total for parameter	13	

Flow		
Discharge eliminated	2	15.4%
Significantly improved	6	46.2%
No significant difference	5	38.5%
Significantly degraded	0	0.0%
Total for parameter	13	

Water Quality Results by BMP - Passive Treatment System Construction

Acidity	# Discharges	Percent of Discharges	Manganese	# Discharges	Percent of Discharges
Discharge eliminated	0	0.0%	Discharge eliminated	1	100.0%
Significantly improved	0	0.0%	Significantly improved	0	0.0%
No significant difference	1	100.0%	No significant difference	0	0.0%
Significantly degraded	0	0.0%	Significantly degraded	0	0.0%
Total for parameter	1		Total for parameter	1	
Iron			Aluminum		
Discharge eliminated	1	50.0%	Discharge eliminated	0	0.0%
Significantly improved	0	0.0%	Significantly improved	0	0.0%
No significant difference	1	50.0%	No significant difference	1	100.0%
Significantly degraded	0	0.0%	Significantly degraded	0	0.0%
Total for parameter	2		Total for parameter	1	
Sulfate			Flow		
Discharge eliminated	0	0.0%	Discharge eliminated	0	0.0%
Significantly improved	1	50.0%	Significantly improved	1	50.0%
No significant difference	1	50.0%	No significant difference	1	50.0%
Significantly degraded	0	0.0%	Significantly degraded	0	0.0%
Total for parameter	2		Total for parameter	2	

Water Quality Results by BMP - Special Handling of Acid-forming Material

Acidity	# Discharges	Percent of Discharges	Manganese	# Discharges	Percent of Discharges
Discharge eliminated	11	14.1%	Discharge eliminated	12	23.5%
Significantly improved	17	21.8%	Significantly improved	8	15.7%
No significant difference	48	61.5%	No significant difference	28	54.9%
Significantly degraded	2	2.6%	Significantly degraded	3	5.9%
Total for parameter	78		Total for parameter	51	
Iron			Aluminum		
Discharge eliminated	11	15.7%	Discharge eliminated	6	15.8%
Significantly improved	15	21.4%	Significantly improved	6	15.8%
No significant difference	39	55.7%	No significant difference	25	65.8%
Significantly degraded	5	7.1%	Significantly degraded	1	2.6%
Total for parameter	70		Total for parameter	38	
Sulfate			Flow		
Discharge eliminated	11	13.8%	Discharge eliminated	11	13.8%
Significantly improved	15	18.8%	Significantly improved	16	20.0%
No significant difference	42	52.5%	No significant difference	47	58.8%
Significantly degraded	12	15.0%	Significantly degraded	6	7.5%
Total for parameter	80		Total for parameter	80	

Water Quality Results by BMP - Surface Regrading

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	30	19.5%
Significantly improved	41	26.6%
No significant difference	82	53.2%
Significantly degraded	1	0.6%
Total for parameter	154	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	21	18.9%
Significantly improved	23	20.7%
No significant difference	58	52.3%
Significantly degraded	9	8.1%
Total for parameter	111	

Iron		
Discharge eliminated	33	24.1%
Significantly improved	25	18.2%
No significant difference	72	52.6%
Significantly degraded	7	5.1%
Total for parameter	137	

Aluminum		
Discharge eliminated	14	16.7%
Significantly improved	17	20.2%
No significant difference	51	60.7%
Significantly degraded	2	2.4%
Total for parameter	84	

Sulfate		
Discharge eliminated	27	17.4%
Significantly improved	32	20.6%
No significant difference	81	52.3%
Significantly degraded	15	9.7%
Total for parameter	155	

Flow		
Discharge eliminated	26	16.7%
Significantly improved	42	26.9%
No significant difference	78	50.0%
Significantly degraded	10	6.4%
Total for parameter	156	

Water Quality Results by BMP - Surface Revegetation

Acidity	# Discharges	Percent of Discharges
Discharge eliminated	35	20.1%
Significantly improved	46	26.4%
No significant difference	93	53.4%
Significantly degraded	0	0.0%
Total for parameter	174	

Manganese	# Discharges	Percent of Discharges
Discharge eliminated	26	20.5%
Significantly improved	25	19.7%
No significant difference	67	52.8%
Significantly degraded	9	7.1%
Total for parameter	127	

Iron		
Discharge eliminated	40	25.3%
Significantly improved	29	18.4%
No significant difference	82	51.9%
Significantly degraded	7	4.4%
Total for parameter	158	

Aluminum		
Discharge eliminated	17	17.3%
Significantly improved	20	20.4%
No significant difference	58	59.2%
Significantly degraded	3	3.1%
Total for parameter	98	

Sulfate		
Discharge eliminated	34	19.3%
Significantly improved	40	22.7%
No significant difference	85	48.3%
Significantly degraded	17	9.7%
Total for parameter	176	

Flow		
Discharge eliminated	33	18.6%
Significantly improved	46	26.0%
No significant difference	88	49.7%
Significantly degraded	10	5.7%
Total for parameter	177	

Of the 12 BMPs assessed, only three were reported to be used singly, accounting for effects on 8.7 percent (20) of 231 discharges. The BMPs reported as being implemented singly were regrading (affecting one discharge), revegetation (affecting five discharges), and daylighting (affecting 14 discharges). However, the possibility that regrading was implemented alone, without revegetation, is doubtful. The pollution abatement of the remaining discharges was affected by BMP groups containing up to six BMPs. Table 6.2b lists the observed effects of the various BMP groupings implemented on 231 pre-existing discharges or hydrologic units.

Table 6.2b: PA Remining Study - Observed Effects of BMP Groupings on Discharges

BMP Group Code

(a)	Regrading
(b)	Revegetation
(c)	Daylighting
(d)	Special Handling
(e)	Alkaline Addition < 100 tons/acre
(f)	Special Water Handling Facilities
(g)	Passive Treatment
(h)	Coal Refuse Removal
(i)	Biosolids Application
(j)	Mining High Alkaline Strata
(k)	Alkaline Addition > 100 tons/acre
(l)	On-Site Alkaline Redistribution

Ratings Code

4	Eliminated
3	Improved
2	Unchanged
1	Degraded

BMP Group	Discharges Affected	Parameter	Rating				Improved or Eliminated %	Degraded %
			1	2	3	4		
c	14	acidity	0	9	3	1	30.8%	0.0%
		iron	0	5	4	3	58.3%	0.0%
		manganese	1	4	4	2	54.5%	9.1%
		aluminum	1	5	2	2	40.0%	10.0%
		flow	0	12	1	1	14.3%	0.0%
		sulfate	2	8	3	1	28.6%	14.3%
b	5	acidity	0	3	2	0	40.0%	0.0%
		iron	1	3	1	0	20.0%	20.0%
		manganese	0	4	1	0	20.0%	0.0%
		aluminum	0	2	3	0	60.0%	0.0%
		flow	0	2	3	0	60.0%	0.0%
		sulfate	1	1	3	0	60.0%	20.0%
a	1	acidity	0	0	1	0	100.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	0	1	0	100.0%	0.0%
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
c, l	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
c, h	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	1	0	0	0.0%	0.0%
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
c, e	12	acidity	0	8	3	1	33.3%	0.0%
		iron	0	8	2	1	27.3%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	1	0	0	0.0%	0.0%
		flow	1	8	1	2	25.0%	8.3%
		sulfate	0	9	1	2	25.0%	0.0%
c, d	5	acidity	1	4	0	0	0.0%	20.0%
		iron	1	3	0	0	0.0%	25.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	1	0	0	0.0%	0.0%
		flow	1	4	0	0	0.0%	20.0%
		sulfate	3	2	0	0	0.0%	60.0%
b, i	1	acidity	0	0	1	0	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	1	100.0%	0.0%
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%
b, c	5	acidity	0	1	2	2	80.0%	0.0%
		iron	0	1	2	2	80.0%	0.0%
		manganese	0	2	1	2	60.0%	0.0%
		aluminum	1	2	0	2	40.0%	20.0%
		flow	0	1	2	2	80.0%	0.0%
		sulfate	0	1	2	2	80.0%	0.0%
a, b	18	acidity	0	9	2	7	50.0%	0.0%
		iron	0	6	2	2	40.0%	0.0%
		manganese	2	4	2	3	45.5%	18.2%
		aluminum	0	3	2	1	50.0%	0.0%
		flow	0	6	5	7	66.7%	0.0%
		sulfate	1	7	3	7	55.6%	5.6%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
c, h, j	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
c, e, f	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	1	100.0%	0.0%
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%
c, d, k	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
c, d, j	3	acidity	0	0	2	0	100.0%	0.0%
		iron	2	1	0	0	0.0%	66.7%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	1	2	0	66.7%	0.0%
		sulfate	0	2	1	0	33.3%	0.0%
c, d, e	5	acidity	0	3	0	2	40.0%	0.0%
		iron	0	3	0	2	40.0%	0.0%
		manganese	0	3	0	2	40.0%	0.0%
		aluminum	0	3	0	0	0.0%	0.0%
		flow	0	3	0	2	40.0%	0.0%
		sulfate	2	1	0	2	40.0%	40.0%
b, d, l	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
b, d, k	1	acidity	0	0	1	0	100.0%	0.0%
		iron	0	0	1	0	100.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
b, d, e	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
b, c, k	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%
b, c, g	1	acidity	0	0	0	0	-	-
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%
b, c, f	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	0	1	0	100.0%	0.0%
		flow	1	0	0	0	0.0%	100.0%
		sulfate	1	0	0	0	0.0%	100.0%
b, c, e	4	acidity	0	2	0	2	50.0%	0.0%
		iron	0	2	0	1	33.3%	0.0%
		manganese	1	1	1	1	50.0%	25.0%
		aluminum	0	2	0	1	33.3%	0.0%
		flow	0	3	0	1	25.0%	0.0%
		sulfate	0	3	0	1	25.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
b, c, d	2	acidity	0	1	1	0	50.0%	0.0%
		iron	0	1	1	0	50.0%	0.0%
		manganese	0	2	0	0	0.0%	0.0%
		aluminum	0	1	0	0	0.0%	0.0%
		flow	0	1	1	0	50.0%	0.0%
		sulfate	0	0	2	0	100.0%	0.0%
a, d, k	1	acidity	1	0	0	0	0.0%	100.0%
		iron	1	0	0	0	0.0%	100.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	0	0	0	-	-
		flow	1	0	0	0	0.0%	100.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, d, e	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, c, j	2	acidity	0	1	1	0	50.0%	0.0%
		iron	0	0	1	1	100.0%	0.0%
		manganese	0	1	1	0	50.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	2	0	100.0%	0.0%
		sulfate	0	1	1	0	50.0%	0.0%
a, c, d	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	0	-	-
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	1	100.0%	0.0%
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%
a, b, k	2	acidity	0	0	0	2	100.0%	0.0%
		iron	0	0	0	2	100.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	0	1	1	100.0%	0.0%
		sulfate	0	0	0	2	100.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
a, b, h	3	acidity	0	1	2	0	66.7%	0.0%
		iron	1	1	0	0	0.0%	50.0%
		manganese	1	1	0	0	0.0%	50.0%
		aluminum	0	2	0	0	0.0%	0.0%
		flow	0	2	1	0	33.3%	0.0%
		sulfate	0	2	1	0	33.3%	0.0%
a, b, g	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	1	0	0	0.0%	0.0%
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, b, f	4	acidity	0	0	3	1	100.0%	0.0%
		iron	0	0	2	2	100.0%	0.0%
		manganese	0	0	2	2	100.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	1	2	1	75.0%	0.0%
		sulfate	0	1	2	1	75.0%	0.0%
a, b, e	4	acidity	0	4	0	0	0.0%	0.0%
		iron	0	3	1	0	25.0%	0.0%
		manganese	1	3	0	0	0.0%	25.0%
		aluminum	0	0	0	0	-	-
		flow	0	3	1	0	25.0%	0.0%
		sulfate	0	4	0	0	0.0%	0.0%
a, b, d	4	acidity	0	2	2	0	50.0%	0.0%
		iron	0	2	2	0	50.0%	0.0%
		manganese	0	1	2	0	66.7%	0.0%
		aluminum	0	1	2	0	66.7%	0.0%
		flow	0	2	2	0	50.0%	0.0%
		sulfate	0	4	0	0	0.0%	0.0%
a, b, c	37	acidity	0	20	10	6	44.4%	0.0%
		iron	2	22	4	9	35.1%	5.4%
		manganese	1	19	7	3	33.3%	3.3%
		aluminum	1	12	7	4	45.8%	4.2%
		flow	3	18	11	5	43.2%	8.1%
		sulfate	3	19	9	5	38.9%	8.3%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
c, e, f, j	2	acidity	0	0	1	1	100.0%	0.0%
		iron	0	1	0	1	50.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	0	0	2	100.0%	0.0%
		sulfate	0	0	0	2	100.0%	0.0%
c, d, e, f	1	acidity	0	0	0	0	-	-
		iron	0	0	1	0	100.0%	0.0%
		manganese	0	0	1	0	100.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%
b, c, d, e	5	acidity	0	5	0	0	0.0%	0.0%
		iron	0	4	0	1	20.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	3	0	2	40.0%	0.0%
		sulfate	0	2	1	2	60.0%	0.0%
a, c, i, k	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, b, i, k	2	acidity	0	0	2	0	100.0%	0.0%
		iron	0	1	0	1	50.0%	0.0%
		manganese	0	1	0	1	50.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	1	1	100.0%	0.0%
		sulfate	0	0	1	1	100.0%	0.0%
a, b, e, f	1	acidity	0	1	0	0	0.0%	0.0%
		iron	1	0	0	0	0.0%	100.0%
		manganese	1	0	0	0	0.0%	100.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
a, b, d, l	3	acidity	0	0	0	3	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	3	100.0%	0.0%
		aluminum	0	0	0	2	100.0%	0.0%
		flow	0	0	1	2	100.0%	0.0%
		sulfate	0	0	1	2	100.0%	0.0%
a, b, d, k	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	1	0	0	0.0%	0.0%
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, b, d, j	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	0	1	0	100.0%	0.0%
		manganese	0	0	1	0	100.0%	0.0%
		aluminum	0	0	0	0	-	-
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%
a, b, d, h	3	acidity	0	1	1	1	66.7%	0.0%
		iron	0	1	1	0	50.0%	0.0%
		manganese	0	2	0	0	0.0%	0.0%
		aluminum	0	1	1	0	50.0%	0.0%
		flow	0	3	0	0	0.0%	0.0%
		sulfate	0	3	0	0	0.0%	0.0%
a, b, d, f	1	acidity	0	1	0	0	0.0%	0.0%
		iron	0	1	0	0	0.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	1	0	0	0	0.0%	100.0%
		sulfate	0	1	0	0	0.0%	0.0%
a, b, c, l	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	0	-	-
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	1	100.0%	0.0%
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
a, b, c, k	1	acidity	0	0	0	1	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	0	0	1	100.0%	0.0%
		sulfate	0	0	0	1	100.0%	0.0%
a, b, c, j	1	acidity	0	0	0	1	100.0%	0.0%
		iron	1	0	0	0	0.0%	100.0%
		manganese	0	0	0	0	-	-
		aluminum	0	0	0	0	-	-
		flow	0	1	0	0	0.0%	0.0%
		sulfate	1	0	0	0	0.0%	100.0%
a, b, c, i	1	acidity	0	0	1	0	100.0%	0.0%
		iron	0	0	0	1	100.0%	0.0%
		manganese	0	0	0	1	100.0%	0.0%
		aluminum	0	0	0	1	100.0%	0.0%
		flow	0	0	1	0	100.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%
a, b, c, f	4	acidity	0	1	2	1	75.0%	0.0%
		iron	0	1	1	2	75.0%	0.0%
		manganese	0	1	1	1	66.7%	0.0%
		aluminum	0	1	0	0	0.0%	0.0%
		flow	0	3	0	1	25.0%	0.0%
		sulfate	0	3	0	1	25.0%	0.0%
a, b, c, e	14	acidity	0	8	3	2	38.5%	0.0%
		iron	0	8	2	2	33.3%	0.0%
		manganese	1	7	3	1	33.3%	8.3%
		aluminum	0	9	1	1	18.2%	0.0%
		flow	2	8	2	2	28.6%	14.3%
		sulfate	3	7	2	2	28.6%	21.4%
a, b, c, d	18	acidity	0	11	7	0	38.9%	0.0%
		iron	1	8	5	2	43.8%	6.3%
		manganese	0	4	4	1	55.6%	0.0%
		aluminum	1	9	2	0	16.7%	8.3%
		flow	3	10	5	0	27.8%	16.7%
		sulfate	5	9	4	0	22.2%	27.8%

BMP Group	Discharges Affected	Parameter	1	2	3	4	Improved or Eliminated %	Degraded %
a, b, c, e, j	3	acidity	0	2	1	0	33.3%	0.0%
		iron	0	2	0	1	33.3%	0.0%
		manganese	0	0	0	0	-	-
		aluminum	0	3	0	0	0.0%	0.0%
		flow	0	2	1	0	33.3%	0.0%
		sulfate	0	2	1	0	33.3%	0.0%
a, b, c, d, f	8	acidity	0	7	0	1	12.5%	0.0%
		iron	0	7	0	1	12.5%	0.0%
		manganese	0	7	0	1	12.5%	0.0%
		aluminum	0	7	0	1	12.5%	0.0%
		flow	0	6	1	1	25.0%	0.0%
		sulfate	0	7	0	1	12.5%	0.0%
a, b, c, d, e	12	acidity	0	8	2	2	33.3%	0.0%
		iron	0	4	2	3	55.6%	0.0%
		manganese	0	4	0	3	42.9%	0.0%
		aluminum	0	1	0	2	66.7%	0.0%
		flow	0	8	2	2	33.3%	0.0%
		sulfate	1	6	3	2	41.7%	8.3%
a, b, d, e, h, i	1	acidity	0	0	1	0	100.0%	0.0%
		iron	0	0	1	0	100.0%	0.0%
		manganese	0	1	0	0	0.0%	0.0%
		aluminum	0	0	1	0	100.0%	0.0%
		flow	0	1	0	0	0.0%	0.0%
		sulfate	0	0	1	0	100.0%	0.0%

6.3 Predicted Efficiencies

The ratings of BMP effects presented in Table 6.2b were used to predict the effects that individual BMPs would have on pollution loadings of acidity, iron, manganese, aluminum and sulfate and on flow rates of pre-existing discharges.

6.3.1 Statistical Approach

Because the effect of BMPs on pollutant loadings in each discharge were summarized using a rating on a four point scale (degraded, no difference, improved, eliminated), the effects of the various BMPs on discharges were assessed statistically using a logit-link logistic regression model (Agresti, 1990). This model is based on the assumption that the natural logarithm of the odds of an event (in this case, that a discharge at least improves) is linearly related to certain predictor variables (in this case, 10 to 12 BMP variables, each indicating whether a specific BMP affected a discharge). The model can be used to predict the odds of an event's occurrence (i.e. the odds of a BMP improving or eliminating a discharge pollution load). In this way, the model can be used to evaluate the effect of each BMP separately, and make predictions of the likelihood of a discharge pollution load improving or being eliminated for a given BMP.

A number of assumptions were made while applying this model in order to predict BMP effects and determine BMP efficiencies. These assumptions include:

- The number of discharges that were observed to be significantly degraded by BMPs or BMP groups was so low that these discharges could not be used for meaningful statistical analyses. For example, the occurrences of "significantly degraded" in regards to acidity and aluminum loading were infrequent (occurred with acidity in two out of 225 discharges and occurred with aluminum in four out of 117 discharges). This is illustrative of how successful remining and the use of appropriate BMPs can be when properly implemented.

- It was assumed that both elimination and improvement of discharge pollution loadings are measures of success and could be combined into a single rating (i.e., "at least improved").

- The ratings of "no significant difference" and "significantly degraded" were not combined. Rahall permits stipulate that pollution loadings in pre-existing discharges must at least maintain baseline levels.
- The ratings "significantly improved" and "eliminated" were combined and assessed against "no significant difference." Therefore, the prediction variable had two possible outcomes (no difference or at least improved) and a logit model for a binary outcome was used.
- Summary data for the effects of passive treatment were only available for one discharge for acidity, manganese or aluminum. Summary data for alkaline addition greater than 100 tons/acre were only available for one discharge for aluminum. Therefore, passive treatment was not assessed in regards to acidity, manganese or aluminum, and alkaline addition greater than 100 tons/acre was not assessed in regards to aluminum.
- All discharges or hydrologic units were treated independently regardless of hydrologic connection or proximity to other discharges. It is probable that ratings for multiple discharges within the same permit would correlate more highly with each other than discharges from different permits. However, due to the wide range in numbers of discharges per permit (from one to ten), and the two-category nature of the outcome variable, a reliable estimate of this correlation could not be made.

6.3.2 Statistical Results

Model prediction results for individual BMP efficiencies in regards to acidity, iron, manganese, aluminum, sulfate, and flow, are reported in Tables 6.3a through 6.3f. Tables 6.3e and 6.3f present sulfate loadings and flow rate, respectively. As previously stated, sulfate and flow typically are not regulated, but but can provide insight into the causes of BMP effectiveness or ineffectiveness. The prediction results are indicated as follows:

Probability: Out of 100 events, how frequently would discharges be improved with implementation of this BMP(s)

Ratio of Odds: What are the odds of improvement if the BMP(s) is implemented vs if the BMP(s) is not implemented (odds are the probability of at least improvement divided by the probability of no improvement). Due to the low number of discharges made significantly worse, this calculation does not include the possibility of degradation.

Odds Ratio for Interaction Terms: Compares odds when both BMPs are implemented to odds when only one of the two BMPs is implemented.

Intercept term: Estimated by separately assessing discharges both with and without each BMP, and extrapolating to the case where no BMPs are present. The intercept term estimates odds or probability of at least improvement when no BMPs are implemented.

6.3.2.1 *Individual BMPs*

The first column of Tables 6.3a through 6.3f identifies the BMP assessed, including the intercept term. The first row of this column reports the intercept term that was used to predict odds ratios and probabilities, and reports the predicted probability of at least improvement given the situation where no BMPs are implemented. Because no discharges existed that were not affected by at least one BMP, the intercept was estimated by assessing the effect of the presence of each BMP individually and extrapolating to the case where all those effects are absent.

The second column (Probability of at Least Improvement) of Tables 6.3a through 6.3f gives the model-predicted percentage of discharges that would be improved or eliminated in all discharges affected by that BMP. Since no data for discharges getting significantly worse were used, the percentages should be interpreted as the predicted percentage of discharges that would at least improve, as compared to those that would remain unchanged. The third column (Ratio of Odds) lists the ratio of odds of at least improvement where the given BMP is used with or without other BMPs compared with the odds of at least improvement where the BMP is not used. For example, a ratio of 2.0 indicates that the odds of at least improvement are two times higher when the BMP is used. Column 4 lists the number of discharges (n) that were affected by the particular BMP in regards to the parameter being assessed (i.e., acidity, iron, manganese, aluminum, sulfate, or flow).

Statistical Significance

Because some BMPs affected a small number of discharges, the odds ratios were reviewed for statistical significance. Column 5 lists the p-values calculated from the Wald Chi-square test for the statistical significance of odds ratios (i.e., that the corresponding odds ratio in Column 3 was significantly different from 1.0) tested at the 95 percent significance level (i.e., $\alpha = 0.05$) (Agresti, 1990). The value of α denotes the probability of a false positive, or the probability (based on the Wald test) that the model would determine that a BMP will have a significant effect on the odds of at least improvement, when in actuality the BMP does not have an effect. An odds ratio (from Column 3) significantly greater than one is an indication that inclusion of that BMP would significantly increase the odds of improvement. An odds ratio significantly less than one is an indication that inclusion of that BMP would significantly decrease the odds of improvement.

The p-values reported in Column 5 give the probability of observing (in a similar data set) an odds ratio equal to or greater than that in Column 3, if in truth that BMP does not have an effect on the odds of at least improvement. If the odds ratio in Column 3 is less than 1.0, the p-value gives the probability of observing an odds ratio equal to or less than the predicted odds ratio in Column 3. If the calculated p-value is less than the designated α (0.05), it can be concluded that the BMP has a significant effect on the odds of at least improvement at $\alpha = 0.05$. In other words, the α level of 0.05 indicates that with 95 percent confidence, the BMP has an effect on the discharge. For example, the calculated odds ratio for mining of high alkaline strata in regards to sulfate loading is 5.081 (based on 13 discharges that were affected). This means that, with 95 percent confidence, the odds of at least improvement are greater than 1.0 when mining of high alkaline strata is applied. This is an indication that the mining of high alkaline strata appears to have a significant positive effect on the chances of a discharge improving in regards to sulfate.

The last rows of Tables 6.3a through 6.3f (except for Table 6.3d) list significant interaction terms. These interaction terms state that the combined effect of the two BMPs is different from what would be expected given the sum of the predicted effects for those BMPs individually. For example, the significant interaction between special handling and water handling for acidity (Table 6.3a) shows that the odds of discharges at least improving are significantly less than would be expected given the combined positive effects of the two separate BMPs. Two odds ratios are listed for interaction terms in this table. Each term gives the odds ratio comparing the odds when both BMPs are present compared to the odds when only one of the two BMPs is present.

The presence of a significant interaction term alters the interpretation of the two BMP included in that interaction. For example, because there is a significant interaction between special handling and water handling for acidity (Table 6.3a), the odds ratio of 4.013 for water handling holds for all cases when water handling is implemented except when combined with special handling. Likewise, the odds ratio of 0.755 for special handling holds for all cases when special handling is implemented except when combined with water handling. In addition, the odds of at least improvement are 0.186 times higher (5.38 times lower) when water handling is used in conjunction with a BMP group that includes mining of high-alkaline strata than when a BMP group that includes special handling is used without water handling. Because the odds ratio for a BMP present in a significant interaction does not apply in situations when the second BMP of the interaction is present, the test for significant interactions cannot lead to the conclusion that the BMP is significant in all cases, merely that it is significant when the second BMP is not present.

Table 6.3a: PA Remining Study - Predicted Odds of Acidity Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=0.05)
None (Intercept term)	37.3	1.00	----	----
Regrading	34.7	0.893	154	0.783
Revegetation	50.1	1.684	174	0.279 *
Daylighting	37.1	0.991	164	0.981
Special Handling	31.0	0.755	78	0.387 *
Alkaline Addition <100 tons/acre	25.4	0.570	65	0.098
Water Handling	71.4	4.182	22	0.040 *
Passive Treatment	Passive treatment affected only 1 discharge / discharge was unchanged			
Coal Refuse Removal	57.6	2.283	9	0.285
Biosolids Addition	71.5	4.216	6	0.215
Mining of Alk. Strata	64.2	3.005	12	0.098 *
Alkaline Addition >100 tons/acre	56.6	2.190	11	0.312
Alkaline Redistribution	80.9	7.127	6	0.083
[1]Special Handling/ Water Handling	7.7	vs. Spec. Hand.: 0.186 vs. Water Hand.: 0.020	9	0.018

* Assessment of significance not meaningful due to presence in significant interaction term

Interaction terms: [1] Combined effect is less than expected from combining single effects

2 discharges got worse: These discharges were not used in statistical assessments of improvement or elimination of acidity. No predictions regarding discharges getting worse were made.

Discharge	BMPs Affecting Discharge
1	Daylighting, Special Handling
2	Regrading, Special Handling, Alkaline Addition >100 tons/acre

Table 6.3b: PA Remining Study - Predicted Odds of Iron Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=0.05)
None (Intercept term)	40.3	1.00	----	----
Regrading	36.0	0.831	137	0.657
Revegetation	51.3	1.559	158	0.359
Daylighting	37.7	0.896	156	0.775
Special Handling	42.1	1.075	70	0.833 *
Alk. Add.<100 tons/ac.	32.2	0.703	60	0.311
Water Handling	73.1	4.013	23	0.049 *
Passive Treatment	42.6	1.010	2	0.947
Coal Refuse Removal	26.2	0.525	7	0.492
Biosolids Addition	62.9	2.504	6	0.348
Mining of Alk. Strata	49.7	1.463	13	0.590
Alk. Add. >100 tons/ac	48.6	1.400	11	0.649
Alkaline Redistribution	61.3	2.340	3	0.505
[1]Special Handling/ Water Handling	18.3	vs. Spec. Hand.: 0.308 vs. Water Hand.:0.083	10	0.021

* Assessment of significance not meaningful due to presence in significant interaction term
Interaction terms: [1]Combined effect is less than expected from combining single effects

<u>11 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of iron. No predictions regarding discharges getting worse were made.

Discharge	BMPs Affecting Discharge
1	Revegetation
2	Daylighting, Special Handling
3-4	Daylighting, Special Handling, Mining of High Alkaline Strata
5	Regrading, Special Handling, Alkaline Addition >100 tons/acre
6	Regrading, Revegetation, Coal Refuse Removal
7-8	Regrading, Revegetation, Daylighting
9	Regrading, Revegetation, Alkaline Addition <100 tons/acre, Water Handling
10	Regrading, Revegetation, Daylighting, Mining of High Alkaline Strata
11	Regrading, Revegetation, Daylighting, Special Handling

Table 6.3c: PA Study - Predicted Odds of Manganese Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=.05)
None (Intercept term)	54.0	1.00	----	----
Regrading	50.0	0.850	111	0.717 *
Revegetation	44.6	0.685	127	0.493
Daylighting	55.1	1.043	108	0.923 *
Special Handling	60.3	1.290	51	0.534
Alk. Add.<100 ton/ac	42.3	0.624	39	0.250
Water Handling	90.4	8.010	19	0.024
Passive Treatment	Passive treatment affected only 1 discharge/discharge was eliminated			
Coal Refuse Removal	2.8	0.024	6	0.047
Biosolids Addition	96.1	21.150	5	0.060
Mining of Alk. Strata	68.8	1.877	4	0.551
Alk.Add>100ton/ac	6.2	0.056	6	0.098
Alkaline Redistribution	92.6	10.597	4	0.130
[1]Special Handling/ Water Handling	39.5	vs. Special Handling: 0.43 vs. Water Handling: 0.069	9	0.016

* Assessment of significance not meaningful due to presence in significant interaction term

Interaction terms: [1]Combined effect is less than expected from combining single effects

14 discharges got worse: These discharges were not used in statistical assessments of improvement or elimination of manganese. No predictions regarding discharges getting worse were made.

Discharges	BMPs Affecting Discharge
1	Daylighting
2	Regrading
3	Daylighting, Special Handling
4, 5	Regrading, Revegetation
6	Daylighting, Special Handling, Alkaline Addition >100 tons/acre
7	Revegetation, Daylighting, Water Handling
8	Revegetation, Daylighting, Alkaline Addition <100 tons/acre
9	Regrading, Special Handling, Alkaline Addition >100 tons/acre
10	Regrading, Revegetation, Coal Refuse Removal
11	Regrading, Revegetation, Alkaline Addition <100 tons/acre
12	Regrading, Revegetation, Daylighting
13	Regrading, Revegetation, Alkaline Addition <100 tons/acre, Water Handling
14	Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre

Table 6.3d: PA Remining Study - Predicted Odds of Aluminum Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=0.05)
None (Intercept term)	59.1	1.00	----	----
Regrading	61.2	1.094	84	0.862
Revegetation	55.0	0.847	98	0.784
Daylighting	43.0	0.522	92	0.198
Special Handling	47.5	0.625	38	0.278
Alkaline Addition <100 tons/acre	49.9	0.690	26	0.446
Water Handling	59.5	1.017	11	0.980
Passive Treatment	Passive treatment affected only 1 discharge/discharge was unchanged			
Coal Refuse Removal	34.0	0.356	6	0.257
Biosolids Addition	96.4	18.587	3	0.074
Mining of Alk. Strata	26.1	0.245	3	0.372
Alkaline Addition >100 tons/acre	Alkaline addition >100 affected only 1 discharge/discharge was unchanged			
Alkaline Redistribution	93.3	9.711	3	0.139

<u>4 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of aluminum. No predictions regarding discharges getting worse were made.

Discharges	BMPs Affecting Discharge
1	Daylighting
2	Revegetation, Daylighting
3	Regrading, Revegetation, Daylighting
4	Regrading, Revegetation, Daylighting, Special Handling

Table 6.3e: PA Remining Study - Predicted Odds of Sulfate Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=0.05)
None (Intercept term)	27.1	1.00	----	----
Regrading	12.3	0.377	155	0.030
Revegetation	75.1	8.113	176	0.002 *
Daylighting	24.1	0.852	169	0.678
Special Handling	10.8	0.326	80	0.010 *
Alk. Add.<100 tons/ac	38.9	1.708	67	0.457 *
Water Handling	31.8	1.251	23	0.660
Passive Treatment	17.9	0.585	2	0.716
Coal Refuse Removal	9.0	0.267	9	0.167
Biosolids Addition	76.0	8.492	6	0.106
Mining of Alk. Strata	65.4	5.081	13	0.022
Alk. Add.>100 tons/ac	37.0	1.579	11	0.599
Alkaline Redistribution	80.1	10.794	6	0.041
[1] Revegetation/ Alk. Add.<100 tons/ac	44.8	vs. Revegetation: 0.269 vs. Alk. Add.: 1.277	45	0.029
[2]Special Handling/ Alk. Add.<100 tons/ac	63.4	vs. Spec. Hand.: 14.275 vs. Alk. Add.: 2.721	26	0.004

* Assessment of significance not meaningful due to presence in significant interaction term.

Interaction terms: [1]Combined effect is less than expected from combining single effects.
[2]Combined effect is more than expected from combining single effects .

<u>24 discharges got worse</u>: These discharges were not used in statistical assessments of improvement or elimination of sulfate. No predictions regarding discharges getting worse were made.

Discharges	BMPs Affecting Discharge
1, 2	Daylighting
3, 4, 5	Daylighting, Special Handling
6, 7	Daylighting, Special Handling, Alkaline Addition <100 tons/acre
8	Revegetation
9	Revegetation, Daylighting, Water Handling
10	Regrading, Revegetation
11	Regrading, Revegetation, Special Handling, Alkaline Addition >100 tons/acre
12-14	Regrading, Revegetation, Daylighting
15	Regrading, Revegetation, Daylighting, Mining of High Alkaline Strata
16-18	Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre
19-23	Regrading, Revegetation, Daylighting, Special Handling
24	Regrading, Revegetation, Daylighting, Special Handling, Alk. Add. < 100 tons/acre

Table 6.3f: PA Remining Study - Predicted Odds of Flow Improvement or Elimination

BMP or BMP Group	Probability of at Least Improvement	Ratio of Odds with BMP(s) vs. Odds without BMP(s)	Discharges Affected (n)	p-value of Wald test (at α=.05)
None (Intercept term)	19.5	1.00	----	----
Regrading	16.4	0.807	156	0.621
Revegetation	66.0	8.009	177	0.005 *
Daylighting	13.3	0.631	170	0.212
Special Handling	12.7	0.601	80	0.121
Alk.Add.<100 ton/ac	52.3	4.529	67	0.054 *
Water Handling	21.3	1.118	23	0.827
Passive Treatment	14.9	0.721	2	0.821
Coal Refuse Removal	1.4	0.061	9	0.025
Biosolids Addition	80.4	16.897	6	0.072
Mining of Alk. Strata	88.7	32.367	13	0.002 *
Alkaline Addition >100 tons/acre	30.4	1.798	11	0.489
Alk. Redistribution	66.3	8.109	6	0.082 *
[1]Revegetation/ Alk.Add.100tons/ac	50.7	vs. Revegetation: 0.529 vs. Alk. Addition: 0.935	45	0.014
[1] Revegetation/ Mining of Alk. Strata	65.8	vs. Revegetation: 0.989 vs. Mining Alk.Strata: 0.245	12	0.019

* Assessment of significance not meaningful due to presence in significant interaction term.
Interaction terms: [1]Combined effect is less than expected from combining single effects.
13 discharges got worse: These discharges were not used in statistical assessments of improvement or elimination of sulfate. No predictions regarding discharges getting worse were made.

Discharges	BMPs Affecting Discharge
1	Daylighting, Alkaline Addition < 100 tons/acre
2	Daylighting, Special Handling
3	Revegetation, Daylighting, Water Handling
4	Regrading, Special Handling, Alkaline Addition > 100 tons/acre
5	Regrading, Revegetation, Special Handling, Water Handling
6, 7, 8	Regrading, Revegetation, Daylighting
9, 10	Regrading, Revegetation, Daylighting, Alkaline Addition <100 tons/acre
11-13	Regrading, Revegetation, Daylighting, Special Handling

6.3.2.2 *BMP Combinations*

Selection of BMP combinations that are regularly employed during remining operations allows for a true determination of the efficiencies, rather than projected efficiencies for BMP combinations not presently occurring in the real world. BMP groups were selected for evaluation based on the observed implementation of the combinations in the Pennsylvania Remining Study. A secondary BMP group selection criterion was that each group affected a minimum of four discharges that were not significantly degraded. With under four discharges impacted by a BMP combination, the data subset is too small to allow credible conclusions and predictions based on the results. This selection of BMP combinations affecting four or more discharges allows study of the most frequently used combinations, by default.

The BMP groups of: (1) regrading and revegetation, (2) daylighting, and (3) regrading, revegetation, and daylighting were employed as control (reference) groups for comparison with groups containing additional BMPs. These three reference groups were selected for control because they are implemented as part of remining and occur as stand-alone BMPs. An operation would not be considered to be a remining operation unless one or more of these BMPs is conducted or coal refuse reprocessing is performed. These three BMP reference groups are directly related to the re-affecting of previously mined areas, because regrading and revegetation are used at abandoned surface-mined lands and daylighting is used for abandoned underground mines. Coal refuse reprocessing is seldom conducted (affected 9 out of 231 total discharges in the data set) and therefore was excluded as a control BMP.

This BMP group selection precluded the determination of potential efficacy of some BMP groups that, based on experience, may be highly successful in reducing pollution loads. Some BMPs, including mining into alkaline strata and alkaline addition (>100 tons per acre), are used infrequently, but have been shown to be quite successful when implemented.

The observed results were used to compare the three reference groupings to the selected BMP combinations. Performances of selected BMP combinations were compared to BMP reference groups using the observed study results (number of discharges eliminated, improved or unchanged) presented in Table 6.2b. This comparison provides an indication of relative observed performance, and does not necessarily predict BMP group efficiencies. Each reference group was compared to only those BMP groups that included the reference group (although groups did not need to include revegetation when compared to the reference group containing regrading and revegetation). Again, only those BMP groups that affected at least four non-degraded discharges were used in the calculation.

Observed Percent Improved: For each group, the percent of discharges that at least improved was determined by dividing the number of discharges that were improved or eliminated, by the number that were improved, eliminated, or did not significantly change (significantly degraded discharges were not included in the calculations because of their small number) and multiplying by 100.

Observed Odds of Improvement: For each group, the odds of at least improvement were calculated as the number of improved or eliminated discharges affected, divided by the number of discharges that did not significantly change.

Observed Odds Ratio Compared to Reference: The odds ratio for a given group represents the odds of at least improvement for that group, divided by the odds of at least improvement for the reference group.

Percent Improved minus Reference Percent Improved: The last column in Tables 6.3g through 6.3x gives the difference between the percentage of discharges affected by the BMP group that at least improved minus the percentage of discharges at least improved by the reference group.

For example, in Table 6.3m, Daylighting (reference group) improved or eliminated acidity loading in four discharges, and did not change acidity loading in nine other discharges. Therefore, the observed percentage of discharges that at least improved is 4/13 x 100 = 30.8 percent, and the observed odds of at least improvement is 4/9 = 0.444. The group of Daylighting and Alkaline Addition <100 tons/acre affected four discharges that were improved or eliminated, and affected 8 discharges that did not significantly change. Therefore, the observed percentage of discharges that at least improved is 4/12 x 100 = 33.3 percent, and the observed odds of at least improvement was 4/8 = 0.500. The odds ratio comparing Daylighting and Alkaline Addition <100 tons/acre to the reference group (Daylighting) is 0.500/0.444 = 1.125. According to the observed data, the odds of at least improvement is 1.125 times higher when Daylighting and Alkaline Addition <100 tons/acre were used compared to when Daylighting was used alone.

For some BMP groups (i.e., Regrading, Revegetation, and Water Handling for acidity and iron), all discharges affected were improved or eliminated. This yields infinite odds, since the number of discharges improved or eliminated is divided by 0. Therefore, an odds ratio cannot be calculated for these groups.

Table 6.3g: Analysis of Discrete Groups based on Observed Acidity Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	18	9	9	50.0	---	---
Regrading, Revegetation, Daylighting	36	16	20	44.4	0.800	-5.6
Regrading, Revegetation, Special Handling	4	2	2	50.0	1.000	0.0
Regrading, Revegetation, Alkaline Addition <100	4	0	4	0.0	0.0	-50.0
Regrading, Revegetation, Water Handling	4	4	0	100.0	∞ *	50.0
Regrading, Revegetation, Daylighting, Special Handling	18	7	11	38.9	0.636	-11.1
Regrading, Revegetation, Daylighting, Alkaline Addition <100	13	5	8	38.5	0.625	-11.5
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	0.500	-16.7
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.143	-37.5

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 4 divided by 0. Therefore, the odds ratio is infinite.

Table 6.3h: Analysis of Discrete Groups based on Observed Iron Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	12	6	6	50.0	---	---
Regrading, Revegetation, Daylighting	37	13	22	37.1	0.591	-12.9
Regrading, Revegetation, Special Handling	4	2	2	50.0	1.000	0.0
Regrading, Revegetation, Alkaline Addition <100	4	1	3	25.0	0.333	-25.0
Regrading, Revegetation, Water Handling	4	4	0	100.0	∞ *	50.0
Regrading, Revegetation, Daylighting, Special Handling	16	7	8	46.7	0.875	3.3
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	8	33.3	0.500	-16.7
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	9	5	4	55.6	1.250	5.6
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.143	-37.5

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 5 divided by 0. Therefore, the odds ratio is infinite.

Table 6.3i: Analysis of Discrete Groups based on Observed Manganese Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	11	5	4	55.6	---	---
Regrading, Revegetation, Daylighting	30	10	19	34.5	0.421	-21.1
Regrading, Revegetation, Alkaline Addition <100	4	0	3	0.0	0.0	-55.6
Regrading, Revegetation, Water Handling	4	4	0	100.0	∞ *	44.4
Regrading, Revegetation, Daylighting, Special Handling	9	5	4	55.6	1.000	-0.0
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	7	36.4	0.457	-19.2
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	7	3	4	42.9	0.600	-12.7
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.114	-43.1

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 5 divided by 0. Therefore, the odds ratio is infinite.

Table 6.3j: Analysis of Discrete Groups based on Observed Aluminum Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	6	3	3	50.0	---	---
Regrading, Revegetation, Daylighting	24	11	12	47.8	0.917	-2.2
Regrading, Revegetation, Daylighting, Special Handling	12	2	9	18.2	0.222	-31.8
Regrading, Revegetation, Daylighting, Alkaline Addition <100	11	2	9	18.2	0.222	-31.8
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.143	-37.5

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

Table 6.3k: Analysis of Discrete Groups based on Observed Sulfate Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	18	10	7	58.8	---	---
Regrading, Revegetation, Daylighting	36	14	19	42.4	0.516	-16.4
Regrading, Revegetation, Special Handling	4	0	4	0.0	0.000	-58.8
Regrading, Revegetation, Alkaline Addition <100	4	0	4	0.0	0.000	-58.8
Regrading, Revegetation, Water Handling	4	3	1	75.0	2.099	16.2
Regrading, Revegetation, Daylighting, Special Handling	18	4	9	30.8	0.311	-28.0
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	7	36.4	0.400	-22.4
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	5	6	45.5	0.583	-13.3
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.100	-46.3

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

Table 6.3l: Analysis of Discrete Groups based on Observed Flow Results Using Regrading and Revegetation as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation **(Reference)**	18	12	6	66.7	---	---
Regrading, Revegetation, Daylighting	37	16	18	47.1	0.444	-19.6
Regrading, Revegetation, Special Handling	4	2	2	50.0	0.500	-16.7
Regrading, Revegetation, Alkaline Addition <100	4	1	3	25.0	0.167	-41.7
Regrading, Revegetation, Water Handling	4	3	1	75.0	1.500	8.3
Regrading, Revegetation, Daylighting, Special Handling	18	5	10	33.3	0.250	-33.3
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	8	33.3	0.250	-33.3
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	0.250	-33.3
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	2	6	25.0	0.167	-41.7

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading & Revegetation) is implemented

Table 6.3m: Analysis of Discrete Groups based on Observed Acidity Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	13	4	9	30.8	---	---
Daylighting, Alkaline Addition <100	12	4	8	33.3	1.125	-2.5
Regrading, Revegetation, Daylighting	36	16	20	44.4	1.800	13.6
Daylighting, Special Handling, Alkaline Addition <100	5	2	3	40.0	1.500	9.2
Regrading, Revegetation, Daylighting, Special Handling	18	7	11	38.9	1.432	8.1
Regrading, Revegetation, Daylighting, Alkaline Addition <100	13	5	8	38.5	1.406	7.7
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	1.125	2.5
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.321	-18.3

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

* Because all discharges for this grouping were improved, the odds of improvement would be 4 divided by 0. Therefore, the odds ratio is infinite.

Table 6.3n: Analysis of Discrete Groups based on Observed Iron Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	12	7	5	58.3	---	---
Daylighting, Alkaline Addition <100	11	3	8	27.3	0.268	-31.0
Regrading, Revegetation, Daylighting	37	13	22	37.1	0.422	-21.2
Daylighting, Special Handling, Alkaline Addition <100	5	2	3	40.0	0.476	-18.3
Regrading, Revegetation, Daylighting, Special Handling	16	7	8	46.7	0.625	-11.6
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	8	33.3	0.357	-25.0
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	9	5	4	55.6	0.893	-2.7
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.102	-45.8

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

Table 6.3o: Analysis of Discrete Groups based on Observed Manganese Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	11	6	4	60.0	---	---
Regrading, Revegetation, Daylighting	30	10	19	34.5	0.351	-25.5
Daylighting, Special Handling, Alkaline Addition <100	5	2	3	40.0	0.444	-20.0
Regrading, Revegetation, Daylighting, Special Handling	9	5	4	55.6	0.833	-4.4
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	7	36.4	0.381	-23.6
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	7	3	4	42.9	0.500	-17.1
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.095	–47.5

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

Table 6.3p: Analysis of Discrete Groups based on Observed Aluminum Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	10	4	5	44.4	---	---
Regrading, Revegetation, Daylighting	24	11	12	47.8	1.146	3.4
Regrading, Revegetation, Daylighting, Special Handling	12	2	9	18.2	0.278	-26.2
Regrading, Revegetation, Daylighting, Alkaline Addition <100	11	2	9	18.2	0.278	-26.2
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.179	–31.9

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

Table 6.3q: Analysis of Discrete Groups based on Observed Sulfate Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	14	4	8	33.3	---	---
Daylighting, Alkaline Addition <100	12	3	9	25.0	0.666	-8.3
Regrading, Revegetation, Daylighting	36	14	19	42.4	0.516	9.1
Regrading, Revegetation, Daylighting, Special Handling	18	4	9	30.8	0.889	-2.5
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	7	36.4	1.143	3.1
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	5	6	45.5	1.667	12.2
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.286	-20.8

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

Table 6.3r: Analysis of Discrete Groups based on Observed Flow Results Using Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Daylighting **(Reference)**	14	2	12	14.3	---	---
Daylighting, Alkaline Addition <100	12	3	9	25.0	2.000	10.7
Regrading, Revegetation, Daylighting	37	16	18	47.1	5.333	32.8
Daylighting, Special Handling, Alkaline Addition <100	5	2	3	40.0	4.000	25.7
Regrading, Revegetation, Daylighting, Special Handling	18	5	10	33.3	3.000	19.0
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	8	33.3	3.000	19.0
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	3.000	19.0
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	2	6	25.0	2.000	10.7

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Daylighting) is implemented

Table 6.3s: Analysis of Discrete Groups based on Observed Acidity Results Using Regrading, Revegetation, and Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	36	16	20	44.4	—	---
Regrading, Revegetation, Daylighting, Special Handling	18	7	11	38.9	0.795	-5.5
Regrading, Revegetation, Daylighting, Alkaline Addition <100	13	5	8	38.5	0.781	-5.9
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	0.625	-11.1
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.179	-31.9

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

Table 6.3t: Analysis of Discrete Groups based on Observed Iron Results Using Regrading, Revegetation, and Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	37	13	22	37.1	---	---
Regrading, Revegetation, Daylighting, Special Handling	16	7	8	46.7	1.481	9.6
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	8	33.3	0.846	-3.8
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	9	5	4	55.6	2.115	18.5
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.242	-24.6

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

Table 6.3u: Analysis of Discrete Groups based on Observed Manganese Results Using Regrading, Revegetation and Daylighting as a Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	30	10	19	34.5	---	---
Regrading, Revegetation, Daylighting, Special Handling	9	5	4	55.6	2.376	21.1
Regrading, Revegetation, Daylighting, Alkaline Addition <100	12	4	7	36.4	1.086	1.9
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	7	3	4	42.9	1.426	8.4
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.272	-22.0

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

Table 6.3v: Analysis of Discrete Groups based on Observed Aluminum Results Using Regrading, Revegetation and Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	24	11	12	47.8	---	---
Regrading, Revegetation, Daylighting, Special Handling	12	2	9	18.2	0.242	-29.6
Regrading, Revegetation, Daylighting, Alkaline Addition <100	11	2	9	18.2	0.242	-29.6
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.156	-35.3

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

Table 6.3w: Analysis of Discrete Groups based on Observed Sulfate Results Using Regrading, Revegetation, and Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	36	14	19	42.4	---	---
Regrading, Revegetation, Daylighting, Special Handling	18	4	9	30.8	0.603	-11.6
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	7	36.4	0.775	-6.0
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	5	6	45.5	1.131	3.1
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	1	7	12.5	0.194	-29.9

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

Table 6.3x: Analysis of Discrete Groups based on Observed Flow Results Using Regrading, Revegetation, and Daylighting as Reference Group

BMP Group	Number of Discharges Affected	Number of Discharges Improved or Eliminated	Number of Discharges Unchanged	Observed Percent Improved	Observed Odds Ratio compared to Reference	Percent Improved minus Reference Percent Improved
Regrading, Revegetation, Daylighting **(Reference)**	37	16	18	47.1	---	---
Regrading, Revegetation, Daylighting, Special Handling	18	5	10	33.3	0.563	-13.8
Regrading, Revegetation, Daylighting, Alkaline Addition <100	14	4	8	33.3	0.563	-13.8
Regrading, Revegetation, Daylighting, Special Handling, Alkaline Addition <100	12	4	8	33.3	0.563	-13.8
Regrading, Revegetation, Daylighting, Special Handling, Water Handling	8	2	6	25.0	0.375	-22.1

Observed Percentage Improvement:	On a scale of 0-100, how frequently were discharges improved with implementation of this BMP grouping
Observed Odds of Improvement:	Number improved or eliminated divided by number with no significant difference
Ratio of Odds:	What are the odds of improvement if BMP grouping is implemented vs. if reference grouping (Regrading, Revegetation & Daylighting) is implemented

6.4 Discussion

6.4.1 Observed Results

The combinations of BMPs affecting the most discharges at the completed Pennsylvania remining sites in order of decreasing frequency of occurrence are as follows:

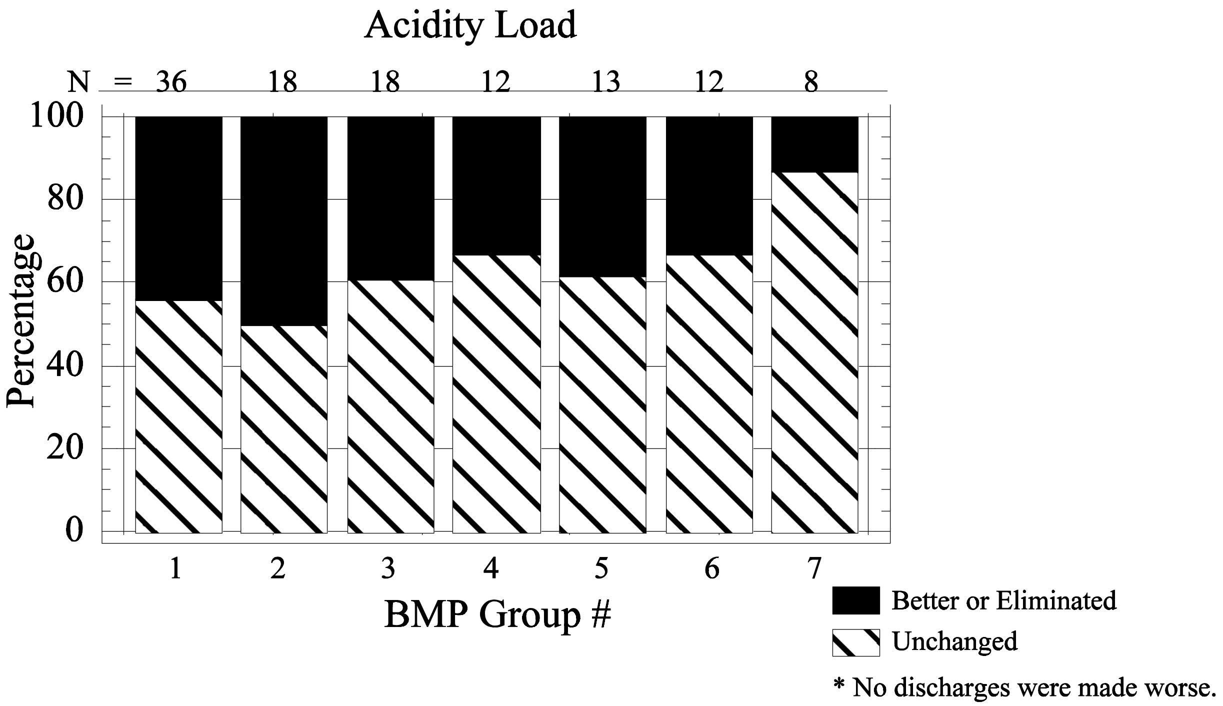
Group #		Discharges Affected
1	Daylighting, Regrading, Revegetation	37
2	Regrading, Revegetation	18
3	Daylighting, Regrading, Revegetation, Special Materials Handling	18
4	Daylighting, Regrading, Revegetation, Special Materials Handling, Alkaline Addition (<100 tons/acre)	12
5	Daylighting, Regrading, Revegetation, Alkaline Addition (<100 tons/acre)	14
6	Daylighting, Alkaline Addition (<100 tons $CaCO_3$ equivalent/acre)	12
7	Daylighting, Regrading, Revegetation, Special Materials Handling, Special Water Handling Facilities	8

Acidity Loading

Only three BMPs (regrading, revegetation, and daylighting) were reported to be used singly at the Pennsylvania study remining sites (Table 6.2b). Of these BMPs, only daylighting impacted acidity loading in a significant number of discharges (13). Daylighting alone significantly improved 30.8 percent of the discharges for acidity loading with no discharges significantly degraded. Revegetation used singly significantly improved acidity loading in 40 percent of 5 discharges affected with the remainder unchanged. Regrading used singly affected one discharge which was shown to be significantly improved. However, it is doubtful that regrading was used without corresponding revegetation.

The seven most common BMP groups (listed previously) were highly successful in not degrading the discharges in terms of acidity loadings. All of the discharges affected by these BMP groups were either significantly improved or unchanged (Figure 6.4a) with improvement ranging from 12.5 to 50 percent of the discharges depending on BMP group. No discharges were significantly degraded. The most successful BMP combination was regrading and revegetation (#2), followed by daylighting, regrading, and revegetation (#1), and daylighting, regrading, revegetation, and alkaline addition (#5). BMP group #2 significantly improved 50 percent of the discharges and had no significant effect on 50 percent of the discharges. Over 44 percent of the discharges were improved under BMP group #1 with the remainder unchanged. The success of these BMP combinations (#1 and #2) in decreasing acidity loading may be due to the fact that these BMP groups are generally used for remining operations that are environmentally uncomplicated and do not require elaborate BMP plans to effect improvement. Additionally, these BMPs greatly impact the amount of water moving through the reclaimed site and, to a lesser extent, affect the water quality. This may be an indication that flow-reducing BMPs may be more effective in reducing loads than those that work primarily geochemically. This determination is supported by Smith (1988) and Hawkins (1995) who both observed flow to be the predominant determinant of pollution loadings (see Section 1.2, Figure 2.1a).

Figure 6.4a: Impacts of BMP Combinations on Acidity Loading



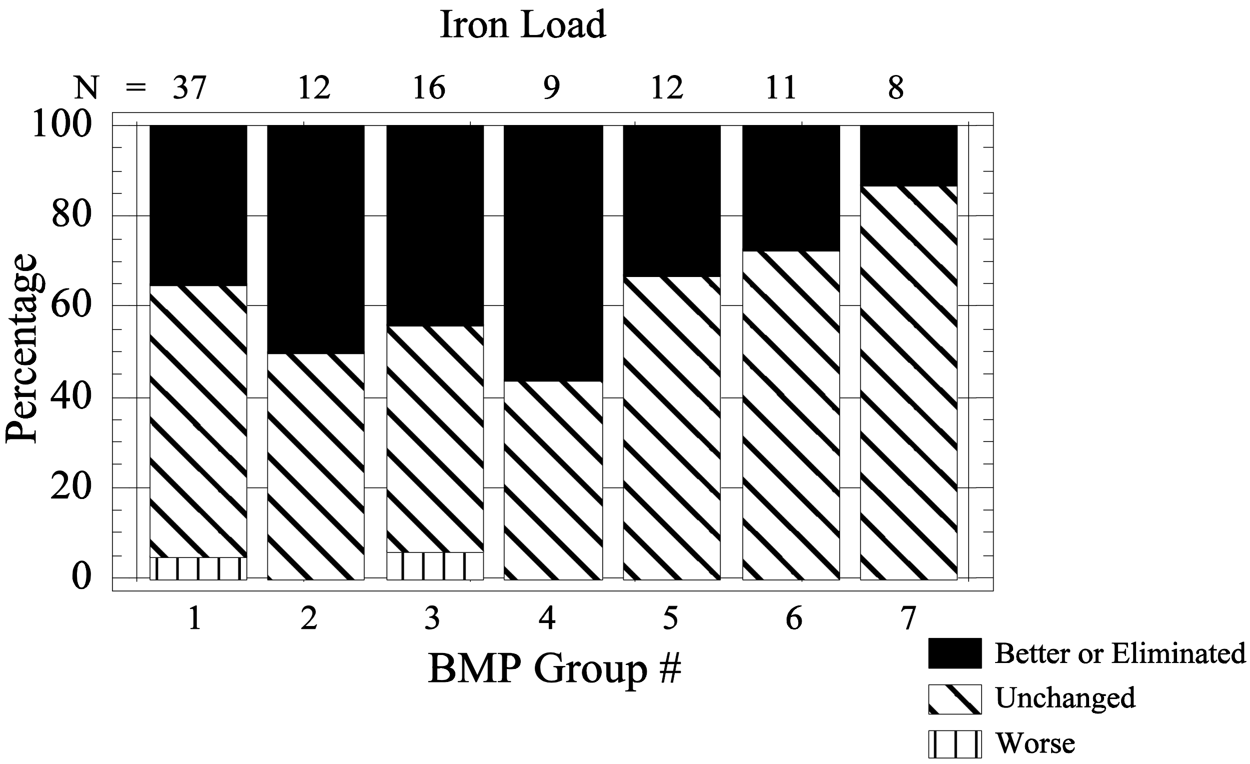
Iron Loading

As previously stated, only three BMPs (regrading, revegetation, and daylighting) were reported to be used singly at the Pennsylvania study remining sites and of these BMPs, only daylighting impacted a significant number of discharges (12) for iron loadings. Daylighting singly improved more than half (58 percent) of the discharges for iron loading and had no effect on the remaining 42 percent. No discharges were significantly degraded. Revegetation alone significantly improved 20 percent of discharges (1 discharge), significantly degraded 20 percent of the discharges and did not affect the remaining discharges. Regrading alone was shown to be used for one discharge which was unchanged. However, as previously stated, it is doubtful that regrading was used without corresponding revegetation.

The seven BMP combinations quite successfully left most of the discharges improved or unchanged in terms of the iron load. The two most successful BMP combinations for discharge iron load improvement were daylighting, regrading, revegetation, special materials handling, and alkaline addition (#4) which improved 55.6 percent of the discharges and regrading, revegetation, and alkaline addition (#8) which improved 50 percent of the discharges. The remaining discharges affected by those two BMP groups were unchanged. Implementation of two other BMP groups (daylighting, regrading, and revegetation, #1) and daylighting, regrading, revegetation and special materials handling, #3), resulted in a few discharges exhibiting higher iron loadings (failures). The failure rates were 5.4 and 6.7 percent, respectively. However, the actual number of degraded discharges for either BMP group was small, a total of 2. The impact of the seven BMP groups on iron loading rates is illustrated in Figure 6.4b.

The two BMP groups with the highest iron loading improvement rates (#4 and #2) included alkaline addition (<100 tons per acre), which may have raised the pH of the water enough to permit some of the iron to precipitate within the backfill. However, two other BMP groups with that level of alkaline addition (#5 and #6) did not exhibit similar rates of iron loading improvement. This situation can occur in cases where a large amount of acidic material is encountered during daylighting and naturally occurring alkaline material was not present in the overburden. The amount of alkaline addition may have been insufficient to offset the acidity production.

Figure 6.4b: Impacts of BMP Combinations on Iron Loading



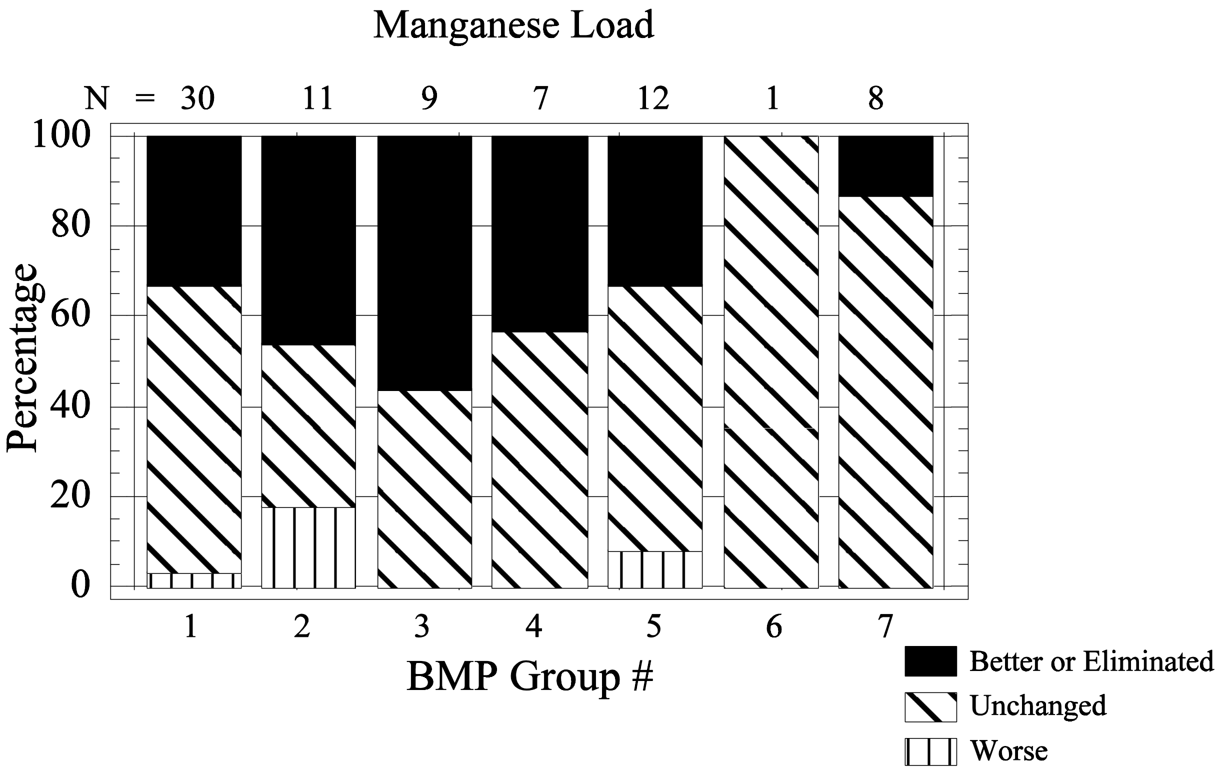
Manganese Loading

Of the three BMPs (regrading, revegetation, and daylighting) used singly at the Pennsylvania study remining sites, only daylighting impacted manganese loading in a significant number of discharges (11). Daylighting singly improved 54.5 percent of the discharges for manganese loading with 9.1 percent (one discharge) significantly degraded. Revegetation significantly improved one (20 percent) of five discharges and did not affect the remaining discharges. Implementation of regrading affected one discharge which was significantly degraded.

Two of the BMP groups induced some of the highest improvement rates observed for any of the contaminant loadings (see Figure 6.4c). The combinations of regrading and revegetation (#2) and daylighting, regrading, revegetation and special materials handling (#3) exhibited discharge improvement rates for manganese of 45.5 and 55.6 percent, respectively. It is difficult to determine what may have allowed these two BMP combinations to be so effective. Manganese concentrations are extremely difficult to predict. Exactly where manganese originates is unclear. However, the main source of manganese appears to be as a solid-solution replacement of iron in siderite ($FeCO_3$) (Rose and Cravotta, 1998). The actual amount of manganese replacement is quite low (~1 percent) (Rose, 1999). Ongoing research may improve the predictive capabilities.

The highest rates of discharge degradation (failure) for the seven BMP groups were exhibited for manganese loadings. Three of seven BMP combinations had at least one discharge that was degraded with respect to manganese loadings. BMP groups regrading and revegetation (#2) and regrading, revegetation, daylighting, and alkaline addition (#5) exhibited the highest failure rates of 18.2 and 8.3 percent, respectively. It is interesting to note that the highest discharge failure rate for manganese loading occurred with BMP group #2, which also had the second highest manganese loading improvement rate. This illustrates the problematic nature of manganese effluent predictions.

Figure 6.4c: Impacts of BMP Combinations on Manganese Loading

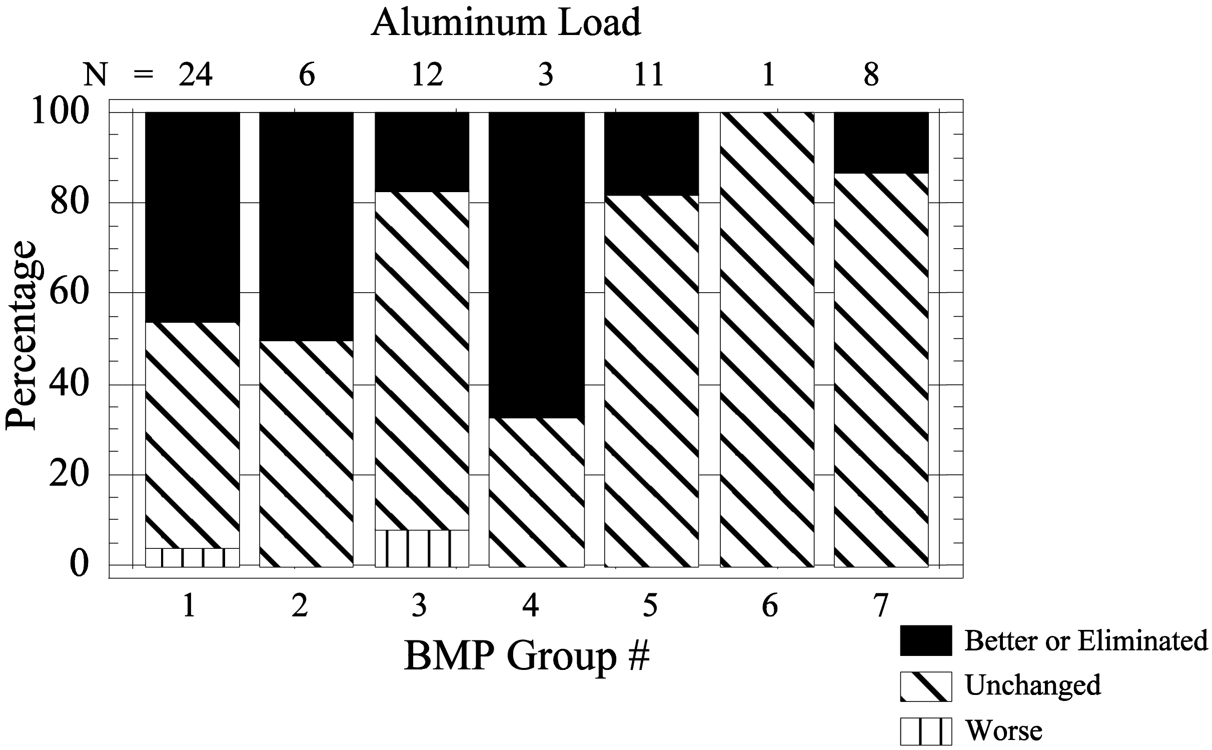


Aluminum Loading

Of the three BMPs (regrading, revegetation, and daylighting) reported to be used singly at the Pennsylvania study remining permits, only daylighting impacted a significant number of discharges (10) for aluminum loadings. Daylighting implemented alone significantly improved 40 percent of the affected discharges for aluminum loading and significantly degraded 10 percent (one discharge). Revegetation significantly improved 60 percent of the five affected discharges and had no effect on the remaining two discharges. Regrading implemented alone affected one discharge which was shown to be significantly improved.

The most successful BMP group in improving the aluminum loads was daylighting, regrading, revegetation, special materials handling, and alkaline addition (#4) with 66.7 percent of the discharges exhibiting significant improvement. This was the highest improvement rate exhibited by any of the BMP groups for any of the contaminants, although this group affected only three discharges in terms of aluminum loading. BMP groups of daylighting, regrading, and revegetation (#1) and regrading and revegetation (#2) were the next most successful in improving the aluminum loadings with 45.8 and 50 percent improvement, respectively.

Figure 6.4d: Impacts of BMP Combinations on Aluminum Loading

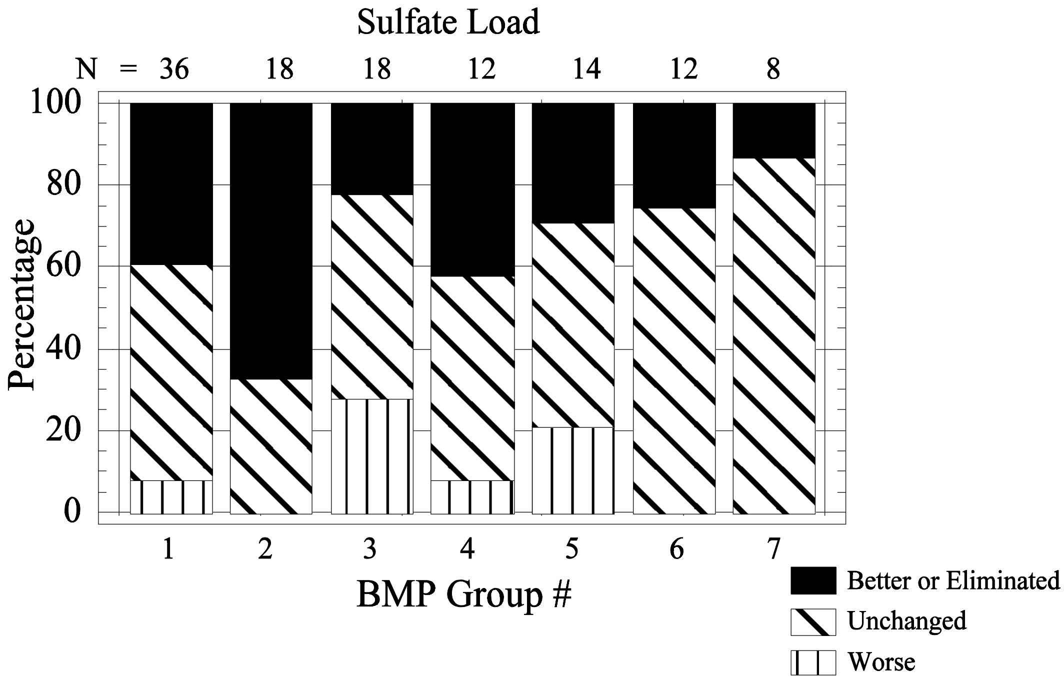


Sulfate Loading

As previously stated, sulfate loading is not a regulated effluent parameter, but is included herein to permit a clearer analysis of the effectiveness of BMPs to geochemically reduce the acidity, iron, manganese, and aluminum loadings. Of the three BMPs (regrading, revegetation, and daylighting) reported to be used singly at the Pennsylvania study remining sites, only daylighting impacted sulfate loading in a significant number of discharges (14). Daylighting singly improved 28.6 percent of the discharges for sulfate loading with 14.3 percent (two discharges) significantly degraded. Revegetation significantly improved three (60 percent) of five discharges, did not affect one discharge, and significantly degraded one discharge. Implementation of regrading affected one discharge which was improved.

The most successful BMP group in improving sulfate loading was regrading and revegetation (#2) with 55.6 percent. The next two most successful BMP combinations were daylighting, regrading, revegetation, special materials handling, alkaline addition < 100 tons/acre (#4) and daylighting, regrading, and revegetation (#1) exhibiting improvements of 41.7 and 38.9 percent, respectively. The presence of regrading and revegetation in the three most successful groups indicates that simply reclaiming an abandoned site may greatly decrease acid production.

Figure 6.4e: Impacts of BMP Combinations on Sulfate Loading

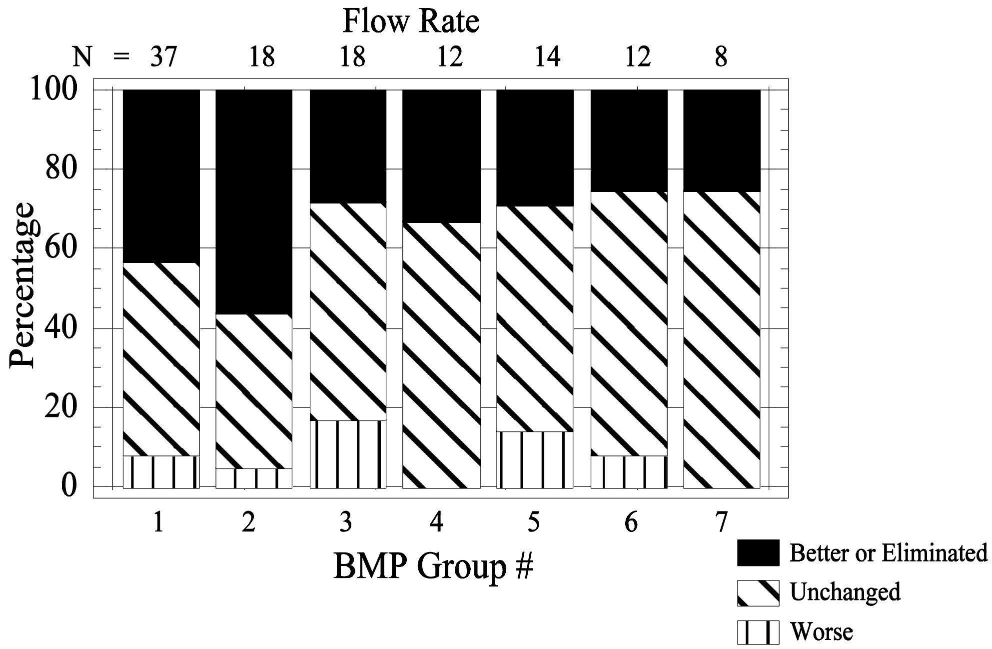


Flow Rate

As previously stated, flow rate is not a regulated effluent parameter, but is included herein to permit a clearer analysis of the effectiveness of BMPs that work to physically reduce the pollution loadings. Of the three BMPs (regrading, revegetation, and daylighting) used singly at the Pennsylvania study remining sites, only daylighting impacted flow rate in a significant number of discharges (14). Daylighting singly improved (decreased or eliminated flow) 28.6 percent of the discharges, with none of the discharges significantly increasing in flow. Revegetation significantly improved three (60 percent) of five discharges and effected no change of the remaining discharges. Implementation of regrading affected one discharge which was unchanged.

The most successful BMP group in improving flow rate was regrading and revegetation (#2) with 66.7 percent, followed by daylighting, regrading, and revegetation (#1) and daylighting, regrading, revegetation, special materials handling, alkaline addition < 100 tons/acre (#4) exhibiting improvements of 43.2 and 33.3 percent, respectively. As with sulfate, the presence of regrading and revegetation in both these groups, indicates that simply reclaiming a site will reduce infiltration into the spoil, which ultimately reduces the outflow.

Figure 6.4f: Impacts of BMP Combinations on Flow Rate



6.4.2 Predicted Results

The data obtained from the Pennsylvania study remining sites were statistically analyzed using the methodology described in Section 6.3.1. These analyses, applied to single BMPs, determined the predicted percentage of discharges that would be improved, the odds that a discharge would be improved, and the odds of improvement over doing nothing at all in terms of BMPs. The results of these analyses are listed in Tables 6.3a through 6.3d (BMPs implemented alone). Tables 6.3e and 6.3f are the same analyses conducted for sulfate loadings and flow rate to allow for an in depth determination of the possible impacts (physical or geochemical) of specific BMPs and BMP combinations.

6.4.2.1 *BMPs Implemented Alone*

Acidity Loading

The predicted probabilities of improvement for all of the single-use BMPs (Revegetation, Regrading, and Daylighting) range from 27.4 to 50.1 percent. The remaining BMPs were not implemented alone, and therefore, do not have associated observed results. However, the statistical analyses can provide some insight into their efficiency. Alkaline redistribution (80.9 percent) and biosolids addition (71.5 percent) exhibit the highest predicted probabilities of improvement of acidity loading of all of the BMPs followed by special water handling (71.4 percent), mining alkaline strata (64.2 percent) and coal refuse removal (57.6 percent). It is interesting to note that alkaline addition of <100 tons per acre yielded the lowest predicted improvement probability of 25.4 percent, while half of the four highest predicted percentages also deal with increasing the amount of alkaline material in the backfill. The results may indicate that the amount of alkaline material added (<100 tons per acre) was too low. Brady and others (1990) observed that alkaline addition application rates at surface mines frequently are too low to improve the water quality.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see Table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 11 percent of the time (one out of nine discharges). However, when water handling but not special handling affect a discharge, the result is at least improvement 77 percent (10 out of 13 discharges) of the time. It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs. Eight of the nine discharges affected by both water handling and special handling were affected additionally by regrading, revegetation and daylighting. The failure of special handling may be because it is frequently employed where a substantial amount of acid-forming materials is present, perhaps too much to be offset by any single BMP or group of BMPs.

Iron Loading

Predicted probabilities of improvement in iron loading for all of the single-use BMPs range from 36.0 to 51.3 percent. Special water handling facilities (73.1 percent) and biosolids addition (62.9 percent) exhibit the highest predicted improvement percentages followed by alkaline redistribution (61.3 percent), revegetation (51.3 percent), and mining of alkaline strata (49.7 percent). The lowest predicted probability of improvement is coal refuse removal (26.2 percent). The relatively low number of discharges affected (7) may bring into question the usefulness of this prediction value. In addition, the low predicted discharge improvement may be due to a delayed response in regards to water quality, compared with other BMPs. Refuse is typically acid-producing and when removed, fresh refuse is exposed to weathering or flushing of existing weathered products. It may take more time than the limited monitoring periods available to see improvements in some water quality parameters.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 20 percent (2 out of 10 discharges) of the time. However, when water handling but not special handling affect a discharge, the result is at least improvement 75 percent (9 out of 12 discharges). It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs. Eight of the ten discharges affected by both water handling and special handling were also affected by regrading, revegetation and daylighting.

Manganese Loading

Predicted probabilities of discharge improvement for single-use BMPs range from 44.6 to 54.0 percent. Alkaline material redistribution (92.6 percent) and biosolids application (96.1 percent) exhibit the highest predicted improvement, followed by water handling (90.4 percent), mining alkaline strata (68.8 percent) and special handling (60.3 percent). The lowest probabilities of improvement were predicted for coal refuse removal (2.8 percent) and alkaline addition >100 tons per acre (6.2 percent). However, these BMPs each affected 6 discharges and the strength of the prediction is weak. In addition, an improvement in manganese loading in discharges affected by coal refuse removal may be delayed as explained in regards to iron loading.

The significant interaction between special handling and water handling indicates that the positive effect of water handling on the odds of at least improvement is greatly diminished when special handling is also present. This can be best explained by comparing the observed results for water handling with and without special handling (see table 6.2b). When water handling and special handling both affect a discharge, the result is at least improvement 22 percent (2 out of 9 discharges) of the time. However, when water handling but not special handling affect a discharge, the result is at least improvement 88 percent (7 out of 8 discharges) of the time. It is worth noting that these two BMPs never affect a discharge without being combined with other BMPs.

Aluminum Loading

The number of discharges (117) analyzed for aluminum loading is considerably lower than for any of the other contaminants. Therefore, the results of the statistical analyses are much less definitive. The predicted probabilities of improvement for single-use BMPs ranges from 43.0 to 61.2 percent. Biosolids application (96.4 percent) and alkaline material redistribution (93.3 percent) exhibit the highest improvement predictions, followed by regrading (21.2 percent), special water handling (59.5 percent), and revegetation (55.0 percent). The lowest improvement predictions are for coal refuse removal (34.0 percent) and mining of high-alkaline strata (26.1

percent). However, these BMPs impacted six and three discharges respectively, and the strength of the prediction is questionable. In addition, an improvement in aluminum loading in discharges affected by coal refuse removal may be delayed as explained in regards to iron and manganese loading.

Sulfate Loading

Predicted probabilities of discharge improvement for single-use BMPs range from 12.3 to 75.1 percent. Alkaline material redistribution (80.1 percent) and biosolids application (76.0 percent) exhibit the highest predicted improvement of all of the BMPs, followed by mining alkaline strata (65.4 percent). The lowest probabilities of improvement were predicted for coal refuse removal (9.0 percent) and special handling (10.8 percent).

Flow Rate

Predicted probabilities of discharge improvement for single-use BMPs range from 19.5 to 66.0 percent. Mining of alkaline strata (88.7 percent), biosolids addition (80.4 percent), and alkaline redistribution (66.3 percent) exhibit the highest predicted improvement of all of the BMPs, followed by alkaline addition < 100 tons per acre with 52.3 percent. The lowest probabilities of improvement were predicted for coal refuse removal (1.4 percent) and special handling (12.7 percent).

6.4.2.2 *BMP Groups*

The term "remining" implies that mining will be occurring on an area that has been previously mined. Specifically, for the sake of this manual, it also implies that the area was mined prior to implementation of SMCRA (1977) and modern reclamation standards. There are four basic types of abandoned mine lands that are remined: (1) sites that were previously surface mined, (2) sites that were previously underground mined, (3) sites that were previously surface mined andunderground mined, and (4) sites that had coal refuse deposited on the surface. These areas cannot be reaffected or remined without implementation of some minimal BMPs. Table 6.4a shows the type of previous mining and the associated minimal BMP(s).

Table 6.4a: Types of Mining and Minimal BMPs

Type of Previous Mining	Minimal Best Management Practices
Surface Mining	Regrading, Revegetation
Underground Mining	Daylighting
Surface and Underground Mining	Regrading, Revegetation and Daylighting
Refuse Disposal	Refuse Removal, Regrading, Revegetation

Of the discharges affected by remining, 156 were affected by regrading, 170 by daylighting and only nine by coal refuse removal. There were also a large number of discharges that were affected by both regrading and daylighting. Nearly all discharges affected by regrading were also affected by revegetation. The group of regrading and revegetation and the group of daylighting occurred enough times that it was possible to compare the effectiveness of these minimum BMPs against the minimum BMPs plus other select BMPs (Tables 6.3g through 6.3r). Likewise, the group of regrading and revegetation combined with daylighting, together, affected enough discharges for similar evaluation (Table 6.3s through 6.3x). These minimum BMP combinations were compared against the minimum combination plus select other BMPs. The BMP groups were selected based on their having affected at least four discharges that did not get significantly worse. The BMP groups were evaluated for effects on flow and for effects on acidity, iron, manganese, aluminum, and sulfate loadings.

Unfortunately some BMPs that had a high rate of success (i.e., alkaline redistribution, mining of alkaline strata, and alkaline addition at application rates greater than 100 tons per acre, Table 6.3a) could not be evaluated because they affected too few discharges.

Results of the evaluations of BMP groups are reported in Tables 6.3g through 6.3x. Interpretation of these tables is as follows:

- The first BMP group represents the reference BMP(s).
- If the observed percent improved is greater than the percent improved by the reference group. This suggests that the combined BMPs may have been more effective than the reference group.
- If the observed odds ratio is greater than one, the combined BMPs were possibly more effective than the reference BMP group.
- If the observed odds ratio is less than one, the combined BMPs were possibly less effective than the reference BMP group.
- If the percent improved minus the reference group percent improved is positive, the combined BMPs may have been more effective than the reference group used alone. If negative, the combined BMPs were possibly less effective.

Interpretation of these results cannot be made blindly. A combination of BMPs that is less effective than the reference does not necessarily imply that the "added" BMP(s) are detrimental. It should also be kept in mind that the comparisons are between discharges that had pre- and post-mining water quality that was not statistically different vs pre- and post-mining water quality that showed at least a statistically significant improvement (improved or eliminated) after remining. Failures were not evaluated because they were so infrequent. Climatic differences also were not taken into account.

Regrading and Revegetation

Regrading and revegetation, as mentioned above, are the basic BMPs required for reclamation of previously surface mined land. They occur together, but without other BMPs, to affect at least 18 discharges. Tables 6.3g through 6.3l compare the success of regrading and revegetation, against regrading and revegetation in addition to other select BMPs for acidity, iron, manganese and aluminum loading. Tables 6.3k and 6.3l show the analysis of sulfate loadings and flow rate.

Acidity Loading (Table 6.3g): Of the discharges affected by this BMP reference group, the number of discharges that stayed the same and that at least improved, in regards to acidity, were the same. One other BMP group (regrading, revegetation, and special handling) had similar results, although the sample size was the minimum of four. Only one BMP combination (regrading, revegetation, and water handling) performed better than the reference. Again the sample size was the minimum, but all four samples improved or were eliminated. All other BMP combinations performed less effectively than the reference group. The least effective BMP combination was regrading, revegetation, daylighting, special handling, and water handling, with only one of eight discharges improving.

Iron Loading (Table 6.3h): Two of seven BMP combinations were more effective than the reference group, and one was as effective, at least with regard to improving iron loading, compared to the control. The most effective BMP group was water handling combined with the reference BMPs. Iron in all four of the discharges effected, either was improved or eliminated. The least effective BMP combination was that of regrading, revegetation, daylighting, special handling, and water handling, where only one of eight discharges improved.

Manganese Loading (Table 6.3i): Again, the combination of regrading, revegetation and water handling proved the most effective BMP combination, with all four discharges showing improvement or elimination. This was the only combination that was more successful than the reference BMP group. The combination of regrading, revegetation, daylighting, special handling, and water handling, again proved least effective. In general, manganese had the most failures (resulted in the most discharges with loadings that were significantly unchanged) of any parameter. As discussed in Section 6.4.1, the ability to predict manganese is severely limited.

Aluminum Loading (Table 6.3j): Results for aluminum loading were reported less often than were results for the other parameter loadings, and less BMP combinations are available for comparison to the reference. Although all BMP combinations performed less effectively than the reference group in regards to aluminum loading, the combination of regrading, revegetation, daylighting, special handling and water handling was the least effective.

Sulfate Loading (Table 6.3k): As for other parameters, the combination of regrading, revegetation, and water handling proved the most effective BMP combination, with three of four discharges (75.0 percent) showing improvement or elimination. This was the only combination that was more successful than the reference BMP group with 58.8 percent. The combinations of regrading, revegetation, and special handling and regrading, revegetation, and alkaline addition < 100 tons proved least effective with no discharges exhibiting improvement.

Flow Rate (Table 6.3l): As for other parameters, the combination of regrading, revegetation and water handling proved the most effective BMP combination, with three of four discharges (75.0 percent) showing improvement or elimination. This was the only combination that was more successful than the reference BMP group with 66.7 percent. The BMP combination of regrading, revegetation, daylighting, special handling, and water handling was the least effective.

Overall

The BMP reference group of regrading and revegetation includes BMPs that are effective for reducing pollution load by reducing flow. This is reflected by the fact that half the discharges using only these BMPs showed improvement (Tables 6.3g through 6.3l). Most of the other BMPs in the groupings are BMPs that are typically applied to sites that have acidic materials and/or a lack of calcareous rocks. These BMPs are "geochemical" and affect water chemistry rather than flow. The reference group out-performed 6 of the 8 other groupings that were compared. This is probably because, in cases where regrading and revegetation were used alone, the overburden was of good quality and there was no need for additional BMPs. The implementation of special handling and alkaline addition imply that there was acidic material present and a lack of calcareous rocks. Special handling of acidic materials alone may reduce acid production, but cannot produce alkaline drainage. Alkaline addition, where it does occur in a comparison group, is always less than 100 tons/acre. It has been shown by various studies that addition rates less than 100 tons/acre are not generally capable of producing alkaline drainage. It should be kept in mind that alkaline drainage is not necessarily a goal of remining sites, the goal is that the water not be degraded. The BMP comparisons with alkaline addition at less than 100 tons per acre do suggest that alkaline addition rates greater than 100 tons per acre could result in more improvements.

For acidity, iron, and manganese, the most effective BMP combination that included the reference group was that of regrading, revegetation, and water handling. Water handling is a physical BMP and may have further reduced flow which would further reduce load. The BMP combination that consistently performed the worst was regrading, revegetation, daylighting, special handling, and water handling. This combination performed poorly for each parameter and for each evaluation of reference BMPs. There is no intuitive explanation for this. Daylighting generally results in acidic materials that need to be handled, and the inclusion of special handling implies that this was the case.

Daylighting

Daylighting is the minimum BMP required when an abandoned underground mine exists within a coal seam proposed for surface mining. Daylighting by itself occurred 14 times and was associated with seven other BMP combinations that occurred at least four times.

Acidity Loading (Table 6.3m): Daylighting implemented alone improved or eliminated acidity loading in four affected discharges and resulted in no change in nine discharges. Six of the seven BMP combinations were more effective than the reference combination. The least effective performance was for the same least effective combination in respect to regrading and revegetation (regrading, revegetation, daylighting, special handling, and water handling).

Iron Loading (Table 6.3n): Daylighting implemented alone resulted in the improvement of seven discharges and resulted in no change in the remaining five discharges. None of the seven BMP combinations were as effective as the control. The least effective combination was the same as the least effective combination in regards to acidity (regrading, revegetation, daylighting, special handling, and water handling).

Manganese Loading (Table 6.3o): Six of the discharges affected by the reference group in terms of manganese loading, improved or were eliminated and four remained unchanged. No BMP combination was more effective than the reference combination. The least effective combination was the same as the least effective combination in regards to acidity and iron (regrading, revegetation, daylighting, special handling, and water handling).

Aluminum Loading (Table 6.3p): Because fewer data on aluminum were available, there are only four BMP combinations that were compared to the reference group. One of these combinations (regrading, revegetation, and daylighting) was slightly more effective than the control group. The other three combinations were less effective, with the least effective combination being the same as the least effective combination in regards to acidity and iron and manganese (regrading, revegetation, daylighting, special handling, and water handling).

Sulfate Loading (Table 6.3q): Four of the discharges (33.3 percent) affected by the reference group in terms of sulfate loading improved or were eliminated and eight remained unchanged. Three BMP groups (regrading, revegetation, and daylighting; regrading, revegetation, daylighting, and alkaline addition < 100 tons/acre; and regrading, revegetation, daylighting, special handling and alkaline addition < 100 tons/acre) were more effective than the reference combination. The least effective combination was the same as the least effective combination with regard to the other parameters (regrading, revegetation, daylighting, special handling, and water handling) with 12.5 percent.

Flow Rate (Table 6.3r): Two of the discharges (14.3 percent) affected by the reference group in terms of flow improved or were eliminated and 12 remained unchanged. All of the seven BMP combinations were more effective than the reference group. The least effective BMP group other than the reference group, was daylighting, regrading, revegetation, daylighting, special handling, and water handling.

Overall

The percentage of discharges that improved with regard to acidity from the implementation of daylighting alone (Table 6.3m) is less than the percentage that improved from the implementation of regrading and revegetation alone (Table 6.3g). Percentages of improved discharges were 30.8 and 50 respectively. This result is not surprising because daylighting often results in a large amount of acidic material that is spoiled. It is interesting that six of the seven groupings, when compared to the reference group, were more effective in regards to acidity loading. This suggests that many of the BMPs, such as special handling and alkaline addition (even applied at lower rates), helped to offset some of the natural potential of these sites to produce acidic water.

The least effective BMP group was again the combination of regrading, revegetation, daylighting, special handling and water handling.

Regrading, Revegetation, and Daylighting

A large number of remining operations encountered both abandoned surface mines and underground mines. Therefore, the minimum BMPs implemented at these sites, are a combination of those in the first two reference groups, namely regrading, revegetation, and daylighting.

Acidity Loading (Table 6.3s): A total of 36 discharges were affected by the reference BMP group. Sixteen discharges were improved or eliminated and twenty remained unchanged. Four other BMP combinations affected enough discharges to be compared to the reference group. None were as effective as the reference group (although three of the four were only slightly less effective). The least effective, as in all cases cited thus far, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

Iron Loading (Table 6.3t): Thirty-seven discharges were affected by the reference BMP group. Thirteen were improved or eliminated and 22 remained unchanged. Two of the four BMP groups (regrading, revegetation, daylighting and special handling; and regrading, revegetation, daylighting, special handling, and alkaline addition less then 100 tons per acre) were more effective than the reference group. A third group (regrading, revegetation, daylighting, and alkaline addition less than 100 tons/acre) was almost as effective as the reference group. The least effective, again, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

Manganese Loading (Table 6.3u): Thirty discharges were affected by the reference BMP group in terms of manganese loading. Ten were improved or eliminated and 19 remained unchanged. Three of the four BMP groups were more effective than the reference group. The least effective, again, was the combination of regrading, revegetation, daylighting, special handling, and water handling.

Aluminum Loading (Table 6.3v): Twenty-four discharges were affected by the reference BMP group in regards to aluminum loading. Eleven were improved or eliminated and 12 remained unchanged. All three other BMP combinations that affected enough discharges to allow comparison to the reference group were less effective than the reference group in terms of at least improving aluminum loading. Again, the least effective was the combination of regrading, revegetation, daylighting, special handling, and water handling.

Sulfate Loading (Table 6.3w): Thirty-six discharges were affected by the reference BMP group in regards to sulfate loading. Fourteen (42.4 percent) were improved or eliminated and 19 remained unchanged. Four other BMP groups affected enough discharges to allow for a comparison. Only one of these four BMP groups (regrading, revegetation, daylighting, special handling, and alkaline addition < 100 tons/acre) exceeded the reference group for effectiveness by improving 45.5 percent of the discharges. The group of regrading, revegetation, daylighting, special handling, and water handling was the least effective improving only 12.5 percent.

Flow Rate (Table 6.3x): Thirty-seven discharges were affected by the reference BMP group in regards to flow rate. Sixteen (47.1 percent) were improved or eliminated and 18 remained unchanged. Four BMP combinations affected enough discharges to allow for a comparison.

None of these four BMP groups exceeded the effectiveness of the reference group. The BMP group of regrading, revegetation, daylighting, special handling, and water handling was the least effective in reducing the flow rate at 25.0 percent improvement.

Overall

The effectiveness of the four BMP groups in terms of acidity compared to the reference grouping was always less than that of the reference grouping (Tables 6.3s through 6.3x). The last grouping (regrading, revegetation, daylighting, special handling, and water handling) was again substantially less effective. Daylighting of underground mines adds additional acidic material to the mine spoil and as discussed under the reference group of regrading and revegetation, if other BMPs are not used the overburden was probably of good quality. If other BMPs are used, the overburden was probably considered problematic (acidic and/or a lack of calcareous strata).

Coal Refuse Removal

Coal refuse removal is the minimum BMP implemented when mining coal refuse, although an examination of coal refuse removal sites indicates that regrading and revegetation also are typically implemented. BMP groups that included coal refuse removal did not affect a sufficient number of discharges to compare with a reference set. Four discharges were affected by special handling in addition to coal refuse removal, one by biosolids application in addition to coal refuse removal, and one by alkaline addition in addition to coal refuse removal. Special handling of coal refuse, a material that is generally acid-producing, is not easy to perform, because it would require special handling of 100 percent of the material. Isolation of 100 percent of the material is not possible. Implementation of biosolids application or alkaline addition are more reasonable. Abandoned coal refuse disposal areas are typically characterized by sparse vegetation and lack of "topsoil." Biosolids could aid in the establishment of a growth medium.

Because refuse is often acid-producing, the addition of alkaline material would be an appropriate additional BMP. The results of the implementation of coal refuse removal are presented in Table 6.2a, and are discussed below.

Acidity Loading: Coal refuse removal affected only nine discharges in regards to acidity loading. Six discharges were improved or eliminated and three remained unchanged.

Iron Loading: Coal refuse removal affected seven discharges in regards to iron loading. Two discharges were significantly improved or eliminated, four remained the same, and one became significantly worse.

Manganese Loading: Coal refuse removal affected six discharges in terms of manganese loading. No discharges improved, five remained the same and one was significantly degraded.

Aluminum Loading: Coal refuse removal affected six discharges in terms of aluminum loading. Two discharges improved, four remained the same and none were degraded.

Sulfate Loading: Coal refuse removal affected nine discharges in terms of sulfate loading. Of these discharges two improved and the remainder were unchanged. None exhibited increased loadings (possible increase in acid production).

Flow Rate: Coal refuse removal affected nine discharges in terms of flow rate. One discharge exhibited an improvement (reduced flow rate), while the remaining discharges were unchanged. None showed an increase in flow.

Overall

Two thirds of the nine discharges showed improvements in acidity load. This is not surprising because the removal of coal refuse can only be beneficial. Coal refuse is typically an acid-producing material and is often associated with severe acid mine drainage. Removal of the coal refuse is the removal of an acid-producing material. The two BMPs that typically accompany coal refuse removal are regrading and revegetation. Both of these BMPs tend to decrease water infiltration into the refuse material and thus, tend to decrease load.

Overall Evaluation

Many of the multiple BMP groups when compared with the reference BMP group were not as effective as the reference group. This should not be interpreted to mean that the addition of BMP(s) to the reference groups were not effective or that discharges would have improved if the additional BMPs had not been implemented. The very nature of many of the BMPs that were implemented indicates that they were added to counter either the potential for acid production or to compensate for a lack of naturally calcareous material. For example, special handling generally implies that acid-forming materials are present; alkaline addition < 100 tons per acre suggests that naturally calcareous materials were lacking. Conversely, discharges affected by the minimum BMPs may have had better quality overburden, and thus may not have required additional BMPs. Also, some BMPs listed in Tables 6.3a through 6.3d that were shown to positively influence water quality (e.g., alkaline redistribution and mining high-alkaline strata) were not used for comparison because of small number of discharges they affected.

In addition, although many of the BMP groups were not as effective as the control group, it is not an indication that they were not successful. The fact is that very few sites in the entire data set were degraded. This may not have been the case if these additional BMPs had not been not used.

The least effective BMP combination was regrading, revegetation, daylighting, special handling, and water handling. Only one of eight discharges affected by this BMP combination improved. None of the BMPs in this group will add alkalinity to mine sites, and it is known that special handling will not produce alkaline water in the absence of calcareous rock. Perhaps this should be interpreted to signify that alkaline-deficient sites can benefit from alkaline addition. The failure of this group may be due to these sites having considerable problems in terms of contaminant loadings and in order to offset these existing and potential future problems, a variety of BMPs are applied. This sort of a “shotgun approach” to pollution abatement on marginal sites may not be viable.

The low success rate of the BMP group of regrading, revegetation, daylighting, special handling, and water handling also was seen in the significant interaction terms presented in Tables 6.3a, 6.3b, and 6.3c. For acidity, iron, and manganese, there was a significant negative interaction between water handling and special handling. These interactions suggest that the positive effect of water handling on the odds of at least improvement is diminished when special handling is also present. For 89 percent of the discharges (with regard to acidity and manganese) and 80 percent of the discharges (with regard to iron) that were affected by water handling and special handling, the discharges were also affected by regrading, revegetation and daylighting. Of these five BMPs, water handling was the most efficient in dealing with acidity and iron loadings for other discharges. Since special handling and water handling rarely occurred together in BMP groups, the percentage of discharges affected by the combination of the two that at least improved was very low. Therefore, the statistical models for acidity and iron isolated these two BMPs as interacting significantly. However, since the interaction was significant, mainly due to this group of five BMPs, conclusions about the behavior of these two BMPs combined alone should not be made without first examining why the five-BMP group yielded such low results.

Studies cited earlier by Smith (1988) and Hawkins (1995) showed that reduction in flow is the most significant influence on load reduction. Regrading and revegetation are both significant BMPs in terms of reducing flow. The other BMPs evaluated, with the exception of water handling, are predominantly geochemical BMPs, which would have a less marked effect on flow reduction.

Limitations

As previously stated, this remining water quality data set for pre-existing discharges is the most comprehensive available at this time. However, the results of these analyses should be considered with the following limitations in mind:

- Once the actual subsets of the 231 discharges that were impacted by specific BMPs or BMP combinations are separated out, the number impacted, in some cases, becomes relatively small. In cases where smaller subsets of data represent each BMP or BMP group, the number of results that are statistically significant at the 95 percent confidence level are few.
- The data collected for pre-, during, and post-mining does not take into consideration the variability of precipitation during the sampling periods. Water quality and flow data recorded during unusually low or high precipitation periods can greatly impact determined efficiency results.
- No consideration has been given to the probability that, some discharges within a mine site have gained some or all of the flow that previously went to another. One discharge may appear to have been degraded, while others may appear to have significantly improved. However, the overall pollution load for the hydrologic unit may not have changed or may have substantially improved. With the anticipated changes in the ground water flow system, this scenario is not uncommon.
- Data evaluated included contaminant loading and flow rate information, and did not include contaminant concentration data. For this reason, it is not possible at this time to determine whether discharge improvement is in terms of water volume, contaminant concentration or both. The effects of geochemical BMPs vs hydrologic control BMPs are difficult to determine. With the evaluation of concentration data, efficiency determinations of individual BMPs and BMP combinations are expected to improve.

6.5 Summary

Even with the aforementioned limitations, the analyses strongly indicate the high rate of success of BMPs and BMP combinations implemented at remining operations throughout Pennsylvania. Very few of the single-use BMPs or BMP combinations had less than a 90 percent success rate. Those BMPs that exhibited a significant failure rate for any pollutant had no more than 2 discharges with significantly higher loadings. The most efficient BMPs varied according to the target contaminant. The number of discharges that were observed to be made worse during remining was so low that they could not be used for meaningful statistical analyses. This is illustrative how successful remining and the use of appropriate BMPs can be when properly implemented.

Remining falls into four categories: (1) reaffecting previously surface mined areas, (2) daylighting of underground mines, (3) refuse removal, and (4) reaffecting previously surface mined areas and daylighting underground mines. Each of these remining activities has minimum BMP(s) associated with them. For example, remining of previously surface mined areas requires regrading and revegetation and where deep mines are present the minimal BMP is daylighting. Minimal BMP groups were determined for each of the above four remining categories. Frequently, in addition to the minimum BMPs, other BMPs were also employed during each of the four remining operations. This allowed a comparison between the minimum BMPs for a category against situations were other BMPs were also used (minimum plus other BMPs). In many instances, the discharges affected by the minimum BMPs plus additional BMPs were less effective (had fewer "improved" discharges) than the minimal BMPs used alone. This is attributed to the fact that, in situations where more than the minimum number of BMPs were implemented, it was probably due to the presence of acid-forming materials and/or a lack of naturally occurring calcareous rock. In these cases, additional BMPs were added to counter negative characteristics of the mine site overburden. In contrast, remining operations that implemented the minumum BMPs probably had overburden that was of better quality.

The BMPs predicted to be most efficient for acidity load were those that added alkalinity to the operation, such as mining into alkaline strata and alkaline redistribution. However, when the amount of alkaline material added was small (< 100 tons per acre), the predicted success rate (at least improvement) was one of the lowest (25.4 percent). This amount of added alkalinity was insufficient to successfully prevent or treat AMD production. The finding that BMPs that incorporate calcareous materials into mine spoil have a positive influence on acidity load (i.e., a reduction in load) may seem obvious, but is significant. Previous studies of remining have emphasized the role of physical BMPs in reducing load through a reduction of flow. Chemical BMPs, such as alkaline addition or alkaline redistribution, are unlikely to have much, if any, influence on flow. Therefore, the positive effects are almost certainly due to added alkalinity and neutralization of acid contributed from the calcareous materials.

The BMPs that were predicted to be most effective in terms of iron loadings were special water handling (73.1 percent) and biosolids addition (62.9 percent). Special water handling is primarily a physically effective BMP, whereas biosolids addition functions geochemically and perhaps physically, through increased plant growth and density which may increase water consumption. Therefore, no common causation trend between these BMPs was definite, in terms of how they functioned to improve iron loadings. The BMPs that were predicted to be most effective in terms of manganese loadings were alkaline redistribution (92.6 percent) and biosolids application (96.1 percent). The total number of discharges affected by each of these BMPs was low (five for biosolids and four for alkaline redistribution). Therefore, these conclusions are not definitive. As with manganese loadings, the most successful predicted single-use BMPs dealing with aluminum loadings were biosolids application (96.4 percent) and alkaline redistribution (93.3 percent). Again, the number of discharges affected by each of these BMPs was low (< 4), and these conclusions are not definitive.

The efficiency predictions of BMPs indicate that most BMPs, if properly employed, will improve contaminant loadings. No BMP was shown to be overall detrimental in terms of increasing contaminant loadings. With further analysis of flow and concentration data, the determination of whether the change in loadings was physical or geochemical is expected to be more definite.

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Section 7.0 Best Management Practices - Costs

This section provides a summary of the Best Management Practice (BMP) cost information obtained during the preparation of this document. Although not specifically requested, a significant amount of BMP cost information was obtained. This information should provide mine engineers and permitters with at least preliminary or "ballpark" costs for the BMPs. This cost information should not preclude detailed engineering analysis and design efforts to include such things as location, climate, and site limitations.

When sufficient data were available, a least-squares-best-fit linear regression was done on the data to come up with a cost equation. When limited data were available, unit costs were developed and presented.

The primary source of information used in the preparation of this section was 61 data packages gathered from six states and representing remining or reclamation activities during which these BMPs were implemented (Appendix A: EPA Remining Database). A limited amount of cost information was found in the literature. Abatement plans from several state's mining permit applications require the applicant to define which BMPs will be used to abate or ameliorate pollutional discharges, and estimate what the BMP implementation cost would be. This cost information has been summarized in this Section in table form. Very little has been done with the cost information other than indexing to today's dollars with the aid of the Engineering News Record (ENR) Construction Cost Index (ENR, 1999).

Unless otherwise noted, the costs were considered current with the date of permit application and have been indexed to January 1999 dollars with the use of ENR's Construction Cost Index. January 1999 has an ENR index value of 6000. For example, the index for September 1995 is 5491. Dividing the January 1999 index by the September 1995 index yields a factor of 1.09. Costs in September 1995 were multiplied by this factor to derive costs in January 1999 dollars.

The cost information has been summarized alphabetically by BMP. Within each BMP the cost information is summarized by mine followed by assumptions underlying the costs, and finally, cost equations generated from the available cost information (if possible). Cost information for the following BMPs are summarized in the following tables:

Table 7a: Alkaline Addition

Mine	Acres	Alkaline Material (tons/acre)	Location	Alkaline Addition Cost ($/ton)	Cost (Date)	Unit Cost ENR 6000 ($/ton)
Lime Addition						
PA (10)	28.6	3	Spoil	$ 17.50	$1,501 (2/90)	$ 22.40
PA(1)	26.1	30	Pit Floor	$ 16.85[2]	$13,194 (3/90)	$ 21.55
PA(11)	61.3	50	Pit Floor	$ 6.00	$18,390 (9/89)	$ 7.73
PA (8)	22.68	403-493	Blast Holes, & Pit Floor	$ 5.00[3]	$68,040 (2/93)	NA
PA (19)	9.8	1050	NA	$ 10.00	$102,900 (12/97)	$ 10.24
Ash Addition						
PA (2)	50[1]				$2,608,000 (8/88)	$ 2.55

NA = Not Available.

[1] Ash and refuse will be placed in alternating two foot lifts, reconstructed pile estimated to contain 1,650,000 tons of refuse and 1,350,000 tons of ash.

[2] Cost includes $2.25/ton handling, $6.00/ton trucking, and $8.60/ton lime.

[3] Cost includes $1.00/ton handling, $1.00/ton trucking, and $3.00/ton lime.

Assumptions:

- Costs include lime, trucking, and spreading.

Cost Equation: Not developed.

Table 7b: Anoxic Limestone Drains (ALDs)

Mine	Design Flow (gpm)	Loss of Limestone (mg/L)	Design Life (Years)	Design Loading (tons $CaCO_3$/gal·min)	Cost (Date)	Unit Cost ENR 6000 ($/Ton of Limestone)
TN (3)	8	250	40	33	NA	NA
TN (5)	160	250	30	20[1]	$ 90,014 (5/94)	$ 31.42
TN (2)	200	370	10	20	$ 230,000[2] (1995)	NA

NA = Not Available.

[1] Design loading required 4,000 tons of limestone; 5,000 actually used to provide safety factor.

[2] Costs are for a 5,000 ton ALD and a 2.35 acre oxidation pond.

Assumptions:

- TN(2) - 5,000 tons of limestone used; loss of limestone 370 mg/L; design life 10 years.
- TN(3) - 264 tons of limestone used; loss of limestone 250 mg/L; design life 40 years; safety factor 1.5.
- TN(5) - 3,180 tons of limestone used; loss of limestone 250 mg/L; design life 30 years; safety factor 1.2.

Cost Equation: Not developed, only one point available.

Table 7c: Ash Fill Placement

Mine	Cubic Yards	Cost ($/cu. yd.)	Cost (Date)	Unit Cost ENR 6000 ($/ cu. yd.)
PA (18)	15,000,000	$ 0.25	$ 3,750,000 (12/96)	$ 0.26

Assumptions:

- Costs are for handling ash only (hauling, spreading, and compacting)

Cost Equation: Not developed, only one point available.

Table 7d: Bactericides

Mine	Acres	Cost/Acre	Cost (Date)	Unit Cost ENR 6000 ($/acre)
PA (10)	13.0	$ 2,100	$ 27,300 (2/90)	$ 2,689

Assumptions:

- Use B.F. Goodrich's "ProMac"
- Applied before top cover is spread and revegetated

Cost Equation: Not developed, only one point available.

Table 7e: Check Dams

Source			Cost (Date)	Cost ENR 6000
Ref. (USEPA, 1992)				See Below

Assumptions:

- Check dams are appropriate for use in the following locations:
    1. Across swales or drainage ditches to reduce the velocity of flow.
    2. Where velocity should be reduced because a vegetated channel lining has not yet been established.
- Check dams may never be used in a live stream unless approved by the appropriate government agency.
- The drainage area above the check dam should be two to ten acres.
- The dams should be spaced so that the toe of the upstream dam is never any higher than the top of the downstream dam.
- The center of the dam must be six to nine inches lower than either edge, and the maximum height of the dam should be 24 inches.
- The check dam should be as much as 18 inches wider than the banks of the channel to prevent undercutting as overland flow water re-enters the channel.
- Excavating a sump immediately upstream from the check dam improves its effectiveness.
- Provide outlet stabilization below the lowest check dam where the risk of erosion is greatest.
- Consider the use of channel linings or protection such as plastic sheeting or rip rap where there may be significant erosion or prolonged submergence.

Cost Equation:

The costs for the construction of check dams varies with the material used. Rock costs about $100 per dam ($ 119 => ENR = 6000). Log check dams are usually slightly less expensive than rock check dams. All costs vary depending on the width of the channel to be checked.

Table 7f: Constructed Wetlands

Mine	Fe Loading (gr/day/m^2)	Mn Loading (gr/day/m^2)	Ox. Pond (acres)	Marsh (acres)	Total Acres (acres)	Cost (Date)	Cost ENR 6000 ($1,000)
TN (5)[1]	20	0.5	0.76[2]	2.69	3.45	$ 21,559 (5/94)	$ 23.93
VA (8)			14.2		14.2	$ 284,000 (9/96)	$ 299.84
TN (2)	17.2		2.35[3]	2.0	4.35	$ 21,000[4]	$ 23.03

NA = Not Available

[1] This wetlands design includes areas for an oxidation pond and marshes in the calculation for required area of wetland. Oxidation pond designed for 24 hours retention at 160 gpm and 5 foot depth of 6,160 sq. ft. (Actually used 33,450 sq. ft. At 6 ft. depth). The remainder of the wetland will be marsh (150,790 sq.ft. - 33,450 sq.ft = 117,340 sq.ft.).

[2] Twenty-four hour retention minimum.

[3] Minimum 1 to 2 days retention; 11.0 actual.

[4] Costs are for the 2.0 acre marsh area only.

Assumptions:

- Refer to design criteria in table above.

Cost Equation:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR = 6000):

Equation: $y = 6.41x^{1.405}$

where:
x = acres
y = Cost ($1,000)
$n = 3$
$r^2 = 0.93$

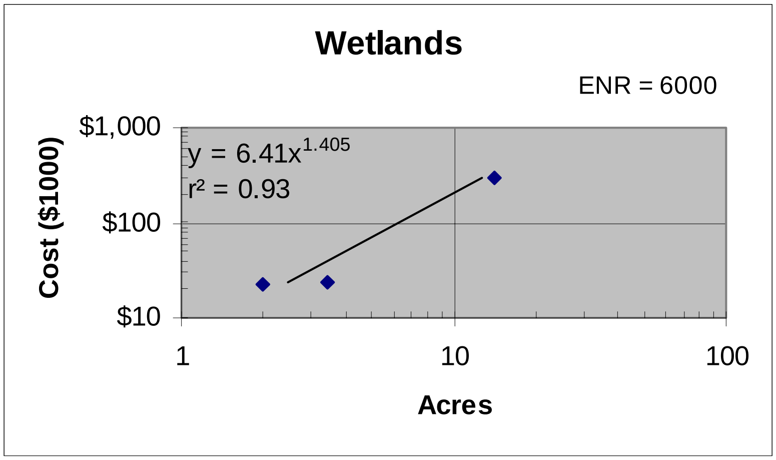


Table 7g: Daylighting

Mine	Acres Daylighted	Recoverable Coal (1,000 tons)	Cost/Ton of Recovered Coal	Cost (Date)	Cost ENR 6000 ($1,000)
PA (6)	5.0	9.72	$ 0.25	$ 2,430 (9/89)	$ 3.13
PA (1)	3.6	8.957	$ 1.21	$ 10,880 (4/90)	$ 13.91
PA (7)	15.1	26.550	$ 1.54	$ 40,770 (10/89)	$ 52.52
PA (11)	23.7	47.988	$ 1.67	$79,988 (10/93)	$ 91.17
PA (9)	103.5	229.767	$ 2.00	$ 459,534 (8/94)	$ 508.33
PA (3)	90	550.785	$ 1.21	$ 666,450 (12/88)	$ 875.37

[1] Complete.

[2] Partial.

Assumptions:

- Mining ratio cannot exceed 18:1 or 60 ft max. Highwall
- 60 ft. Max. Highwall

Cost Equation:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR=6000):

Equation: $y = 0.60x^{1.21}$

where: x = Tons of Recoverable Coal (1,000)
y = Cost ($1,000)
n = 6
$r^2 = 0.91$

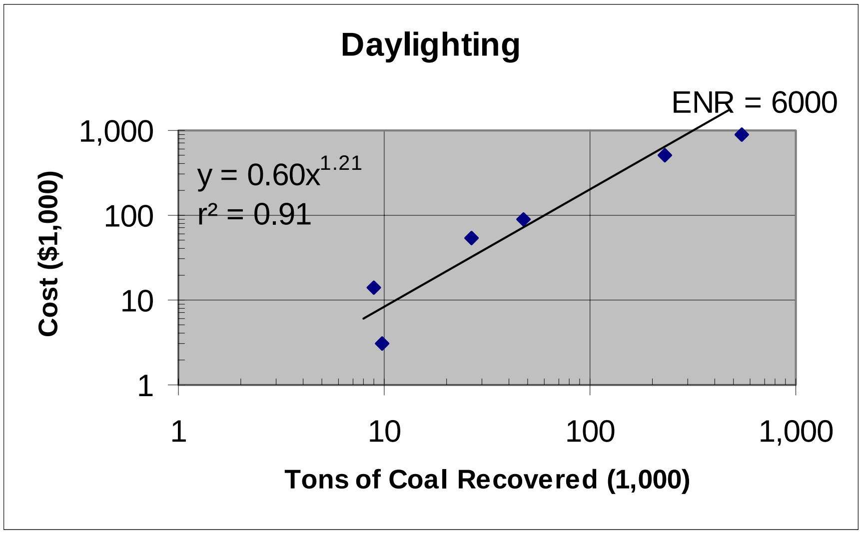


Table 7h: Diversion Ditch

Mine	Length (Ft.)	Design Flow (cfs)	Cost (Date)	Cost ENR 6000	Unit Cost ENR 6000 ($/Ft.)
TN (5)	875[1]	195	$ 7,925 (5/94)	$ 8,797	$10.05

[1] Estimated.

Assumptions:

Bottom Width	20'
Side Slopes	2H:1V
Ditch Slope	1%
Constructed Depth	3'
Flow Depth (Design)	1.85'
Lining	Rip rap for a 2.25' flow depth

Cost Equation: Not developed, only one point available.

Table 7i: Diversion Wells, Alkalinity Producing

Reference	Materials	Labor	Total Cost ENR 6000
McClintock, 1993	$ 5,000	$ 6,000	$ 11,000 ea.

Assumptions:

- From page ten of the reference: “A rough estimate is about $5,000 for the materials and equipment rental.”
- From page 7 of the reference;” About 8 to 10 people working 8 hour per day for 2 to 3 days are needed for construction of a diversion well.”
  (10 people x 8 hours/day x 3 days x $ 25.00/hr = $ 6,000)

Cost Equation: Not developed, only one point available.

Table 7j: Drains, Pit Floor

Mine	Total Length (Ft.)	Cost (Date)	Unit Cost ENR 6000 ($/Ft.)
PA (8)	2,600	$ 132,500 (2/93)	$ 60.31

Assumptions:

- Details not available in permit file.

Cost Equation: Not developed, only one point available.

Table 7k: Regrading of Abandoned Mine Spoil/Highwalls

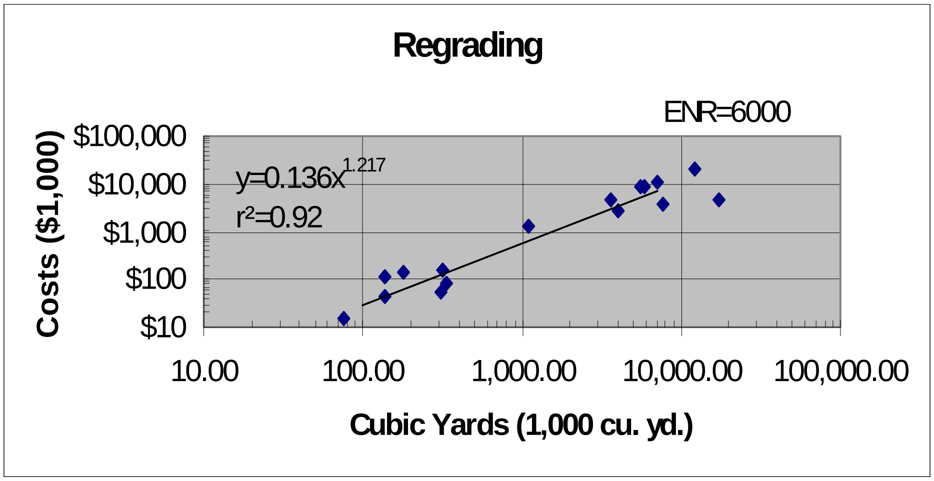
Mine	Cubic Yards (1,000)	Cost/cu.yd.	Cost (Date)	Cost ENR 6000 ($ 1,000)
PA(7)	76.550	$ 0.16	$ 12,060 (10/89)	$ 15.545
PA (10)	138.905	$ 0.25	$ 34,171 (2/90)	$ 43.76
PA (11)	304.944	$ 0.16	$ 48,150 (10/93)	$ 54.88
KY (4)	332.046	$ 0.23	$ 76,039 (9/94)	$ 83.91
PA (6)	136.660	$0.65	$ 88,829 (9/89)	$ 114.42
PA (5)	178.100	$ 0.75	$ 133,575 (9/94)	$ 147.76
PA (19)	321.376	$ 0.50	$ 160,688 (12/97)	$ 164.58
PA (3)	1,090.613	$ 0.90	$ 981,552 (12/88)	$ 1,289.25
PA (18)	4,000	$ 0.65	$ 2,600,000 (9/97)	$ 2,666.21
PA (9)	7,743	$ 0.45	$ 3,484,350 (8/94)	$ 3,854.37
WV (4)	3,630	$ 1.00	$ 3,630,000 (2/90)	$ 4,648.88
KY (3)	17,250.378	$ 0.23	$ 3,950,378 (8/91)	$ 4,845.11
WV (9)	5,488.314	$ 1.00	$ 5,488,314 (10/81)	$ 8,997.24
WV (7)	5,848	$ 1.00	$ 5,848,000 (9/83)	$ 8,471.27
WV (10)	7,139	$ 1.00	$ 7,139,000 (3/85)	$ 10,318.96
WV (2)	12,100	$ 1.00	$ 12,100,000 (1981)	$ 20,537.48

Assumptions:

- Regrading of abandoned mine spoil
- Elimination of abandoned highwalls

Cost Equation:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR=6000):



Equation:

$y=0.136x^{1.217}$

where: x = Cu.Yds. (1,000)
y = Cost ($1,000)

n = 16
$r^2 = 0.92$

Table 7l: Revegetation

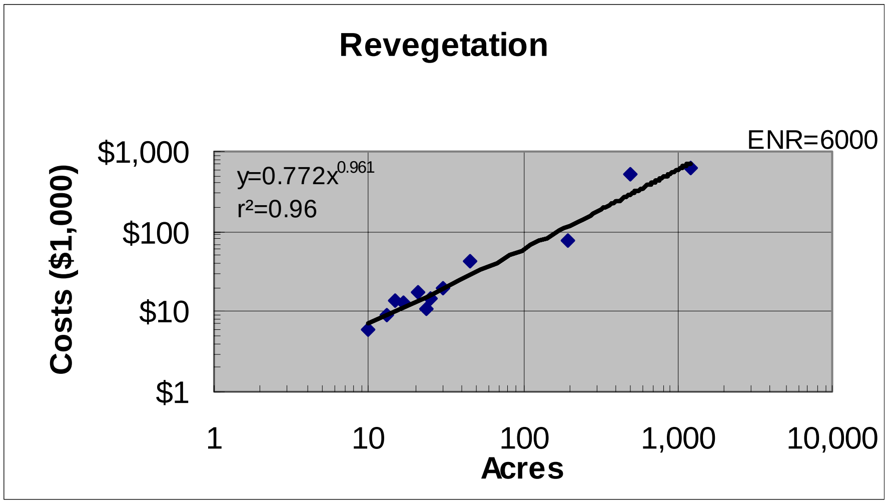
Mine	Acres	Cost/Acre	Cost (Date)	Cost ENR 6000 ($ 1,000)
PA (7)	10	$ 450	$ 4,500 (10/89)	$ 5.80
PA (10)	13	$ 550	$ 7,150 (2/90)	$ 9.16
KY (4)	23.4	$ 409	$ 9,570 (9/94)	$10.56
PA (6)	17	$ 600	$ 10,200 (9/89)	$ 13.14
VA (6)	15	$ 750	$ 11,250 (10/91)	$ 13.80
PA(11)	25.2	$ 450	$ 11,340 (9/89)	$ 14.61
PA (8)	21	$ 720	$ 16,200 (12/94)	$ 17.87
PA (19)	30.3	$ 650	$ 19,695 (12/97)	$ 20.17
PA (4)	45	$ 800	$ 36,000 (2/93)	$ 42.60
KY (1)	195.7	$ 625	$ 69,264 (7/97)	$ 69.60
PA (18)	500	$ 1,000	$ 500,000 (9/97)	$ 512.73
KY (3)	1,215.7	$ 409	$ 497,221 (8/91)	$ 609.84

Assumptions:

- Lime
- Fertilizer
- Seed
- Mulch
- Handling and spreading of above.

Cost Equation:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR=6000).



Equation:

$y = 0.772x^{0.961}$

where: x = Acres

y = Cost ($1,000)

$r^2 = 0.96$

n = 12

Table 7m: Sealing and Rerouting of Mine Water from Abandoned Workings

Mine	Lin. Ft. (1000)	Cost/ Lin. Ft.	Clay (Cu. Yd.)	Cost/ Cu. Yd.	Cost (Date)	Cost ENR 6000 ($ 1,000)
Highwall Seal						
PA (1)	1.75	$ 4.69	4,111	$ 2.00	$ 8,222 (3/90)	$ 10.52
PA(3)	10.50	$ 3.80	20,000	$ 2.00	$ 40,000 (12/88)	$ 52.54
Clay Barrier						
PA (10)	1.75	$ 0.67	583	$ 2.00	$ 1,166 (9/96)	$ 1.23
Auger Holes						
KY (4)	1.88	$ 0.20	1,671	$ 0.23	$ 380 (9/94)	$ 0.42
KY (3)	11.16	$ 0.20	9,920	$ 0.23	$ 2,275 (8/91)	$ 2.79

Assumptions:

Highwall Seal
- 10' - 12' at base
- 8' high
- slope away from highwall face
- Mine void to be filled with clay to a width and depth of a minimum of 3 times the diameter of the exposed opening.
- Clay available on-site.

Clay Barrier
- 3' high
- 3' wide
- Clay available on-site

Auger Hole Seals
- 4' high
- 6' wide
- Clay available on-site

Cost Equations:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR=6000):

Highwall Seal ==> $y = 6.37x^{0.90}$ where: x = Linear Feet (1,000) $r^2 = 1.0$
y = Cost ($1,000) $n = 2$

Clay Barrier ==> $y = 0.703x^{1.0}$ where: x = Linear Feet (1,000)
y = Cost ($1,000)

Auger Hole Seal ==> $y = 0.215x^{1.06}$ where: x = Linear Feet (1,000) $r^2 = 1.0$
y = Cost ($1,000) $n = 2$

Table 7n: Silt Fences

Source		**Unit Cost (Date)**	**Unit Cost ENR 6000 ($/Ft.)**
Ref.(USEPA, 1992)		$ 6.00/Ft. (1992)	$ 7.22[1]

[1] Installation costs only.

Assumptions:

- Silt fences are appropriate at the following general locations:
  (1) Immediately upstream of point(s) of runoff discharge from a site before
  flow becomes concentrated (maximum design flow rate should not exceed 0.5 cubic feet per second).
  (2) Below disturbed areas where runoff may occur in the form of overland flow.
- Ponding should not be allowed behind silt fences since they will collapse under high pressure; the design should provide sufficient outlets to prevent overtopping.
- The drainage area should not exceed 0.25 acre per 100 feet of fence length.
- For slopes between 50:1 and 5:1, the maximum allowable upstream flow path length to the fence is 100 feet; for slopes 2:1 and steeper, the maximum is 20 feet.
- The maximum up slope grade perpendicular to the fence line should not exceed 1:1.
- Synthetic silt fences should be designed for six months of service; burlap is only acceptable for periods of up to 60 days.

Cost Equation: Not developed with only one point available.

Table 7o: Special Handling for Toxic and Acid Forming Materials

Mine	Cubic Yards (1,000)	Cost/cu.yd.	Cost (Date)	Cost ENR 6000 ($ 1,000)
PA (11)	17.58	$ 0.20	$ 3,516 (9/89)	$ 4.53
PA (19)	15.81	$ 1.00	$ 15,811 (12/97)	$16.19
PA (7)	216.13	$ 0.25	$ 54,032 (6/88)	$ 71.64
PA (3)	2,468.4	$ 0.90	$2,221,560 (12/88)	$2,917.99

Assumptions:

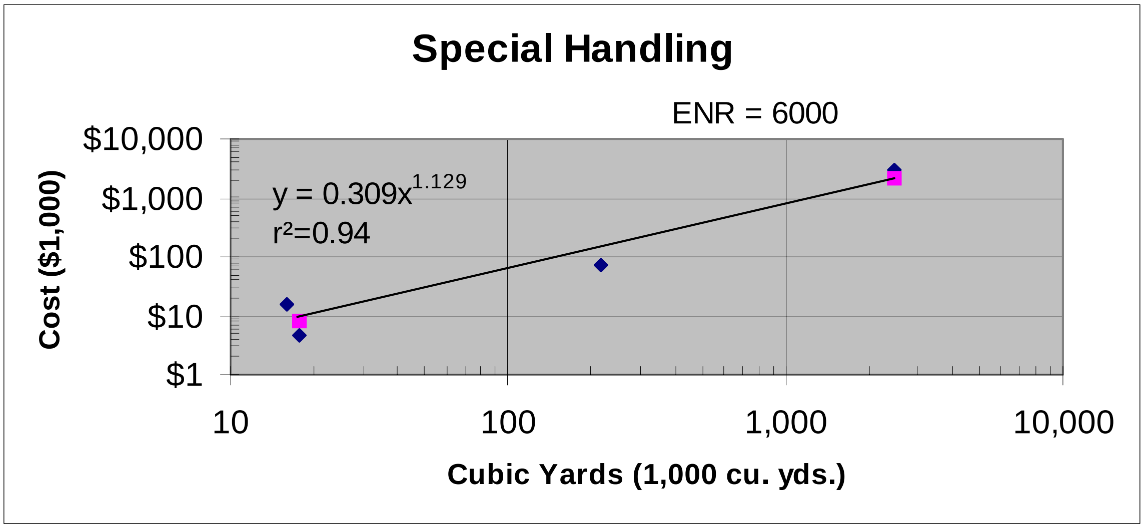
- Material placed 25' above floor
- Placed in 2' layers
- Up to 30" clean fill in between
- 25 tons/acre of lime on top
- 25' from outcrops
- 4' clean cover

Cost Equation:

Least Squares Best Fit Linear Regression expressed as $y = ax^b$, (ENR=6000):

$y = 0.309x^{1.129}$ where: x = Cubic Yards (1,000) $r^2 = 0.94$

y = Cost ($1,000) $n = 4$



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APPENDIX A: EPA Coal Remining Database - 61 State Data Packages

Information Collection

In an effort to assess the implementation of Best Management Practices during remining and reclamation activities in the Eastern United States, the EPA requested that the Interstate Mining Compact Commission (IMCC) collect information from stakeholder States involved in the IMCC Remining Task Force. The information was to support EPA's efforts to propose a coal remining subcategory under 40 CFR part 434. The goal of the information request was to collect existing information and data for assessment of the benefits, limitations, and feasibility of maintaining or improving environmental quality during and after remining operations. IMCC specifically requested information on abandoned mine land conditions, BMP implementation plans, water quality data, cost information, production statistics, and remining operations.

Six states (Alabama, Kentucky, Pennsylvania, Tennessee, Virginia, and West Virginia) responded to the request for information and submitted a total of 61 individual data packages from remining operations and reclamation projects. The data and information were submitted to EPA and were used to develop this BMP Guidance Manual in support of proposal of a Remining subcategory. Details of the types of information and data collected are provided in Table A.1. Data and information submitted included permits, permit applications, water quality monitoring reports, inspection reports, bore hole analysis logs, and operational information.

Table A.1: Data Targeted by EPA Information Request

Water Quality / Environmental Benefits

- Environmental Assessment
- Abatement Plans
- Impact Statistics:
  - Abandoned Surface Mine acres affected
  - Abandoned Underground Mine acres affected
  - Abandoned Highwall linear feet affected/removed
  - Pre-existing discharges encountered/affected
  - Stream Miles degraded by AMD (EPA 303(d) list)

Industry Profile - by State

- Number of companies
- Number of mine sites
- Types of mining activities
- Production statistics

Permit Applications

Permits

Environmental Resources Maps

Geology Information

- Overburden Analyses
- Borehole Analyses

Hydrologic Assessment

- Chemical Analysis (Background Monitoring Reports - Concentration)
  - (Flow, pH, Conductivity, Temp., Alkalinity, Acidity, Fe, Mn, Al, SO_4, TSS/TDS)

- Ground Water Information
- Surface Water Information
- Pre-existing Discharge Information
- Public Water Supply Information

Operational Information

- Reclamation/Operation Description and Maps
- Reclamation Cost Estimate / Time Schedule
- Identification of Final Grading and Drainage Pattern

Production Statistics

- Annual and overall coal production (tonnage)
- Annual and overall profit
- Number of employees

Cost Information

- Cost of BMP implementation versus cost of treatment (pre-existing discharges)

Best Management Practices (BMPs) - descriptions/typical combinations

- Regrading
- Daylighting
- Management of toxic and acid forming materials
- Addition of alkaline materials
- Hydrologic controls: diversion ditches, mine seals, hydraulic barriers
- Revegetation
- Stabilization
- Application of Biosolids

Remining Plans

- Identification of Affected Abandoned Mine Areas, Highwalls, and Preexisting Discharges
- Background History of Preexisting Discharges
- Baseline Pollution Load Analysis and Data
- Abatement Plan / BMP Application and Description / BMP Implementation Costs
- Water Quality Monitoring Program
- Anticipated Pollution Reduction Benefits - Impact on Water Quality - Benefits
- Treatment Costs Schedule

Topographic Maps

Remining Database

All data submitted for the 61 mining and reclamation operations has been entered into EPA's Remining Database, 1999, which was designed specifically to contain the data and information provided in these data packages. The database design is shown in Figure A-1. The final version of the database (May, 1999) is available on CD-ROM from EPA's Sample Control Center, and can be requested by calling the Sample Control Center at 703/461-2025. The CD-ROM is accompanied by the Coal Remining Database User's Manual and Database Data Element Dictionary.

The Remining Database contains both qualitative and quantitative data. Because not all solicited information was available or applicable to all 61 sites, some database fields are empty. Numeric data is provided in the geology, surface water, ground water, and mine discharge sections of the database and was entered as was reported by the States. The narrative information was taken from the mine site permits, permit applications, abatement plans, or related information.

Figure A.1: EPA Remining Database Design

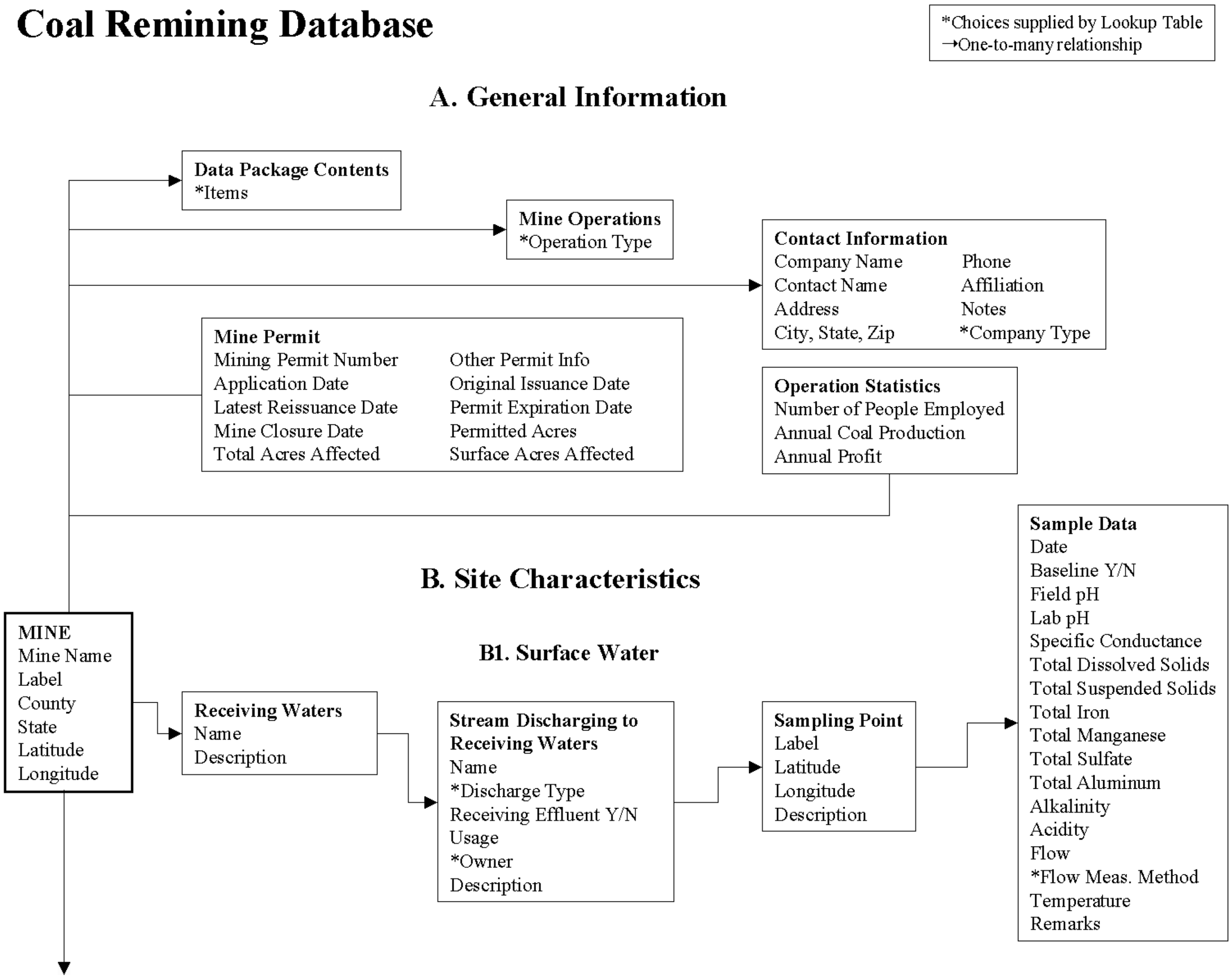


Figure A.1: EPA Remining Database (continued)

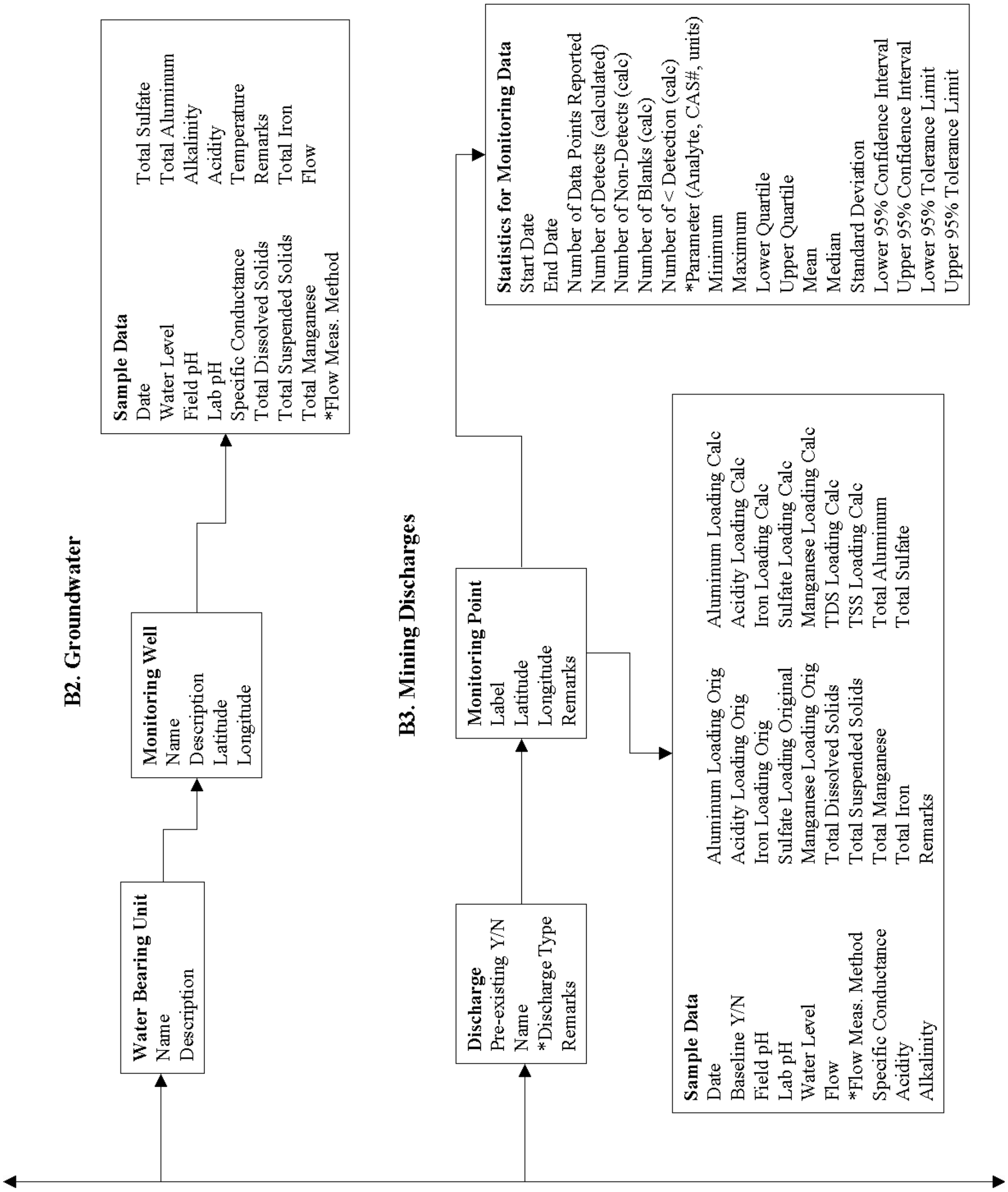
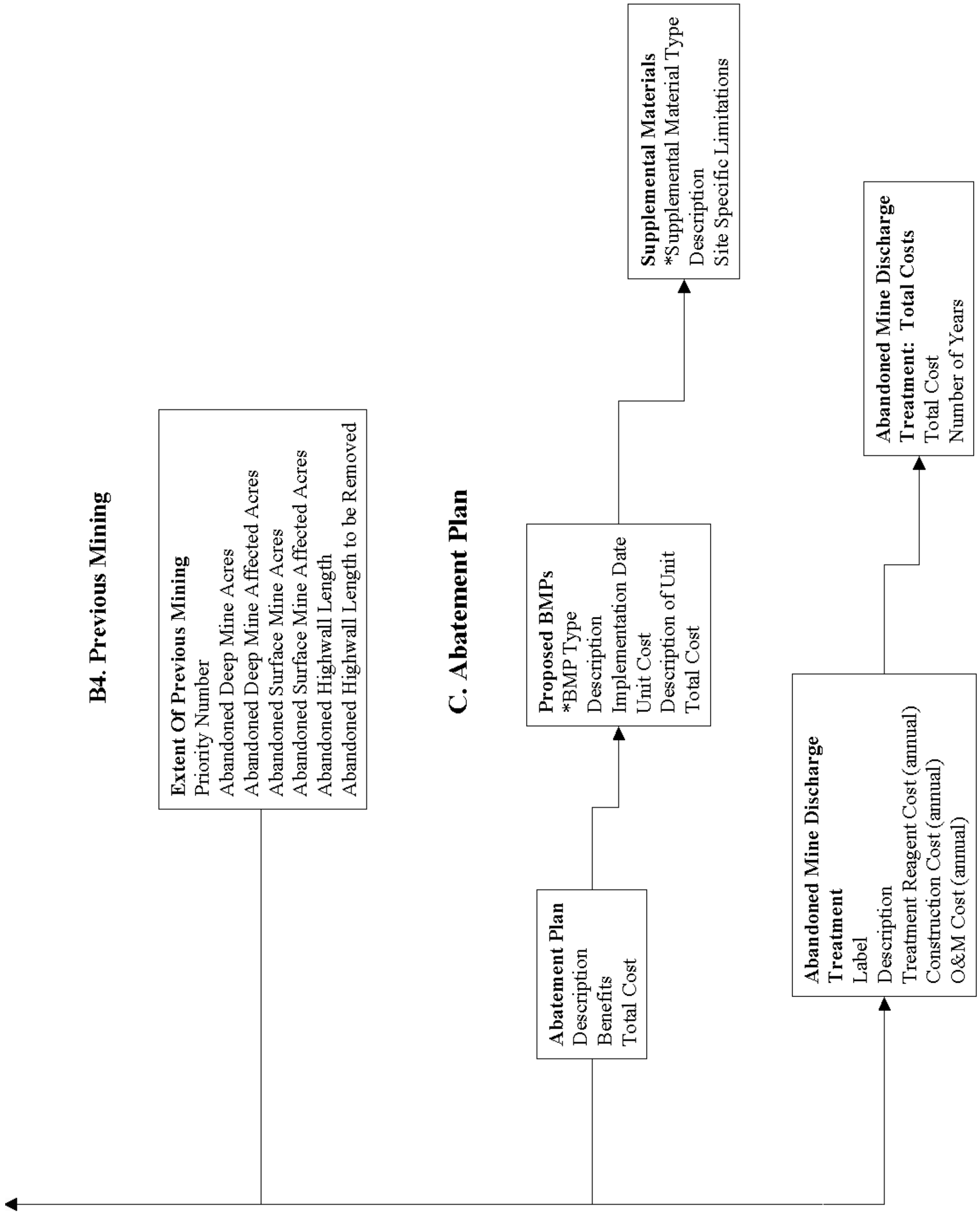


Figure A.1: EPA Remining Database (continued)



Information Summary

A summary of the information is given in the following tables.

- **Table A.2:** According to the information provided by the data packages and subsequent contact responses, 30 of the 61 operations were closed as of the date the data were submitted. Mine closure dates for mines that are known to be closed, are included in Table A.2.

- **Table A.3:** Contains information on the extent and type of abandoned mine land and the extent the abandoned mine land was expected to be affected by remining operations.

- **Table A.4:** Contains the type of mining or reclamation operations and the coal seams mined for each site. In some cases, a remining operation involved reclamation of abandoned spoils piles and no coal seams were mined.

- **Table A.5:** Lists the BMPs implemented during remining or reclamation activities. The BMPs are listed in the order presented in this document with the mine sites that implemented each BMP.

- **Table A.6:** Lists the BMPs implemented during remining or reclamation activities. The BMPs are organized by the mine sites which implemented them.

Table A.2: Mine Site Status and Permit Information

Mine ID	Issuance Date	Expiration Date	Mine Closure Date	Rahall Permit
AL(1)	07/05/1983	07/04/2003	Active Site	Yes
AL(2)	08/24/1989	08/23/1994	Early 1991	Yes
AL(3)	09/11/1989	09/10/1999	08/18/1998	Yes
AL(4)	12/06/1989	12/05/1999	Active Site	Yes
AL(5)	03/16/1990	03/15/2000	10/1995	Yes
AL(6)	09/19/1990	09/18/1995	08/1994	Yes
AL(7)	03/06/1991	03/05/1996	07/17/1992	Yes
AL(8)	06/03/1992	06/02/1999	Active Site	Yes
AL(9)	06/09/1992	06/08/1997	03/1994	Yes
AL(10)	03/08/1994	03/07/1999	02/1996	Yes
AL(11)	Unknown	Unknown	Mining Suspended	Yes
AL(12)	07/30/1991	Unknown	12/01/1998	Yes
AL(13)	01/23/1991	Unknown	10/10/1994	Yes
AL(14)	12/08/1986	Unknown	Early 1990	Yes
AL(15)	01/28/1988	01/27/1993	Permitted, but never mined	Yes
AL(16)	Unknown	Unknown	Reclaiming	Yes
KY(1)	07/18/1997	07/18/2002	Active	Yes
KY(2)	09/19/1997	09/19/2002	Active	Yes
KY(3)	08/13/1991	09/13/1994	Shut down 11/1998, may reopen	Yes
KY(4)	04/04/1995	08/31/2002	Active	Yes
PA (1)	04/02/1991	04/02/2001	10/30/1998	Yes
PA(2)	05/23/1989	05/23/1999	Active	Yes
PA(3)	05/25/1990	05/25/1995	06/23/1998	Yes
PA(4)	04/13/1988	04/13/2003	Active	Yes
PA(5)	02/01/1995	02/01/2000	04/09/1998	Yes
PA(6)	04/13/1990	04/13/2000	08/15/1996	Yes
PA(7)	09/15/1989	09/15/1999	05/01/1996	Yes
PA(8)	09/01/1993	09/01/1998	Active	Yes
PA(9)	Unknown	Unknown	Active	Yes
PA(10)	11/06/1990	11/06/1995	11/06/1995	Yes
PA(11)	04/25/1990	04/25/2000	Active	Yes
PA(12)	05/11/1992	05/11/2000	Active	Yes
PA(13)	02/24/1989	06/13/1999	Unknown	Yes
PA(14)	08/24/1987	08/24/2002	Active	Yes
PA(15)	03/15/1985	03/15/2000	Active	Yes
PA(16)	06/01/1992	06/01/2002	Active	Yes
PA(17)	02/12/1990	02/12/2000	Active	Yes
PA(18)	12/12/1996	12/12/2001	Active	Yes
PA(19)	12/23/1997	12/23/2002	Active	Yes
TN(1)	01/24/1992	Unknown	Active	No
TN(2)	07/25/1980	07/25/1981	Bond returned by State, 1984	No
TN(3)	05/08/1997	Unknown	04/09/1998, Phase I Bond Release Only	No

Mine ID	Issuance Date	Expiration Date	Mine Closure Date	Rahall Permit
TN(4)	11/22/1996	06/27/1998	Active	No
TN(5)	12/16/1991	Unknown	12/16/1994, Bond Forfeited	No
VA(1)	12/05/1994	07/24/2002	10/05/1998	No
VA(2)	10/03/1990	Unknown	12/07/1993	No
VA(3)	01/16/1988	Unknown	12/12/1997	No
VA(4)	None	None	Closed	No
VA(5)	None	None	Closed	No
VA(6)	01/16/1992	Unknown	Active	Yes
VA(7)	06/20/1990	Unknown	Active	Yes
VA(8)	09/27/1996	Unknown	Active	Yes
WV(1)	Unknown	Unknown	Active	Yes
WV(2)	10/16/1987	09/14/1992	12/05/1991	No
WV(3)	Unknown	07/14/1999	Active	Yes
WV(4)	02/21/1990	01/16/2003	11/16/1995, Phase I only	No
WV(5)	01/06/1994	01/06/1999	Active	Yes
WV(6)	03/26/1985	01/10/2000	Active	Yes
WV(7)	09/23/1983	09/23/1988	11/26/1991	No
WV(8)	08/05/1993	08/05/1998	Active	Yes
WV(9)	10/01/1981	09/14/1997	03/10/1997	No
WV(10)	03/25/1985	03/25/1990	07/10/1996	No

Table A.3: Extent of Abandoned Mine Lands

Mine ID	ADM[1] (Acres)	Affected ADM (Acres)	ASM[2] (Acres)	Affected ASM (Acres)	AH[3] (feet)	AH Removed (feet)
AL(1)	0	0				
AL(2)	0	0			0	0
AL(3)	0	0				
AL(4)	0	0				
AL(5)						
AL(6)	0	0	21			
AL(7)			64			
AL(8)						
AL(9)	0	0			0	0
AL(10)			18	18		
AL(11)						
AL(12)						
AL(13)						
AL(14)	0	0	9	9	0	0
AL(15)						
AL(16)						
KY(1)	36.1	36.1	186.7	186.7		
KY(2)			246.4	246.4		
KY(3)			181	181		
KY(4)			186.1	186.1		
PA (1)	29.8	3.6	0	0	0	0
PA(2)	56.5	0	50	50	0	0
PA(3)	90	49	69.9	33.8	0	0
PA(4)	81.8	0	43.8	43.8		
PA(5)	0	0	77.4	63.9	1100	1100
PA(6)	28.3	5	24.8	15.5	2600	1700
PA(7)					35; 50	
PA(8)	27.2	27.2	0	0	0	0
PA(9)	128.9	103.5	187.4	187.4	11,788	11,788
PA(10)	0	0	32.2	15.6	2150	1800
PA(11)	66.1	23.7	65	37.8		
PA(12)						
PA(13)						
PA(14)						
PA(15)						
PA(16)	0		311	311		
PA(17)	0	0	729.7	60.6 to 678	61730	10880 to 61730
PA(18)	2725	640	650	500	106,350	52,300
PA(19)	0	0	29.3	3	1450	1450
TN(1)						

Mine ID	ADM[1] (Acres)	Affected ADM (Acres)	ASM[2] (Acres)	Affected ASM (Acres)	AH[3] (feet)	AH Removed (feet)
TN(2)						
TN(3)						
TN(4)						
TN(5)						
VA(1)			265			
VA(2)			37.4			
VA(3)			105			
VA(4)						
VA(5)						
VA(6)	252.19		590	485.19		
VA(7)			1140.25	1140.25		
VA(8)			1440	1440		
WV(1)						
WV(2)						12000
WV(3)						
WV(4)	0	0	67	67	2,400	
WV(5)			92	92		
WV(6)						
WV(7)					13,000	
WV(8)						
WV(9)	94	94	54	54	8400	
WV(10)					17,832	

Note: Blank cells indicate that no mention was made of the existence of that type of abandoned mine land. Zeros are used in the table to show that the mining operator specifically mentioned that the type of abandoned mine land was not present or affected.

[1] Abandoned deep mine
[2] Abandoned surface mine
[3] Abandoned highwall

Table A.4: Type of Mining and Coal Seams Mined

Mine ID	Coal Seams Mined	Type of mining
AL(1)	Jefferson and Lick Creek	Surface Mining
AL(2)	Suwanee	Surface Mining
AL(3)	Blue Creek and Jefferson	Surface Mining
AL(4)	Black Creek	Surface Mining
AL(5)	Pratt Group	Surface Mining
AL(6)	Black Creek and Jefferson	Bituminous and Surface Mining
AL(7)	Utley Coal Group	Surface Mining
AL(8)	Mary Lee	Surface Mining
AL(9)	Atna, Cliff, and Underwood	Surface Mining
AL(10)	Guide, Upper Brookwood, Lower Brookwood, Milldale, Carter, and Johnson	Auger Mining and Surface Mining
AL(11)	Unknown	Bituminous and Surface Mining
AL(12)	Pratt, Nickel Plate, and America	Bituminous and Surface Mining
AL(13)	Guide, Brookwood, Upper Milldale, Lower Milldale, and Carter	Surface Mining
AL(14)	None	Bituminous, Surface Mining, and Coal Refuse Disposal
AL(15)	Unknown	Bituminous and Surface Mining
AL(16)	None	Coal Preparation Plant and Surface Mining
KY(1)	None	Coal Refuse Reprocessing, Surface Mining, and Remining
KY(2)	Amburgey, Hazard No. 4, Hazard No.4 Rider, Hz #7, Hz A, and Whitesburg	Surface Mining, Auger Mining, and Remining
KY(3)	USGS #11, USGS #12, and USGS #13	Auger Mining, Refuse Storage, and Surface Mining
KY(4)	USGS #11, USGS #12, USGS #13, USGS #14, and USGS #9	Auger Mining and Surface Mining
PA(1)	Lower Freeport, Upper Freeport, and Upper Freeport Rider	Bituminous, Surface Mining, and Reclamation Operations
PA(2)	USGS #11	Bituminous, Coal Refuse Reprocessing, Fly Ash/Bottom Ash Disposal, and Surface Mining
PA(3)	Pittsburgh	Bituminous and Surface Mining

Mine ID	Coal Seams Mined	Type of mining
PA(4)	Pittsburgh	Bituminous, Coal Refuse Reprocessing, and Remining
PA(5)	Lower Kittanning and Middle Kittanning	Bituminous and Surface Mining
PA(6)	Upper Freeport	Auger Mining, Bituminous, Remining, and Surface Mining
PA(7)	Boney, Lower Freeport, Upper Freeport, and Upper Kittanning	Auger Mining, Coal Refuse Disposal, and Surface Mining
PA(8)	Lower Kittanning and Middle Kittanning,	Surface Mining
PA(9)	Lower Freeport, Lower Kittanning, Middle Kittanning, and Upper Kittanning	Mobile Coal/ Rock Processing, Remining, and Surface Mining
PA(10)	Lower Bakerstown	Remining and Surface Mining
PA(11)	Lower Freeport, Upper Freeport, and Upper Kittanning	Auger Mining, Bituminous, and Surface Mining
PA(12)	Upper Freeport	Auger Mining, Bituminous, Coal Refuse Reprocessing, Fly Ash/Bottom Ash Disposal, and Surface Mining
PA(13)	Lower Freeport, Lower Kittanning, Middle Kittanning, and Upper Kittanning	Auger Mining, Bituminous, and Surface Mining
PA(14)	None	Anthracite, Coal Preparation Plant, Coal Refuse Disposal, Coal Refuse Reprocessing, and Fly Ash/Bottom Ash Disposal
PA(15)	Buck Mountain, Holmes, Mammoth Bottom, Mammoth Top, Orchard, Primrose, Seven Foot Vein, and Skidmore	Anthracite and Surface Mining
PA(16)	Buck Mountain, Holmes, Little Buck Mountain, Mammoth Bottom, Mammoth Top, Seven Foot Vein, and Skidmore	Anthracite, Coal Refuse Disposal, Coal Refuse Reprocessing, and Surface Mining
PA(17)	Bottom Split Mammoth Vein, Diamond Vein, Holmes, Middle Split, Mammoth Vein, Primrose, Seven Foot Vein, and Skidmore	Anthracite, Coal Refuse Disposal, Remining, and Surface Mining
PA(18)	Holmes, Mammoth, and Primrose	Anthracite, Coal Refuse Disposal, Coal Refuse Reprocessing, Fly Ash/Bottom Ash Disposal, Reclamation Operations, and Remining
PA(19)	Lower Kittanning No. 2 and Lower Kittanning No. 3	Remining and Surface Mining
TN(1)	Blue Gem, Coal Creek, and Jellico	Auger Mining and Surface Mining
TN(2)	Sewanee	Surface Mining
TN(3)	Sewanee	Deep Mining Reclamation and Surface Mining

Mine ID	**Coal Seams Mined**	**Type of mining**
TN(4)	Sewanee	Auger Mining and Surface Mining
TN(5)	Coal Creek	Reclamation Operations
VA(1)	Clintwood, Lower Bolling, Lower Standiford, Meade Fork, Pinhook, Upper Bolling, and Upper Standiford	Auger Mining, Remining, and Surface Mining
VA(2)	Lower Clintwood, Middle Clintwood, and Upper Clintwood	Auger Mining, Bituminous, Remining, and Surface Mining
VA(3)	Blairs, Clintwood, Dorchester, Lyons, and Norton	Auger Mining, Remining, and Surface Mining
VA(4)	No Seams Mined	Reclamation Operation
VA(5)	No Seams Mined	Reclamation Operation
VA(6)	Bastard Seam, Cedar Grove, Housecoal, Imboden Marker, Jackrock, Low Splint, Lower Kelly, Lower Standiford, Owl, Taggart, Taggart Marker, and Upper Standiford	Bituminous, Remining, and Surface Mining
VA(7)	Bottom Taggart, Cedar Grove, Imboden Marker, Kelly Rider, Lower Kelly, Lower Standiford, Owl, Taggart Marker, Top Taggart, Upper Kelly, and Upper Standiford	Surface Mining
VA(8)	Clintwood	Surface Mining
WV(1)	Clarion, Lower Kittanning, Lower Mercer, Middle Kittanning, and Upper Mercer	Deep Mining Reclamation, Remining, Surface Mining, and Underground Mining
WV(2)	Upper Freeport	Auger Mining and Surface Mining
WV(3)	Bakerstown, Brush Creek, Harlem, and Upper Freeport	Fly Ash/Bottom Ash Disposal, Remining Modification, and Surface Mining
WV(4)	Castle and Sewell	Surface Mining
WV(5)	Upper Freeport	Fly Ash/Bottom Ash Disposal and Surface Mining
WV(6)	Upper Freeport	Fly Ash/Bottom Ash Disposal and Surface Mining
WV(7)	Pittsburgh and Redstone	Surface Mining
WV(8)	Pittsburgh	Deep Mining Reclamation, Fly Ash/Bottom Ash Disposal, and Surface Mining
WV(9)	Big Inch, Little Pittsburgh, and Morantown	Reclamation Operations and Surface Mining
WV(10)	Unknown	Surface Mining

Table A.5: BMPs and the mines that implemented them

BMP	Mine ID
Exclusion of Infiltrating Surface Water	
Regrading Abandoned Mine Spoil	All mines
Installation of Surface Water Diversion Ditches	AL(1), AL(3), AL(4), AL(5), AL(11), KY(3), TN(5), VA(1), VA(4), VA(6), WV(1), WV(5), WV(6), WV(8)
Low-Permeability Caps or Seals	VA(5)
Revegetation	All mines
Stream Sealing	None
Control of Infiltrating Ground Water	
Daylighting of Underground Mines	AL(12), KY(2), PA(1), PA(3), PA(6), PA(7), PA(8), PA(9), PA(11), PA(12), PA(17), PA(18), TN(3), VA(1), VA(7), VA(8), WV(1), WV(2)
Sealing and Rerouting of Mine Water from Abandoned Workings	KY(3), KY(4), PA(1), PA(3), PA(10), TN(3), TN(4), VA(6)
Highwall Drains	None
Pit Floor Drains	TN(1), TN(2), TN(3), TN(5), VA(6), VA(8)
Grout Curtains	None
Ground Water Diversion Wells	None
Sediment control	
Site Stabilization	TN(4), VA(6)
Channel, Ditch, and Gulley Stabilization	None
Check Dams	None
Geochemical Best Management Practices	
Alkaline Addition	PA(1), PA(2), PA(8), PA(10), PA(11), PA(12), PA(14), PA(17), PA(18), PA(19), TN(3), TN(4), TN(5), WV(1), WV(3), WV(5), WV(6), WV(8)
Special Handling of Acid Forming Materials	AL(1), AL(2), AL(7), AL(10), AL(11), AL(14), KY(1), KY(2), KY(3), KY(4), PA(3), PA(5), PA(6), PA(7), PA(8), PA(11), PA(13), PA(14), PA(19), TN(1), TN(2), TN(4), VA(1), VA(2), VA(3), VA(4), VA(6), VA(7), WV(1), WV(4), WV(5), WV(6), WV(7), WV(8), WV(9)
Bactericides/ Anionic Surfactants	PA(10), VA(4)
Passive Treatment	TN(2), TN(3), TN(5), VA(4), VA(8), WV(5)

Table A.6: Mines and the BMPs implemented

Mine ID	BMPs Implemented
AL(1)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Special Handling of Acid Forming Materials
AL(2)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
AL(3)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches
AL(4)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches
AL(5)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches
AL(6)	Regrading Abandoned Mine Spoil, Revegetation
AL(7)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
AL(8)	Regrading Abandoned Mine Spoil, Revegetation
AL(9)	Regrading Abandoned Mine Spoil, Revegetation
AL(10)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
AL(11)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Special Handling of Acid Forming Materials
AL(12)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines
AL(13)	Regrading Abandoned Mine Spoil, Revegetation
AL(14)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
AL(15)	Regrading Abandoned Mine Spoil, Revegetation
AL(16)	Regrading Abandoned Mine Spoil, Revegetation
KY(1)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
KY(2)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials, Daylighting of Underground Mines
KY(3)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Sealing and Rerouting of Mine Water from Abandoned Workings, Special Handling of Acid Forming Materials
KY(4)	Regrading Abandoned Mine Spoil, Revegetation, Sealing and Rerouting of Mine Water from Abandoned Workings, Special Handling of Acid Forming Materials
PA(1)	Regrading Abandoned Mine Spoil, Revegetation, Sealing and Rerouting of Mine Water from Abandoned Workings, Alkaline Addition, Daylighting of Underground Mines
PA(2)	Regrading Abandoned Mine Spoil, Revegetation, Alkaline Addition
PA(3)	Regrading Abandoned Mine Spoil, Revegetation, Sealing and Rerouting of Mine Water from Abandoned Workings, Daylighting of Underground Mines, Special Handling of Acid Forming Materials
PA(4)	Regrading Abandoned Mine Spoil, Revegetation
PA(5)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials

Mine ID	**BMPs Implemented**
PA(6)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Special Handling of Acid Forming Materials
PA(7)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Special Handling of Acid Forming Materials
PA(8)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition, Special Handling of Acid Forming Materials
PA(9)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines
PA(10)	Regrading Abandoned Mine Spoil, Revegetation, Sealing and Rerouting of Mine Water from Abandoned Workings, Bactericides/ Anionic Surfactants, Alkaline Addition
PA(11)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition, Special Handling of Acid Forming Materials
PA(12)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition
PA(13)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
PA(14)	Regrading Abandoned Mine Spoil, Revegetation, Alkaline Addition, Special Handling of Acid Forming Materials
PA(15)	Regrading Abandoned Mine Spoil, Revegetation
PA(16)	Regrading Abandoned Mine Spoil, Revegetation
PA(17)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition
PA(18)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition
PA(19)	Regrading Abandoned Mine Spoil, Revegetation, Alkaline Addition, Special Handling of Acid Forming Materials
TN(1)	Regrading Abandoned Mine Spoil, Revegetation, Pit Floor Drains, Special Handling of Acid Forming Materials
TN(2)	Regrading Abandoned Mine Spoil, Revegetation, Pit Floor Drains, Special Handling of Acid Forming Materials, Passive Treatment
TN(3)	Regrading Abandoned Mine Spoil, Revegetation, Pit Floor Drains, Daylighting of Underground Mines, Special Handling of Acid Forming Materials, Sealing and Rerouting of Mine Water from Abandoned Workings, Alkaline Addition, Passive Treatment

Mine ID	BMPs Implemented
TN(4)	Regrading Abandoned Mine Spoil, Revegetation, Sealing and Rerouting of Mine Water from Abandoned Workings, Alkaline Addition, Special Handling of Acid Forming Materials, Site Stabilization
TN(5)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion, Ditches, Pit Floor Drains, Alkaline Addition, Passive Treatment
VA(1)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Installation of Surface Water Diversion Ditches, Special Handling of Acid Forming Materials
VA(2)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
VA(3)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
VA(4)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Special Handling of Acid Forming Materials, Bactericides/ Anionic Surfactants, Passive Treatment
VA(5)	Regrading Abandoned Mine Spoil, Revegetation, Low-Permeability Caps or Seals
VA(6)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Sealing and Rerouting of Mine Water from Abandoned Workings, Special Handling of Acid Forming Materials, Site Stabilization, Pit Floor Drains
VA(7)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Special Handling of Acid Forming Materials
VA(8)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Pit Floor Drains, Passive Treatment
WV(1)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines, Alkaline Addition, Installation of Surface Water Diversion Ditches, Special Handling of Acid Forming Materials
WV(2)	Regrading Abandoned Mine Spoil, Revegetation, Daylighting of Underground Mines
WV(3)	Regrading Abandoned Mine Spoil, Revegetation, Alkaline Addition
WV(4)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
WV(5)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Alkaline Addition, Passive Treatment, Special Handling of Acid Forming Materials
WV(6)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Alkaline Addition, Special Handling of Acid Forming Materials
WV(7)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
WV(8)	Regrading Abandoned Mine Spoil, Revegetation, Installation of Surface Water Diversion Ditches, Alkaline Addition, Special Handling of Acid Forming Materials
WV(9)	Regrading Abandoned Mine Spoil, Revegetation, Special Handling of Acid Forming Materials
WV(10)	Regrading Abandoned Mine Spoil, Revegetation

Appendix B: Pennsylvania Remining Site Study

The Pennsylvania Department of Environmental Protection (PA DEP) has been issuing remining permits since 1984. By 1997, over 260 remining permits had been issued throughout Pennsylvania. This number includes currently active and reclaimed sites. PA DEP routinely reviews self-monitoring reports from these permits to verify that water quality loading limits have not been exceeded. On an annual basis and for all bond release applications, the baseline pollution load is compared to recent pollution load data using a statistical protocol for determining whether there has been a significant increase in the baseline pollution load. If the analysis shows a statistically significant increase in the baseline pollution load, then the operator is required to treat the discharge to at least its original baseline loading rate and reclamation bonds are withheld until the discharge returns to baseline levels or below. Over 10 years of experience shows that baseline excedences are a very rare occurrence. Of these 260 permits, only 5, or less than 2 percent, have ever registered significant increases from baseline pollution load, requiring long-term treatment. In 1998, PA DEP developed a remining database to determine the success of Pennsylvania's remining program in terms of water quality compliance, and the extent to which remining has reduced pollution loads from pre-existing mine discharges. These evaluations were made by comparing pre-mining and post-mining loads at individual pre-existing discharges for acidity, iron, manganese, aluminum, sulfate, and flow. Additionally, the data were broken down by best management practices (BMPs) that were implemented hydrologically upgradient from each discharge to allow evaluation of the efficiencies of individual and combined BMPs.

The database consists of 241 groundwater discharges (or hydrologic units) from 112 mine sites that were used for statistical analysis. These discharges are hydrologically connected to the mining and reflect the effects of the upgradient remining. Only mines that were Stage II bond released (completely backfilled and revegetated) were included. The sites in the database were further restricted to Pennsylvania's Bituminous Coal Field. This restriction was made because (1) the geology, hydrology, mining methods, and some of the BMPs in the Anthracite Region are substantially different from the Bituminous Region, (2) the Bituminous Region has had a much greater number of remining permits issued and for a longer period of time, and (3) the Bituminous Region has geology, hydrology, mining methods, and BMPs similar to the rest of the Appalachians. The distribution of mine sites and discharges in the database are depicted by county on Figure B.1. As can be seen, remining sites are spread across the Bituminous Region. The remining sites are surface mines, with the exception of six coal refuse removal sites. There is a total of eight discharges associated with the coal refuse removal sites, compared to 233 discharges associated with surface mining.

The effluent limits which are typically established by best professional judgement (BPJ) analysis are acidity, total iron, total manganese, and total aluminum. Load based BPJ limits are established using baseline data. If water quality concentrations are below best available technology (BAT) limits, then BAT limits are applied. Acidity and sulfate are the most common post-mining pollutants from remining sites, thus their greater representation in the statistical database (Table B.1) than for other pollutants. Iron, manganese, and aluminum to varying degrees meet BAT requirements and therefore do not always undergo a BPJ analysis, thus their less frequent representation in the database.

Acidity has been selected in Pennsylvania for BPJ analysis preferentially to pH because a baseline load can be calculated for acidity, whereas pH does not readily lend itself to calculation of load. Acidity includes "potential" acidity which is latent in "mineral" acidity, a form that is often not represented by pH. Mineral acidity is that portion of acidity that is generated when iron, manganese, aluminum, and some other metals precipitate from solution (see equation 1, Section 2.0). When determining the amount of chemical treatment needed to neutralize acid or to bring the pH up to a certain level, it is acidity that is used to perform these calculations, not pH. Acidity is in units of mg/L calcium carbonate, the same as used for alkalinity.

Figure B.1 Mine Sites and Discharges by County in Pennsylvania

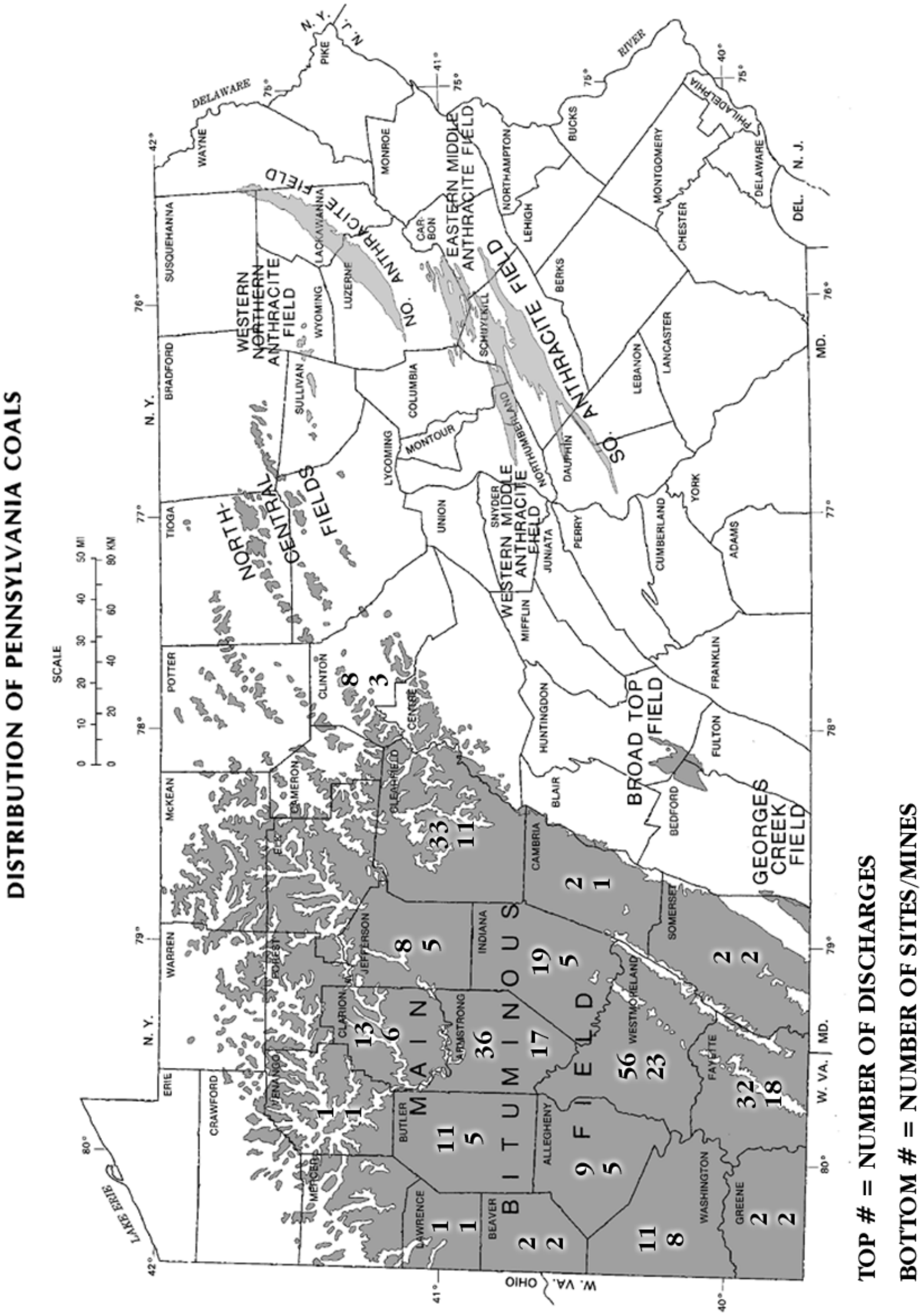


Table B.1 is a compilation of baseline and post-mining median loading for acidity, iron, manganese, aluminum, sulfate, and flow for each discharge, and a sum of the total change in pollution load for each water quality parameter. From left to right, Table B.1 shows monitoring point ID (listed by permit number), permit baseline year (pre-mining data), review year (post-mining data), baseline median load, post-mining median load, percent change in median, baseline upper confidence interval, baseline lower confidence interval, post-mining upper confidence interval, post-mining lower confidence interval, and "evaluation." The statistical summaries for baseline and post-mining loads typically include 12 monthly samples. The confidence intervals give the range of values around the median in which the true population median occurs with a 95% probability. Thus, a comparison between baseline and post-mining confidence intervals indicates whether or not there has been a statistically significant change in water quality. The four evaluation categories are no significant difference, significantly better, significantly worse and eliminated.

- The eliminated category occurs where the post-mining upper confidence interval is zero lbs/day.
- Significantly better occurs where the post-mining upper confidence limit is less than the baseline lower confidence limit.
- Significantly worse occurs where the post-mining lower confidence limit is higher than the baseline upper confidence limit.
- No significant difference occurs where the confidence intervals overlap.

Table B.1: Summary Statistics of Baseline and Post-Mining Loadings, by Parameter

1= Discharge Significantly Worsened
2= No Significant Difference in Discharge
3= Discharge Significantly Better
4= Discharge Eliminated

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Acidity											
Allegheny-1	10	1986	1995	26.81	66.8	149.16%	34.87	18.71	105.34	28.26	2
	2	1986	1995	18.01	2.34	-87.01%	21.25	14.76	2.92	1.76	3
Allegheny-2	S-6	1989	1998	5.83	6.04	3.60%	12.43	-0.77	8.54	3.55	2
	S-7	1989	1989	554.92	0	-100.00%	844.09	265.74	0	0	4
Allegheny-3	d-1p	1991	1998	4.18	1.3	-68.90%	5.04	3.33	1.96	0.64	3
Allegheny-4	BS12	1991	1995	196.4	10.07	-94.87%	209.51	183.29	22.36	-2.22	3
	MD1	1991	1995	119.48	22.44	-81.22%	139.22	99.73	37.96	6.93	3
	MD2	1991	1995	14.85	0	-100.00%	26.68	3.02	0.19	-0.19	3
Allegheny-5	MP-2	1993	1995	8.17	1.33	-83.72%	15.64	0.7	2.52	0.14	2
Armstrong-1	1A	1984	1990	2.04	1.57	-23.04%	3.28	0.79	3.5	-0.37	2
Armstrong-2	D-1	1986	1995	7.5	5.65	-24.67%	17.71	-2.71	9.21	2.09	2
	D-112	1986	1995	0.42	0.75	78.57%	1.05	-0.21	1.2	0.3	2
	D-4	1986	1995	6.83	9.91	45.10%	11.34	2.32	20.45	-0.63	2
Armstrong-3	w-1A	1986	1992	11.65	9.38	-19.48%	15.64	7.65	12.72	6.02	2
	w-2A	1986	1992	11.12	37.5	237.23%	16.24	5.98	57.3	16.3	1
	w-3A	1986	1992	0.72	0.24	-66.67%	1.57	-0.14	0.28	0.19	2
Armstrong-4	GK-13	1987	1993	0.54	0.2	-62.96%	0.75	0.31	0.46	-0.07	2
	GK-17	1987	1988	0	0.01	N/A	0.01	0	0.03	0	2
Armstrong-5	MP-2	1988	1993	4.27	0	-100.00%	6.28	2.26	0	0	4
Armstrong-7	MP14	1988	1997	1.54	2.5	62.34%	2.72	0.36	3.2	1.8	2
	MP15	1988	1997	11.01	1.42	-87.10%	18.7	3.32	6.08	-3.25	2
	MP17	1988	1997	0.79	12.43	1473.42%	5.46	-3.89	20.58	4.27	2
	MP21	1988	1997	0.04	0.2	400.00%	0.15	-0.06	0.84	-0.45	2
	MP22	1988	1997	0.1	1.72	1620.00%	0.75	-0.55	6.64	-3.22	2
	MP23	1988	1997	13.72	9.41	-31.41%	21.27	6.18	21.87	-3.07	2
	MP24	1988	1997	1.2	1.25	4.17%	2.02	0.38	2.09	0.41	2
Armstrong-8	c3-a	1988	1998	13.97	0	-100.00%	24.98	2.96	0	0	4
	md-2	1988	1998	1.85	4.76	157.30%	3.63	0.06	7.13	2.39	2
Armstrong-9	HU1	1988	1998	19.56	22.82	16.67%	28.78	10.35	34.62	11.01	2
Armstrong-10	C-11	1989	1995	2.9	1.66	-42.76%	3.44	2.36	2.54	0.77	2
	S-20	1989	1995	47.1	50.13	6.43%	54.02	40.18	61.63	38.63	2
Armstrong-11	HU1	1990	1997	3.02	0	-100.00%	6.69	-0.65	0	0	4

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Armstrong-12	mp2	1991	1995	19.73	0.5	-97.47%	33.38	6.09	0.79	0.21	3
	mph	1991	1995	3.92	1.09	-72.19%	14.64	-6.8	1.64	0.54	2
Armstrong-13	41	1990	1995	9.17	0	-100.00%	12.13	6.2	0.02	-0.02	3
	Unit 2	1990	1995	185.99	3.32	-98.21%	212.48	159.5	5.43	1.2	3
Armstrong-14	1	1991	1993	2.38	0	-100.00%	4.82	-0.07	0	0	4
Armstrong-15	V2	1992	1997	32.79	10.96	-66.58%	42.53	23.05	22.33	-0.41	3
Armstrong-16	HU1	1993	1998	0.07	0	-100.00%	0.57	-0.43	0	0	4
Armstrong-17	HU1	1994	1998	0.39	0.17	-56.41%	0.63	0.15	0.4	-0.05	2
Armstrong-18	D1	1994	1998	0.26	0	-100.00%	0.37	0.14	0.01	-0.01	3
Beaver-1	S-10	1988	1995	4.84	0.43	-91.12%	6.67	3.01	3.35	-2.49	2
Butler-1	5W	1986	1991	1.71	1.95	14.04%	6.77	-3.35	3.55	0.35	2
Butler-2	2W	1984	1989	0.11	0	-100.00%	0.36	-0.14	0	0	4
	5AW	1984	1989	0.17	0.28	64.71%	0.66	-0.32	0.7	-0.14	2
	8W	1984	1989	0.94	0.19	-79.79%	1.55	0.33	0.36	0.03	2
Butler-3	S-116	86	1994	29.85	7.45	-75.04%	35.8	23.9	12.66	2.24	3
	S-13	86	1994	5.34	0	-100.00%	7.52	3.16	0	0	4
	S-200	86	1994	0.85	0	-100.00%	2.33	-0.63	0	0	4
	S-91	86	1994	3.59	0	-100.00%	5.31	1.87	0	0	4
	S-95/96	86	1994	1.7	0	-100.00%	3.01	0.39	1.62	-1.62	2
Butler-4	DR2	1991	1998	17.62	0	-98.58%	22.9	12.34	0	0	4
Butler-5	1	1991	1998	50.75	20.95	-58.72%	62.77	38.72	70.79	-28.89	2
Cambria-1	MP 9	1990	1995	3.49	0.03	-99.14%	4.63	2.35	0.06	0	3
	MP 13	1990	1995	6.65	0	-100.00%	8.71	4.58	0	0	4
Clarion-1	SP-1	1985	1995	192.07	83.01	-56.78%	244.57	139.57	100.01	66.01	3
	SP-28	1985	1995	31.73	12.22	-61.49%	44.73	18.73	16.4	8.05	3
	SP-5	1985	1995	4.32	0	-100.00%	5.81	2.83	0.27	-0.27	3
	SP-6	1985	1995	75	0	-100.00%	99.91	50.09	0	0	4
Clarion-2	1	1986	1989	0.19	0.401	111.05%	0.35	0.03	1.01	-0.2	2
Clarion-3	RH-78	1990	1994	4.95	0	-100.00%	5.81	4.1	0	0	4
	RH-79	1990	1994	3.91	0	-100.00%	4.71	3.11	0	0	4
	RH-82	1990	1994	2.48	0.05	-97.98%	3.08	1.87	0.1	-0.01	3
	RH-84	1990	1994	1.44	0.58	-59.72%	1.82	1.07	1.53	-0.37	2
	RH-91	1990	1994	0.07	0	-100.00%	0.13	0.02	0.02	-0.02	2
	RH-93	1990	1994	0.17	0.01	-94.12%	0.27	0.08	0.02	0	3
	RH-94	1990	1994	1.56	0	-100.00%	1.82	1.3	0	0	4
	RH-96	1990	1994	4.81	0	-100.00%	8.15	1.46	0	0	4
Clarion-4	1	1990	1996	0.47	0	-100.00%	0.62	0.32	0	0	4
	2	1990	1996	0.84	0.13	-84.52%	1.07	0.61	0.25	0.02	3
Clarion-5	DR-1	1990	1992	17.6	39.67	125.40%	29.46	10.52	73.23	6.11	2

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Clarion-6	1	1992	1998	0.11	0	-100.00%	0.22	0	0	0	4
	2	1992	1998	0.01	0	-100.00%	0.06	-0.04	0	0	4
	3	1992	1998	0.66	0	-100.00%	1.22	0.09	0	0	4
Clearfield-1	unit 1	1985	1998	230.02	71.33	-68.99%	289.12	170.92	107.81	34.85	3
Clearfield-2	W10	1985	1998	23.08	23.6	2.25%	38.1	8.04	50.89	-3.69	2
	W42	1985	1998	31.27	47.17	50.85%	48.42	14.11	73.56	20.78	2
	W43	1985	1998	69.05	125.32	81.49%	111.18	26.91	215.63	35.02	2
	W44	1985	1998	36.61	47.08	28.60%	61.14	12.06	70.36	23.8	2
Clearfield-3	SF-1	1986	1998	0.42	0.11	-73.81%	0.59	0.24	0.18	0.03	3
	SF10	1986	1998	2.15	0.03	-98.60%	3.69	0.59	0.07	0	3
	SF4	1986	1998	0.14	0.06	-57.14%	0.25	0.02	0.13	-0.01	2
	SF6	1986	1998	0.59	0.49	-16.95%	9.14	-7.97	0.98	0.01	2
	SF61	1986	1998	8.47	1.06	-87.49%	14.84	2.08	6.53	-4.42	2
Clearfield-4	tk-18	1985	1997	35.59	42.44	19.25%	48.81	22.37	51.62	33.26	2
	tk-21	1985	1997	18.3	1.65	-90.98%	29.08	7.52	6.35	-3.06	3
	TK-3	1985	1997	38.46	29.6	-23.04%	42.63	34.29	38.05	21.16	2
	tk-37	1985	1997	7.19	5.33	-25.87%	11.29	3.09	6.67	3.98	2
	tk-4	1985	1997	1.28	0.41	-67.97%	1.77	0.79	0.52	0.3	3
	tk-7	1985	1997	4.33	0	-100.00%	5.47	3.19	0.01	-0.01	3
Clearfield-5	SV-5	1988	1992	8.15	12	47.24%	10.56	5.73	15	10	2
	SV-8	1988	1992	12.78	11.56	-9.55%	19.68	5.87	15.02	8.1	2
Clearfield-6	R-3	1988	1995	10.58	0.065	-99.39%	15.01	6.14	0.4	-0.27	3
	R-5	1988	1995	4.19	1.4	-66.59%	6.47	1.9	2.09	0.71	2
	R-8	1988	1995	12.18	0	-100.00%	19.48	4.87	0	0	4
Clearfield-7	12	1989	1997	1.35	0.97	-28.15%	2.28	0.41	1.68	0.26	2
	13	1989	1997	209.67	173.81	-17.10%	269.13	150.12	203.94	143.68	2
Clearfield-8	TK4	1990	1996	0.92	0.4	-56.52%	1.24	0.6	0.54	0.31	3
	TK7	1990	1996	1.44	0	-100.00%	2.1	0.78	0.01	-0.01	3
Clearfield-9	1	1990	1994	18.03	0	-100.00%	29.12	6.94	0	0	4
	2	1990	1994	0.19	0	-100.00%	0.75	-0.87	0	0	4
Clearfield-10	HU 1	1992	1998	4.85	4.34	-10.52%	8.22	1.48	6.86	1.82	2
	HU 2	1992	1998	1.5	0.75	-50.00%	1.99	1	1.15	0.35	2
	HU 3	1992	1998	8.24	3.17	-61.53%	10.62	5.86	4.39	1.95	3
Clearfield-11	subf-a	1993	1994	5.84	6.5	11.30%	8.95	2.74	8.53	4.46	2
	subf-b	1993	1994	0.4	0.13	-67.50%	0.67	0.14	0.35	0	2
	subf-c	1993	1994	8.57	2.85	-66.74%	10.88	6.26	5.09	0.61	3
Clinton-1	96	1981	1995	11.12	0	-100.00%	18.63	3.6	0	0	4
	97	1981	1995	11.12	0	-100.00%	18.63	3.6	0	0	4
	13	1981	1995	20.49	0	-100.00%	31.44	9.53	0	0	4
	15A	1981	1995	8.11	0	-100.00%	13.64	2.58	0	0	4
	SNW 1A	1981	1996	41.22	32.27	-21.71%	61.34	21.06	51.09	13.5	2
Clinton-2	GR-9	1988	1993	21.45	2.59	-87.93%	44.59	-1.69	24.17	-18.99	2
Clinton-3	SEH-31	1990	1993	19.94	6.21	-68.86%	25.79	14.09	-6.02	18.44	3
	SHE-30	1990	1993	0.95	5.1	436.84%	1.85	0.05	7.09	3.1	1
Fayette-1	mp-4	1989	1993	12.9	4.88	-62.17%	16.95	8.84	5.12	4.64	3
	mp-5	1989	1993	14.95	0	-100.00%	20.33	9.56	0	0	4
	mp-6	1989	1993	2.24	0	-100.00%	4.79	-0.32	0	0	4
	mp-8	1989	1993	15.11	1.17	-92.26%	19.63	10.58	1.23	1.11	3

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Fayette-2	HU-1	1984	1992	622.81	167.96	-73.03%	919.04	326.57	185.12	150.79	3
Fayette-3	MS100	1988	1995	38.94	0.3	-99.23%	54.78	23.1	0.72	-0.12	3
Fayette-4	MP6	1988	1993	2.97	3.09	4.04%	6.72	-0.79	11.17	-4.98	2
Fayette-5	mp-4	1988	1998	1408.74	932.4	-33.81%	1723	1094	1063	801	3
	mp-hua	1988	1998	1441	1039	-27.9%	2218	663	1384	694	2
Fayette-6	MP-1	1988	1994	170.29	15.73	-90.76%	252.6	87.98	44.07	-12.61	3
Fayette-7	MP48	1989	1996	418.49	317.51	-24.13%	546.47	290.51	505.22	129.79	2
	MP49	1989	1996	92.84	135.78	46.25%	134.95	50.72	177.84	93.72	2
Fayette-8	MP-15	1988	1994	142.71	64.08	-55.10%	170.13	115.29	193.76	-65.6	2
Fayette-9	MP-28	1990	1998	149.83	123.78	-17.39%	247.01	52.65	200.72	46.85	2
Fayette-10	mp-1	1989	1992	161.85	38.45	-76.24%	204.87	118.84	62.16	14.74	3
	mp-11	1989	1992	30.61	15.88	-48.12%	43.13	18.09	34.52	-2.77	2
	mp-2	1989	1992	4.23	8.51	101.18%	5.87	2.59	12.05	4.98	2
Fayette-11	mp 29	1991	1998	30.78	28.22	-8.32%	71.31	-9.75	45.92	10.52	2
Fayette-12	Mp68	1991	1997	2.46	3.75	52.44%	4.91	0.01	6.47	1.03	2
Fayette-13	D5	1991	1995	12.85	9.84	-23.42%	17.64	8.05	13.08	6.59	2
Fayette-14	mp-19	1991	1998	5.84	0	-100.00%	12.46	-0.77	0	0	4
	mp-57	1991	1998	29.06	3.33	-88.54%	58.11	0	8.56	-1.89	2
	mp-60	1991	1998	79.71	32.07	-59.77%	130.24	29.18	71	-6.86	2
	mp56	1991	1998	54.62	511.67	836.78%	175.15	-65.91	918.61	104.72	2
Fayette-15	MD1/MD2	1991	1995	1.68	0.04	-97.62%	5.61	-2.26	0.1	-0.03	2
	MD8/BS29	1991	1995	14.59	1.06	-92.73%	36.39	-7.21	1.31	0.8	2
Fayette-16	MP-42	1994	1996	3.8	0.65	-82.89%	22.71	-15.12	11.82	-10.52	2
	MP-8	1994	1996	92.32	32.94	-64.32%	132.84	51.79	78.99	-13.11	2
Greene-1	MP-51	1987	1988	16.35	0	-100.00%	22.77	9.93	0	0	4
Greene-2	hu1	1989	1994	106.48	19.65	-81.55%	186.91	26.06	34.31	4.99	2
Indiana-1	H	1988	1995	150.24	173.09	15.21%	225.69	74.77	222.89	123.29	2
	J	1988	1995	52.76	55.06	4.36%	90.82	14.69	113.87	-3.76	2
	K	1988	1995	19.6	23.88	21.84%	24.89	14.3	38.6	9.15	2
	L	1988	1995	23.93	0.42	-98.24%	31.92	15.93	12.56	-11.73	3
	M	1988	1995	11.58	7.4	-36.10%	25.25	-2.1	16.13	-1.33	2
	N	1988	1995	3.98	0.56	-85.93%	10.29	-2.34	1.01	0.11	2
	O	1988	1995	0	0	N/A	0.01	0	0	0	4
Indiana-2	MP-5	1988	1997	209.22	116.77	-44.19%	348.3	70.12	200.3	33.25	2
	MP-15	1988	1997	6.09	0.28	-95.40%	9.93	2.23	0.56	0	3
Indiana-3	1 (A)	1992	1998	1.34	0	-100.00%	2.62	0.07	0.01	-0.01	3
	2 (B)	1992	1998	147.38	15.38	-89.56%	180.55	114.2	23.62	7.13	3
	3 (C)	1992	1996	171.92	83.29	-51.55%	213.48	130.36	234.27	-67.69	2
	4 (D)	1992	1998	70.4	7.64	-89.15%	87.85	52.95	16.45	-1.17	3
Indiana-4	1	1992	1998	6.12	6.16	0.65%	7.18	5.07	8.85	3.47	2
	MP-51	1992	1998	15.39	0	-100.00%	19	11.78	0	0	4
	MP-52	1992	1998	1.2	0.54	-55.00%	6.24	-3.84	0.86	0.22	2
Jefferson-1	1	1984	1993	14.28	66.62	366.53%	29.91	-1.35	154.42	-21.17	2
Jefferson-2	MP-13	1986	1996	1.6	2.38	48.75%	2.14	1.06	4.87	-0.11	2
Jefferson-3	HU-1	1989	1992	0.01	0	-100.00%	0.09	-0.07	0	0	4
Jefferson-4	HU-1	1989	1996	48.11	1.09	-97.73%	56.81	39.41	4.25	-2.07	3
Jefferson-5	MP-33	1989	1998	3.97	3.77	-5.04	6.6	1.34	5.43	2.1	2
	MP-8B	1989	1998	152.39	99.52	-34.69%	187.55	117.23	162.98	36.06	2
Jefferson-6	S-25	1993	1998	1.67	0.11	-93.41%	2.86	0.48	0.18	0.04	3
	s-34	1993	1998	1.8	1.05	-41.67%	2.93	1.1	2.89	-0.89	2

Permit ID	**Monitoring Point ID**	**Permit Baseline Year**	**Review Year**	**Baseline Median**	**Post-Mining Median**	**% Change In Median**	**Baseline Upper Limit**	**Baseline Lower Limit**	**Post-Mining Upper Limit**	**Post-Mining Lower Limit**	**Evaluation**
Jefferson-7	MP-1	1991	1995	0.36	0	-100.00%	0.52	0.19	0	0	4
Lawrence-1	1	1992	1998	3.47	0	-100.00%	4.98	1.96	0	0	4
Somerset-1	SP16	1989	1998	20.18	22.12	9.61%	26	14.36	24.09	20.14	2
Venango-1	1	1989	1994	20.94	11.49	-45.13%	39.36	11.14	21.25	1.72	2
Wash. -1	HU1	1986	1993	295.51	39.39	-86.67%	388.62	202.78	57.28	21.49	3
Wash. -2	A	1985	1998	115.68	0.1	-99.91%	160.2	71.16	0.17	0.03	3
Wash. -3	CV103	1985	1998	9411.66	1324.6	-85.93%	11146.92	7676.39	2020.61	628.6	3
	CV4	1985	1998	1350.09	118.4	-91.23%	1585.7	1114.47	142.12	94.67	3
Wash. -4	MP-1	1989	1998	652.11	6.03	-99.08%	1044.41	259.8	8.44	3.61	3
	MP-2	1989	1998	535.6	0	-100.00%	747.88	322.24	0	0	4
Wash. -5	d-1	1987	1996	4.18	0.79	-81.10%	5.04	3.33	1.71	-0.14	3
Wash. -7	se1a	1995	1998	1.1	0	-100.00%	3.57	-1.38	0	0	4
Westmoreland-1	MP10	1984	1993	30.64	27.71	-9.56%	39.11	22.16	47.49	7.91	2
	MP7	1984	1993	30.28	45.08	48.88%	40.96	19.59	67.15	23	2
	MP9	1984	1993	0.21	0.69	228.57%	0.48	-0.05	1.29	0.08	2
Westmoreland-2	S8	1985	1994	30.84	7.78	-74.77%	43.85	17.83	17.79	-2.23	3
Westmoreland-3	CP2	1986	1990	11.77	4.52	-61.60%	16.98	6.55	6.84	2.19	2
	Culvert	1986	1986	3.58	0.22	-93.85%	6.03	1.12	0.54	-0.11	3
Westmoreland-4	MD-1	1986	1990	3.74	5.41	44.65%	25.67	-18.2	18.86	-8.05	2
	MD-3	1986	1990	5.94	0	-100.00%	54.68	-42.8	0.12	-0.13	2
	MD-4	1986	1990	16.99	9.68	-43.03%	41.96	-7.98	13.7	5.64	2
	MD-6	1986	1990	167.25	0.97	-99.42%	443.44	-108.96	0.98	0.96	2
	MD-7	1986	1990	125.77	28.78	-77.12%	250.89	0.63	50.23	7.32	2
Westmoreland-5	HU-1	1986	1996	570.84	401.91	-29.59%	972.94	168.74	602.25	201.56	2
Westmoreland-6	M	1985	1993	8.21	7.02	-14.49%	14.86	1.55	9.76	4.28	2
	N	1985	1993	2.13	0.57	-73.24%	5.18	0	2.64	-1.52	2
Westmoreland-7	MP-3	1986	1991	9.76	0.92	-90.57%	10.48	9.03	1.49	0.36	3
	MP-4	1986	1991	284	365.04	28.54%	569.5	-1.5	608.76	121.33	2
Westmoreland-8	MP-4	1987	1998	12.15	0	-100.00%	18.04	6.26	0	0	4
Westmoreland-9	MP-46	1987	1993	590.44	525.86	-10.94%	748.65	432.22	762.95	288.77	2
	MP-47	1987	1993	469.53	663.91	41.40%	687.42	251.63	1230.27	97.53	2
	MP-51	1987	1993	8.1	18.78	131.85%	11.25	4.94	30.47	7.08	2
	MP-52	1987	1993	2.96	2.26	-23.65%	3.96	1.95	9.6	-5.08	2
	MP-56	1987	1993	6.34	6.06	-4.42%	9.69	2.98	10.54	1.57	2
	MP-60	1987	1993	6.36	2.69	-57.70%	9.68	3.02	6.94	-1.58	2
	MP-A	1987	1995	5.95	1.4	-76.47%	12.75	-0.87	2.06	0.75	2

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West-moreland-10	MP12	1988	1995	37.68	0.76	-97.98%	93.48	-18.13	1.11	0.41	2
West-moreland-11	MP3	1988	1992	1245.66	842.7	-32.35%	1413.04	1078.28	1042.3	643.1	3
West-moreland-12	MP-1	1988	1995	439.13	0	-100.00%	594.61	283.65	0	0	4
	MP-2	1988	1995	8.55	7.76	-9.24%	14.41	2.68	14.77	0.75	2
	MP-3	1988	1995	41.79	30.24	-27.64%	72.07	11.51	36.04	24.44	2
	MP-4	1988	1995	81.63	0.37	-99.55%	129.46	33.8	3.54	-2.79	3
	MP-5	1988	1995	34.39	83.86	143.85%	73.68	-4.91	131.99	34.73	2
	MP-6	1988	1995	59.26	106.05	78.96%	88.79	29.73	222.74	-10.64	2
	MP-A	1988	1995	55.37	42.1	-23.97%	92.66	16.08	67.76	16.43	2
	MP-B	1988	1995	34.61	18.24	-47.30%	51.68	17.54	26.01	10.48	2
	MP-C	1988	1995	12.69	20.34	60.28%	28.11	-2.73	28.62	12.06	2
	MP-D	1988	1995	1.76	0.5	-71.59%	2.82	0.69	1.18	-0.18	2
West-moreland-13	mp-a	1989	1993	5.89	3.17	-46.18%	7.44	4.35	7.38	-1.06	2
	mp-b	1989	1993	48.24	18.1	-62.48%	58.58	37.89	31.2	5	3
West-moreland-14	HU-1	1988	1995	32.71	10.66	-67.41%	38.39	27.02	15.82	5.49	3
West-moreland-15	SLK-GW-27	1994	1999	5.87	0.9	-84.67%	6.99	4.75	1.56	0.25	3
West-moreland-16	mp-8	1990	1995	21.31	18.58	-12.81%	26.52	16.09	28.22	8.97	2
West-moreland-17	SW18	1989	1993	1.23	0	-100.00%	1.4	1.05	0	0	4
West-moreland-18	1	1989	1995	0.85	0.67	-21.18%	0.99	0.71	0.99	0.35	2
	2	1989	1995	5.3	5.1	-3.77%	7.71	2.89	11.45	-1.25	2
	3	1989	1995	4.27	7.17	67.92%	6.49	2.05	15.75	-1.41	2
West-moreland-19	MP16	1993	1999	0.75	0.49	-34.67%	0.95	0.55	0.65	0.32	2
	MP5	1993	1999	1.1	0.02	-98.18%	1.58	0.63	0.09	-0.05	3
	MP6	1993	1999	2.2	1.74	-20.91%	2.82	1.58	2.79	0.69	2
West-moreland-20	mp-7	1991	1998	1.02	0	-100.00%	1.71	0.34	0.07	-0.07	3
West-moreland-21	MP3	1992	1997	4.44	0.88	-80.18%	6.05	2.83	1.69	0.06	3
West-moreland-22	103	1994	1998	1.44	0	-100.00%	1.76	1.13	0	0	4
	69	1994	1998	6.52	0	-100.00%	13.9	-0.86	0	0	4
	mp-13	1994	1998	0.24	0	-100.00%	0.63	-0.16	0	0	4

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	mp-16	1994	1998	0.07	0	-100.00%	0.12	0.01	0	0	4
Aluminum											
Allegheny-1	10	1986	1995	2.86	6.15	115.03%	4.9	0.82	9.27	3.01	2
	2	1986	1995	1.46	0.16	-89.04%	2.47	0.48	0.2	0.11	3
Allegheny-3	d-1p	1991	1998	0.59	0.12	-79.66%	0.61	0.57	0.15	0.08	3
Allegheny-4	BS12	1991	1995	22.01	4.07	-81.51%	23.99	20.03	5.73	2.4	3
	MD1	1991	1995	11.78	6.17	-47.62%	12.74	10.82	8.3	4.05	3
	MD2	1991	1995	0.09	0	-100.00%	0.73	-0.55	0.06	-0.06	2
Armstrong-5	MP-2	1988	1993	0.3	0	-100.00%	0.36	0.23	0	0	4
Armstrong-7	MP14	1988	1997	0.18	0.25	38.89%	0.31	0.05	0.29	0.2	2
	MP15	1988	1997	0.56	0.11	-80.36%	1.08	0.04	0.68	-0.47	2
	MP17	1988	1997	0.1	1.42	1320.00%	0.3	-0.09	2.27	0.55	1
	MP22	1988	1997	0.01	0.1	900.00%	0.05	-0.03	0.37	-0.18	2
	MP23	1988	1997	1.04	0.5	-51.92%	1.5	0.08	1.04	-0.05	2
	MP24	1988	1997	0.1	0.11	10.00%	0.17	0.03	0.17	0.04	2
Armstrong-12	mp2	1991	1995	0.43	0.1	-76.74%	0.66	0.2	0.15	0.06	3
	mph	1991	1995	0.43	0.2	-53.49%	0.66	0.2	0.27	0.13	2
Armstrong-13	41	1990	1995	1.23	0	-100.00%	1.77	0.7	0	0	4
	Unit 2	1990	1995	20.53	0.21	-98.98%	22.47	18.6	0.39	0.09	3
Armstrong-14	1	1991	1993	0.2	0	-100.00%	0.31	0.1	0	0	4
Armstrong-15	V2	1992	1997	2.2	0.78	-64.55%	2.85	1.55	1.34	0.22	3
Butler-3	S-116	86	1994	3.55	0.37	-89.58%	4.43	2.67	2.95	-2.2	2
	S-13	86	1994	0.59	0	-100.00%	0.91	0.26	0	0	4
	S-200	86	1994	0.12	0.1	-16.67%	0.35	-0.11	0.62	-0.43	2
	S-91	86	1994	0.44	0	-100.00%	0.69	0.198	0	0	4
	S-95/96	86	1994	0.26	0	-100.00%	0.45	0.07	0.09	-0.09	2
Butler-4	DR2	1991	1998	0.39	0	-100%	0.57	0.22	0	0	4
Clarion-4	2	1990	1996	0.02	0.01	-50.00%	0.03	0.02	0.02	0	2
Clarion-5	DR-1	1990	1992	1.96	3.56	81.63%	4.19	0.92	6.19	0.93	2
Clearfield-4	tk-18	1985	1997	4.65	2.2	-52.69%	6.22	3.08	2.76	1.65	3
	tk-21	1985	1997	3.34	0.22	-93.41%	5.35	1.33	0.69	-0.26	3
	TK-3	1985	1997	2.77	0.91	-67.15%	3.88	1.66	1.1	0.72	3
	tk-37	1985	1997	0.34	0.63	85.29%	0.91	-0.23	0.83	0.43	2
	tk-4	1985	1997	0.06	0.01	-83.33%	0.15	-0.03	0.02	0.01	2
	tk-7	1985	1997	0.39	0	-100.00%	0.45	0.33	0	0	4
Clearfield-7	12	1989	1997	0.08	0.08	0.00%	0.14	0.02	0.13	0.03	2
	13	1989	1997	10.45	9.21	-11.87%	13.55	7.34	11.19	7.24	2

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Clearfield-11	subf-a	1993	1994	0.58	0.61	5.17%	0.79	0.37	0.79	0.42	2
	subf-b	1993	1994	0.11	0.03	-72.73%	0.16	0.06	0.06	0	2
	subf-c	1993	1994	0.63	0.24	-61.90%	0.87	0.38	0.42	0.05	2
Fayette-1	mp-4	1989	1993	0.92	0.52	-43.48%	1.42	0.41	0.54	0.5	2
	mp-5	1989	1993	1.24	0	-100.00%	1.56	0.92	0	0	4
	mp-6	1989	1993	0.17	0	-100.00%	0.34	-0.01	0	0	4
	mp-8	1989	1993	0.29	0.02	-93.10%	0.72	-0.16	0.02	0.02	2
Fayette-2	HU-1	1984	1992	81.56	22.39	-72.55%	119.91	43.2	28.44	16.33	3
Fayette-4	MP6	1988	1993	0.06	0.27	350.00%	0.55	-0.44	0.95	-0.4	2
Fayette-6	MP-1	1988	1994	11.94	1.04	-91.29%	16.8	7.07	3.23	-1.15	3
Fayette-7	MP48	1989	1996	23.55	28.69	21.83%	34.15	12.95	43.05	14.33	2
	MP49	1989	1996	6.88	12.82	86.34%	10.99	2.77	16.3	9.34	2
Fayette-8	MP-15	1988	1994	10.21	6.13	-39.96%	14.83	5.59	23.1	-10.84	2
Fayette-9	MP-28	1990	1998	16.57	6.9	-58.36%	26.52	6.62	12.9	1.9	2
Fayette-10	mp-11	1989	1992	3.14	1.27	-59.55%	4.89	1.39	3.18	-0.64	2
	mp-2	1989	1992	0.39	0.97	148.72%	0.52	0.26	1.33	0.6	1
Fayette-11	mp 29	1991	1998	2.23	2.24	0.45%	6.05	-1.59	2.97	1.51	2
Fayette-12	Mp68	1991	1997	0.34	0.43	26.47%	0.65	0.03	0.75	0.1	2
Fayette-14	mp-19	1991	1998	0.65	0	-100.00%	1.17	0.14	0	0	4
	mp-57	1991	1998	2.9	0.16	-94.48%	5.89	-0.08	0.4	-0.07	2
	mp-60	1991	1998	7.83	3.5	-55.30%	12.09	3.58	6.7	0.3	2
	mp56	1991	1998	6.85	53.42	679.85%	16.56	-2.85	91.33	15.52	2
Fayette-15	MD8/BS29	1991	1995	1.35	0	-100.00%	3.57	-0.86	0	0	4
Fayette-16	MP-42	1994	1996	0.37	0.07	-81.08%	1.7	-0.97	0.69	-0.55	2
	MP-8	1994	1996	6.23	2.22	-64.37%	8.55	3.91	4.32	0.13	2
Jefferson-3	HU-1	1989	1992	0	0	N/A	0.01	0	0	0	4
Jefferson-4	HU-1	1989	1996	2.73	0.02	-99.27%	3.4	2.06	0.04	-0.01	3
Jefferson-5	MP-33	1989	1998	0.24	0	-100.00%	0.62	-0.13	0	0	4
	MP-8B	1989	1998	7.32	4.59	-37.30%	8.52	6.13	6.44	2.74	2
Jefferson-6	S-25	1993	1998	0.07	0.01	-85.71%	0.12	0.04	0.01	0.01	3
	s-34	1993	1998	0.08	0.11	37.50%	0.12	0.05	0.26	-0.04	2
Jefferson-7	MP-1	1991	1995	0.04	0	-100.00%	0.05	0.02	0	0	4
Venango-1	1	1989	1994	4.08	1.45	-64.46%	12.46	1.34	2.37	0.53	2
Wash. -1	HU1	1986	1993	36.3	2.45	-93.25%	47.26	25.34	4.03	0.86	3
Wash. -2	A	1985	1998	20.02	0.04	-99.80%	29.31	10.73	0.09	0	3
Wash. -4	MP-1	1989	1998	50.9	0.18	-99.65%	72.81	28.99	0.3	0.06	3
	MP-2	1989	1998	44.76	0	-100.00%	58.22	31.31	0	0	4
Wash. -5	d-1	1987	1996	0.59	0.1	-83.05%	0.61	0.57	0.33	-0.13	3
Wash. -7	se1a	1995	1998	0.09	0	-100.00%	0.42	-0.23	0	0	4
West-moreland-1	MP10	1984	1993	1.14	2.96	159.65%	2.29	-0.01	4.7	1.21	2
	MP7	1984	1993	1.51	3.88	156.95%	2.43	0.6	5.62	2.14	2
	MP9	1984	1993	0.01	0.07	600.00%	0.04	-0.03	0.12	0.01	2
West-moreland-2	S8	1985	1994	2.63	0.78	-70.34%	3.94	1.31	1.47	0.1	2
West-moreland-3	CP2	1986	1990	1.68	0.63	-62.50%	2.48	0.87	0.88	0.36	2
	Culvert	1986	1986	1.54	0.13	-91.56%	5.2	-2.12	0.25	0	2
West-moreland-5	HU-1	1986	1996	52.83	26.86	-49.16%	114.57	-8.91	46.87	6.85	2

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West-moreland-6	M	1985	1993	0.4	0.54	35.00%	0.73	0.07	0.8	0.28	2
	N	1985	1993	0.11	0.07	-36.36%	0.33	0	0.36	-0.24	2
West-moreland-7	MP-3	1986	1991	0.77	0.01	-98.70%	1.04	0.48	0.02	0.01	3
	MP-4	1986	1991	23.86	38.29	60.48%	47.88	-0.18	44.81	31.76	2
West-moreland-8	MP-4	1987	1998	0.64	0	-100.00%	0.9	0.38	0	0	4
West-moreland-9	MP-46	1987	1993	40.11	39.55	-1.40%	50.39	29.84	55.21	23.88	2
	MP-47	1987	1993	40.8	53.41	30.91%	58.68	22.92	105.82	1	2
	MP-51	1987	1993	0.56	1.88	235.71%	0.8	0.3	2.91	0.84	1
	MP-52	1987	1993	0.34	0.29	-14.71%	0.45	0.22	1.3	-0.72	2
	MP-56	1987	1993	0.71	0.77	8.45%	1.03	0.37	1.49	0.04	2
	MP-60	1987	1993	1.12	0.6	-46.43%	1.58	0.65	1.17	0.03	2
	MP-A	1987	1995	0.24	0.03	-87.50%	0.79	-0.31	0.06	-0.01	2
West-moreland-10	MP12	1988	1995	4.53	5.73	26.49%	10.49	-1.45	8.81	2.65	2
West-moreland-12	MP-1	1988	1995	28.77	0	-100.00%	40.45	17.09	0	0	4
	MP-2	1988	1995	0.98	0.87	-11.22%	1.7	0.26	1.57	0.17	2
	MP-3	1988	1995	4.08	3.37	-17.40%	6.39	1.77	4.25	2.48	2
	MP-4	1988	1995	5.65	0.03	-99.47%	8.74	2.56	0.34	-0.27	3
	MP-5	1988	1995	3.34	6.88	105.99%	6.18	0.49	10.78	2.97	2
	MP-6	1988	1995	5.39	8.22	52.50%	7.69	3.09	17.67	-1.24	2
	MP-A	1988	1995	6.65	4.95	-25.56%	10.84	2.46	8.09	1.8	2
	MP-B	1988	1995	4.57	2.13	-53.39%	6.77	2.37	2.98	1.29	2
	MP-C	1988	1995	1.18	1.98	67.80%	2.47	-0.11	2.68	1.29	2
	MP-D	1988	1995	0.23	0.07	-69.57%	0.35	0.11	0.15	-0.02	2
West-moreland-13	mp-a	1989	1993	0.79	0.72	-8.86%	0.97	0.62	1.23	0.2	2
	mp-b	1989	1993	7.74	0.23	-97.03%	9.64	5.83	0.29	0.15	3
West-moreland-14	HU-1	1988	1995	2.73	0.08	-97.07%	3.33	2.14	0.23	-0.07	3
West-moreland-15	SLK-GW-27	1994	1999	0.03	0.02	-33.33%	0.04	0	0.05	0	2
West-moreland-16	mp-8	1990	1995	1.83	0.74	-59.56%	2.23	1.43	1.2	0.29	3
West-moreland-18	1	1989	1995	0.02	0.02	0.00%	0.02	0.01	0.03	0.01	2
	2	1989	1995	0.67	0.64	-4.48%	1	0.35	1.46	-0.19	2
	3	1989	1995	0.53	0.89	67.92%	0.84	0.21	1.79	0	2
West-moreland-19	MP16	1993	1999	0.07	0.03	-57.14%	0.09	0.06	0.03	0.02	3
	MP5	1993	1999	0.16	0	-100.00%	0.21	0.11	0	0	4
	MP6	1993	1999	0.07	0.26	271.43%	0.09	0.06	0.42	0.1	1

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West-moreland-23	103	1994	1998	0.12	0	-100.00%	0.17	0.08	0	0	4
	69	1994	1998	0.69	0	-100.00%	1.41	-0.04	0	0	4
Iron											
Allegheny-1	10	1986	1995	0.1	0.11	10.00%	0.15	0.04	0.19	0.03	2
	2	1986	1995	0.09	0.12	33.33%	0.11	0.05	0.15	0.07	2
Allegheny-2	S-6	1989	1998	0.37	3.5	845.95%	0.62	0.12	4.74	2.27	1
	S-7	1989	1989	24.63	1.55	-93.71%	33.57	15.68	3.41	-0.42	3
Allegheny-3	d-1p	1991	1998	0.06	0.03	-50.00%	0.09	0.02	0.05	0.01	2
Allegheny-4	BS12	1991	1995	4.7	0.88	-81.28%	4.91	4.49	1.06	0.7	3
	MD1	1991	1995	1.81	1.37	-24.31%	2.27	1.35	1.71	1.04	2
	MD2	1991	1995	0.02	0	-100.00%	0.04	0	0	0	4
Allegheny-5	MP-2	1993	1995	0.03	0.01	-66.67%	0.04	0.01	0.02	0	2
Armstrong-1	1A	1984	1990	0.39	0.34	-12.82%	0.7	0.07	0.55	0.13	2
Armstrong-2	D-1	1986	1995	1.55	0.01	-99.35%	3.73	-0.64	0.02	0	2
	D-112	1986	1995	0	0.02	N/A	0.01	0	0.03	0	2
	D-4	1986	1995	0.05	0.06	20.00%	0.09	0.01	0.11	0.01	2
Armstrong-3	w-1A	1986	1992	0.27	0.16	-40.74%	0.39	0.13	0.22	0.1	2
	w-2A	1986	1992	0.78	5.36	587.18%	1.26	0.3	8.13	2.59	1
	w-3A	1986	1992	0.14	0.23	64.29%	0.23	0.03	0.29	0.1	2
Armstrong-5	MP-2	1988	1993	0.02	0	-100.00%	0.02	0.01	0	0	4
Armstrong-6	1	1988	1995	0.41	0.02	-95.12%	0.58	0.25	0.02	0.01	3
Armstrong-7	MP14	1988	1997	0.01	0.01	0.00%	0.01	0	0.01	0	2
	MP15	1988	1997	0.75	0.29	-61.33%	1.07	0.43	0.91	-0.34	2
	MP17	1988	1997	0.03	0.29	866.67%	0.08	-0.01	0.43	0.14	1
	MP22	1988	1997	0	0.03	N/A	0.75	-0.55	0.27	-0.21	2
	MP23	1988	1997	0.16	0.09	-43.75%	0.29	0.02	0.27	-0.1	2
	MP24	1988	1997	0.01	0.01	0.00%	0.03	-0.01	0.02	0	2
Armstrong-9	HU1	1988	1998	0.13	0.03	-76.92%	0.21	0.06	0.05	0.01	3
Armstrong-10	C-11	1989	1995	0.51	0.24	-52.94%	0.6	0.42	0.3	0.19	3
	S-20	1989	1995	9.21	7.09	-23.02%	10.45	7.97	8.73	5.44	2
Armstrong-11	HU1	1990	1997	0.04	0	-100.00%	0.07	0	0	0	4
Armstrong-12	mp2	1991	1995	1.97	0.27	-86.29%	3.21	0.72	0.33	0.21	3
	mph	1991	1995	0.02	0.01	-50.00%	0.03	0	0.01	0	2
Armstrong-13	41	1990	1995	0.02	0	-100.00%	0.03	0.01	0	0	4
	48	1990	1995	0.24	0	-100.00%	0.32	0.17	0	0	4
	Unit 2	1990	1995	23.76	0.42	-98.23%	27.89	19.62	0.62	0.22	3
Armstrong-14	1	1991	1993	0.21	0	-100.00%	0.43	0	0	0	4

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Armstrong-15	V2	1992	1997	0.3	0.13	-56.67%	0.44	0.16	0.3	-0.04	2
Armstrong-16	HU1	1993	1998	0.08	0.34	325.00%	0.16	0	0.5	0.18	1
Beaver-1	S-10	1988	1995	3.81	2.99	-21.52%	4.43	3.18	3.99	1.99	2
Butler-1	5W	1986	1991	0.51	0.22	-56.86%	0.76	0.26	0.36	0.08	2
Butler-2	2W	1984	1989	0.01	0	-100.00%	0.01	0.01	0	0	4
	5AW	1984	1989	0.02	0.01	-50.00%	0.03	0.01	0.02	0	2
	8W	1984	1989	0.02	0	-100.00%	0.02	0.02	0.01	0	3
Butler-3	S-116	1986	1994	0.01	0.01	0.00%	0.01	0.01	0.02	0	2
	S-13	1986	1994	0.02	0	-100.00%	0.05	-0.02	0	0	4
	S-200	1986	1994	0.03	0.01	-66.67%	0.04	0.02	0.05	-0.03	2
	S-91	1986	1994	0	0	N/A	0.01	-0.01	0	0	4
Butler-4	DR-2	1991	1998	7.05	0	-100%	8.97	5.13	0	0	4
Butler-5	1	1991	1998	0.36	0.17	-52.78%	0.47	0.26	0.42	-0.09	2
Cambria-1	MP 9	1990	1995	0.01	0.02	100.00%	0.02	0	0.03	0.01	2
	MP 13	1990	1995	0.02	0	-100.00%	0.03	0	0	0	4
Clarion-1	SP-1	1985	1995	107.89	24.34	-77.44%	119.01	96.77	30.16	18.52	3
	SP-28	1985	1995	45.56	15.51	-65.96%	61.06	30.06	19.19	11.82	3
	SP-5	1985	1995	0.11	0	-100.00%	0.19	0.02	0	0	4
	SP-6	1985	1995	27.58	0	-100.00%	36.23	18.94	0	0	4
Clarion-2	1	1986	1989	0.02	1.125	5525.00%	0.04	0	1.54	0.7	1
Clarion-3	RH-78	1990	1994	1.52	0	-100.00%	1.76	1.29	0	0	4
	RH-79	1990	1994	0.36	0	-100.00%	0.46	0.27	0	0	4
	RH-82	1990	1994	0.23	0	-100.00%	0.27	0.2	0	0	4
	RH-84	1990	1994	0.28	0.25	-10.71%	0.35	0.22	0.48	0.01	2
	RH-91	1990	1994	0.38	0	-100.00%	0.46	0.29	0.11	-0.11	3
	RH-93	1990	1994	0.28	0.07	-75.00%	0.32	0.24	0.17	-0.03	3
	RH-94	1990	1994	0.65	0	-100.00%	0.74	0.56	0	0	4
	RH-96	1990	1994	0.03	0	-100.00%	0.06	0.01	0	0	4
Clarion-4	1	1990	1996	0.04	0	-100.00%	0.06	0.02	0	0	4
	2	1990	1996	0.22	0.08	-63.64%	0.27	0.16	0.11	0.04	3
Clarion-5	DR-1	1990	1992	0.36	2.63	630.56%	0.53	0.24	5.85	-0.6	2
Clearfield-1	unit 1	1985	1998	47.81	18.73	-60.82%	59.45	36.17	23.58	13.88	3
Clearfield-2	W10	1985	1998	1.34	0.61	-54.48%	1.82	0.85	0.95	0.28	2
	W42	1985	1998	0.59	0.27	-54.24%	0.74	0.43	0.35	0.18	3
	W43	1985	1998	0.94	0.91	-3.19%	1.45	0.43	1.49	0.34	2
	W44	1985	1998	0.5	0.41	-18.00%	0.85	0.13	0.54	0.29	2
Clearfield-3	SF-1	1986	1998	0.23	0.06	-73.91%	0.29	0.16	0.12	0.01	3
	SF10	1986	1998	0.18	0	-100.00%	0.29	0.06	0	0	4
	SF4	1986	1998	0.03	0	-100.00%	0.05	0	0.01	-0.01	2
	SF6	1986	1998	0.01	0	-100.00%	0.02	-0.01	0.01	0	2
	SF61	1986	1998	0.49	0.05	-89.80%	0.94	0.03	0.22	-0.12	2
Clearfield-4	tk-18	1985	1997	6.47	9.87	52.55%	8.85	4.09	10.22	9.51	1
	tk-21	1985	1997	0.08	0.03	-62.50%	0.14	0.02	0.06	0	2
	TK-3	1985	1997	13.52	8.71	-35.58%	14.68	12.36	11.32	6.1	3
	tk-37	1985	1997	0.01	0.01	0.00%	0.01	0.01	0.01	0	2
	tk-4	1985	1997	0.21	0.16	-23.81%	0.31	0.11	0.24	0.09	2

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	tk-7	1985	1997	0.21	0	-100.00%	0.29	0.13	0	0	4
Clearfield-5	SV-5	1988	1992	0.3	0.36	20.00%	0.35	0.23	0.43	0.33	2
	SV-8	1988	1992	0.09	0.1	11.11%	0.12	0.05	0.13	0.07	2
Clearfield-6	R-3	1988	1995	0.04	0	-100.00%	0.06	0.02	0.01	-0.01	3
	R-5	1988	1995	0.01	0	-100.00%	0	0	0	0	4
	R-8	1988	1995	3.38	2.06	-39.05%	4.99	1.75	3.44	0.67	2
Clearfield-7	12	1989	1997	0.04	0.01	-75.00%	0.08	0.01	0.02	0	2
	13	1989	1997	10.52	6.75	-35.84%	14.5	6.54	7.83	5.67	2
Clearfield-8	TK4	1990	1996	0.22	0.12	-45.45%	0.3	0.15	0.2	0.04	2
	TK7	1990	1996	0.04	0	-100.00%	0.06	0.01	0	0	4
Clearfield-9	1	1990	1994	2.81	0	-100.00%	4.1	1.52	0	0	4
	2	1990	1994	0.01	0	-100.00%	0.04	0	0	0	4
Clearfield-10	HU 1	1992	1998	0.02	0.01	-50.00%	0.05	-0.01	0.02	0	2
	HU 2	1992	1998	0.01	0	-100.00%	0.01	0.01	0	0	4
	HU 3	1992	1998	0.01	0	-100.00%	0.02	0.01	0	0	4
Clearfield-11	subf-a	1993	1994	0.03	0.02	-33.33%	0.04	0.02	0.03	0.01	2
	subf-b	1993	1994	0.01	0	-100.00%	0.01	0	0	0	4
	subf-c	1993	1994	0.02	0.01	-50.00%	0.03	0.01	0.01	0	2
Clinton-1	96	1981	1995	0.04	0	-100.00%	0.06	0.01	0	0	4
	97	1981	1995	0.04	0	-100.00%	0.06	0.01	0	0	4
	13	1981	1995	0.08	0	-100.00%	0.1	0.05	0	0	4
	15A	1981	1995	0.07	0	-100.00%	0.1	0.03	0	0	4
	SNW 1A	1981	1996	1.7	1.23	-27.65%	2.57	0.8	1.7	0.76	2
Clinton-2	GR-9	1988	1993	2.6	0.37	-85.77%	5.05	0.15	4.02	-3.28	2
Clinton-3	SEH-31	1990	1993	0.17	0.07	-58.82%	0.23	0.11	0.09	0.05	3
	SHE-30	1990	1993	0.37	1.11	200.00%	0.76	-0.02	1.31	0.91	1
Fayette-1	mp-4	1989	1993	0.88	0.22	-75.00%	1.25	0.51	0.23	0.2	3
	mp-5	1989	1993	1.6	0	-100.00%	2.31	0.87	0	0	4
	mp-6	1989	1993	0.39	0	-100.00%	0.75	0.03	0	0	4
	mp-8	1989	1993	2.49	0.09	-96.39%	3.87	1.11	0.1	0.09	3
Fayette-2	HU-1	1984	1992	37.36	11.59	-68.98%	45.42	29.29	13.08	10.08	3
Fayette-4	MP6	1988	1993	0.17	0.11	-35.29%	0.39	-0.06	0.49	-0.26	2
Fayette-5	mp-4	1988	1998	286	68.69	-75.98%	338	235	80.46	56.91	3
	mp-hua	1988	1998	211	55.27	-73.81%	295	127	72.69	37.85	3
Fayette-6	MP-1	1988	1994	15.4	0.6	-96.10%	21.44	9.36	1.37	-0.16	3
Fayette-7	MP48	1989	1996	28.52	23.44	-17.81%	40.04	17	38.42	8.47	2
	MP49	1989	1996	3.03	5.87	93.73%	4.78	1.27	7.92	3.81	2
Fayette-8	MP-15	1988	1994	0.05	0.05	0.00%	0.07	0.04	0.15	-0.06	2
Fayette-9	MP-28	1990	1998	1.47	0.77	-47.62%	2.83	0.1	1.31	0.23	2
Fayette-10	mp-1	1989	1992	4.27	1.25	-70.73%	5.34	3.21	1.95	0.54	3
	mp-11	1989	1992	0.34	0.2	-41.18%	0.43	0.26	0.34	0.06	2
	mp-2	1989	1992	0.05	0.16	220.00%	0.09	0.02	0.27	0.05	2
Fayette-11	mp 29	1991	1998	1.94	1.72	-11.34%	4.13	-0.25	3.78	-0.35	2
Fayette-12	Mp68	1991	1997	0.05	0.06	20.00%	0.08	0.02	0.08	0.04	2
Fayette-13	D5	1991	1995	1.19	1.71	43.70%	1.8	0.58	2.33	1.09	2
Fayette-14	mp-19	1991	1998	0.27	0	-100.00%	0.41	0.13	0	0	4
	mp-57	1991	1998	0.12	0.01	-91.67%	0.28	-0.04	0.03	-0.01	2
	mp-60	1991	1998	0.38	0.17	-55.26%	0.79	-0.02	0.29	0.04	2
	mp56	1991	1998	1.11	11.29	917.12%	3.75	-1.53	19.48	3.09	2

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Fayette-15	MD1/MD2	1991	1995	0.03	0.01	-66.67%	0.06	-0.01	0.02	0	2
	MD8/BS29	1991	1995	0.23	0.17	-26.09%	0.52	-0.05	0.21	0.12	2
Fayette-16	MP-42	1994	1996	0.05	0	-100.00%	0.43	-0.34	0.14	-0.14	2
	MP-8	1994	1996	1.79	0.61	-65.92%	2.41	1.17	1.18	0.04	2
Greene-1	MP-51	1987	1988	0.05	0	-100.00%	0.11	-0.02	0	0	4
Greene-2	hu1	1989	1994	4.01	0.41	-89.78%	4.74	3.29	0.86	-0.05	3
Indiana-1	H	1988	1995	6.96	5.19	-25.43%	9.9	4.01	6.77	3.6	2
	J	1988	1995	1.84	1.07	-41.85%	3.02	0.65	2.01	0.24	2
	K	1988	1995	0.62	0.43	-30.65%	0.83	0.41	0.69	0.18	2
	L	1988	1995	1.35	0.01	-99.26%	2.14	0.54	0.41	-0.38	3
	M	1988	1995	0.11	0.07	-36.36%	0.25	-0.04	0.15	0	2
	N	1988	1995	0.05	0.01	-80.00%	0.58	-0.49	0.02	0	2
	O	1988	1995	0	0	N/A	0.01	0	0	0	4
Indiana-2	MP 5	1988	1997	13.63	4.34	-68.16%	22.86	4.38	6.77	1.92	2
	MP 15	1988	1997	0.18	0.09	-50.00%	0.25	0.1	0.15	0.04	3
Indiana-3	1 (A)	1992	1998	0.01	0	-100.00%	0.02	-0.01	0	0	4
	2 (B)	1992	1998	6.66	1.79	-73.12%	9.08	4.25	2.3	1.28	3
	3 (C)	1992	1996	4.76	18.73	293.49%	5.96	3.55	56.41	-18.95	2
Jefferson-1	1	1984	1993	0.23	0.31	34.78%	0.36	0.1	0.75	-0.12	2
Jefferson-2	MP-13	1986	1996	0.02	0.03	50.00%	0.03	-0.01	0.05	0.02	2
Jefferson-4	HU-1	1989	1996	0.71	0.53	-25.35%	1.13	0.29	1.32	-0.25	2
Jefferson-5	MP-33	1989	1998	0.17	0	-100.00%	0.28	0.06	0	0	4
	MP-8B	1989	1998	8.55	4.57	-46.55%	10.54	6.55	6.3	2.84	3
Jefferson-6	S-25	1993	1998	0.01	0.01	0.00%	0.01	0	0.01	0.01	2
	s-34	1993	1998	0.01	0.01	0.00%	0.01	0	0.01	0.01	2
Jefferson-7	MP-1	1991	1995	0	0	N/A	0.01	0	0	0	4
Lawrence-1	1	1992	1998	0.25	0	-100.00%	0.42	0.07	0	0	4
Somerset-1	SP16	1989	1998	0.04	0.03	-25.00%	0.04	0.03	0.04	0.02	2
Somerset-2	1	1993	1998	0.09	0.31	244.44%	0.11	0.06	0.97	-0.34	2
Venango-1	1	1989	1994	0.25	0.64	156.00%	0.41	0.16	0.95	0.33	2
Wash. -1	HU1	1986	1993	29.24	18.77	-35.81%	52.38	6.1	27.17	10.37	2
Wash. -2	A	1985	1998	1.93	0.02	-98.96%	2.55	1.32	0.03	0.01	3
Wash. -3	CV103	1985	1998	38.7	353.52	813.49%	47.19	30.19	460.23	246.8	1
	CV4	1985	1998	17.36	31.59	81.97%	23.31	11.4	39.81	23.36	1
Wash. -4	MP-1	1989	1998	8.49	0.22	-97.41%	11.52	5.47	0.32	0.12	3
	MP-2	1989	1998	6.38	0	-100.00%	8.84	3.91	0	0	4
Wash. -5	d-1	1987	1996	0.06	0.02	-66.67%	0.09	0.02	0.03	0.01	2
Wash. -6	D5	1992	1997	4.08	0.46	-88.73%	5.44	2.72	0.55	0.36	3
West-moreland-1	MP10	1984	1993	0.1	0.1	0.00%	0.15	0.05	0.14	0.05	2
	MP7	1984	1993	0.76	0.74	-2.63%	1.14	0.38	1.28	0.2	2
	MP9	1984	1993	0.03	0.02	-33.33%	0.04	0.01	0.04	-0.01	2
West-moreland-2	S8	1985	1994	0.1	0.02	-80.00%	0.13	0.06	0.04	-0.01	3
West-moreland-3	CP2	1986	1990	0.03	0.17	466.67%	0.08	-0.03	0.24	0.09	1
	Culvert	1986	1986	0.15	0.02	-86.67%	1.12	-0.84	0.04	0	2

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
West-moreland-4	MD-1	1986	1990	0.08	0.17	112.50%	0.7	-0.55	0.49	-0.16	2
	MD-3	1986	1990	0.17	0	-100.00%	2	-1.67	0	-0.01	4
	MD-4	1986	1990	0.75	0.28	-62.67%	2.15	-0.66	0.44	0.11	2
	MD-6	1986	1990	7.3	0.97	-86.71%	15.38	-0.8	1.55	0.39	2
	MD-7	1986	1990	3.8	0.89	-76.58%	7.68	-0.08	1.42	0.35	2
West-moreland-5	HU-1	1986	1996	46.62	22.48	-51.78%	79.07	14.16	38.11	6.85	2
West-moreland-6	M	1985	1993	0.08	0.09	12.50%	0.12	0.03	0.12	0.05	2
	N	1985	1993	0.02	0	-100.00%	0.05	0	0	0	4
West-moreland-7	MP-3	1986	1991	0.57	0.1	-82.46%	0.7	0.4	0.16	0.04	3
	MP-4	1986	1991	7.1	9.19	29.44%	13.29	0.89	13.83	4.56	2
West-moreland-8	MP-4	1987	1998	1.04	0	-100.00%	1.48	0.59	0	0	4
West-moreland-9	MP-46	1987	1993	53.49	63.29	18.32%	72.28	34.7	90.51	36.05	2
	MP-47	1987	1993	32.67	37.44	14.60%	50.74	14.59	84.01	-9.15	2
	MP-51	1987	1993	0.04	0.41	925.00%	0.06	0.02	0.74	0.07	1
	MP-52	1987	1993	0.01	0.01	0.00%	0.01	0	0.03	-0.01	2
	MP-56	1987	1993	0.01	0	-100.00%	0.01	0	0	0	4
	MP-60	1987	1993	0.04	0.02	-50.00%	0.11	-0.04	0.03	0	2
	MP-A	1987	1995	3.21	0.84	-73.83%	4.63	1.79	1.82	-0.14	2
West-moreland-10	MP12	1988	1995	0.27	0.76	181.48%	0.79	-0.27	1.11	0.41	2
West-moreland-11	MP3	1988	1992	94.65	54.32	-42.61%	110.31	78.98	62.26	46.77	3
West-moreland-12	MP-1	1988	1995	71.8	0	-100.00%	102.04	41.56	0	0	4
	MP-2	1988	1995	0.2	0.14	-30.00%	0.34	0.06	0.28	0	2
	MP-3	1988	1995	4.03	0.78	-80.65%	8.36	-0.3	1.06	5	2
	MP-4	1988	1995	16.32	0.06	-99.63%	24.41	8.23	0.34	-0.23	3
	MP-5	1988	1995	3.67	8.13	121.53%	8.69	-1.35	13.57	2.69	2
	MP-6	1988	1995	7.11	10.03	41.07%	10.57	3.65	22.16	-2.11	2
	MP-A	1988	1995	0.92	0.47	-48.91%	1.84	0	0.76	0.18	2
	MP-B	1988	1995	0.42	0.18	-57.14%	0.75	0.09	0.28	0.07	2
	MP-C	1988	1995	0.5	0.73	46.00%	1.5	-0.5	1.19	0.27	2
West-moreland-13	mp-a	1989	1993	0.03	0.02	-33.33%	0.03	0.02	0.04	-0.01	2
	mp-b	1989	1993	0.25	0.06	-76.00%	0.32	0.18	0.09	0.01	3
West-moreland-14	HU-1	1988	1995	2.48	3.94	58.87%	3.4	1.56	5.31	2.56	2
	MP-5A	1988	1995	0	0.01	N/A	0.02	-0.02	0.03	-0.02	2
West-moreland-15	SLK-GW-27	1994	1999	0.37	0	-100.00%	0.69	0.04	0	0	4

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Westmoreland-16	mp-8	1990	1995	0.67	0.96	43.28%	0.87	0.46	1.38	0.55	2
Westmoreland-17	SW18	1989	1993	0.04	0	-100.00%	0.05	0.03	0	0	4
Westmoreland-18	1	1989	1995	0.06	0.06	0.00%	0.08	0	0.09	0.03	2
	2	1989	1995	0.08	0.06	-25.00%	0.11	0.05	0.12	0	2
	3	1989	1995	0.05	0.06	20.00%	0.08	0.01	0.16	0	2
Westmoreland-19	MP5	1993	1999	0	0	N/A	0.01	0	0	0	4
Westmoreland-20	mp-7	1991	1998	0	0	N/A	0.01	0	0	0	4
Westmoreland-21	MP3	1992	1997	0.04	0	-100.00%	0.06	0.02	0.01	0	3
Westmoreland-22	mp-13	1994	1998	0.02	0	-100.00%	0.11	-0.07	0	0	4
	mp-16	1994	1998	0.03	0	-100.00%	0.05	0.01	0	0	4
Manganese											
Allegheny-1	10	1986	1995	0.25	0.88	252.00%	0.3	0.18	1.28	0.47	1
	2	1986	1995	0.56	0.12	-78.57%	0.79	0.32	0.18	0.05	3
Allegheny-3	d-1p	1991	1998	0.15	0.07	-53.33%	0.17	0.14	0.1	0.03	3
Allegheny-4	BS12	1991	1995	1.14	0.24	-78.95%	1.32	0.96	0.31	0.16	3
	MD1	1991	1995	0.74	0.52	-29.73%	0.79	0.69	0.65	0.39	3
	MD2	1991	1995	0.07	0	-100.00%	0.12	0.02	0.01	-0.01	3
Allegheny-5	MP-2	1993	1995	0.13	0.02	-84.62%	0.21	0.05	0.03	0.01	3
Armstrong-1	1A	1984	1990	0.51	0.33	-35.29%	0.75	0.26	0.53	0.13	2
Armstrong-6	1	1988	1995	1.09	0.25	-77.06%	1.39	0.8	0.29	0.21	3
Armstrong-10	C-11	1989	1995	0.07	0.01	-85.71%	0.09	0.05	0.01	0	3
	S-20	1989	1995	0.5	0.22	-56.00%	0.68	0.31	0.3	0.14	3
Armstrong-12	mp2	1991	1995	0.23	0.05	-78.26%	0.38	0.07	0.06	0.04	3
	mph	1991	1995	0.09	0.06	-33.33%	0.14	0.05	0.09	0.04	2
Armstrong-13	41	1990	1995	0.37	0	-100.00%	0.46	0.28	0	0	4
	48	1990	1995	0.12	0	-100.00%	0.14	0.1	0	0	4
	Unit 2	1990	1995	6.35	0.31	-95.12%	7.12	5.58	0.44	0.18	3

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Armstrong-14	1	1991	1993	0.91	0	-100.00%	1.51	0.31	0	0	4
Armstrong-15	V2	1992	1997	0.35	0.12	-65.71%	0.45	0.25	0.24	0	3
Beaver-1	S-10	1988	1995	1.93	3.17	64.25%	2.39	1.46	4.02	2.33	2
Butler-1	5W	1986	1991	0.8	1.28	60.00%	1.65	-0.05	1.8	0.72	2
Butler-2	2W	1984	1989	0.01	0	-100.00%	0.02	0	0	0	4
	5AW	1984	1989	0.03	0.51	1600.00%	0.07	0	0.76	0.27	1
	8W	1984	1989	0.04	0.07	75.00%	0.06	0.02	0.1	0.04	2
Butler-3	S-116	1986	1994	3.6	0.42	-88.33%	4.22	2.98	0.95	-0.1	3
	S-13	1986	1994	0.44	0	-100.00%	0.58	0.28	0	0	4
	S-200	1986	1994	0.15	0.04	-73.33%	0.34	-0.04	0.22	-0.43	2
	S-91	1986	1994	0.24	0	-100.00%	0.36	0.12	0	0	4
	S-95/96	1986	1994	0.24	0	-100.00%	0.36	0.12	0.06	-0.06	3
Butler-4	DR2	1991	1998	0.12	0	-100.00%	0.14	0.1	0	0	4
Clarion-1	SP-1	1985	1995	5.78	1.11	-80.80%	6.27	5.29	1.54	0.68	3
	SP-28	1985	1995	3.94	1.14	-71.07%	4.57	3.31	1.46	0.82	3
	SP-5	1985	1995	0.13	0	-100.00%	0.17	0.08	0	0	4
	SP-6	1985	1995	1.22	0	-100.00%	1.55	0.89	0	0	4
Clarion-2	1	1986	1989	0.05	0.693	1286.00%	0.1	0	1.07	0.31	1
Clarion-3	RH-78	1990	1994	0.84	0	-100.00%	0.97	0.71	0	0	4
	RH-79	1990	1994	0.38	0	-100.00%	0.44	0.32	0	0	4
	RH-82	1990	1994	0.55	0	-100.00%	0.66	0.44	0.01	0	3
	RH-84	1990	1994	0.38	0.28	-26.32%	0.46	0.29	0.53	0.04	2
	RH-91	1990	1994	0.48	0	-100.00%	0.52	0.43	0.19	-0.19	3
	RH-93	1990	1994	0.25	0.06	-76.00%	0.3	0.21	0.16	-0.04	3
	RH-94	1990	1994	0.19	0	-100.00%	0.22	0.16	0	0	4
	RH-96	1990	1994	0.61	0	-100.00%	0.94	0.27	0	0	4
Clarion-4	1	1990	1996	0.04	0	-100.00%	0.05	0.03	0	0	4
	2	1990	1996	0.95	0.38	-60.00%	1.09	0.81	0.57	0.18	3
Clarion-5	DR-1	1990	1992	0.33	3.34	912.12%	0.47	0.23	7	-0.32	2
Clearfield-2	W10	1985	1998	3.99	4.15	4.01%	6.16	1.8	7.95	0.35	2
	W42	1985	1998	7.26	10.79	48.62%	11.04	3.47	15.05	6.54	2
	W43	1985	1998	0.94	29.81	3071.28%	1.45	0.43	49.54	10.09	1
	W44	1985	1998	9.54	8.21	-13.94%	14.61	4.46	13.32	3.11	2
Clearfield-3	SF-1	1986	1998	0.05	0.01	-80.00%	0.06	0.03	0.02	0	3
	SF10	1986	1998	0.05	0	-100.00%	0.08	0.01	0	0	4
	SF4	1986	1998	0.02	0.01	-50.00%	0.03	0	0.02	-0.01	2
	SF6	1986	1998	0.04	0.01	-75.00%	0.66	-0.59	0.04	-0.02	2
	SF61	1986	1998	0.11	0.02	-81.82%	0.19	0.02	0.07	-0.03	2
Clearfield-4	tk-18	1985	1997	6.2	8.12	30.97%	8.01	4.39	8.76	7.49	2
	tk-21	1985	1997	1.7	0.19	-88.82%	2.53	0.87	0.51	-0.13	3
	TK-3	1985	1997	6.9	5.77	-16.38%	7.75	6.05	7.43	4.11	2
	tk-37	1985	1997	2.11	1.59	-24.64%	3.54	0.68	2.07	1.11	2
	tk-4	1985	1997	0.31	0.11	-64.52%	0.46	0.16	0.16	0.07	2
	tk-7	1985	1997	0.4	0	-100.00%	0.49	0.31	0	0	4
Clearfield-5	SV-5	1988	1992	0.38	0.46	21.05%	0.43	0.32	0.62	0.37	2
	SV-8	1988	1992	0.98	0.78	-20.41%	1.51	0.45	1.07	0.6	2
Clearfield-6	R-3	1988	1995	0.47	0.02	-95.74%	0.64	0.28	0.07	-0.03	3
	R-5	1988	1995	0.42	0.31	-26.19%	0.62	0.21	0.51	0.11	2
	R-8	1988	1995	2.23	1.48	-33.63%	2.77	1.68	1.87	1.09	2

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Clearfield-7	12	1989	1997	0.02	0.07	250.00%	0.03	0	0.12	0.02	2
	13	1989	1997	1.42	2.2	54.93%	1.84	1.01	2.56	1.84	2
Clearfield-8	TK4	1990	1996	0.21	0.11	-47.62%	0.3	0.12	0.16	0.06	2
	TK7	1990	1996	0.2	0	-100.00%	0.27	0.13	0	0	4
Clearfield-9	1	1990	1994	0.02	0	-100.00%	0.05	0.01	0	0	4
	2	1990	1994	0	0	N/A	0.01	0	0	0	4
Clearfield-10	HU 1	1992	1998	0.15	0.21	40.00%	0.3	0.01	0.34	0.07	2
	HU 2	1992	1998	0.14	0.01	-92.86%	0.2	0.08	0.01	0	3
	HU 3	1992	1998	0.4	0.18	-55.00%	0.56	0.23	0.26	0.1	2
Clinton-2	GR-9	1988	1993	0.1	0.34	240.00%	0.2	-0.02	-1.97	2.65	1
Clinton-3	SEH-31	1990	1993	3.43	1.9	-44.61%	4.45	2.41	3.3	0.5	2
	SHE-30	1990	1993	0.14	1.29	821.43%	0.27	0.01	1.9	0.67	1
Fayette-1	mp-4	1989	1993	0.27	0.15	-44.44%	0.43	0.1	0.16	0.14	2
	mp-5	1989	1993	0.15	0	-100.00%	0.2	0.1	0	0	4
	mp-6	1989	1993	0.03	0	-100.00%	0.05	0	0	0	4
	mp-8	1989	1993	0.2	0.05	-75.00%	0.3	0.08	0.05	0.05	3
Fayette-2	HU-1	1984	1992	3.4	2.82	-17.06%	4.48	2.3	3.2	2.43	2
Fayette-4	MP6	1988	1993	0.05	0.08	60.00%	0.09	0	0.29	-0.13	2
Fayette-6	MP-1	1988	1994	2.13	0.84	-60.56%	2.75	1.5	2.29	-0.61	2
Fayette-7	MP48	1989	1996	3.34	2.88	-13.77%	4.37	2.32	4.02	1.74	2
	MP49	1989	1996	0.97	1.26	29.90%	1.34	0.59	1.7	0.83	2
Fayette-8	MP-15	1988	1994	1.25	0.7	-44.00%	1.52	0.98	2.38	-0.99	2
Fayette-10	mp-1	1989	1992	1.11	0.62	-44.14%	1.35	0.87	1.13	0.11	2
	mp-11	1989	1992	0.93	0.43	-53.76%	1.22	0.64	0.82	0.04	2
	mp-2	1989	1992	0.08	0.16	100.00%	0.1	0.05	0.26	0.05	2
Fayette-11	mp 29	1991	1998	0.06	0.67	1016.67%	0.2	-0.08	1.04	0.3	1
Fayette-12	Mp68	1991	1997	0.04	0.05	25.00%	0.07	0.01	0.1	0.01	2
Fayette-13	D5	1991	1995	1.91	1.79	-6.28%	2.68	1.14	2.3	1.28	2
Fayette-14	mp-19	1991	1998	0.04	0	-100.00%	0.08	0.01	0	0	4
	mp-57	1991	1998	0.41	0.32	-21.95%	0.8	0.03	0.77	-0.14	2
	mp-60	1991	1998	1.13	1.06	-6.19%	1.64	0.62	1.65	0.48	2
	mp56	1991	1998	1.01	5.64	458.42%	2.14	-0.13	9.37	1.91	2
Fayette-15	MD1/MD2	1991	1995	0.09	0	-100.00%	0.2	-0.02	0.01	-0.01	2
	MD8/BS29	1991	1995	0.18	0.43	138.89%	0.47	-0.12	0.54	0.32	2
Fayette-16	MP-42	1994	1996	0.03	0.01	-66.67%	0.08	-0.02	0.05	-0.02	2
	MP-8	1994	1996	0.24	0.13	-45.83%	0.33	0.14	0.19	0.06	2
Greene-1	MP-51	1987	1988	1.75	0	-100.00%	3.3	0.19	0	0	4
Greene-2	hu1	1989	1994	18.65	3.31	-82.25%	26.91	10.39	3.9	2.72	3
Indiana-3	1 (A)	1992	1998	0.23	0	-100.00%	0.44	0.02	0	0	4
	2 (B)	1992	1998	30.87	6.04	-80.43%	37.76	23.98	7.07	5	3
	3 (C)	1992	1996	17.87	15.8	-11.58%	20.29	15.46	24.83	6.77	2
Jefferson-1	1	1984	1993	0.1	3.87	3770.00%	0.21	-0.01	8.19	-0.44	2
Jefferson-2	MP-13	1986	1996	0.1	6.36	6260.00%	0.13	0.07	11.22	1.5	1
Jefferson-4	HU-1	1989	1996	1.18	0.64	-45.76%	1.49	0.87	0.88	0.39	2
Jefferson-5	MP-33	1989	1998	0.32	0	-100.00%	0.51	0.14	0	0	4
	MP-8B	1989	1998	0.18	0.14	-22.22%	0.22	0.14	0.21	0.07	2
Jefferson-6	S-25	1993	1998	0.08	2.05	2462.50%	0.11	0.06	3.38	0.72	1
	s-34	1993	1998	0.18	0.15	-16.67%	0.29	0.11	0.45	-0.15	2
Jefferson-7	MP-1	1991	1995	0.3	0	-100.00%	0.4	0.2	0	0	4
Venango-1	1	1989	1994	0.71	0.94	32.39%	1.05	0.48	2.17	-0.28	2

Permit ID	**Monitoring Point ID**	**Permit Baseline Year**	**Review Year**	**Baseline Median**	**Post-Mining Median**	**% Change In Median**	**Baseline Upper Limit**	**Baseline Lower Limit**	**Post-Mining Upper Limit**	**Post-Mining Lower Limit**	**Evaluation**
Wash. -2	A	1985	1998	3.58	0.31	-91.34%	5.09	2.07	0.45	0.17	3
Wash. -4	MP-1	1989	1998	9.49	1.91	-79.87%	18.63	2.34	2.58	1.23	2
	MP-2	1989	1998	6.59	0	-100.00%	8.37	4.82	0	0	4
Wash. -5	d-1	1987	1996	0.15	0.03	-80.00%	0.17	0.14	0.11	-0.05	3
Wash. -6	D5	1992	1997	1.53	2.46	60.78%	2.17	0.89	2.59	2.34	1
Wash. -7	se1a	1995	1998	0.11	0	-100.00%	0.27	-0.04	0	0	4
West-moreland-1	MP10	1984	1993	1.05	1.09	3.81%	1.35	0.74	1.75	0.42	2
	MP7	1984	1993	0.63	1.37	117.46%	0.86	0.4	1.95	0.78	2
	MP9	1984	1993	0.02	0.04	100.00%	0.04	0.01	0.07	-0.01	2
West-moreland-2	S8	1985	1994	1.32	0.57	-56.82%	1.76	0.87	1.1	0.03	2
West-moreland-3	CP2	1986	1990	0.05	0.18	260.00%	0.05	0.04	0.28	0.07	1
	Culvert	1986	1986	0.05	0.09	80.00%	0.09	0.01	0.14	0.03	2
West-moreland-7	MP-3	1986	1991	0.34	0.04	-88.24%	0.44	0.22	0.05	0.03	3
	MP-4	1986	1991	6.9	12.1	75.36%	13.63	0.16	15.19	9.01	2
West-moreland-8	MP-4	1987	1998	0.07	0	-100.00%	0.09	0.03	0	0	4
West-moreland-9	MP-46	1987	1993	9.78	7.4	-24.34%	12.05	7.5	9.59	5.22	2
	MP-47	1987	1993	8.03	10.29	28.14%	11.74	4.3	19.25	1.33	2
	MP-51	1987	1993	0.24	0.27	12.50%	0.33	0.13	0.42	0.11	2
	MP-52	1987	1993	0.14	0.14	0.00%	0.18	0.09	0.34	-0.07	2
	MP-56	1987	1993	0.33	0.32	-3.03%	0.55	0.1	0.59	0.04	2
	MP-60	1987	1993	0.31	0.15	-51.61%	0.43	0.18	0.26	0.04	2
	MP-A	1987	1995	0.98	0.45	-54.08%	1.28	0.67	0.63	0.27	3
West-moreland-10	MP12	1988	1995	1.88	5.54	194.68%	4.4	-0.66	7.29	3.79	2
West-moreland-12	MP-1	1988	1995	4.58	0	-100.00%	6.56	2.6	0	0	4
	MP-2	1988	1995	0.19	0.9	373.68%	0.29	0.09	1.66	0.14	2
	MP-3	1988	1995	0.7	4.36	522.86%	1.08	0.32	6.26	2.47	1
	MP-4	1988	1995	1	0.02	-98.00%	1.56	0.44	0.14	-0.11	3
	MP-5	1988	1995	0.62	1.59	156.45%	1.23	0	2.48	0.7	2
	MP-6	1988	1995	1.01	1.65	63.37%	1.45	0.57	3.34	-0.03	2
	MP-A	1988	1995	1.42	1.38	-2.82%	2.21	0.63	2.17	0.6	2
	MP-B	1988	1995	0.88	0.48	-45.45%	1.32	0.44	0.65	0.31	2
	MP-C	1988	1995	0.17	0.32	88.24%	0.42	-0.08	0.41	0.23	2
	MP-D	1988	1995	0.15	0.04	-73.33%	0.24	0.06	0.07	0	2
West-moreland-13	mp-a	1989	1993	0.07	0.06	-14.29%	0.09	0.06	0.1	0	2
	mp-b	1989	1993	0.59	0.23	-61.02%	0.69	0.48	0.29	0.15	3
West-moreland-14	HU-1	1988	1995	0.77	2.64	242.86%	0.91	0.64	3.64	1.64	1
	MP-5A	1988	1995	0	0.02	N/A	0.02	-0.02	0.03	0	2
West-moreland-15	SLK-GW-27	1994	1999	0.02	0.01	-50.00%	0.03	0	0.03	0	2

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
Westmoreland-16	mp-8	1990	1995	0.3	3.3	1000.00%	0.37	0.24	5.12	1.47	1
Westmoreland-18	1	1989	1995	0.34	0.36	5.88%	0.39	0.3	0.44	0.28	2
	2	1989	1995	0.19	0.09	-52.63%	0.26	0.12	0.27	-0.09	2
	3	1989	1995	0.17	0.11	-35.29%	0.24	0.11	0.28	0	2
Westmoreland-19	MP16	1993	1999	0.08	0.03	-62.50%	0.09	0.06	0.04	0.02	3
	MP5	1993	1999	0.1	0	-100.00%	0.14	0.07	0	0	4
	MP6	1993	1999	0.08	0.11	37.50%	0.09	0.06	0.18	0.03	2
Westmoreland-22	103	1994	1998	0.11	0	-100.00%	0.14	0.08	0	0	4
	69	1994	1998	0.42	0	-100.00%	0.75	0.09	0	0	4
	mp-13	1994	1998	0.03	0	-100.00%	0.24	-0.18	0	0	4
	mp-16	1994	1998	0.04	0	-100.00%	0.06	0.01	0	0	4
Sulfate											
Allegheny-1	10	1986	1995	16.35	44.62	172.91%	52.47	-19.78	160.3	-71.05	2
	2	1986	1995	72.12	10.59	-85.32%	122.38	21.86	15.02	6.16	3
Allegheny-2	S-6	1989	1998	22.72	307.44	1253.17%	34.39	11.04	418.26	196.63	1
	S-7	1989	1989	1244.61	266.69	-78.57%	1521.2	968.02	305.96	227.43	3
Allegheny-3	d-1p	1991	1998	19.4	7.93	-59.12%	27.14	11.66	11.89	3.97	2
Allegheny-4	BS12	1991	1995	343.77	88.47	-74.26%	804.78	-117.24	182.02	-5.08	2
	MD1	1991	1995	202.67	88.88	-56.15%	261.68	143.66	150.33	27.42	2
	MD2	1991	1995	70.92	0	-100.00%	114.68	27.16	4.16	-4.16	3
Allegheny-5	MP-2	1993	1995	16.93	16.31	-3.66%	34.81	-0.95	20.65	11.97	2
Armstrong-1	1A	1984	1990	41.83	34.29	-18.03%	67.92	15.74	55.96	12.62	2
Armstrong-2	D-1	1986	1995	2.42	69.01	2751.65%	13.02	-8.18	136.72	1.31	2
	D-112	1986	1995	3.26	20.56	530.67%	4.63	1.9	67.13	-26	2
	D-4	1986	1995	43.27	30.44	-29.65%	69.89	16.66	56.41	4.48	2
Armstrong-3	w-1A	1986	1992	28.48	80.23	181.71%	35.42	21.54	120.57	39.9	1
	w-2A	1986	1992	13.63	59.2	334.34%	18.41	8.85	102.51	15.88	2
	w-3A	1986	1992	3.7	105.18	2742.70%	4.8	2.6	126.41	83.94	1
Armstrong-4	GK-13	1987	1993	8.33	2.58	-69.03%	12.01	4.65	5.38	-0.21	2
	GK-17	1987	1988	0.03	0	-100.00%	0.17	-0.11	0	0	4
Armstrong-5	MP-2	1988	1993	48.95	3.41	-93.03%	70.64	27.26	8.17	-1.35	3
Armstrong-6	1	1988	1995	137.56	20.75	-84.92%	177.66	97.45	35.76	5.76	3
Armstrong-7	MP14	1988	1997	0.46	3.74	713.04%	0.67	0.24	4.63	2.84	1
	MP15	1988	1997	10.08	46.41	360.42%	16.47	3.69	65.85	26.97	1
	MP17	1988	1997	1.1	25.92	2256.36%	1.28	0.91	43.87	7.97	1
	MP21	1988	1997	0.07	0.32	357.14%	0.12	0.02	0.93	-0.29	2
	MP22	1988	1997	0.11	2.53	2200.00%	0.16	0.06	5.52	-0.46	2
	MP23	1988	1997	0.45	16.95	3666.67%	4.76	-3.86	25.22	8.68	1
	MP24	1988	1997	1.06	1.11	4.72%	2.86	-0.74	1.65	0.58	2

Permit ID	**Monitoring Point ID**	**Permit Baseline Year**	**Review Year**	**Baseline Median**	**Post-Mining Median**	**% Change In Median**	**Baseline Upper Limit**	**Baseline Lower Limit**	**Post-Mining Upper Limit**	**Post-Mining Lower Limit**	**Evaluation**
Armstrong-8	c3-a	1988	1998	21.04	59.9	184.70%	60.05	-17.98	84.17	35.62	2
	md-2	1988	1998	4.62	97.77	2016.23%	10.15	-0.92	137.71	57.83	1
Armstrong-9	HU1	1988	1998	195.5	239.86	22.69%	322.4	68.61	324.3	155.42	2
Armstrong-10	C-11	1989	1995	3.98	5.22	31.16%	4.8	3.15	10.36	-0.12	2
	S-20	1989	1995	56.82	90.44	59.17%	68.1	45.55	112.59	68.28	1
Armstrong-11	HU1	1990	1997	1.17	0	-100.00%	2.69	-0.36	0	0	4
Armstrong-12	mp2	1991	1995	45.44	6.63	-85.41%	83.26	7.63	7.93	5.33	2
	mph	1991	1995	4.96	6.55	32.06%	9.08	0.84	8.45	4.64	2
Armstrong-13	41	1990	1995	17.8	0	-100.00%	21.79	13.81	0.01	-0.01	3
	48	1990	1995	9.33	0	-100.00%	12.51	6.14	0.05	-0.05	3
	Unit 2	1990	1995	312.42	4.94	-98.42%	345.91	278.92	7.17	2.7	3
Armstrong-14	1	1991	1993	27.75	0	-100.00%	35.42	20.08	0	0	4
Armstrong-16	HU1	1993	1998	2.35	7.14	203.83%	3.9	0.8	9.26	5.02	1
Armstrong-17	HU1	1994	1998	0.51	0.54	5.88%	0.95	0.07	0.89	0.19	2
Armstrong-18	D1	1994	1998	1.7	0	-100.00%	2.62	0.77	0	0	4
Beaver-1	S-10	1988	1995	174.39	23.48	-86.54%	211.44	137.35	34.01	12.94	3
Butler-1	5W	1986	1991	162.27	281.84	73.69%	233.31	91.23	427.5	136.19	2
Butler-2	2W	1984	1989	1.88	0	-100.00%	2.33	1.42	0	0	4
	5AW	1984	1989	4.49	116.99	2505.57%	5.96	3.02	169.27	64.7	1
	8W	1984	1989	11.36	40.41	255.72%	18.9	3.82	63.6	17.21	2
Butler-3	S-116	86	1994	117.45	37	-68.50%	144.07	90.82	66.27	7.73	3
	S-13	86	1994	29.13	0	-100.00%	34.81	23.45	0	0	4
	S-200	86	1994	9	37.12	312.44%	18.55	-0.55	84.46	-10.21	2
	S-91	86	1994	7.47	0	-100.00%	9.82	5.12	0	0	4
	S-95/96	86	1994	12.56	5.26	-58.12%	17.7	7.42	11.51	-1	2
Butler-4	DR2	1991	1998	32.65	0	-100.00%	37.19	28.11	0	0	4
Butler-5	1	1991	1998	162.91	264.13	62.13%	200.48	125.35	367.06	161.21	2
Cambria-1	MP 9	1990	1995	18.08	0	-100.00%	25.98	10.17	0	0	4
	Mp 13	1990	1995	35.65	0	-100.00%	50.56	20.74	0	0	4
Clarion-1	SP-1	1985	1995	540.9	111.79	-79.33%	633.8	448	172.58	51	3
	SP-28	1985	1995	219.97	142.8	-35.08%	276.11	163.82	190.45	95.14	2
	SP-5	1985	1995	8.16	0	-100.00%	12.28	4.03	0.3	-0.3	3
	SP-6	1985	1995	74.84	0	-100.00%	134.82	14.85	0	0	4
Clarion-2	1	1986	1989	2.77	0	-100.00%	4.87	0.68	0.31	-0.31	3
Clarion-3	RH-78	1990	1994	0.54	0	-100.00%	0.92	0.15	0	0	4
Clarion-4	1	1990	1996	0	0	N/A	2.27	-2.27	0	0	4
	2	1990	1996	31.35	40.06	27.78%	48.78	13.92	46.12	34	2
Clarion-5	DR-1	1990	1992	19.88	306.33	1440.90%	34.02	5.75	427.54	185.13	1
Clarion-6	1	1992	1998	1.15	0	-100.00%	2.27	0.04	0	0	4
	2	1992	1998	1.95	0	-100.00%	3.03	0.86	0	0	4
	3	1992	1998	8.8	0	-100.00%	12.73	4.87	0	0	4
Clearfield-1	unit 1	1985	1998	318.53	113.2	-64.46%	387.19	249.87	173.83	52.56	3
Clearfield-2	W10	1985	1998	63.04	22.66	-64.05%	114.45	11.63	31.77	13.56	2
	W42	1985	1998	143.29	51.1	-64.34%	226.07	60.52	74.32	27.87	2

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	W43	1985	1998	293.17	208.7	-28.81%	484.05	102.29	288.67	127.46	2
	W44	1985	1998	95.95	56.08	-41.55%	194.56	-2.66	79.96	32.2	2
Clearfield-3	SF-1	1986	1998	3.11	0.98	-68.49%	3.86	2.36	1.78	0.18	3
	SF10	1986	1998	0	0.09	N/A	1.23	-1.23	0.14	0.04	2
	SF4	1986	1998	4.11	0.64	-84.43%	5.94	2.28	1.87	-0.58	3
	SF6	1986	1998	0.31	44.64	14300.00%	5.53	-4.91	67.84	21.43	1
	SF61	1986	1998	16.74	5.79	-65.41%	26.47	7.01	23.25	-11.67	2
Clearfield-4	TK-3	1985	1997	179.92	159.05	-11.60%	206.99	152.86	203.61	114.49	2
	tk-18	1985	1997	125.04	240.43	92.28%	174.87	75.2	305.94	174.92	1
	tk-21	1985	1997	58.65	6.49	-88.93%	86.47	30.83	25.78	-12.81	3
	tk-37	1985	1997	90.44	30.31	-66.49%	113.97	66.91	45.8	14.82	3
	tk-4	1985	1997	7.93	1.52	-80.83%	10.8	5.05	2.13	0.92	3
	tk-7	1985	1997	18.15	0	-100.00%	21.79	14.51	0	0	4
Clearfield-5	SV-5	1988	1992	13.9	19.82	42.59%	15.88	11.91	27.06	12.58	2
	SV-8	1988	1992	29.68	35.54	19.74%	43.09	16.26	69.97	1.11	2
Clearfield-6	R-3	1988	1995	19.28	0.53	-97.25%	26.03	12.53	4.51	-3.46	3
	R-5	1988	1995	15.84	8.43	-46.78%	20.95	10.73	14.08	2.78	2
	R-8	1988	1995	143.19	136.72	-4.52%	163.3	123.07	179.82	93.61	2
Clearfield-7	12	1989	1997	1.93	3.85	99.48%	3.35	0.5	6.71	1	2
	13	1989	1997	290.52	310.11	6.74%	380.4	200.64	393.72	226.51	2
Clearfield-8	TK4	1990	1996	8.83	1.6	-81.88%	11.63	6.04	2.42	0.79	3
	TK7	1990	1996	11.51	0	-100.00%	20.58	2.45	0	0	4
Clearfield-9	1	1990	1994	26.83	0	-100.00%	47.73	5.94	0	0	4
	2	1990	1994	0.33	0	-100.00%	1.34	-0.67	0	0	4
Clearfield-10	HU 1	1992	1998	21.08	19.4	-7.97%	27.11	15.04	29.44	9.37	2
	HU 2	1992	1998	4.4	4.64	5.45%	6.23	2.57	5.82	3.46	2
	HU 3	1992	1998	27.93	16.65	-40.39%	35.69	20.18	24.77	8.52	2
Clearfield-11	subf-a	1993	1994	14.09	17.12	21.50%	20.65	7.53	21.97	12.27	2
	subf-b	1993	1994	8.22	2.72	-66.91%	11.76	4.68	5.72	-0.29	2
	subf-c	1993	1994	26.61	8.31	-68.77%	32.29	20.93	15.04	1.58	3
Clinton-1	13	1981	1995	60.58	0	-100.00%	108.73	12.43	0	0	4
	15A	1981	1995	6.61	0	-100.00%	18.51	-5.29	0	0	4
	96	1981	1995	8.65	0	-100.00%	17.39	-0.08	0	0	4
	97	1981	1995	9.59	0	-100.00%	20.74	-1.55	0	0	4
	SNW 1A	1981	1996	344.25	225.93	-34.37%	502.02	186.49	255.83	196.03	2
Clinton-2	GR-9	1988	1993	45.73	20.26	-55.70%	72.46	19.01	102.41	-61.89	2
Clinton-3	SEH-31	1990	1993	68.76	52.82	-23.18%	115.31	22.22	81.62	24.02	2
	SHE-30	1990	1993	14.52	32.98	127.13%	23.92	5.12	47.26	18.69	2
Fayette-1	mp-4	1989	1993	34.26	10.4	-69.64%	41.9	26.61	10.69	10.11	3
	mp-5	1989	1993	30.65	0	-100.00%	35.98	25.32	0	0	4
	mp-6	1989	1993	5.47	0	-100.00%	10.99	-0.05	0	0	4
	mp-8	1989	1993	36.78	1.14	-96.90%	40.65	32.91	1.15	1.12	3
Fayette-2	HU-1	1984	1992	955.89	448.05	-53.13%	1207.33	704.45	530.84	365.25	3
Fayette-3	MS100	1988	1995	158.66	0.35	-99.78%	190.73	126.59	2.31	-1.61	3
Fayette-4	MP6	1988	1993	6.73	3.22	-52.15%	12.23	1.23	5.53	0.91	2
Fayette-5	mp-4	1988	1998	2297.02	708.19	-69.17%	3795.72	798.32	959.29	457.08	2
	mp-hua	1988	1998	1119.78	539.57	-51.81%	1531.05	708.51	820.34	258.8	2
Fayette-6	MP-1	1988	1994	151.45	223.12	47.32%	224.93	77.98	850.22	-403.98	2
Fayette-7	MP48	1989	1996	735.46	1286.57	74.93%	1143.47	328.44	1605.91	967.24	2
	MP49	1989	1996	108.52	286.36	163.88%	165.54	51.5	413.41	159.31	2
Fayette-8	MP-15	1988	1994	217.8	367.84	68.89%	322.73	112.88	693.39	42.29	2

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Fayette-9	MP-28	1990	1998	245.8	473.19	92.51%	400.45	91.16	640.08	306.3	2
Fayette-10	mp-1	1989	1992	285.84	55.97	-80.42%	330.13	241.56	89.13	22.8	3
	mp-11	1989	1992	84.96	18.15	-78.64%	116.43	53.49	49.56	-13.25	3
	mp-2	1989	1992	14.41	15.07	4.58%	18.96	9.87	22.1	8.05	2
Fayette-11	mp 29	1991	1998	33.76	65.81	94.93%	87.9	-20.38	88.03	43.6	2
Fayette-12	Mp68	1991	1997	10.39	4.76	-54.19%	18.34	2.44	7.88	1.64	2
Fayette-13	D5	1991	1995	30.29	42.96	41.83%	44.7	15.88	49.26	36.67	2
Fayette-14	mp-19	1991	1998	0	0	N/A	2.65	-2.65	0	0	4
	mp-57	1991	1998	12.93	26.87	107.81%	25.11	0.76	58.1	-4.37	2
	mp-60	1991	1998	44.43	58.07	30.70%	94	-5.14	132.99	-16.86	2
	mp56	1991	1998	61.09	382.1	525.47%	132.49	-10.32	886	-121.8	2
Fayette-15	MD1/MD2	1991	1995	9.73	0	-100.00%	42.8	-23.34	0	0	4
	MD8/BS29	1991	1995	8.46	11.81	39.60%	16.88	0.05	14.16	9.46	2
Fayette-16	MP-42	1994	1996	8.39	2.81	-66.51%	13.97	2.81	8.57	-2.95	2
	MP-8	1994	1996	280.52	307.8	9.72%	383.92	177.11	366.2	249.4	2
Greene-1	MP-51	1987	1988	1.86	0	-100.00%	1.86	1.86	0	0	4
Greene-2	hu1	1989	1994	1454.81	101.56	-93.02%	2238.44	671.19	171.51	31.61	3
Indiana-1	H	1988	1995	256.37	335.11	30.71%	345.93	166.81	441.72	228.5	2
	J	1988	1995	152	150.81	-0.78%	218.05	85.94	309.17	-7.55	2
	K	1988	1995	42.49	65.77	54.79%	48.17	36.17	99.71	31.83	2
	L	1988	1995	57.1	2.34	-95.90%	78.35	35.86	30.89	-26.22	3
	M	1988	1995	23.31	63.05	170.48%	38.3	8.32	120.47	5.67	2
	N	1988	1995	6.28	1.47	-76.59%	11.89	0.66	2.56	0.37	2
	O	1988	1995	0	0	N/A	0.08	-0.08	0	0	4
Indiana-2	MP 15	1988	1997	32.32	6.64	-79.46%	41.22	23.42	8.17	5.11	3
	MP 5	1988	1997	280.64	415.5	48.05%	501.73	59.56	694.68	136.33	2
Indiana-3	1 (A)	1992	1998	0	0	N/A	6.71	-6.71	0.79	-0.79	2
	2 (B)	1992	1998	1359.89	182.71	-86.56%	2016.81	702.97	299.61	65.82	3
	3 (C)	1992	1996	901.6	840.32	-6.80%	1388	415.2	1019.61	661.02	2
	4 (D)	1992	1998	279.41	63.79	-77.17%	432.03	126.78	87.33	40.26	3
Indiana-4	1	1992	1998	34.96	30.09	-13.93%	40.73	29.19	39.26	20.92	2
	MP 51	1992	1998	30.82	0	-100.00%	38.16	23.48	0	0	4
	MP 52	1992	1998	19.63	8.13	-58.58%	32.18	7.09	10.67	5.59	2
Jefferson-2	MP-13	1986	1996	7.32	117.06	1499.18%	10.16	4.48	263.62	-29.5	2
Jefferson-3	HU-1	1989	1992	1.37	0	-100.00%	3.36	-0.61	0	0	4
	HU-2	1989	1992	11.41	1.57	-86.24%	48.26	-25.43	2.35	0.78	2
Jefferson-5	MP-33	1989	1998	207	42.74	-79.35%	226.98	187.02	87.47	-1.98	3
	MP-8B	1989	1998	160.44	138.56	-13.64%	206.68	114.2	210.39	66.73	2
Jefferson-6	S-25	1993	1998	2.2	44.92	1941.82%	5.78	-1.37	87.85	1.99	2
	s-34	1993	1998	11.3	0	-100.00%	17.07	5.53	7.84	-7.84	2
Jefferson-7	MP-1	1991	1995	11.88	0.95	-92.00%	15.31	8.46	3.4	-1.5	3
Lawrence-1	1	1992	1998	10.94	0	-100.00%	14.02	7.85	0	0	4
Somerset-1	SP 16	1989	1998	0.91	7.48	721.98%	1.47	0.34	15.11	-0.15	2
Somerset-2	1	1993	1998	96.17	141.8	47.45%	132.01	60.33	165.67	117.93	2
Venango-1	1	1989	1994	53.53	46.16	-13.77%	70.53	36.53	133.65	-41.34	2
Washington-1	HU1	1986	1993	593.85	2519.02	324.18%	759.01	428.69	3237.63	1800.42	1
Washington-2	A	1985	1998	167.85	84.59	-49.60%	198.99	136.71	125.67	43.52	3
Washington-3	CV103	1985	1998	8369.96	3305.5	-60.51%	9446.53	7293.39	3305.5	3305.5	3
	CV4	1985	1998	1107.28	1189.98	7.47%	1680.24	534.32	1357.27	1022.69	2

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Washington-4	MP-1	1989	1998	1891.27	297.08	-84.29%	2361.95	1420.6	424.19	169.97	3
	MP-2	1989	1998	2602.83	0	-100.00%	2998.6	2207.1	0	0	4
Washington-5	d-1	1987	1996	14.86	10.31	-30.62%	24.26	5.46	13.71	6.92	2
Washington-6	D5	1992	1997	584.17	601	2.88%	707.38	460.96	762.56	439.44	2
Washington-7	se1a	1995	1998	2.49	0	-100.00%	4.23	0.76	0	0	4
Westmoreland-1	MP10	1984	1993	101.17	77.16	-23.73%	187.84	14.5	102.55	51.77	2
	MP7	1984	1993	47.7	181.95	281.45%	125.51	-30.1	233.17	130.73	1
Westmoreland-1	MP9	1984	1993	0	7.97	N/A	0.82	-0.82	12.26	3.68	1
Westmoreland-2	S8	1985	1994	192.77	85.18	-55.81%	265.22	120.31	187.77	-17.41	2
Westmoreland-3	CP2	1986	1990	12.62	8.54	-32.33%	18.84	6.4	11.66	5.42	2
	Culvert	1986	1986	5.86	6.49	10.75%	6.32	5.4	9.94	3.04	2
Westmoreland-4	MD-1	1986	1990	76.03	41.83	-44.98%	333.63	-181.58	59.17	24.49	2
	MD-3	1986	1990	15.84	0	-100.00%	122.67	-90.99	0	0	4
	MD-4	1986	1990	32.78	21.46	-34.53%	65.64	-0.08	30.87	12.04	2
	MD-6	1986	1990	493.48	0	-100.00%	935.48	51.48	0	0	4
	MD-7	1986	1990	328.92	59.5	-81.91%	563.98	93.85	93.37	25.63	3
Westmoreland-5	HU-1	1986	1996	1117.86	641.62	-42.60%	1601.29	634.43	900.54	382.7	2
Westmoreland-6	M	1985	1993	62.34	121.18	94.39%	157.63	-32.95	143.16	99.2	2
	N	1985	1993	5.96	2.96	-50.34%	14.6	-2.67	11.07	-5.15	2
Westmoreland-7	MP-3	1986	1991	24.53	2.34	-90.46%	33.54	15.53	3.76	0.93	3
	MP-4	1986	1991	482.45	1238.06	156.62%	728.08	236.82	1718.41	757.71	1
Westmoreland-8	MP-4	1987	1998	4.65	0	-100.00%	8.17	1.14	0	0	4
Westmoreland-9	MP-46	1987	1993	917.57	688.07	-25.01%	1135.08	700.05	808.37	567.76	2
	MP-47	1987	1993	972.18	2728.85	180.69%	1342.1	602.25	3508.84	1948.87	1
	MP-51	1987	1993	18.78	5.77	-69.28%	21.13	16.44	10.28	1.27	3
	MP-52	1987	1993	8.02	19.59	144.26%	10.34	5.7	31.64	7.55	2
	MP-56	1987	1993	36.3	49.58	36.58%	50.69	21.92	105.57	-6.41	2
	MP-60	1987	1993	48.43	24.66	-49.08%	58.37	38.49	44.69	4.63	2
	MP-A	1987	1995	89.82	20.15	-77.57%	111.52	68.12	25.7	14.61	3
Westmoreland-10	MP12	1988	1995	96.47	128.95	33.67%	214.68	-21.74	157.23	100.67	2
Westmoreland-11	MP3	1988	1992	3386.86	3201.9	-5.46%	4387.86	2385.85	3961.25	2442.54	2
Westmoreland-12	MP-1	1988	1995	78.61	0	-100.00%	210.22	-53	0	0	4
	MP-2	1988	1995	7.73	68.42	785.12%	10.57	4.89	107.27	29.58	1
	MP-3	1988	1995	36.09	126.28	249.90%	56.99	15.19	162.88	89.68	1
	MP-4	1988	1995	77.27	17.73	-77.05%	137.74	16.8	29.58	5.89	2
	MP-5	1988	1995	15.63	90.44	478.63%	67.65	-36.39	127.46	53.42	2
	MP-6	1988	1995	60.51	130.71	116.01%	102.61	18.4	173.81	87.6	2
	MP-A	1988	1995	0.06	19.42	32266.67%	22.35	-22.23	43.08	-4.23	2
	MP-B	1988	1995	0	19.7	N/A	9.53	-9.53	35.23	4.17	2
	MP-C	1988	1995	1.83	18.49	910.38%	5.56	-1.9	31.35	5.64	1

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	MP-D	1988	1995	0	0.7	N/A	0.31	-0.31	1.41	-0.01	2
Westmoreland-13	mp-a	1989	1993	14.9	10.06	-32.48%	18.78	11.03	25.39	-5.27	2
	mp-b	1989	1993	105.94	7.77	-92.67%	135.65	76.24	24.56	-9.03	3
Westmoreland-14	HU-1	1988	1995	145.68	142.81	-1.97%	189.91	101.44	171.31	114.3	2
	MP-5A	1988	1995	21.31	2.74	-87.14%	27.82	14.81	4.44	1.03	3
Westmoreland-15	SLK-GW-27	1994	1999	15.89	2.45	-84.58%	19.66	12.12	4.26	0.63	3
Westmoreland-16	mp-8	1990	1995	25.18	62.75	149.21%	33.46	16.89	79.47	46.02	1
Westmoreland-17	SW18	1989	1993	3.89	0	-100.00%	4.28	3.51	0	0	4
Westmoreland-18	1	1989	1995	8.78	4.9	-44.19%	12.99	4.57	6.7	3.1	2
	2	1989	1995	10.96	19.28	75.91%	14.7	7.23	34.18	4.38	2
	3	1989	1995	20.59	8.14	-60.47%	39.32	1.87	12.98	3.3	2
Westmoreland-19	MP16	1993	1999	5.81	3.82	-34.25%	6.52	5.1	5.35	2.29	2
	MP5	1993	1999	5.74	0.44	-92.33%	7.38	4.09	1.55	-0.67	3
	MP6	1993	1999	7.04	0	-100.00%	11.33	2.75	2.65	-2.65	3
Westmoreland-20	mp-7	1991	1998	4.09	14.03	243.03%	5.52	2.65	24	4.06	2
Westmoreland-21	MP3	1992	1997	0.3	4.7	1466.67%	0.46	0.14	6.77	2.63	1
Westmoreland-22	103	1994	1998	14.86	0	-100.00%	20.61	9.1	0	0	4
	69	1994	1998	77.99	0	-100.00%	110.87	45.11	0.39	-0.39	3
	mp-13	1994	1998	6.63	0	-100.00%	33.83	-20.57	0	0	4
	mp-16	1994	1998	3.88	0	-100.00%	7.13	0.64	0	0	4
Flow											
Allegheny-1	10	1986	1995	8	4.5	-43.75%	15.74	0.26	13.04	-4.04	2
	2	1986	1995	10	0.5	-95.00%	16.33	3.67	0.67	0.33	3
Allegheny-2	S-6	1989	1998	2.4	29.7	1137.50%	3.77	1.03	41.26	18.14	1
	S-7	1989	1989	136	29	-78.68%	158.12	113.88	34.38	23.62	3
Allegheny-3	d-1p	1991	1998	2.4	1.2	-50.00%	2.56	2.24	1.6	0.8	3
Allegheny-4	BS12	1991	1995	52.98	15	-71.69%	94.38	11.58	30.31	-0.31	2
	MD1	1991	1995	28.65	14	-51.13%	33.24	24.06	23.77	4.23	3
	MD2	1991	1995	11	0	-100.00%	20.51	1.49	0.87	-0.87	3
Allegheny-5	MP-2	1993	1995	2.5	2.2	-12.00%	4.67	0.33	2.58	1.82	2
Armstrong-1	1A	1984	1990	66	50.13	-24.05%	93.93	38.07	78.47	21.78	2
Armstrong-2	D-1	1986	1995	18	22.38	24.33%	32.04	3.96	45.23	-0.47	2
	D-112	1986	1995	2	14.98	649.00%	2.93	1.07	52.54	-22.58	2
	D-4	1986	1995	25	20.47	-18.12%	38.84	11.16	42.88	-1.94	2
Armstrong-3	w-1A	1986	1992	18.06	13.05	-27.74%	21.75	14.37	17.61	9.39	2
	w-2A	1986	1992	15.33	8	-47.81%	21.07	9.59	14.35	1.65	2
	w-3A	1986	1992	6.72	10	48.81%	8.98	4.46	12.54	7.46	2

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Armstrong-4	GK-13	1987	1993	1.98	0.75	-62.12%	2.93	1.03	1.29	0.21	2
	GK-17	1987	1988	0.02	0	-100.00%	0.11	-0.08	0	0	4
Armstrong-5	MP-2	1988	1993	8.1	0.58	-92.84%	11.83	4.37	1.56	-0.41	3
Armstrong-6	1	1988	1995	10	1	-90.00%	15.89	4.11	1.95	0.05	3
Armstrong-7	MP14	1988	1997	0.1	1.63	1530.00%	0.18	0.02	1.93	1.32	1
	MP15	1988	1997	2.6	13.5	419.23%	4.51	0.69	20.78	6.22	1
	MP17	1988	1997	0.1	3.25	3150.00%	0.15	0.05	5.78	0.72	1
	MP21	1988	1997	0.1	0.63	530.00%	0.13	0.07	1.97	-0.72	2
	MP22	1988	1997	0.1	3.15	3050.00%	0.13	0.07	7.11	-0.81	2
	MP23	1988	1997	0.25	20	7900.00%	7.02	-6.52	33.67	6.33	2
	MP24	1988	1997	1	1.2	20.00%	1.88	0.12	2.26	0.14	2
Armstrong-8	c3-a	1988	1998	7	15.1	115.71%	23.21	-9.21	19.83	10.37	2
	md-2	1988	1998	2.7	27.1	903.70%	5.49	-0.09	36.45	17.75	1
Armstrong-9	HU1	1988	1998	27.73	12.03	-56.62%	43.19	12.26	17.92	6.14	2
Armstrong-10	C-11	1989	1995	0.6	0.5	-16.67%	0.77	0.43	0.7	0.3	2
	S-20	1989	1995	7.1	6.7	-5.63%	8.61	5.59	9.72	3.68	2
Armstrong-11	HU1	1990	1997	0.5	0	-100.00%	1.15	-0.15	0	0	4
Armstrong-12	mp2	1991	1995	6.4	0.95	-85.16%	9.73	3.07	1.25	0.65	3
	mph	1991	1995	0.9	2	122.22%	1.54	0.26	2.81	1.19	2
Armstrong-13	41	1990	1995	2.18	0	-100.00%	2.41	1.94	0.01	-0.01	3
	48	1990	1995	2.48	0	-100.00%	3.15	1.81	0.01	-0.01	3
	Unit 2	1990	1995	13	0.74	-94.31%	15.04	10.96	1.04	0.44	3
Armstrong-14	1	1991	1993	4.5	0	-100.00%	6.11	2.89	0	0	4
Armstrong-15	V2	1992	1997	31.5	0.85	-97.30%	40.3	22.7	1.39	0.31	3
Armstrong-16	HU1	1993	1998	4.1	1.35	-67.07%	9.36	-1.16	1.76	0.94	2
Armstrong-17	HU1	1994	1998	0.3	0.25	-16.67%	0.58	0.02	0.54	-0.04	2
Armstrong-18	D1	1994	1998	1.33	0	-100.00%	2.13	0.52	0	0	4
Beaver-1	S-10	1988	1995	29.7	6.6	-77.78%	34.94	24.46	10.96	2.24	3
Butler-1	5W	1986	1991	70	73	4.29%	110.16	29.83	107.36	38.64	2
Butler-2	2W	1984	1989	2	0	-100.00%	2.42	1.58	0	0	4
	5AW	1984	1989	7.5	13.8	84.00%	10.98	4.02	20.47	7.13	2
	8W	1984	1989	11	2.7	-75.45%	14.9	7.1	4.9	0.5	3
Butler-3	S-116	86	1994	14.06	3.7	-73.68%	18.35	9.77	8.23	-0.83	3
	S-13	86	1994	14.1	0	-100.00%	16.23	11.97	0	0	4
	S-200	86	1994	1.91	11.05	478.53%	4.32	-0.5	21.99	0.11	2
	S-91	86	1994	0.99	0	-100.00%	1.2	0.78	0	0	4
	S-95/96	86	1994	1.46	0.55	-62.33%	2.14	0.77	1.66	-0.56	2
Butler-4	DR2	1991	1998	1.59	0	-100.00%	1.98	1.2	0	0	4
Butler-5	1	1991	1998	86	52.4	-39.07%	108.1	63.9	91.03	13.77	2
Cambria-1	MP 9	1990	1995	12.4	0	-100.00%	19.42	5.38	0	0	4

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	Mp 13	1990	1995	30	0	-100.00%	40.68	19.32	0	0	4
Clarion-1	SP-1	1985	1995	25	6	-76.00%	33.45	16.55	9.27	2.73	3
	SP-28	1985	1995	15	9	-40.00%	18.38	11.62	12.93	5.07	2
	SP-5	1985	1995	1	0	-100.00%	1	1	0.11	-0.11	3
	SP-6	1985	1995	3.5	0	-100.00%	5.05	1.95	0	0	4
Clarion-2	1	1986	1989	1.76	0	-100.00%	2.38	1.14	0.13	-0.13	3
Clarion-3	RH-78	1990	1994	3	0	-100.00%	3.61	2.39	0	0	4
Clarion-4	1	1990	1996	0	0	N/A	0.49	-0.49	0	0	4
	2	1990	1996	6	5.35	-10.83%	6.98	5.02	6.19	4.51	2
Clarion-5	DR-1	1990	1992	7.95	16	101.26%	13.93	1.97	21.7	10.3	2
Clarion-6	1	1992	1998	1	0	-100.00%	1.46	0.54	0	0	4
	2	1992	1998	1	0	-100.00%	1.44	0.56	0	0	4
	3	1992	1998	1	0	-100.00%	1.55	0.45	0	0	4
Clearfield-1	unit 1	1985	1998	45.06	13.89	-69.17%	57.49	32.63	23.21	4.57	3
Clearfield-2	W10	1985	1998	5.5	2.2	-60.00%	12.62	-1.62	6.34	-1.62	2
	W42	1985	1998	13.1	3.9	-70.23%	19.84	6.36	5.52	2.28	3
	W43	1985	1998	18	21.3	18.33%	30.22	5.78	30.02	12.58	2
	W44	1985	1998	9.5	12.7	33.68%	20.93	-1.93	18.91	6.49	2
Clearfield-3	SF-1	1986	1998	0.3	0.1	-66.67%	0.38	0.22	0.17	0.03	3
	SF10	1986	1998	0.35	0.07	-80.00%	0.81	-0.11	0.1	0.04	2
	SF4	1986	1998	1	0.1	-90.00%	1.62	0.38	0.52	-0.32	2
	SF6	1986	1998	0.2	2.2	1000.00%	2.53	-2.13	3.7	0.7	2
	SF61	1986	1998	4.35	2.2	-49.43%	6.77	1.93	7.32	-2.92	2
Clearfield-4	TK-3	1985	1997	18	12.4	-31.11%	20.48	15.52	17.59	7.21	2
	tk-18	1985	1997	12	21.7	80.83%	17.36	6.64	27.46	15.94	2
	tk-21	1985	1997	4.5	0.5	-88.89%	6.45	2.55	2.02	-1.02	3
	tk-37	1985	1997	9	4	-55.56%	11.74	6.26	5.32	2.68	3
	tk-4	1985	1997	1.6	0.42	-73.75%	2.24	0.96	0.66	0.18	3
	tk-7	1985	1997	6.5	0	-100.00%	9.14	3.86	0	0	4
Clearfield-5	SV-5	1988	1992	6.3	3.6	-42.86%	8.64	3.96	5.17	2.03	2
	SV-8	1988	1992	8	7.7	-3.75%	12.62	3.38	16.99	-1.59	2
Clearfield-6	R-3	1988	1995	2.95	0.1	-96.61%	4.49	1.4	0.85	-0.65	3
	R-5	1988	1995	3.25	1.1	-66.15%	4.73	1.76	1.62	0.58	3
	R-8	1988	1995	31.8	27.4	-13.84%	38.86	24.73	35.05	19.75	2
Clearfield-7	12	1989	1997	0.3	0.56	86.67%	0.56	0.04	1.19	-0.07	2
	13	1989	1997	37	43.94	18.76%	46.79	27.21	57.55	30.33	2
Clearfield-8	TK4	1990	1996	2.19	0.42	-80.82%	2.68	1.7	0.68	0.16	3
	TK7	1990	1996	3.1	0	-100.00%	5.63	0.57	0	0	4
Clearfield-9	1	1990	1994	6.6	0	-100.00%	9.83	3.37	0	0	4
	2	1990	1994	0.15	0	-100.00%	0.7	-0.4	0	0	4
Clearfield-10	HU 1	1992	1998	8.64	7.15	-17.25%	13.55	3.72	10.99	3.31	2
	HU 2	1992	1998	1	2.11	111.00%	1.83	0.17	2.54	1.68	2
	HU 3	1992	1998	8.68	8.74	0.69%	11.41	5.94	12.1	5.38	2
Clearfield-11	subf-a	1993	1994	2.3	4	73.91%	3.67	0.93	4.56	3.44	2
	subf-b	1993	1994	3	2	-33.33%	4.51	1.49	3.48	0.52	2
	subf-c	1993	1994	7.7	1.8	-76.62%	9.58	5.82	3.37	0.23	3
Clinton-1	13	1981	1995	7	0	-100.00%	11.97	2.03	0	0	4
	15A	1981	1995	10	0	-100.00%	16.1	3.9	0	0	4
	96	1981	1995	2.75	0	-100.00%	4.6	0.9	0.66	-0.66	3
	97	1981	1995	5	0	-100.00%	6.56	3.44	0	0	4
	SNW 1A	1981	1996	36	13.5	-62.50%	45.33	26.67	16.85	10.15	3

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Clinton-2	GR-9	1988	1993	8	0.75	-90.63%	12.58	3.42	3.68	-2.18	2
Clinton-3	SEH-31	1990	1993	16.2	12.4	-23.46%	26.28	6.12	17.13	7.67	2
	SHE-30	1990	1993	1	3	200.00%	1.24	0.76	4.06	1.94	1
Fayette-1	mp-4	1989	1993	2.5	0.5	-80.00%	3.13	1.87	0.51	0.49	3
	mp-5	1989	1993	2	0	-100.00%	2.42	1.58	0	0	4
	mp-6	1989	1993	1	0	-100.00%	1	1	0	0	4
	mp-8	1989	1993	2	0.2	-90.00%	2.21	1.79	0.2	0.2	3
Fayette-2	HU-1	1984	1992	27.5	22.75	-17.27%	32.88	22.12	29.15	16.35	2
Fayette-3	MS100	1988	1995	40	0.1	-99.75%	56.59	23.41	1.58	-1.38	3
Fayette-4	MP6	1988	1993	0.9	0.44	-51.11%	2.17	-0.37	0.78	0.09	2
Fayette-5	mp-4	1988	1998	105	35.07	-66.60%	151.13	58.87	54.5	15.64	3
	mp-hua	1988	1998	45.25	35.07	-22.50%	58.47	32.03	54.5	15.64	2
Fayette-6	MP-1	1988	1994	6.1	9.48	55.41%	8.73	3.47	32.43	-13.47	2
Fayette-7	MP48	1989	1996	53.95	69.4	28.64%	86.49	21.41	90.48	48.32	2
	MP49	1989	1996	10.1	19.5	93.07%	15.76	4.44	28.01	10.99	2
Fayette-8	MP-15	1988	1994	6.85	8.64	26.13%	10.13	3.57	18.11	-0.83	2
Fayette-9	MP-28	1990	1998	26.46	50.6	91.23%	54.68	-1.76	69.93	31.27	2
Fayette-10	mp-1	1989	1992	16.03	3.72	-76.79%	18.5	13.56	5.56	1.88	3
	mp-11	1989	1992	8.88	1.81	-79.62%	15.66	2.1	4.61	-1	2
	mp-2	1989	1992	1.35	0.99	-26.67%	1.79	0.91	1.44	0.53	2
Fayette-11	mp 29	1991	1998	4.13	6.6	59.81%	10.56	-2.3	9.07	4.13	2
Fayette-12	Mp68	1991	1997	0.8	0.36	-55.00%	1.63	-0.03	0.78	-0.06	2
Fayette-13	D5	1991	1995	1.5	1.6	6.67%	2.43	0.57	2.21	0.99	2
Fayette-14	mp-19	1991	1998	0	0	N/A	0.51	-0.51	0	0	4
	mp-57	1991	1998	1.7	11.5	576.47%	3.08	0.32	27.76	-4.76	2
	mp-60	1991	1998	8.8	11.2	27.27%	20.18	-2.58	28.36	-5.96	2
	mp56	1991	1998	7.7	25.3	228.57%	15.13	0.27	49.2	1.4	2
Fayette-15	MD1/MD2	1991	1995	2.8	0	-100.00%	8.94	-3.34	0	0	4
	MD8/BS29	1991	1995	1.1	1.2	9.09%	2.05	0.15	1.53	0.87	2
Fayette-16	MP-42	1994	1996	0.9	0.3	-66.67%	1.52	0.28	0.91	-0.31	2
	MP-8	1994	1996	28.6	44.8	56.64%	42.45	14.75	48.7	40.9	2
Greene-1	MP-51	1987	1988	0.01	0	-100.00%	0.01	0.01	0	0	4
Greene-2	hu1	1989	1994	51.5	3.25	-93.69%	68.92	34.08	5.85	0.65	3
Indiana-1	H	1988	1995	27.3	37.9	38.83%	35.46	19.14	49.63	26.17	2
	J	1988	1995	14.6	16.5	13.01%	19.67	9.53	32.77	0.23	2
	K	1988	1995	3.6	5.7	58.33%	4.24	2.96	9.35	2.05	2
	L	1988	1995	4.2	0.25	-94.05%	6.23	2.17	2.89	-2.39	2
	M	1988	1995	3.1	16.5	432.26%	5.31	0.89	23.26	9.74	1
	N	1988	1995	0.8	0.1	-87.50%	1.58	0.02	0.18	0.02	2
	O	1988	1995	0.01	0	-100.00%	0.05	-0.03	0	0	4
Indiana-2	MP 15	1988	1997	8.1	3.05	-62.35%	11.35	4.85	3.65	2.45	3
	MP 5	1988	1997	31.5	35.7	13.33%	58.16	4.84	61.41	9.99	2
Indiana-3	1 (A)	1992	1998	0	0	N/A	0.8	-0.8	0.37	-0.37	2
	2 (B)	1992	1998	93.2	21.7	-76.72%	143.58	42.82	36.23	7.17	3
	3 (C)	1992	1996	55.8	45	-19.35%	94.21	17.39	55.96	34.04	2
	4 (D)	1992	1998	16.5	4.5	-72.73%	26.01	6.99	6.93	2.07	3
Indiana-4	1	1992	1998	16.1	13.05	-18.94%	19.58	12.62	18.6	7.5	2
	MP 51	1992	1998	14.9	0	-100.00%	20.26	9.54	0	0	4
	MP 52	1992	1998	12.1	3.8	-68.60%	20.76	3.44	5.3	2.3	2
Jefferson-2	MP-13	1986	1996	7.16	6	-16.20%	9.74	4.58	7	5	2
Jefferson-3	HU-1	1989	1992	1	0	-100.00%	2.8	-0.8	0	0	4

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
	HU-2	1989	1992	5.5	0.4	-92.73%	27.34	-16.34	0.6	0.2	2
Jefferson-5	MP-33	1989	1998	12.71	4	-68.53%	13.93	11.5	7.79	0.21	3
	MP-8B	1989	1998	29	27.63	-4.72%	37.1	20.9	46.59	8.67	2
Jefferson-6	S-25	1993	1998	4.7	8.6	82.98%	11.03	-1.63	12.13	5.07	2
	s-34	1993	1998	7.7	0	-100.00%	12.74	2.66	2.35	-2.35	3
Jefferson-7	MP-1	1991	1995	1.8	0.2	-88.89%	2.6	1	0.91	-0.51	3
Lawrence-1	1	1992	1998	4.5	0	-100.00%	6.98	2.02	0	0	4
Somerset-1	SP 16	1989	1998	1	11.75	1075.00%	1.57	0.43	19.53	3.97	1
Somerset-2	1	1993	1998	20	9.8	-51.00%	27.51	12.49	12.03	7.57	3
Venango-1	1	1989	1994	25.8	20	-22.48%	39.92	11.68	62.86	-22.86	2
Washington-1	HU1	1986	1993	26.1	83.83	221.19%	34.32	17.88	113.59	54.06	1
Washington-2	A	1985	1998	19.6	4.75	-75.77%	25.02	14.18	7.94	1.56	3
Washington-3	CV103	1985	1998	580	500	-13.79%	648.27	511.73	500	500	3
	CV4	1985	1998	100	90	-10.00%	148.38	51.62	96.36	83.64	2
Washington-4	MP-1	1989	1998	151.65	34.7	-77.12%	218.62	84.68	49.26	20.14	3
	MP-2	1989	1998	132	0	-100.00%	155.67	108.73	0	0	4
Washington-5	d-1	1987	1996	2.4	1.2	-50.00%	2.4	2.4	1.52	0.88	3
Washington-6	D5	1992	1997	40	30	-25.00%	49.12	30.88	34.06	25.94	2
Washington-7	se1a	1995	1998	0.38	0	-100.00%	1.27	-0.52	0	0	4
Westmoreland-1	MP10	1984	1993	13.95	8.3	-40.50%	18.1	9.8	12.32	4.28	2
	MP7	1984	1993	6.25	16.9	170.40%	16.73	-4.23	21.18	12.62	2
	MP9	1984	1993	0.29	0.9	210.34%	0.52	0.05	1.31	0.49	2
Westmoreland-2	S8	1985	1994	31.5	8.1	-74.29%	40.8	22.2	18.08	-1.88	3
Westmoreland-3	CP2	1986	1990	1	0.75	-25.00%	1.35	0.65	1.03	0.47	2
	Culvert	1986	1986	1	1	0.00%	1.34	0.66	1.54	0.46	2
Westmoreland-4	MD-1	1986	1990	7	3	-57.14%	27.11	-13.11	4.22	1.78	2
	MD-3	1986	1990	2.05	0	-100.00%	16.21	-12.11	0	0	4
	MD-4	1986	1990	4.5	3	-33.33%	8.3	0.7	4.22	1.78	2
	MD-6	1986	1990	41.5	0	-100.00%	105.9	-22.9	0	0	4
	MD-7	1986	1990	29.8	6	-79.87%	55.12	4.48	8.84	3.16	2
Westmoreland-5	HU-1	1986	1996	106	69.95	-34.01%	162.68	49.32	92.5	47.4	2
Westmoreland-6	M	1985	1993	12.92	11.7	-9.44%	20.99	4.85	14.3	9.1	2
	N	1985	1993	3.38	0.65	-80.77%	6.16	0.59	1.38	-0.08	2
Westmoreland-7	MP-3	1986	1991	4.25	1	-76.47%	5.23	3.27	1.41	0.59	3
	MP-4	1986	1991	61.1	120	96.40%	93.89	28.31	148	92	2
Westmoreland-8	MP-4	1987	1998	2	0	-100.00%	2	2	0	0	4
Westmoreland-9	MP-46	1987	1993	78.5	84.5	7.64%	98.75	58.25	105.99	63.01	2
	MP-47	1987	1993	102.7	288.1	180.53%	140.31	65.09	360.96	215.24	1
	MP-51	1987	1993	3.95	1.72	-56.46%	4.62	3.28	3.63	-0.19	2
	MP-52	1987	1993	1.19	3.5	194.12%	1.63	0.74	5.93	1.07	2
	MP-56	1987	1993	8.2	11.05	34.76%	11.49	4.91	23.83	-1.73	2

Permit ID	Monitoring Point ID	Permit Baseline Year	Review Year	Baseline Median	Post-Mining Median	% Change In Median	Baseline Upper Limit	Baseline Lower Limit	Post-Mining Upper Limit	Post-Mining Lower Limit	Evaluation
	MP-60	1987	1993	8.1	5.25	-35.19%	9.71	6.49	9.55	0.95	2
	MP-A	1987	1995	9.3	2.9	-68.82%	11.76	6.84	4.92	0.88	3
Westmoreland-10	MP12	1988	1995	6.9	7.2	4.35%	19.55	-5.75	11.58	2.82	2
Westmoreland-11	MP3	1988	1992	371.33	321.4	-13.45%	474.26	268.4	386.85	255.95	2
Westmoreland-12	MP-1	1988	1995	4	0	-100.00%	12.01	-4.01	0	0	4
	MP-2	1988	1995	0.88	2.9	229.55%	1.32	0.43	4.15	1.65	1
	MP-3	1988	1995	2.99	5.1	70.57%	5.21	0.77	6.05	4.15	2
	MP-4	1988	1995	4	0.54	-86.50%	7.9	0.1	0.93	0.15	2
	MP-5	1988	1995	1.1	5.1	363.64%	4.79	-2.59	7.38	2.82	2
	MP-6	1988	1995	4.7	8.1	72.34%	7.53	1.87	11.7	4.5	2
	MP-A	1988	1995	0.06	2.19	3550.00%	2.19	-2.08	4.34	0.03	2
	MP-B	1988	1995	0	2.19	N/A	0.78	-0.78	3.42	0.95	1
	MP-C	1988	1995	0.18	1.5	733.33%	0.54	-0.19	2.64	0.36	2
	MP-D	1988	1995	0	0.2	N/A	0.06	-0.06	0.38	0.02	2
Westmoreland-13	mp-a	1989	1993	1.1	0.8	-27.27%	1.39	0.81	2.22	-0.62	2
	mp-b	1989	1993	4.8	0.5	-89.58%	6.11	3.49	1.72	-0.72	3
Westmoreland-14	HU-1	1988	1995	43.6	31.62	-27.48%	65.28	21.92	38.41	24.83	2
	MP-5A	1988	1995	3	0.31	-89.67%	3.82	2.18	0.52	0.1	3
Westmoreland-15	SLK-GW-27	1994	1999	1.9	0.4	-78.95%	2.38	1.42	0.71	0.09	3
Westmoreland-16	mp-8	1990	1995	2.75	8.3	201.82%	3.58	1.92	10.69	5.91	1
Westmoreland-17	SW18	1989	1993	1.2	0	-100.00%	1.38	1.02	0	0	4
Westmoreland-18	1	1989	1995	2.5	0.48	-80.80%	3.19	1.81	0.79	0.16	3
	2	1989	1995	2.5	2.78	11.20%	3.22	1.78	4.92	0.63	2
	3	1989	1995	2.8	1.4	-50.00%	5.78	-0.18	2.44	0.35	2
Westmoreland-19	MP16	1993	1999	1.5	1.7	13.33%	1.74	1.26	2.53	0.87	2
	MP5	1993	1999	1.4	0.2	-85.71%	1.99	0.81	1.09	-0.69	2
	MP6	1993	1999	1.2	0.1	-91.67%	1.97	0.43	1.03	-0.83	2
Westmoreland-20	mp-7	1991	1998	3.05	1.22	-60.00%	4.04	2.06	2.39	0.05	2
Westmoreland-21	MP3	1992	1997	1	8.62	762.00%	1.93	0.07	16.27	0.96	2
Westmoreland-22	103	1994	1998	8.3	0	-100.00%	12.16	4.44	0	0	4
	69	1994	1998	35.3	0	-100.00%	50.21	20.39	0.4	-0.4	3
	mp-13	1994	1998	3.45	0	-100.00%	12.47	-5.57	0	0	4
	mp-16	1994	1998	0.5	0	-100.00%	1.08	-0.08	0	0	4

The site-by-site statistical comparisons and mine compliance history suggest that remining is conducted with little risk of worsening water quality. However, those data do not provide insights into the broader overall, statewide water quality impacts. The calculations in Table B.2 are derived from the summary numbers for each water quality parameter in Table B.1. The baseline median loads and post-mining median loads for all discharges are each totaled, and then the sum of the baseline load is subtracted from the post-mining load. Table B.2 shows the results in pounds per day (lbs/day) and the percent change in median loads for the cumulative effects of all the remining discharges. The summary numbers shown in Table B.2 provide insights that are not readily evident from the statistical summaries. For example, the first discharge listed in Table B.1 (permit Allegheny-1, MP ID 10) showed no statistical difference in load despite the fact that the post-mining median load was 2.5 times higher than the baseline median load. The summations depicted in Table B.2 show that even though some median loads have increased, overall there has been a decrease in load, particularly acid load. The decreases on a yearly basis are substantial. Table B.2 suggests that remining has decreased the acid load to streams in Pennsylvania's bituminous coal region by over 5.8 million pounds per year. The annual reductions in metals loads are more modest, but nonetheless important. Iron, manganese and aluminum loads have been reduced by 189,000, 11,400, and 110,400 lbs/yr respectively. These calculations confirm that there has been a substantial cumulative improvement in water quality across the bituminous region as a result of remining.

Table B.2 : Summary of load data for select water quality parameters (PA Remining Database).

Parameter	# of Mines	# of Discharges	Total Baseline Median Load	Total Post-Mining Load	Total Change in Load (lbs/day)*	% Change in Median*
Acidity	109	236	26,092	10,174	-15,918	-61
Aluminum	57	121	702	399	-302	-43.09
Iron	104	220	1,485	968	-517	-35
Manganese	75	164	247	216	-31	-13

* Negative numbers indicate a reduction in load.

In addition to showing the overall environmental benefits of remining, the documentation of BMPs used upgradient from discharges has permitted an evaluation of the effectiveness of individual and composite BMPs. This is the largest database currently available for evaluation of BMP effectiveness. Twelve BMPs were selected for evaluation because they were commonly used or there is a potential for increased use in the future. These BMPs are listed below and are defined in Section 6 of this manual. The number of discharges affected by each BMP are indicated in parentheses:

- Surface regrading of spoil (156)
- Revegetation (177)
- Deep mine daylighting (170)
- Special handling of acid-forming materials (80)
- Alkaline addition at < 100 tons/acre (67)
- Special water handling facilities (23)
- Passive treatment system construction (2)
- Coal refuse removal (9)
- Biosolids application (6)
- Mining high alkaline strata (13)
- Alkaline addition at >100 tons/acre (11)
- On-site alkaline redistribution (6)

Table B.3 shows the BMPs affecting each discharge point. Multiple BMPs are routinely used in an attempt to improve discharges. Evaluation of the effectiveness of these BMPs in terms of observed outcome and statistical analysis is presented in Section 6.

Table B.3: BMPs affecting each Monitoring Point

Permit ID	Monitoring Point ID	BMPs Applied
Allegheny-1	10	Surface regrading and Surface revegetation
	2	Surface regrading and Surface revegetation
Allegheny-2	S-6	Daylighting deep mines, Surface regrading, and Surface revegetation
	S-7	Daylighting deep mines, Surface regrading, and Surface revegetation
Allegheny-3	d-1p	Daylighting deep mines, Surface regrading, and Surface revegetation
Allegheny-4	BS12	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MD1	Special handling of acid-forming material, Surface regrading, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
	MD2	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Allegheny-5	MP-2	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-1	1A	Surface regrading and Surface revegetation
Armstrong-2	D-1	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	D-112	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	D-4	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
Armstrong-3	w-1A	Daylighting deep mines and Special handling of acid-forming material
	w-2A	Daylighting deep mines and Special handling of acid-forming material
	w-3A	Daylighting deep mines and Special handling of acid-forming material
Armstrong-4	GK-13	Surface regrading and Surface revegetation
	GK-17	Surface regrading and Surface revegetation
Armstrong-5	MP-2	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-6	1	Alkaline addition (less than 100 tons/acre), Construction of special water handling facilities, Daylighting deep mines, and Special handling of acid-forming material
Armstrong-7	MP14	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP15	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP17	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Armstrong-7	MP21	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP22	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP23	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP24	Passive treatment system construction, Surface regrading, and Surface revegetation
Armstrong-8	c3-a	Coal refuse removal, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	md-2	Daylighting deep mines and Special handling of acid-forming material
Armstrong-9	HU1	Special handling of acid-forming material, Surface regrading, and Surface revegetation
Armstrong-10	C-11	Daylighting deep mines and Other (see comment field)
	S-20	Daylighting deep mines and Other (see comment field)
Armstrong-11	HU1	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-12	mp2	Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mph	Special handling of acid-forming material, Surface regrading, and Surface revegetation
Armstrong-13	41	Biosolids application, Daylighting deep mines, Surface regrading, and Surface revegetation
	48	Daylighting deep mines, Passive treatment system construction, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
	Unit 2	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-14	1	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-15	V2	Daylighting deep mines, Surface regrading, and Surface revegetation
Armstrong-16	HU1	Daylighting deep mines, Mining and handling of highly alkaline strata, Other (see comment field), Surface regrading, and Surface revegetation,
Armstrong-17	HU1	Surface regrading and Surface revegetation
Armstrong-18	D1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Other (see comment field)
Beaver-1	S-10	Daylighting deep mines, Other (see comment field), Surface regrading, and Surface revegetation
Butler-1	5W	Construction of special water handling facilities, Daylighting deep mines, Surface regrading, and Surface revegetation
Butler-2	2W	Surface regrading and Surface revegetation
	5AW	Surface regrading and Surface revegetation
	8W	Surface regrading and Surface revegetation
Butler-3	S-116	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	S-13	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	S-200	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Surface revegetation
	S-91	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Surface revegetation
	S-95/96	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Surface revegetation
Butler-4	DR2	Alkaline addition (less than 100 tons/acre), Construction of special water handling facilities, and Daylighting deep mines
Butler-5	1	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
Cambria-1	MP9	Alkaline addition (less than 100 tons/acre), Construction of special water handling facilities, Daylighting deep mines, and Mining and handling of highly alkaline strata
	MP 13	Alkaline addition (less than 100 tons/acre), Construction of special water handling facilities, Daylighting deep mines, and Mining and handling of highly alkaline strata
Clarion-1	SP-1	Construction of special water handling facilities, Surface regrading, and Surface revegetation
	SP-28	Construction of special water handling facilities, Surface regrading, and Surface revegetation
	SP-5	Construction of special water handling facilities, Surface regrading, and Surface revegetation
	SP-6	Construction of special water handling facilities, Surface regrading, and Surface revegetation
Clarion-2	1	Alkaline addition (less than 100 tons/acre), Construction of special water handling facilities, Surface regrading, and Surface revegetation
Clarion-3	RH-78	Daylighting deep mines, Surface regrading, and Surface revegetation
Clarion-4	1	Construction of special water handling facilities, Daylighting deep mines, Surface regrading, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
	2	Construction of special water handling facilities, Daylighting deep mines, Surface regrading, and Surface revegetation
Clarion-5	DR-1	Alkaline addition (greater than 100 tons/acre), Special handling of acid-forming material, Surface regrading, and Surface revegetation
Clarion-6	1	Surface regrading and Surface revegetation
	2	Surface regrading and Surface revegetation
	3	Surface regrading and Surface revegetation
Clearfield-1	unit 1	Other (see comment field)
Clearfield-2	W10	Alkaline addition (less than 100 tons/acre), Surface regrading, and Surface revegetation
	W42	Alkaline addition (less than 100 tons/acre), Surface regrading, and Surface revegetation
	W43	Alkaline addition (less than 100 tons/acre), Surface regrading, and Surface revegetation
	W44	Alkaline addition (less than 100 tons/acre), Surface regrading, and Surface revegetation
Clearfield-3	SF-1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	SF10	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation
	SF4	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation
	SF6	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation
	SF61	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation
Clearfield-4	TK-3	Surface revegetation
	tk-18	Surface revegetation
	tk-21	Surface revegetation
	tk-37	Surface revegetation
	tk-4	Surface revegetation
	tk-7	Biosolids application and Surface revegetation
Clearfield-5	SV-5	Alkaline addition (less than 100 tons/acre), Special handling of acid-forming material, and Surface regrading
	SV-8	Alkaline addition (less than 100 tons/acre), Special handling of acid-forming material, and Surface revegetation
Clearfield-6	R-3	Daylighting deep mines, Mining and handling of highly alkaline strata, and Surface regrading
	R-5	Daylighting deep mines, Mining and handling of highly alkaline strata, and Surface regrading
	R-8	Coal refuse removal, Daylighting deep mines, and Mining and handling of highly alkaline strata

Permit ID	Monitoring Point ID	BMPs Applied
Clearfield-7	12	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	13	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Clearfield-8	TK4	Alkaline addition (greater than 100 tons/acre), Biosolids application, Surface regrading, and Surface revegetation
	TK7	Alkaline addition (greater than 100 tons/acre), Biosolids application, Surface regrading, and Surface revegetation
Clearfield-9	1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
	2	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
Clearfield-10	HU 1	Daylighting deep mines, Surface regrading, and Surface revegetation
	HU 2	Daylighting deep mines, Surface regrading, and Surface revegetation
	HU 3	Daylighting deep mines, Surface regrading, and Surface revegetation
Clearfield-11	subf-a	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Mining and handling of highly alkaline strata, Surface regrading, and Surface revegetation
	subf-b	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Mining and handling of highly alkaline strata, Surface regrading, and Surface revegetation
	subf-c	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Mining and handling of highly alkaline strata, Surface regrading, and Surface revegetation
Clinton-1	96	Alkaline addition (greater than 100 tons/acre), Surface regrading, and Surface revegetation
	97	Alkaline addition (greater than 100 tons/acre), Surface regrading, and Surface revegetation
	13	Alkaline addition (greater than 100 tons/acre), Daylighting deep mines, and Surface revegetation
	15A	Alkaline addition (greater than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	SNW 1A	Alkaline addition (greater than 100 tons/acre), Biosolids application, Daylighting deep mines, and Surface regrading
Clinton-2	GR-9	Alkaline addition (greater than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
	SEH-31	Alkaline addition (greater than 100 tons/acre), Special handling of acid-forming material, and Surface revegetation
	SHE-30	Alkaline addition (greater than 100 tons/acre), Special handling of acid-forming material, and Surface regrading
Fayette-1	mp-4	Daylighting deep mines and Surface revegetation
	mp-5	Daylighting deep mines and Surface revegetation
	mp-6	Daylighting deep mines and Surface revegetation
	mp-8	Daylighting deep mines and Surface revegetation
Fayette-2	HU-1	Alkaline addition (less than 100 tons/acre), Biosolids application, Coal refuse removal, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Fayette-3	MS100	Coal refuse removal, Surface regrading, and Surface revegetation
Fayette-4	MP6	Daylighting deep mines, Surface regrading, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
Fayette-5	mp-4	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mp-hua	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Fayette-6	MP-1	Coal refuse removal, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Fayette-7	MP48	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP49	Daylighting deep mines, Surface regrading, and Surface revegetation
Fayette-8	MP-15	Coal refuse removal, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Fayette-9	MP-28	Daylighting deep mines, Surface regrading, and Surface revegetation
Fayette-10	mp-1	Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	mp-11	Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	mp-2	Daylighting deep mines and Surface revegetation
Fayette-11	mp 29	Daylighting deep mines, Other (see comment field), and Special handling of acid-forming material
Fayette-12	Mp68	Daylighting deep mines
Fayette-13	D5	Daylighting deep mines, Surface regrading, and Surface revegetation
Fayette-14	mp-19	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mp-57	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mp-60	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mp56	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Fayette-15	MD1/MD2	Daylighting deep mines, Surface regrading, and Surface revegetation
	MD8/BS29	Daylighting deep mines, Surface regrading, and Surface revegetation
Fayette-16	MP-42	Daylighting deep mines
	MP-8	Daylighting deep mines
Greene-1	MP-51	Surface regrading and Surface revegetation
Greene-2	hu1	Mining and handling of highly alkaline strata, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Indiana-1	H	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	J	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	K	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	L	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	M	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
	N	Alkaline redistribution from on-site sources and Daylighting deep mines
	O	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
Indiana-2	1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
	2	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Special handling of acid-forming material, Surface regrading, and Surface revegetation
Indiana-3	1 (A)	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	2 (B)	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	3 (C)	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	4 (D)	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Indiana-4	1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP 51	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP 52	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Jefferson-2	MP-13	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Surface revegetation
Jefferson-3	HU-1	Alkaline redistribution from on-site sources, Daylighting deep mines, Surface regrading, and Surface revegetation
Jefferson-5	MP-33	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP-8B	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Jefferson-6	S-25	Other (see comment field) and Surface regrading
	s-34	Surface regrading and Surface revegetation
Jefferson-7	MP-1	Surface regrading and Surface revegetation
Lawrence-1	1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Other (see comment field), Surface regrading, and Surface revegetation
Somerset-1	SP 16	Construction of special water handling facilities, Other (see comment field), Special handling of acid-forming material, Surface regrading, Surface revegetation
Somerset-2	1	Daylighting deep mines, Special handling of acid-forming material, Mining and handling of highly alkaline material
Venango-1	1	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Washington-1	HU1	Daylighting deep mines, Surface regrading, and Surface revegetation
Washington-2	A	Daylighting deep mines
Washington-3	CV103	Daylighting deep mines, Mining and handling of highly alkaline strata, and Special handling of acid-forming material
	CV4	Daylighting deep mines, Mining and handling of highly alkaline strata, and Special handling of acid-forming material
Washington-4	MP-1	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-2	Daylighting deep mines, Surface regrading, and Surface revegetation
Washington-5	d-1	Daylighting deep mines, Surface regrading, and Surface revegetation
Washington-6	D5	Daylighting deep mines

Permit ID	Monitoring Point ID	BMPs Applied
Washington-7	se1a	Daylighting deep mines, Special handling of acid-forming material, and Surface regrading
Westmoreland-1	MP10	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
	MP7	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
	MP9	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, and Special handling of acid-forming material
Westmoreland-2	S8	Alkaline addition (less than 100 tons/acre) and Daylighting deep mines
Westmoreland-3	CP2	Coal refuse removal, Surface regrading, and Surface revegetation
	Culvert t	Coal refuse removal, Surface regrading, and Surface revegetation
Westmoreland-4	MD-1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	MD-3	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	MD-4	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	MD-6	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
	MD-7	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Special handling of acid-forming material, and Surface revegetation
Westmoreland-5	HU-1	Daylighting deep mines
Westmoreland-6	M	Coal refuse removal and Daylighting deep mines
	N	Daylighting deep mines
Westmoreland-7	MP-3	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	MP-4	Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Westmoreland-8	MP-4	Daylighting deep mines
Westmoreland-9	MP-46	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-47	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-51	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-52	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-56	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-60	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-A	Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-10	MP12	Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-11	MP3	Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-12	MP-1	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-2	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation

Permit ID	Monitoring Point ID	BMPs Applied
	MP-3	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-4	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-5	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-6	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-A	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-B	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-C	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-D	Alkaline addition (less than 100 tons/acre), Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-13	mp-a	Surface regrading and Surface revegetation
	mp-b	Surface regrading and Surface revegetation
Westmoreland-14	HU-1	Daylighting deep mines, Surface regrading, and Surface revegetation
	MP-5A	Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-15	SLK-GW-27	Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-16	mp-8	Construction of special water handling facilities, Daylighting deep mines, and Surface revegetation
Westmoreland-17	SW18	Other (see comment field), Surface regrading, and Surface revegetation
Westmoreland-18	1	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	2	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	3	Construction of special water handling facilities, Daylighting deep mines, Special handling of acid-forming material, Surface regrading, and Surface revegetation
Westmoreland-19	MP16	Daylighting deep mines
	MP5	Daylighting deep mines
	MP6	Daylighting deep mines
Westmoreland-20	mp-7	Construction of special water handling facilities, Daylighting deep mines, Surface regrading, and Surface revegetation
Westmoreland-21	MP3	Daylighting deep mines
Westmoreland-22	103	Alkaline redistribution from on-site sources, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	69	Alkaline redistribution from on-site sources, Special handling of acid-forming material, Surface regrading, and Surface revegetation
	mp-13	Alkaline redistribution from on-site sources, Special handling of acid-forming material, and Surface revegetation
	mp-16	Alkaline redistribution from on-site sources, Special handling of acid-forming material, Surface regrading, and Surface revegetation

Appendix C: Interstate Mining Compact Commission Solicitation Sheet Response Summary

Interstate Mining Compact Commission Solicitation Sheet

Summary of Responses Received from 20 States

Prepared by DynCorp, I & ET

On September 3, 1998, the Interstate Mining Compact Commission distributed a Solicitation Sheet to member states in support of continuing efforts to collect data and information required for proposal of a remining subcategory under 40 CFR 434. The Solicitation Sheet was intended to gather information required to assess current industry remining activity and potential. The Solicitation also was intended to target sources of data and information available for the development of BMP guidance.

Twenty-two responses from twenty states have been received, and are summarized in the tables included in this Appendix. The information has been used to develop a profile of the remining industry, determine the potential for remining activity, and provide an indication of the types and efficiencies of BMPs currently being implemented during remining operations.

Specific questions that were included in the solicitation are outlined below:

1) Types of remining permits issued: Number of traditional Rahall permits
   - Number of non-Rahall remining permits
   - Other remining-type projects
   - % total permits characterized as remining
   - State's definition of "Remining"
   - State's interpretation of "Pre-existing discharge"

2) Characteristics of remining operations:

Coal refuse piles, surface mines, underground mines
Permits with discharges not meeting BAT standards
Geographic distribution of remining sites
Recent remining permit issuance (12 months)

3) Characteristics of potential remining operations: coal refuse piles, surface mines, underground mines, discharges

4) Range of BMPs used in remining operations
5) Indication of available data or information regarding implementation of BMPs
6) Indication of state’s experience with BMPs in terms or success or failure
7) Stream miles impacted by abandoned mine drainage
8) Industry profile of remining operations: mining companies, employees, annual production, potential coal reserves for remining

Question 1. What type of remining permits have been approved in your state?

	Responses by State																					
Question	AK	AL	CO	IL	IN	KY(1) (SMRE)	KY(2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	**Totals 20 States**
1a. Number of traditional Rahall (Sec. 301(p) of CWA) permits issued.	0	71	0	0	0	4	4	2	0	0	0	0	---	0	3	300	0	0	0	3	8	---	**391**
1b. Number of non-Rahall (i.e. those that pre-date Rahall or those where the operator accepts liability for discharges and is meeting BAT) remining permits issued.	0	?	0	41	1	N/A	?	21	20	0	0	0	---	---	?	40	350-450	0	0	158	---	---	**631-731**
1c. Other remining-type projects (e.g. AML) or permits issued.	0	1	15	0	1	1	1	0	0	0	0	14	---	---	100/1	3	0	0	0	501	1	---	**638**
Please specify the nature of these "other" projects or permits:		(a)	(b)		(c)	(d)	(e)					(f)			(g)	(h)	(i)			(j)	(k)		
1d. What percentage of your total permits/inspectable units would be characterized as "remining permits."	0	?	0	0	1	40	?	30	15(l)	0	0	0	---	0	60-70	95/50 (m)	60	0	0	75-80	0.4	---	

Information reported as submitted by State.

See additional footnotes (attached).

N/A = Not applicable.

? = Unknown

--- = No response.

Footnotes for Question 1 Summary Table:

Question 1c. Additional Footnotes

(a)	AL	Blue Creek Project (North Johns Area)
(b)	CO	Coal refuse pile stabilization - 1983 - present; Surface mined areas- Overburden/Highwalls
(c)	IN	The one accepting liability and maintaining compliance in affected area, runoff is carbon extraction from a pre-SMCRA slurry pond. The other is remining an area of abandoned and forfeited interim permits for deeper coal seams.
(d)	KY	An AML project for the re-processing and reclamation of a 200 acre coal waste disposal site.
(e)	KY	An AML project for the reclamation of a 200 acre coal waste disposal site.
(f)	MT	(11) coal mining permits and (3) bond forfieture permits.
(g)	OH	100 - 75 no cost contracts, 25 direct negotiated contracts with states. 1 - FGD-by-product application at an abandoned coal mine in Cosocton County where an ungerground mine seal was installed.
(h)	PA	No cost contract (1); Mine fires (2).
(i)	TN	All remining operations have been SMCRA permits.
(j)	VA	Underground, Loading facilities, AML Projects, Refuse Piles
(k)	WV	Unencountered discharge. Company dewatering a mine pool, that has a pre-existing discharge, to access their mine reserves.

Question 1d. Additional Footnotes

(l)	MO	Of the 55 permits which still retain some level of reclamation liability in Missouri, approximately 15% could be characterized as "remining permits" as per our earlier definition. *Earlier definition: "remining permit" as any surface mining permit which includes at least some "previously mined areas" within the permit boundaries, regardless of whether or not the permittee intends to extract coal from those previously mined areas.*
(m)	PA	Anthracite 95%; Bituminus 50%.

Question 1e. Does your definition of remining differ from that set forth in the cover memo to the solicitation? If so, please explain. (See cover memo definition below).

State	Response
AK	No.
AL	Unknown.
CO	No response.
IL	Illinois deals with "remining" by including all previously disturbed areas into our Title V program. Permits that include previously disturbed areas must meet all applicable performance standards.
IN	We concur with the definitions presented but would also include remining of SMCRA regulated sites that had been abandoned prior to completion of reclamation obligations.
KY(1)	The DSMRE remining definition mirrors the Federal definition. For KY Pollutant and Discharge Elimination System (KPDES) issuance, the definition is the same as the Rahall Amendment definition.
KY(2)	For purposes of KPDES permit issuance, the definition of remining is the Rahall Amendment definition.
MD	No.
MO	Land Reclamation Program will define "remining permit" as any surface mining permit which includes at least some "previously mined areas" within the permit boundaries, regardless of whether or not the permittee intends to extract coal from those previously mined areas.
MS(1)	MS currently does not have a definition for "remining."
MS(2)	No.
MT	"Remining" means conducting surface coal mining and reclamation operations that affect previously mined areas (for example, the recovery of additional mineral from existing gob or tailings piles)
ND	No Response.
NM	None.
OH	It includes mining and reclamation.
PA	No.
TN	No.
TX	No.
UT	Zero.
VA	No.
WV	NPDES Program uses the Rahall Amendment.
WY	No Response.

Information reported as submitted by State.

Cover memo definition:

The remining regulations promulgated by OSM define remining as "conducting surface coal mining and reclamation operations which affect previously mined areas." (30CFR 701.5) "Previously mined area, in turn, is defined as "land previously mined on which there no surface coal mining operations subject to the standards of the [Surface Mining Control and Reclamation] Act." Remining as defined in the 1987 Rahall Amendment to the Clean Water Act refers to "a coal mining operation which begins after the enactment of (Rahall Amendment) at a site on which coal mining was conducted before the effective date of the Surface Mining Control and Reclamation Act of 1977."

Remining can also be defined specifically as the surface mining of abandoned surface and/or underground mines that originally created and continue to discharge waters that fail to meet the applicable effluent standards. Remining permits integrate pollution abatement procedures within the operation plans and operations are designed and conducted to preclude further water quality degradation, with the intent to improve the pre-existing water quality. Alternate effluent limits for pre-existing discharge, based primarily on background water quality and quantity, are established for monitoring operations. Remining should result in an improvement in water quality operations and the inherent abatement programs.

Question 1f. How does your state interpret the term "pre-existing discharge"? (See cover memo definition below).

State	Response
AK	None.
AL	No response.
CO	No response.
IL	There are no variances granted because of pre-existing non-complying discharges.
IN	Any non-complying discharge from coal mine areas, mined before Aug 2, 1977, for which there is no continuing legal responsibility under Indiana Coal regulatory programs.
KY(1)	For KPDES permit issuance, pre-existing discharges are those discharges emanating from a potential remining site prior to any disturbance. For DSMRE permit issuance, the term is interpreted the same as the definition of remining.
KY(2)	Pre-existing discharges are those discharges coming from a potential remining site prior to any disturbance.
MD	Same as Rahall Amendment
MO	Neither the Land Reclamation Program (LRP) nor the Water Pollution Control Program (WPCP) of Missouri's DNR have a specific definition for the term "pre-existing discharge" in their rules or statutes.
MS(1)	There is no interpretation of "pre-existing discharge."
MS(2)	No response.
MT	No definition.
ND	No response.
NM	None.
OH	Means a discharge from surface or subsurface water which is located on previously mined areas prior to 8-3-77.
PA	Discharge from abandoned mine lands having the chemical characteristics of mine drainage, which does not meet BAT effluent limits and will be affected by new mining operation.
TN	Any discharge prior to permit application.
TX	No remining applications have been filed, therefore the Railroad Comission has not had the opportunity to interpret the term "pre-existing discharge."
UT	None.
VA	A discharge that was created by mining prior to August 3, 1977.
WV	Means any discharge the time of permit application under this subsection 301(p) of the Federal Clean Water Act. A pre-existing discharge may originate from within the coal remining operation or from outside the coal remining operation provided there is a demonstration of hydrological connection between the coal remining operation and the pre-existing discharge.
WY	No response.

Information reported as submitted by State.

Cover memo definition:

"Pre-existing discharges" as defined in the Rahall Amendment refers to any "discharge at the time of permit application under [the Rahall Amendment]." Alternatively, pre-existing discharges may be defined as pollutional discharges resulting from previous mining and not encountered during active mining operations.

Question 2a. With regard to the permits identified in question 1, what are the characteristics of your state's existing remining operations? If exact numbers are unknown, please provide estimates.

State	Number of coal refuse piles		Number of surface mined sites		Number of underground mined sites		Number of remining permits that involve discharges not meeting BAT standards	
	Active Mines Under Permit	AML Projects	Active Mines Under Permit	AML Projects	Active Mines Under Permit	AML Projects	Active Mines Under Permit	AML Projects
AK	0	0	0	0	0	0	0	0
AL	4	1	54	--	13	--	?	1
CO	0	4	0	12	0	2	0	0
IL	40	0	1	0	0	0	0	0
IN	1	0	34	--	2	--	0	--
KY(1-SMRE)	--	--	--	--	--	--	--	--
KY(2-CWA)	3	1	1	--	2	--	5	--
MD	0	--	17	--	21	--	2	--
MO	0	0	2	0	0	0	0	0
MS(1-CWA)	0	0	1	0	0	0	0	0
MS(2-SMCRA)	0	0	0	0	0	0	0	0
MT	1	--	11	--	1	--	0	--
ND	--	--	--	--	--	--	--	--
NM	0	0	0	0	0	0	0	0
OH	0	--	2	1	1	--	0	--
PA	173	0	1278*	0	655	2	616	0
TN	5 to 10	0	135 - 180	0	210 - 260	0	0	0
TX	0	0	0	0	0	0	0	0
UT	5	0	2	0	32	N/A	0	N/A
VA	33	38	77	117	107	104	0	2
WV	1	--	7	--	1	--	9	--
WY	--	--	--	--	--	--	--	--
Totals	**266 - 271**	**44**	**1622 - 1667**	**130**	**1045 - 1095**	**108**	**632**	**3**

Information reported as submitted by State.

? = Unknown.

-- = No response.

N/A = Not Applicable.

* With remining.

Question 2b and 2c.

State	2b. How are your remining sites distributed geographically throughout your state (by region, coalfield, etc.)?	2c. How many active remining sites have been permitted in the last 12 months (if available)?
AK	N/A	0
AL	Both	8
CO	All coal fields are affected.	0
IL	70% in Southern IL.	1
IN	SW part of state is coal region.	0
KY(1-SMRE)	There are 2 coalfields in KY; Eastern & Western. Remining occurs in both regions, extensively in Eastern.	--
KY(2-CWA)	All are in the Hopkins & Webster Counties in the Western KY coalfields.	1
MD	Majority located in Allegany Co., Georges Creek area.	2
MO	Historically, sites were located in the North Central and Southwest parts of MO. All remining "active" sites are in Southwest MO.	1
MS(1-CWA)	This issue is not addressed. MS might list sites by county or region.	0
MS(2-SMCRA)	No previously mined sites exist.	0
MT	Region.	0
ND	No response.	--
NM	No remining sites in NM.	N/A
OH	Eastern 1/3 of Ohio affected.	0
PA	See attached map for distribution of "Rahall" sites.	--
TN	Non-Rahall remining sites are distributed evenly throughout the TN coalfield (Cumberland Plateau).	4
TX	No reminng sites currently identified.	0
UT	Utah minesites are located in two major coalfields; the Book Cliffs and Wasatch.	0
VA	All (3 Rahall) are located within one area of the coalfields (Wise County).	16
WV	Northern coalfields.	3
WY	N/A	--
	Total	**36**

Information reported as submitted by State.
N/A = Not Applicable.

Question 3. What are the characteristics of your state's potential remining operations? If exact numbers are unknown, please provide best estimates. Numbers can be drawn from AMLIS or other sources.

State	Number of coal refuse piles	Number of surface mined sites	Number of underground mined sites	Number of Permits that involve discharges not meeting BAT
AK	3	5	1	1
AL	1	--	--	1
CO	400	50	850	<5
IL	30	10	12	0
IN	150	453	615	0
KY(1-SMRE)	200	400-600	800-1000	--
KY(2-CWA)	?	?	?	?
MD	10	75	75	50
MO	0	0	0	0
MS(1-CWA)	0	1	0	0
MS(2-SMCRA)	0	0	0	0
MT	1	11	1	0
ND	--	--	--	--
NM	N/A	N/A	N/A	N/A
OH	1,095 acres	23,000 acres	4,000	0
PA	858	19,128 (a)	8,683 (b)	230
TN	182 acres	46,000 acres	800	?
TX	0	0	0	0
UT	5	2	32	0
VA	400-450	750	800	0
WV	--	3	--	All
WY	0	0	0	?
Totals	**2,058-2,108** **and 1,277 Acres**	**1,760-1,960** **and 227,960 Acres**	**7,986-8,186** **and 31,587 Acres**	**287**

Information reported as submitted by State.
-- = No Response.
N/A = Not Applicable.
? = Unknown.
(a) 19,128 Features (158,960 Acres).
(b) 8,683 Features (31,587 Acres).

Question 4. Using the following list and chart, please indicate the range of best management practices that have been employed in remining permits or in other mining applications in your state. Also, if available, please provide the number of BMPs employed, indicating the number used at active remining sites, those used in other mining applications (e.g., AML projects).

4a. Whether Employed

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	Totals (Y/N)
I. Hydrologic BMPs																							
A. Exclusion of Infiltrating Surface Water	--	--	--	--	Y	Y	--	--	N	Y	N/A	--	--	--	Y	--	--	--	--	Y	Y	N/A	**6/1**
1. Diversion Ditches	Y	Y	--	Y	Y	Y	--	--	N	Y	N/A	Y	--	--	N	Y	--	--	Y	Y	Y	N/A	**11/3**
a. Above highwall	Y	Y	Y	Y	Y	Y	--	Y	N	Y	N/A	Y	--	--	--	Y	Y	--	--	Y	Y	N/A	**13/1**
b. On the spoil	Y	Y	Y	Y	Y	Y	--	N	N	Y	N/A	N	--	--	--	Y	Y	--	--	Y	N	N/A	**10/4**
2. Regrading of dead spoils	--	Y	--	--	Y	Y	--	Y	N	Y	N/A	Y	--	--	Y	--	--	--	--	Y	Y	N/A	**9/1**
a. Elimination of closed contour depressions & pits	Y	Y	N	Y	Y	Y	--	Y	N	Y	N/A	N	--	--	N	Y	Y	--	--	Y	Y	N/A	**11/4**
b. Creation of sufficient slopes to aid runoff of precip.	--	--	N	Y	Y	Y	--	Y	N	Y	N/A	N	--	--	N	Y	Y	--	--	Y	Y	N/A	**9/4**
3. Low-permeability caps	--	Y	--	--	Y	N	--	N	N	N	N/A	N	--	--	N	--	--	--	--	Y	Y	N/A	**4/6**
a. Clays & other natural materials	--	--	N	Y	Y	--	--	N	N	Y	N/A	N	--	--	Y	Y	Y	--	--	Y	N	N/A	**7/5**
b. Coal combustion wastes	--	--	N	Y	Y	--	--	Y	N	N	N/A	N	--	--	Y	Y	N	--	--	--	Y	N/A	**6/5**
c. Cement, bentonite & sim. materials	--	--	N	Y	N	--	--	N	N	N	N/A	N	--	--	N	Y	N	--	--	--	N	N/A	**2/9**
d. Geotextiles	Y	--	N	Y	N	--	--	N	N	N	N/A	Y	--	--	N	Y	Y	--	--	--	N	N/A	**5/7**
B. Exclusion of Infiltrating Ground Water	--	N	--	--	N	Y	--		N	--	N/A	--	--	--	N	--	--	--	--	--	Y	N/A	**2/4**
1. Grout Curtains	--	--	--	--	N	N	--	N	N	N	N/A	N	--	--	--	Y	--	--	--	--	N	N/A	**1/7**
a. Above the highwall	--	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	Y	N	--	--	--	Y	N/A	**2/7**
b. At the highwall	--	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	Y	N	--	--	--	Y	N/A	**2/7**
i. Syn-reclamation	--	--	--	N	N	--	--	--	N	N	N/A	N	--	--	--	--	N	--	--	--	--	N/A	**0/6**
ii. Post reclamation	--	--	--	N	N	--	--	--	N	N	N/A	N	--	--	--	--	N	--	--	--	N	N/A	**0/7**
2. Diversion Wells	Y	--	--	--	N	N	--	N	N	N	N/A	N	--	--	--	N	--	--	--	--	N	N/A	**1/8**
a. Above the highwall	Y	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	N	Y	--	--	--	Y	N/A	**3/7**
b. At the highwall	Y	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	N	Y	--	--	--	Y	N/A	**3/7**
c. Horizontal wells	--	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	N	N	--	--	--	N	N/A	**0/9**
3. Highwall Drains	Y	--	--	--	N	Y	--	--	N	N	N/A	N	--	--	--	Y	--	--	--	--	N	N/A	**3/5**
a. Horizontal	--	--	N	Y	N	Y	--	--	N	N	N/A	N	--	--	--	Y	Y	--	--	--	N	N/A	**4/6**
b. Chimney drains	--	--	N	Y	N	Y	--	--	N	N	N/A	N	--	--	--	N	Y	--	--	--	N	N/A	**3/7**
4. Pit floor drains	Y	--	--	N	N	N	--	N	N	N	N/A	Y	--	--	--	--	--	--	--	Y	Y	N/A	**4/6**
a. Linear (directly down dip)	Y	--	Y	N	N	--	--	--	N	N	N/A	Y	--	--	--	Y	Y	--	--	Y	Y	N/A	**7/4**
b. Forked or dendritic	--	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	N	Y	--	--	--	N	N/A	**1/8**
5. Daylighting (surf. mining of aband. undergr. mine work)	--	Y	N	Y	N	Y	--	Y	N	N/A	N/A	N	--	--	N	Y	Y	--	N	Y	Y	N/A	**8/6**
6. Redirecting water from aband. undergr. mine workings	--	--	--	--	Y	Y	--	N	N	N/A	N/A	N	--	--	N	Y	--	--	N	Y	N	N/A	**4/6**
a. Sealing underground workings	--	Y	N	Y	N	Y	--	--	N	N/A	N/A	N	--	--	--	Y	Y	--	N	Y	Y	N/A	**7/5**
b. Installation of drains directly from underground mines	--	--	Y	N	Y	Y	--	--	N	N/A	N/A	N	--	--	--	Y	Y	--	N	Y	Y	N/A	**7/4**
c. Sealing of auger holes	--	Y	N	Y	N	Y	--	--	N	N/A	N/A	N	--	--	--	Y	Y	--	--	Y	Y	N/A	**7/4**

4a. Whether Employed

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	Totals (Y/N)
7. Sealing of underground mine entries (via flooding)	--	Y	N	Y	N	N	--	N	N	N/A	N/A	tbd	--	--	N	Y	N	--	--	Y	N	N/A	**4/8**
8. Hydrologic routing of ground water	--	N	--	--	N	Y	--	N	N	--	N/A	N	--	--	N	--	--	--	--	Y	Y	N/A	**3/6**
a. Grouting	--	--	N	N	N	N	--	--	N	N	N/A	N	--	--	--	N	N	--	--	Y	N	N/A	**1/10**
b. Limestone Drains	--	--	Y	N	N	Y	--	--	N	N	N/A	N	--	--	--	Y	Y	--	--	Y	Y	N/A	**6/5**
c. Pit floor sealing	--	--	N	N	N	N	--	--	N	N	N/A	N	--	--	--	Y	N	--	--	--	Y	N/A	**2/8**
9. Construction of high-water retention soils	--	N	N	N	N	N	--	N	N	N	N/A	N	--	--	N	?	N	--	--	--	N	N/A	**0/12**
C. Other	--	--	--	Y	--	N	--	--	N	--	N/A	--	--	--	--	--	N	--	--	--	N	N/A	**1/4**
II. Geochemical																							
A. Alkaline addition-strategic placement	--	Y	--	--	Y	Y	--	--	N	--	N/A	N	--	--	Y	--	--	--	--	--	Y	N/A	**5/2**
1. Limestone or calcareous shales	--	Y	Y	Y	Y	Y	--	N	N	Y	N/A	N	--	--	--	Y	Y	--	--	--	Y	N/A	**9/3**
2. Coal cumbustion wastes	--	--	N	Y	Y	N	--	Y	N	N	N/A	N	--	--	Y	Y	Y	--	--	--	Y	N/A	**7/5**
3. Others	--	--	--	--	--	N	--	--	N	--	N/A	--	--	--	--	--	N	--	--	--	N	N/A	**0/4**
B. Induced Alkaline recharge	--	--	--	--	N	N	--	--	N	--	N/A	N	--	--	N	--	--	--	--	--	Y	N/A	**1/5**
1. Trenches	--	--	N	Y	N	--	--	--	N	N	N/A	N	--	--	--	Y	Y	--	--	--	N	N/A	**3/6**
2. Carrucio-like funnels	--	--	N	N	N	--	--	--	N	N	N/A	N	--	--	--	N	N	--	--	--	N	N/A	**0/9**
C. Special handling of AFMs	--	Y	--	--	Y	Y	--	--	N	--	N/A	N	--	--	N	Y	--	--	--	Y	Y	N/A	**6/3**
1. Above postmining water table	--	--	N	Y	Y	Y	--	Y	N	Y	N/A	N	--	--	--	Y	Y	--	--	Y	Y	N/A	**9/3**
2. Removed from potential ground water flowpath	--	Y	N	Y	Y	Y	--	N	N	Y	N/A	N	--	--	--	N	Y	--	--	Y	Y	N/A	**8/5**
D. Anionic Surfactants	--	Y	N	--	N	N	--	N	N	N	N/A	N	--	--	--	N	Y	--	--	Y	N	N/A	**3/9**
E. Other	--	--	--	--	--	--	--	--	N	--	N/A	--	--	--	--	--	N	--	--	Y	N	N/A	**1/3**
III. Revegetation	--	--	--	--	--	--	--	--	N	--	N/A	--	--	--	--	--	--	--	--	--	Y	N/A	**1/1**
A. Runoff promoting plants	--	--	N	--	N	N	--	N	N	Y	N/A	N	--	--	--	N	N	--	--	N	N	N/A	**2/10**
B. High water-use plants	Y	--	N	--	N	N	--	N	N	Y	N/A	N	--	--	--	Y	N	--	--	--	N	N/A	**3/8**
C. Use of biosolids	--	--	N	--	Y	Y	--	N	N	N	N/A	Y	--	--	--	Y	Y	--	--	--	N	N/A	**5/5**
D. Other	--	--	--	--	--	N	--	--	N	N	N/A	--	--	--	Y	--	N	--	--	--	N	N/A	**1/5**
IV. Passive Treatment	--	--	--	--	--	--	--	--	N	--	N/A	--	--	--	--	--	--	--	--	Y	Y	N/A	**2/1**
A. Anoxic limestone drains installed in backfill	--	Y	N	Y	Y	Y	--	N	N	N	N/A	N	--	--	N	Y	Y	--	--	Y	Y	N/A	**8/6**
B. Constructed wetlands	--	Y	Y	Y	Y	Y	--	--	Y	Y	N/A	N	--	--	N	Y	Y	--	--	Y	N	N/A	**10/3**
C. SAPS	--	--	--	--	N	N	--	N	N	?	N/A	?	--	--	N	Y	Y	--	--	--	N	N/A	**2/6**
D. Open limestone trenches	--	Y	N	N	N	Y	--	N	Y	N	N/A	N	--	--	Y	Y	Y	--	--	Y	N	N/A	**7/7**
E. Vail's manganese oxide system	--	--	N	N	N	N	--	Y	N	N	N/A	?	--	--	N	Y	Y	--	--	--	N	N/A	**3/8**
F. Other	--	--	--	N	--	N	--	--	N	N	N/A	--	--	--	--	Y	N	--	--	--	N	N/A	**1/6**
V. Geotechnical	--	--	--	--	--	--	--	--	N	--	N/A	--	--	--	--	--	--	--	--	--	Y	N/A	**1/1**
A. Elimination of landslides	--	--	--	--	N	Y	--	Y	N	N	N/A	N	--	--	N	Y	--	--	--	Y	Y	N/A	**5/5**
1. Regrading for slope stabilization	Y	--	Y	Y	N	Y	--	Y	N	N	N/A	Y	--	--	Y	Y	Y	--	--	Y	Y	N/A	**11/3**
2. Installation of key ways	Y	--	Y	Y	N	Y	--	Y	N	N	N/A	Y	--	--	--	N	N	--	--	Y	N	N/A	**7/6**
B.Other	--	--	--	--	--	R	--	--	N	--	N/A	--	--	--	--	--	N	--	--	--	N	N/A	**0/3**

Information reported as submitted by State.
-- = No Response.
tbd = To be done.
N/A = Not Applicable.
R = Retaining Walls.

4b. Number of (Active) Remining Sites

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	**Totals**
I. Hydrologic BMPs																							
A. Exclusion of Infiltrating Surface Water	--	--	0	--	2	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	3	0	**5**
1. Diversion Ditches	--	71	0	0	2	--	--	--	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	33	3	0	**109**
a. Above highwall	--	--	0	0	--	--	--	4	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	21	2	0	**27**
b. On the spoil	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	28	0	0	**28**
2. Regrading of dead spoils	--	6	0	--	1	--	--	10	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	6	7	0	**30**
a. Elimination of closed contour depressions & pits	--	8	0	0	--	--	--	10	0	N/A	N/A	--	--	--	--	Some	Unk.	--	0	1	7	0	**26**
b. Creation of sufficient slopes to aid runoff of precip.	--	--	0	0	--	--	--	3	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	1	8	0	**12**
3. Low-permeability caps	--	2	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	1	0	**3**
a. Clays & other natural materials	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	3	--	0	**3**
b. Coal combustion wastes	--	--	0	0	--	--	--	2	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	1	0	**3**
c. Cement, bentonite & sim. materials	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
d. Geotextiles	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
B. Exclusion of Infiltrating Ground Water	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	1	0	**1**
1. Grout Curtains	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
a. Above the highwall	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	2	0	**2**
b. At the highwall	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	2	0	**2**
i. Syn-reclamation	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
ii. Post reclamation	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
2. Diversion Wells	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
a. Above the highwall	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	2	0	**2**
b. At the highwall	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	2	0	**2**
c. Horizontal wells	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
3. Highwall Drains	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	--	0	**0**
a. Horizontal	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	--	0	**0**
b. Chimney drains	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
4. Pit floor drains	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	1	0	**1**
a. Linear (directly down dip)	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	4	1	0	**5**
b. Forked or dendritic	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
5. Daylighting (surf. mining of aband. undergr. mine workin	--	13	0	0	--	--	--	2	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	20	4	0	**39**
6. Redirecting water from aband. undergr. mine workings	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	16	--	0	**16**
a. Sealing underground workings	--	13	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	1	0	**14**
b. Installation of drains directly from underground mines	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	31	1	0	**32**
c. Sealing of auger holes	--	2	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Some	Unk.	--	0	23	1	0	**26**
7. Sealing of underground mine entries (via flooding)	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0?	Unk.	--	0	4	--	0	**4**
8. Hydrologic routing of ground water	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	23	7	0	**30**
a. Grouting	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	None	Unk.	--	0	13	--	0	**13**
b. Limestone Drains	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	6	1	0	**7**
c. Pit floor sealing	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Rare	Unk.	--	0	--	7	0	**7**
9. Construction of high-water retention soils	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**0**
C. Other	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**0**
II. Geochemical	--	--	0	--	1	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**1**
A. Alkaline addition-strategic placement	--	3	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	8	0	**11**
1. Limestone or calcareous shales	--	3	0	1	--	--	--	--	0	N/A	N/A	--	--	--	--	Some	Unk.	--	0	--	4	0	**8**
2. Coal cumbustion wastes	--	--	0	0	--	--	--	2	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	3	0	**5**
3. Others	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**0**
B. Induced Alkaline recharge	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	1	0	**1**
1. Trenches	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
2. Carrucio-like funnels	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
C. Special handling of AFMs	--	5	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	7	0	**12**
1. Above postmining water table	--	--	0	0	--	--	--	12	0	N/A	N/A	--	--	--	--	Most	Unk.	--	0	7	7	0	**26**

4b. Number of (Active) Remining Sites

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	**Totals**
2. Removed from potential ground water flowpath	--	5	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	16	7	0	**28**
D. Anionic Surfactants	--	1	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**1**
E. Other	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	7	--	0	**7**
III. Revegetation	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	8	0	**8**
A. Runoff promoting plants	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	3	--	0	**3**
B. High water-use plants	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	--	--	0	**0**
C. Use of biosolids	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	Some	Unk.	--	0	--	--	0	**0**
D. Other	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**0**
IV. Passive Treatment	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	1	0	**1**
A. Anoxic limestone drains installed in backfill	--	1	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	3	1	0	**5**
B. Constructed wetlands	--	2	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Some	Unk.	--	0	2	--	0	**4**
C. SAPS	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	--	0	**0**
D. Open limestone trenches	--	2	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	7	--	0	**9**
E. Vail's manganese oxide system	--	--	0	0	--	--	--	1	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	--	0	**1**
F. Other	--	--	0	0	--	--	--	--	0	N/A	N/A	--	--	--	--	Few	Unk.	--	0	--	--	0	**0**
V. Geotechnical	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	Y	8	0	**8**
A. Elimination of landslides	--	--	0	--	--	--	--	2	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	15	8	0	**25**
1. Regrading for slope stabilization	--	--	0	0	--	--	--	15	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	15	8	0	**38**
2. Installation of key ways	--	--	0	0	--	--	--	1	0	N/A	N/A	--	--	--	--	0	Unk.	--	0	9	--	0	**10**
B.Other	--	--	0	--	--	--	--	--	0	N/A	N/A	--	--	--	--	--	Unk.	--	0	--	--	0	**0**

Information reported as submitted by State.

N/A = Not Applicable.

Unk = Unknown.

-- = No Response.

4c. Number of other Mining Applications

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	Totals
I. Hydrologic BMPs																							
A. Exclusion of Infiltrating Surface Water	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	1	--	0	--	0	--	--	Unk.	2
1. Diversion Ditches	--	--	--	A	--	--	--	--	0	1	N/A	2	--	--	--	Most	0	--	0	--	--	Unk.	3
a. Above highwall	--	--	1	A	2-5	--	--	--	0	1	N/A	1	--	--	--	Few	0	--	0	30	--	Unk.	33-38
b. On the spoil	--	--	5	A	2-5	--	--	--	0	1	N/A	0	--	--	--	Most	0	--	0	100	--	Unk.	108-111
2. Regrading of dead spoils	--	--	0	--	--	--	--	--	0	1	N/A	1	--	--	1	--	0	--	0	--	--	Unk.	3
a. Elimination of closed contour depressions & pits	--	--	0	A	--	--	--	--	0	1	N/A	0	--	--	--	Most	0	--	0	20	--	Unk.	21
b. Creation of sufficient slopes to aid runoff of precip.	--	--	0	A	--	--	--	--	0	1	N/A	0	--	--	--	Most	0	--	0	20	--	Unk.	21
3. Low-permeability caps	--	--	0	--	--	--	--	--	0	1	N/A	0	--	--	--	Some	0	--	0	--	--	Unk.	1
a. Clays & other natural materials	--	--	0	A	--	--	--	--	0	1	N/A	0	--	--	1	Most	0	--	0	--	--	Unk.	2
b. Coal combustion wastes	--	--	0	A	--	--	--	--	0	1	N/A	0	--	--	1	0	0	--	0	--	--	Unk.	2
c. Cement, bentonite & sim. materials	--	--	0	A	--	--	--	--	0	1	N/A	0	--	--	--	Some	0	--	0	--	--	Unk.	1
d. Geotextiles	--	--	0	A	--	--	--	--	0	1	N/A	10	--	--	--	Most	0	--	0	--	--	Unk.	11
B. Exclusion of Infiltrating Ground Water	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
1. Grout Curtains	--	--	0	--	--	--	--	--	0	1	N/A	0	--	--	--	Some	0	--	0	--	--	Unk.	1
a. Above the highwall	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	1
b. At the highwall	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	1
i. Syn-reclamation	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
ii. Post reclamation	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
2. Diversion Wells	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
a. Above the highwall	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
b. At the highwall	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
c. Horizontal wells	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
3. Highwall Drains	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	1
a. Horizontal	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	1
b. Chimney drains	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
4. Pit floor drains	--	--	--	--	--	--	--	--	0	1	N/A	10	--	--	--	0	0	--	0	--	--	Unk.	11
a. Linear (directly down dip)	--	--	1	--	--	--	--	--	0	1	N/A	10	--	--	--	0	0	--	0	--	--	Unk.	12
b. Forked or dendritic	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
5. Daylighting (surf. mining of aband. undergr. mine working)	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
6. Redirecting water from aband. undergr. mine workings	--	--	--	--	3-5	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	4-6
a. Sealing underground workings	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	--	--	Unk.	1
b. Installation of drains directly from underground mines	--	--	2	--	Several	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	100	--	Unk.	103
c. Sealing of auger holes	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	20	--	Unk.	21
7. Sealing of underground mine entries (via flooding)	--	--	0	A	--	--	--	--	0	1	N/A	1	--	--	--	Most	0	--	0	--	--	Unk.	2
8. Hydrologic routing of ground water	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
a. Grouting	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	10	--	Unk.	11
b. Limestone Drains	--	--	1	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	2
c. Pit floor sealing	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	1
9. Construction of high-water retention soils	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
C. Other	--	--	--	A	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
II. Geochemical	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	1
A. Alkaline addition-strategic placement	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	1	--	0	--	0	--	--	Unk.	2

4c. Number of other Mining Applications

	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY	Totals
1. Limestone or calcareous shales	--	--	1	A	Several	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	**2**
2. Coal cumbustion wastes	--	--	0	A	2	--	--	--	0	1	N/A	--	--	--	1	0	0	--	0	--	--	Unk.	**4**
3. Others	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
B. Induced Alkaline recharge	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
1. Trenches	--	--	0	A	--	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	--	--	Unk.	**1**
2. Carrucio-like funnels	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
C. Special handling of AFMs	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Most	0	--	0	--	--	Unk.	**1**
1. Above postmining water table	--	--	0	A	Several	--	--	--	0	1	N/A	--	--	--	--	Most	0	--	0	5	--	Unk.	**6**
2. Removed from potential ground water flow path	--	--	0	A	1-3	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	**2-4**
D. Anionic Surfactants	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	2	--	Unk.	**3**
E. Other	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
III. Revegetation	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
A. Runoff promoting plants	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	0	0	--	0	--	--	Unk.	**1**
B. High water-use plants	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	**1**
C. Use of biosolids	--	--	0	--	6-8	--	--	--	0	1	N/A	1	--	--	--	0?	0	--	0	--	--	Unk.	**8-10**
D. Other	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	1	--	0	--	0	--	--	Unk.	**2**
IV. Passive Treatment	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
A. Anoxic limestone drains installed in backfill	--	--	0	A	3	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	--	--	Unk.	**4**
B. Constructed wetlands	--	--	3	A	2	--	--	--	2	1	N/A	1	--	--	--	Some	0	--	0	5	--	Unk.	**14**
C. SAPS	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	Some	0	--	0	--	--	Unk.	**1**
D. Open limestone trenches	--	--	0	--	--	--	--	--	1	1	N/A	--	--	--	1	Some	0	--	0	--	--	Unk.	**3**
E. Vail's manganese oxide system	--	--	0	--	--	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	--	--	Unk.	**1**
F. Other	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	Few	0	--	0	--	--	Unk.	**1**
V. Geotechnical	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**
A. Elimination of landslides	--	--	--	--	--	--	--	--	0	1	N/A		--	--	--	Few	0	--	0	50	--	Unk.	**51**
1. Regrading for slope stabilization	--	--	7	A	--	--	--	--	0	1	N/A	Y	--	--	1	Most	0	--	0	50	--	Unk.	**59**
2. Installation of key ways	--	--	1	A	--	--	--	--	0	1	N/A	10	--	--	--	0	0	--	0	--	--	Unk.	**12**
B.Other	--	--	--	--	--	--	--	--	0	1	N/A	--	--	--	--	--	0	--	0	--	--	Unk.	**1**

Information reported as submitted by State.

-- = No Response.
N/A = Not Applicable.
Unk. = Unknown.
A = Active mining.

Question 5. Do you have the following data and information on the above described (remining) permits:

	Response by State (Y = Yes, N = No)																					
	AK	AL	CO	IL	IN	KY (1) (SMRE)	KY (2) (CWA)	MD	MO	MS(1) (CWA)	MS(2) (SMCRA)	MT	ND	NM	OH	PA	TN	TX	UT	VA	WV	WY
BMP Performance Information (Success/Failures)	N	N	Y	N	N	Y*	N	N	N	N	N/A	N	--	--	Y	Y	N	N	--	Y	Y	N/A
Description of BMP	N	Y	Y	N	N	Y*	N	N	N	Y	N/A	N	--	--	Y	Y	Y	N	--	Y	Y	N/A
BMP Abatement plan info.	N	Y	Y	N	N	N	N	N	N	N	N/A	N	--	--	Y	Y	Y	N	N	Y	Y	N/A
BMP Cost Information	N	N	Y	N	Y*	Y*	N	N	N	N	N/A	N	--	--	Y	Y	Y	N	N	N	N	N/A
Geologic information	N	Y	Y	Y	Y*	Y*	N	Y	N	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Hydrologic information																						
Background monitoring reports	N	--	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Chemical analysis	N	--	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Ground water info.	N	--	N	Y	Y	Y	N	Y	N	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Surface water info.	N	--	S	Y	Y	Y	Y	Y	Y	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Public water supply info.	N	--	N	Y	N	P*	Y	Y	N	Y	N/A	Y	--	--	N	Y	Y	--	Y	Y	Y	N/A
Hydrologic assessment	N	--	Y	Y	N	Y	N	Y	N	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	Y	N/A
Baseline pollution load analysis & data	N	Y	N	Y	N	Y	Y	Y	N	N	N/A	Y	--	--	N	Y	Y	--	--	Y	Y	N/A
Impact statistics (acres affected, reclaimed, etc.)	N	--	Y	Y	N	Y*	N	Y	Y	Y	N/A	Y	--	--	N	Y	Y	--	Y	Y	Y	N/A
Environmental assessment	N	--	S	Y	N	Y	N		Y	Y	N/A	Y	--	--	N	Y	Y	--	Y	Y	C	N/A
Operational info. (Reclamation/Operation descript.)	N	Y	S	Y	Y	Y	N	Y	N	Y	N/A	Y	--	--	N	Y	Y	--	Y	Y	Y	N/A
Revegetation info. (Temporary & Permanent cover)	N	Y	S	Y	Y	Y	N	Y	Y	Y	N/A	Y	--	--	N	Y	Y	--	Y	Y	Y	N/A
Topographic maps	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	--	--	Y	Y	Y	--	Y	Y	D	N/A
Program guidance regarding remining and or implementation	N	--	Unk.	N	N	Y	N	N	N	Y	N/A	N	--	--	N	Y	Y	--	--	N	Y	N/A
BMP inspection information	N	--	Y	N	N	Y	N	N	N	Y	N/A	N	--	--	N	S	Y	--	--	N	N	N/A
Verification of BMP implementation info.	N	--	Unk.	N	Y	--	N	N	N	Y	N/A	N	--	--	N	S	Y	--	--	Y	N	N/A

Information reported as submitted by State.

Y* = AML only

P* = Partial (AML only)

S = Some

D = Drainage proposal maps

N/A = Not Applicable

-- = No Response

Unk = Unknown

C = Comprehensive Hydrologic Impact Assessment (CHIA).

Question 6: What has your state's experience been with these BMPs in terms of their success or failure of implementation?

State	Response
Alaska	None.
Alabama	No response.
Colorado	Generally successful. Failures have been in some of the details which were corrected with one-time maintenance. Water treatment projects have shown limited success.
Illnois	No response.
Indiana	While several BMPs have been employed effectively they have not been allowed as an exception to normal NPDES limitations as provided by Rahall Amendment. Majority of applications have been in true AML projects and not "remining" senarios.
Kentucky (1) - (SMRE)	Success or failure of BMPs for both Title IV and V programs is indirectly reflected in the "closure" of AML projects & the approval of complete bond releases in this state. These final actions would not occur if the above-utilized BMPs were unsuccessful.
Kentucky (2) - (CWA)	The issuance of a KPDES permit does not require specific knowledge of the types and number of these defined BMPs. Therefore, the division of Water cannot provide non quality related data.
Maryland	Just beginning to implement.
Missouri	To date the constructed wetlands have not obtained the desired water quality.
Mississippi (1) - (CWA)	Fair to good & site specific results.
Mississippi (2)	No response.
Montana	Silt fencing, bales, matting has worked well.
North Dakota	No response.
New Mexico	No response.
Ohio	Application of PFBC by-product during reclamation has proven successful. We applied 125 tons/acre of by-product, plus 50 tons/acre of yard-waste compost to the mine site. Vegetation has been established. pH of interstitial pore waters is near neutral (6.5-7.0). Ne elevated concentration of As, Se, Hg, or Pb were detected. However SO^4 + B concentration have risen, which may be of concern. (Same as Pennsylvania)
Pennsylvania	<u>Regrading of old spoils</u>: highly successful. Often will promote runoff and reduce infiltration. <u>Daylighting of deep mines:</u> successful when alkaline overburden is encountered in daylighting or surface runoff is restored. <u>Alkaline addition:</u> a mixed bag. Can work, but often there is not enough alkaline material added to be effective. <u>Special Handling</u>: can reduce acidity, but cannot produce alkaline water in the absence of calcareous materials. <u>Revegetation</u>: an unqualified success. <u>Biosolids</u>: very successful in promoting vegetation. <u>Hydrogeologic controls</u>: jury still out. We're looking at it.
Tennessee	The most successful BMPs implemented in TN are: limestone drains; surface diversions; geochemical amendments; and special handling of acid forming materials.
Texas	No response.
Utah	No response.
Virginia	Generally, when BMPs are used, we see an improvement in water quality. This can be documented through water monitoring reports that are submitted to the Division on a quarterly basis and then compared to baseline data. Only in a couple of instances did we observe no change in water quality.
West Virginia	Too early to tell.
Wyoming	BMPs have been sucessfully implemented. In Wyoming the primary water quality concern is with sediment. AMD problems associated with coal mining are virtually non-existant.

Information reported as submitted by State.

Question 7. Does your state maintain a listing or inventory of the number of stream miles impacted by AMD. (i.e., EPA 303(d) listing)? If available, please provide mileage.

State	Stream Miles	
AK	0	
AL	65	
CO	Yes	
IL	NA	
IN	No	
KY(1-SMRE)	600	
KY(2-CWA)	600	
MD	430	
MO	52	miles classified, 87 miles unclassified
MS(1-CWA)	No	
MS(2-SMCRA)	0	
MT	--	
ND	--	
NM	0	
OH	1,500	
PA	3,000	
TN	1,750	
TX	0	
UT	0	
VA	No	
WV	2,225	
WY	0	
Total	**9,709**	

Information reported as submitted by State.
NA = Not Available.
-- = No Response.

Question 8. What is the industrial profile of your state's remining operations? If exact numbers are unknown, please provide estimates.

State	Number of mining companies with remining permits	Total employment at remining operations (number of employees)	Annual coal production from remining sites (tons)	Estimated coal reserves that could be remined (tons)
AK	0	0	0	0
AL	20	Unk	Unk	Unk
CO	0	0	0	Unk
IL	35	70	200,000	10,000,000
IN	2	N/A	720,000	N/A
KY(1-SMRE)	---	---	---	---
KY(2-CWA)	4	Unk	Unk	Unk
MD	13	150	650,000	Unk
MO	2	0	0	Unk
MS(1-CWA)	0	0	0	Unk
MS(2-SMCRA)	0	0	0	0
MT	0	---	---	---
ND	---	---	---	---
NM	0	0	0	0
OH	3	Unk	Unk	Unk
PA	50	2,345	17,530,000	100,000,000 +
TN	10	75 - 100	3,000,000	50,000,000
TX	0	0	0	0
UT	0	0	0	Unk
VA	3	300	3,000,000 +	Unk
WV	8	Unk	Unk	Unk
WY	0	0	0	Unk
Totals	**150**	**2,940 - 2,965**	**25,100,000**	**160,000,000**

Information reported as submitted by State.
Unk = Unknown.
N/A = Not Applicable.
--- = No Response.