PROCEEDINGS

West Virginia Mine Drainage Task Force

Symposium

March 31 - April 1, 2009
Morgantown, WV

CO-SPONSORED BY
WEST VIRGINIA MINE DRAINAGE TASK FORCE
AND
WEST VIRGINIA COAL ASSOCIATION

2009 PROGRAM

WEST VIRGINIA MINE DRAINAGE TASK FORCE SYMPOSIUM

Ramada Inn, Morgantown, West Virginia
March 31 - April 1, 2009

Tuesday, March 31, 2009

8:30 – 8:35 a.m. **Welcome and Opening Remarks**
Morning Moderators:
Charlie Miller, Chairman of Task Force
Ben Faulkner, Bratton Farms, Princeton, WV

8:35 – 9:00 a.m. **"Status of West Virginia Mining and Reclamation"**
Randy Huffman and Lewis Halstead
West Virginia Department of Environmental Protection
Charleston, WV

9:00 – 9:30 a.m. **"OSM Update on Mining, Reclamation, and AMD"**
Roger Calhoun
Office of Surface Mining
Charleston, WV

9:30 – 10:00 a.m.	**"Status of West Virginia's AML Program"** Eric Coberly West Virginia Department of Environmental Protection Office of Abandoned Mine Lands and Reclamation Charleston, WV
10:00 - 10:30 a.m.	**BREAK**
10:30 - 11:00 a.m.	**"INAP – Global Acid Rock Drainage (GARD) Best Practices for AMD Control and Treatment"** Terrence Chatwin and Keith Ferguson International Network for Acid Prevention (INAP) Salt Lake City, UT
11:00 - 11:30 a.m.	**"Caps and Covers for Acidic Drainage Control – the Canadian Experience"** Gilles Tremblay CANMET-Mining and Mineral Sciences Laboratories Ottawa, ON
11:30 - 12:00 Noon	**"A Briefing on the WVDEP, OSMRE and DHHR SCR-15 Study on the Underground Injection of Coal Slurry"** Andrew "Nick" Schaer West Virginia Department of Environmental Protection Charleston, WV
12:00 - 1:30 p.m.	**LUNCH**
1:30 - 1: 35 p.m.	**REGROUP** **Afternoon Moderator:** Mike Isabell Consol Energy Bickmore, WV
1:35 - 2:00 p.m.	**"2009 Legislative Issues on Mining, Reclamation, and Water Quality"** Jason Bostic West Virginia Coal Association Charleston, WV
2:00 - 2:30 p.m.	**"Status of Acid Mine Drainage Remediation Program in Ohio"** Mitch Farley Ohio DNR - Division of Mineral Resources Management Athens, OH
2:30 - 3:00 p.m.	**"Flooding Conditions in the Meigs Mine Pool Complex"** Mary Ann Borch Ohio DNR - Division of Mineral Resources Management Athens, OH

3:00 - 3:30 p.m. **BREAK**

3:30 - 4:00 p.m. **"Stream Mitigation and Ecological Function for Mined Watersheds"**
Todd Petty
West Virginia University
Morgantown, WV

4:00 - 4:30 p.m. **"Methods for the Estimation of Mine Infiltration"**
Bruce Leavitt
Leavitt Consulting Hydrologists
Washington, PA

4:30 – 5:00 p.m. **"Restoring the Bennett Branch of Sinnemahoning Creek in PA"**
Eric Cavazza
Pennsylvania Department of Environmental Protection
Bureau of Abandoned Mine Reclamation
Harrisburg, PA

5:30 - 7:30 p.m. **RECEPTION AND POSTER SESSION**

Wednesday, April 1, 2009

8:00 – 8:25 a.m. **Registration**

8:25 - 8:30 a.m. **Welcome and Remarks**
Morning Moderator:
Tiff Hilton
WOPEC
Lewisburg, WV

8:30 – 8:55 a.m. **"Selenium Mobility in Overburden Rocks"**
Randy Maggard
Argus Energy WV, LLC
Dunlow, WV

8:55 - 9:20 a.m. **"At-Source Control of Selenium"**
Paul Ziemkiewicz
West Virginia University
Morgantown, WV

9:20 – 9:45 a.m. **"Analysis and Speciation of Selenium in Environmental and Biological Samples"**
Jason Unrine
University of Kentucky
Lexington, KY

9:45 - 10:10 a.m.	**"Linkages between Acid and Metal Load Reductions from AMD Attenuation to Ecological Recovery in Little Raccoon Creek, Ohio"** Ben McCament Ohio University Athens, OH
10:10 – 10:40 am	**BREAK**
10:40 - 11:05 a.m.	**"*Datashed*: An Online Tool for Passive Treatment System Monitoring and Maintenance"** Margaret Dunn and Shaun Busler Stream Restoration, Inc. Mars, PA
11:05 - 11:30 a.m.	**"Specific Conductance of Water and Effect on Benthic Macroinvertebrates"** Randy Maggard Argus Energy WV, LLC Dunlow, WV
11:30 – 12:00 Noon	**"Status of PA's AMD Set Aside Program"** Pamela Milavec PA Department of Environmental Protection Bureau of Abandoned Mine Reclamation Ebensburg, PA
12:00 Noon	**ADJOURN**
12:30 – 3:00 p.m.	**WORKSHOP: GARD Guide** Terrence Chatwin and Keith Ferguson Meeting Room to be announced

SPEAKERS AND POSTER PRESENTERS
WEST VIRGINIA MINE DRAINAGE TASK FORCE SYMPOSIUM
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INAP – Global Acid Rock Drainage (GARD) Best Practices for AMD Control and Treatment

T.D. Chatwin[1] and K.D. Ferguson[2]

ABSTRACT

The concept of the "Social License to Mine" that the mining industry must maintain with the people and governments of the world is now well accepted within the industry. The mining industry supplies the minerals and employment opportunities while maintaining the local environment to an ever increasing standard of response. Not only are these present standards becoming increasingly stringent, the anticipation of future regulations and maintenance of future conditions will become even more rigorous. For those companies that are mining or encountering sulphide minerals, whose exposure can cause acid rock drainage (ARD) the need to protect the environment and to meet evolving standards can be challenging. In this paper we will discuss INAP's[3] contributions to best practice management of ARD and in particular its efforts to develop the Global Acid Rock Drainage (GARD) Guide as a means to advance best practice management of ARD today and into the future.

INTRODUCTION

The essential task of the mining industry is to provide raw materials to the world's economies at a reasonable cost. Metals and minerals are essential to life as we know it, and they are an important element of all economic activity. For the mining industry to accomplish this mission, they must be effective, efficient and profitable, and they must be good citizens. Don Argus, Chairman of BHP Billiton expanded upon this concept in the 2007 BHP Billiton Annual Review, "While shareholder value is our primary driver, every decision the Board makes takes into account the needs and expectations of all our stakeholders; customers, resources owners, communities and governments, partners, suppliers and our employees." He goes on to say, "We have numerous examples that demonstrate our absolute commitment to improving the quality of life of the communities we work with and to minimising harm to the environment."

For a mining company to be successful, it must pay attention to its bottom line. It must control and reduce risk, and it must be in a position to find and develop future mining opportunities.

For a mining company to be sustainable they must first be profitable. In a free market economy, you just can't have a sustainable unprofitable company. In fact, the level of profitability in large degree determines the resources available to support the social license. But as mining companies are recognizing to be the "preferred mine developer" enhancing their sustainability they must be willing to share those profits with their stakeholders and well as their shareholders. Moreover, they must develop expertise in fields that were not

[1] International Network for Acid Prevention (INAP), Salt Lake City, Utah, USA

[2] Sustainability Engineering, North Vancouver, BC, Canada

[3] INAP is presently composed of 9 member companies including Anglo American, Barrick Gold, BHP Billiton, Freeport McMoRan, Kinross Gold, Newmont Gold, Rio Tinto, Vale INCO and Xstrata.

established 20 years ago in the industry – sociology, community planning and micro-finance, to name three.

By becoming the "preferred mine developer" the mining company reduces its risks. It reduces the risk of not being selected to develop a new mine and to obtain permits and approvals, but also the risk of remediation costs of an unexpected ARD event. Mining companies can not just concentrate on the short term; they must plan for the future and mitigate any potential of adverse occurrences – financial, social or environmental. Mining companies must continually prepare to address future risk. Often times these risks are not just financial, they can impact the very core of a sustainable company - stakeholder trust.

Like every license, the social license to operate or mine, comes with a fee. That fee is the cost of assuring that all employees are safe and healthy, that the quality of life in the communities in which mines operate are improved and the environment is not harmed by the operations. During the past decade, mining companies have accepted this situation as a fact of life. In fact, the social license fee has become the price of entry into the game.

This change of attitude has occurred because the need to access resources has become more competitive, and mining companies must demonstrate their ability to find the ore, to mine the ore, to process the metals and to restore the land better than anyone else. As Paul Skinner, Chairman of Rio Tinto said, "Mining is a long term, capital intensive business, in which assets are often situated in remote locations, and can last for 30 years or more. This extended timescale means that, if we are to deliver financial returns to host governments, to local communities and our shareholders, we need economic, environmental and social stability."

Paul Dowd of Newmont said, "Treating acid drainage once it has occurred, or mitigating environmental impact after it has occurred, is usually an admission that something has gone wrong either in the characterisation, planning, design or operation of a mine. It is Newmont's belief that acid drainage can be prevented if some key principles are followed throughout the life of a mine, from exploration through to closure." Paul Dowd listed some important principles of ARD management that we have modified and expanded:

- Focus on ARD prevention rather than treatment. (The mission of INAP)
- Minimize disturbed material.
- Complete characterization of ore, waste rock and tails.
- Plan and design for closure from the feasibility.
- Update detailed closure costs on a regular basis.
- Integrate mine rehabilitation into the day-to-day mine operations.
- Know the potentially acid forming (PAF) and non-acid forming (NAF) characteristics of all disturbed material
- Maintain good quality control of engineering works.

Rather than placing efforts relating to ARD at the end of the operation during mine closure, ARD planning and implementation activities needs to occur at "day one" of exploration and throughout the mine life. This planning should continue throughout design, construction, operation and closure. Continuous ARD planning and management is imperative to successful ARD prevention.

The cost of ARD mitigation for the United State ranges from $1.2 billion to $20.6 billion USD. These costs estimates were for operating company liabilities at hard rock sites. In addition to these costs, the U.S. Office of Surface Mining (OSM) estimates that the current ARD liability at coal sites as $8 billion USD, which includes liabilities relating to health and safety, as well as environmental costs.

THE PATH FORWARD

The path forward for ARD prevention has a number of participants. The primary drivers for the prevention of ARD are the mining companies. They need to do the planning, make the commitments, and earn the social license through demonstration of excellence. Next are the stakeholders, they in large degree are the beneficiaries of the mining company's good works, but inturn they can enhance and return these good works. INAP is one of those stakeholders. In this section we will present INAP's new initiatives, and update you on the progress of the GARD Guide. The final and perhaps the most important element of the path forward is you.

INAP's Role

INAP is an organization of international mining companies dedicated to reducing liabilities associated with sulphide-bearing materials and metal leaching. INAP was founded in the mid-1990's to develop and share information, experience and resources to prevent and treat acid drainage. To produce potential solutions for this problem INAP facilitates collaborative research. Some of our recent research topics include:

- Treatment of Sulphate in Mine Effluents
- Tailings and Waste Rock Co-Mix
- Rum Jungle Waste Rock Cover
- Store and Release Cover
- Long-term Performance of Dry Covers
- Scale-Up of Country Rock Testing
- Hydrologic and Geochemical characterization of Waste Rock Dumps
- Passivation of Acid Generating materials

One of the key elements of INAP is technology transfer. As our name indicates we are a network to transfer information, data and ideas within the mining industry and its stakeholders. We support forums to present and discuss ARD issues and solutions. INAP is the major sponsor of the International Conference of Acid Rock Drainage (ICARD). ICARD8 will be held in Skelleftea, Sweden on June 22-26, 2009. INAP is also planning to reinstitute technical focused workshops addressing specific needs of the industry. INAP believes that technology transfer and capacity building is key to the successful implementation of our mission. Not only do we as an industry need to develop and expand the technical and managerial capabilities of our people we must support the enhancement of the capacity building among our stakeholders.

The GARD Guide

INAP's largest, potentially most influential activity to-date is the funding of the GARD Guide. The development of the Global Acid Rock Drainage (GARD) Guide is sponsored by INAP with the support of the Global Alliance[3].

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[3] Global Alliance is composed of regional environmental organizations that deal with water issues including mine-influenced waters. The Global Alliance includes Acid Drainage Technology Initiative (ADTI) in the United States, Mine Environmental Neutral Drainage (MEND) in Canada, Partnership for Acid Drainage Remediation in Europe (PADRE), Australian Centre for Extension and Research (ACMER), and the South African Water Research Commission (WRC).

Research into the process of ARD formation and methods to minimize its impact have been conducted for over 50 years. Much progress has been made in the last 20 years through a number of research consortiums. As such, there is a considerable body of scientific and engineering guidance available on ARD already through INAP, MEND, BCARD, WV Mine Drainage Task Force, BC MEMPR, ADTI, ACMER, WRC, PADRE and other programs. The research however is in disparate references, not easily accessible and tends to be issue, commodity or geographical centric. INAP desires to consolidate the information and produce a Guide that would be up-to-date and global in scope.

The objective is to produce a guide that would be a key reference for the mining industry, regulators, NGO's and the public on the subject. The Guide will address the production of contaminants from sulphide mineral oxidation that can result in ARD, neutral mine drainage (NMD) and saline mine drainage (SD).

The Guide will summarize the best technical and management practices with the objective of creating a body of work with high industry and external stakeholder credibility. The Guide will cover all phases of a mining operation from initial discovery through to final closure. In that way it will assist industry in providing high levels of environmental protection, assist governments in the assessment and regulation of affairs under their jurisdiction and enable the public to have a higher degree of confidence in and understanding of acid prevention proposals and practices. Overall, the Guide will provide a structured system to identify and catalogue new analysis techniques, new technology and understanding developed through INAP, the Global Alliance[1] and other organizations.

The overall challenge of the GARD Guide is to identify and synthesize the best available information in order to develop a global state-of-the-art summary while at the same time outlining options for different geo-climatic environments.

A modern GARD Guide will fill a need by being:

- Current with available scientific and engineering understanding
- Comprehensive by covering all aspects of ARD formation and management
- Global by considering geographic differences in climate and environmental setting
- User friendly with web based access and search capability
- Updatable via the web
- Accessible to a broad range of readers from those with a lower technical knowledge (eg. teachers and communities) to those with a technical background but not necessarily in ARD or environmental management

Principles of the GARD Guide

The purpose of the Guide is to articulate the issues and identify sound practices and gaps in knowledge or guidance on particular ARD issues. The guide is intended to promote consistency in approach and improve understanding and application of sound practices for ARD management.

Various definitions and nomenclature have been developed in different countries, regions and individual companies related to ARD management. The GARD Guide will provide key definitions and nomenclature early in the document to develop a common understanding for readers. The development and promotion of one set of definitions, nomenclature, acronyms and standards could be one of the most significant contributions made by the GARD Guide. Care is needed however to ensure the Guide does not have an overall North American bias.

The GARD Guide must be applicable to existing and historic ARD issues not just to new mines. The guide is not a design document as that requires a high level of understanding and site specific knowledge of a particular project or mine. Detailed design of ARD mitigation techniques will continue to be conducted by knowledgeable practitioners.

Specific objectives of the Guide are to:

- Articulate the issues associated with sulphide mineral oxidation;
- Reference and improve the understanding of best global practice, customized where necessary for special geo-climatic conditions;
- Promote a risk-based, pro-active, consistent approach by encouraging planning for and implementation of reduction and control of ARD at the source;
- Leverage the world's ARD expertise and share expertise with developing countries;
- Support the 'Equator Principles' developed by a consortium of lending institutions and ICMM's objectives by achieving 'global best practice' in future mining projects.

Considerable literature exists for the assessment, prediction, control and management of ARD from coal. Therefore key coal ARD guidelines, compendia and references will be summarized and referenced.

Target Audience

The target audience for the GARD guide includes:

- Mining and Mining Service Companies
- Governments (national regulatory or land management agencies, IFC, World Bank, regional development agencies etc.)
- Consultants
- Researchers/ Educators/ Academia
- Community / Communities of interest/ Stakeholders
    - Bankers
    - NGO's
    - Indigenous Peoples

The Guide is a technical document designed primarily for a scientist or engineer with a reasonable background in chemistry and the basics of engineering with little specific knowledge of ARD. The principal user will typically be an employee of the mining industry, regulatory agency, research organization or consulting company.

Status of the GARD Guide

The development of the GARD Guide encompasses four phases:

First Phase
- Beta version prepared by Golder Associates
- Wiki structure developed for Guide
- Further expert input and targeted workshops

Second Phase
- Broad stakeholder review of draft through INAP website

Third Phase
- Update, publish and rollout by June 2009

Fourth Phase
- training sessions on use of Guide
- updates and continuous improvement of Guide

The project is currently in the second phase.

The GARD Guide is being created through the contributions of many individuals and organizations. A team lead by Golder Associates prepared a "beta version" of the Guide in June 2008. INAP established broad-based Steering and Advisory Committees to direct preparation of this document. INAP also received input from several other contributors, peer reviewers, workshop participants and interested stakeholders. INAP sponsored workshops in partnership with ADTI/US EPA and the South African Water Resources Commission in Denver, Colorado and Johannesburg, South Africa respectively to review selected chapters. The workshops were well attended and excellent input was obtained on the Guide. INAP gratefully acknowledges all of this assistance.

The GARD Guide is based on a "Wiki" model. Chapters and subchapters are constructed as pages. Internal links are provided for topics where more detail is available. Links to external web sites will be included to organizations and other more detailed or specific topic references.

The current draft of the GARD Guide has 10 Chapters:

1. Introduction
2. ARD Process
3. Corporate, Regulatory and Community Aspects
4. Characterization
5. Prediction
6. Prevention/Mitigation
7. Treatment
8. Monitoring
9. Management and Performance Assessment
10. Communication and Consultation

Sustainability considerations are woven throughout the draft Guide. The Guide is a "work in progress" and will be updated and improved through its "Wiki" structure.

The draft Guide contains a number of flow charts that guide the reader through the application of the technology. Example draft flow charts are shown in Figures 1 to 3. Where required, a practitioner would develop an ARD management plan fully integrated with mine operations (Figure 3). The successful implementation of an ARD plan is one of the key goals of the process outlined in the GARD Guide.

Draft GARD Guide Availability

The draft Guide is currently available for review at:

http://www480.pair.com/aturner/gardwiki/

INAP plans to hold additional workshops to review the draft Guide in Europe, Australia and South America in 2009. An updated version of the GARD Guide will be produced in May 2009, uploaded to INAP's website and formally launched at the 8th ICARD conference.

YOUR ROLE

The final element of the path forward is you. You are the people that will combat this most serious and potentially enduring environmental problem of the mining industry. If we and our children are to continue a "quality of life" that we have grown to expect, the mining industry must prosper to supply the raw materials that feed the economies of the world. For the mining industry to prosper, the issues of ARD must be addressed. You have the education, the experience, and the ever growing knowledge base. Many people are working to supply the tools that you will need and to support your efforts.

INAP is working to create the GARD Guide as important tool in addressing ARD issues. INAP needs your help and invites all attendees of this workshop to contribute to its development by reviewing the draft Guide and providing comments to INAP by April 1, 2009 via:

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REFERENCES

Argus D, Chairman's Review, 2007 BHP Billiton Annual Review, P. 7, 2007.

Skinner P, Message from the Chairman, Rio Tinto 2006 Sustainable Development Review, P. 1, 2006.

Dowd P J, The Business Case for the Prevention of Acid Drainage, In 'Proceedings of the 5th Australian Workshop on Acid and Metalliferous Drainage', 2005.

Department of the Interior, Office of Surface Mining, Reclamation and enforcement, Abandoned Mine Land program: Accomplishments, Washington, D.C. DOE-OSMRE, 2003

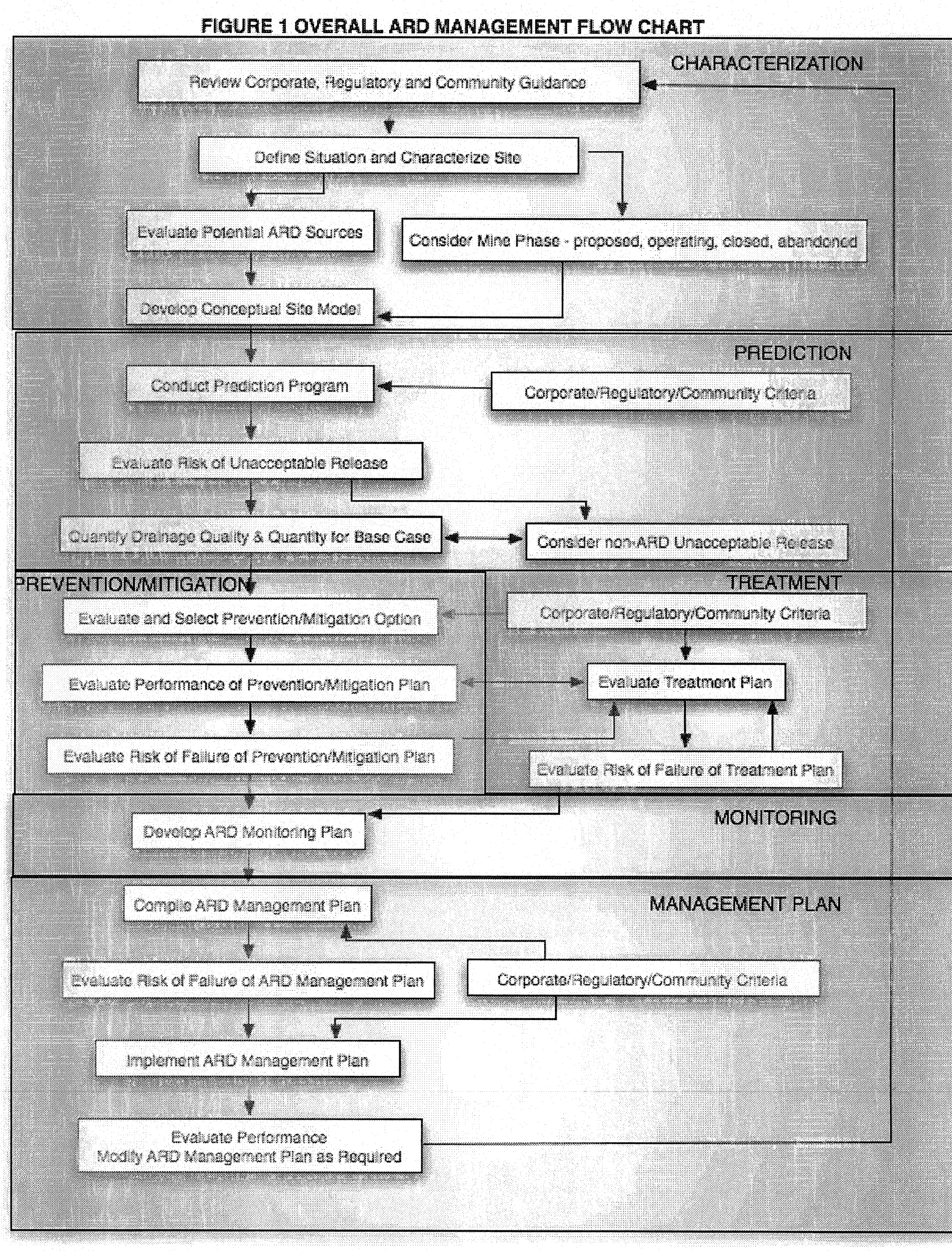

Figure 1 Draft Overall ARD Management Flow Chart

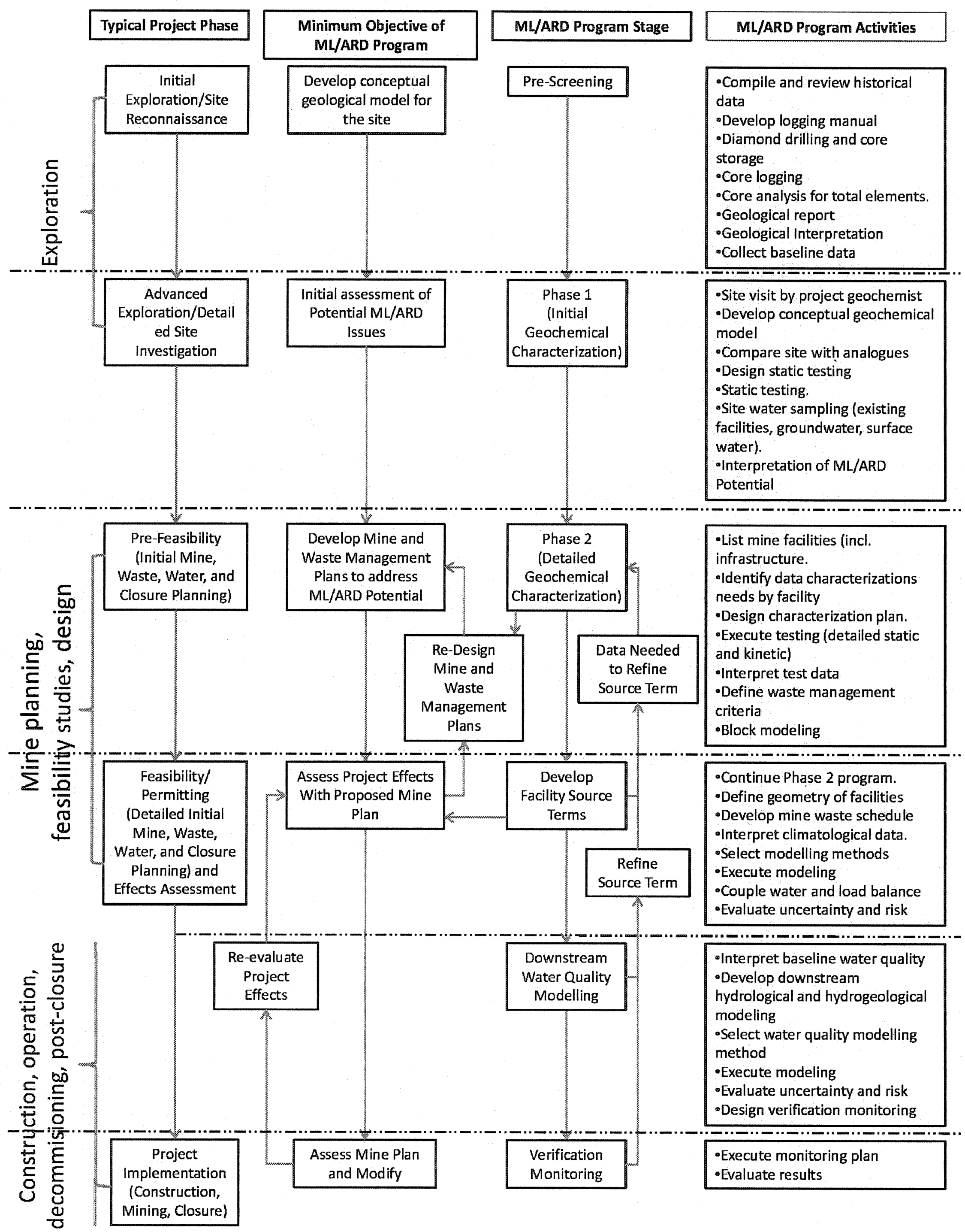

Figure 2 Draft Prediction Program Flow Chart

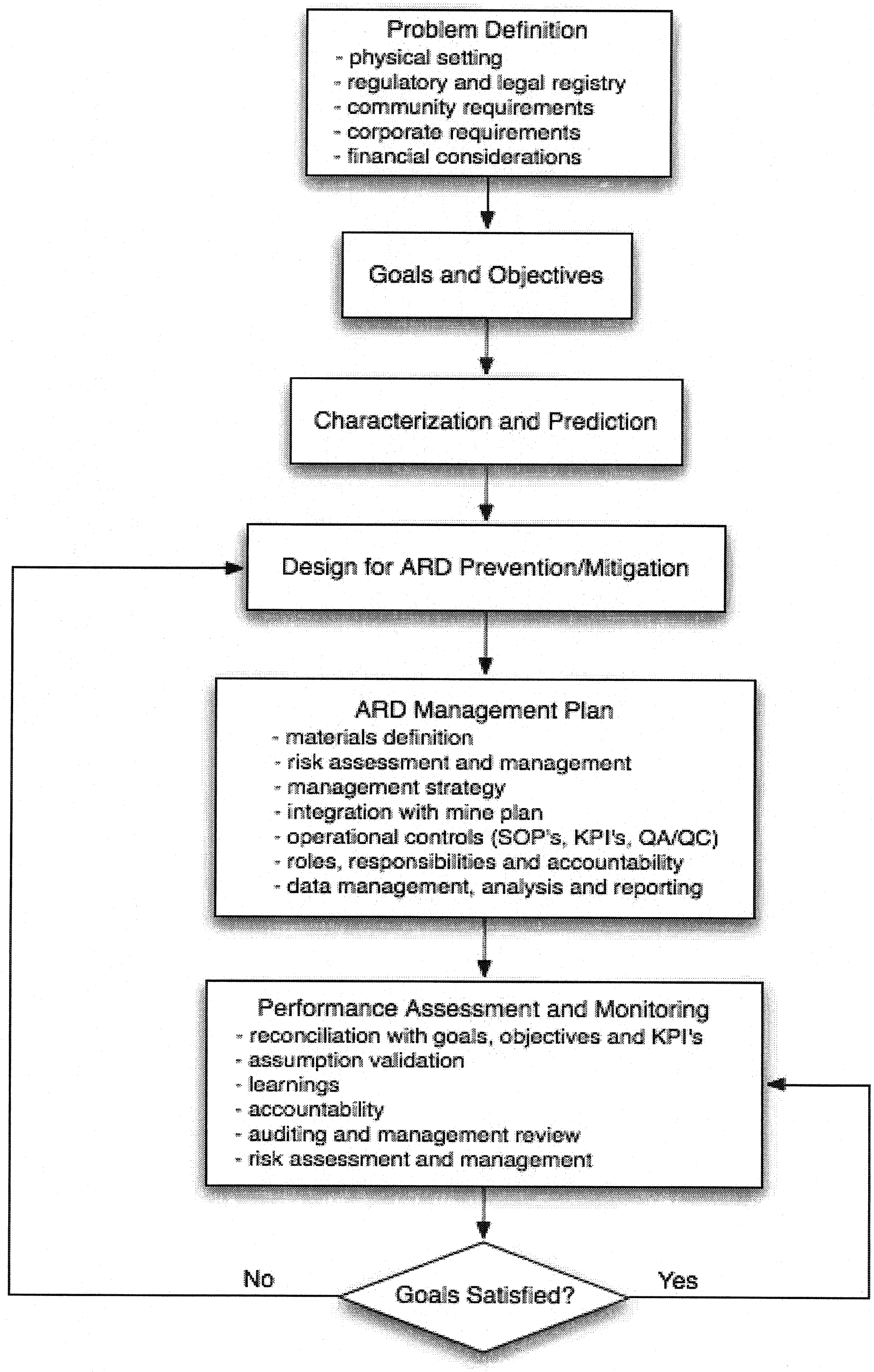

Figure 3 Draft ARD Management Plan Flow Chart

Caps and Covers for Acidic Drainage Control - the Canadian Experience

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Extended Abstract

Introduction

Acidic drainage is recognized as the largest environmental liability facing the Canadian mining industry. Since 1989, the Mine Environment Neutral Drainage (MEND) multi-stakeholder partnership has developed technologies to prevent and control acidic drainage. The initial MEND Program (1989-1997) contributed greatly to the understanding of acidic drainage. Tremendous technical progress was made in the areas of prediction and modelling, prevention and control, disposal technologies, lime treatment, passive treatment and monitoring. In 1998, a three-year program commenced to further verify MEND-developed technologies in the field, and to build technology transfer capacity through workshops, reports, and a website. Linkages between Canadian and international industry and government programs were also strengthened. The main activity for 2001 was release of the six-volume MEND Manual, which addressed key acidic drainage issues (MEND 5.4.2). Information from more than 200 technical documents and workshop notes produced under MEND up to 2000 was summarized, or referenced in this manual.

In 2002, a renewed MEND initiative was created that focussed on Canadian national and/or regional information needs, with a strong emphasis on technology transfer. A multi-stakeholder Strategy Session held in 2002 developed a research framework based on four broad research themes; mine waste management practices, emerging challenges, prediction, and post-closure management (MEND 8.2). Participants at the session recommended a number of research activities for a multi-year program to advance acidic drainage knowledge across these four fronts. Subsequently, the MEND Network was surveyed to help define research priorities. Top priorities were identified as closure management, verification of technologies, metal leaching, passive treatment, early prediction and sludge management. Strong support was also given for research on cold temperature effects, paste backfill and monitoring methodologies. The need for guidance documents and technology transfer activities (e.g. workshops, updates on emerging technologies) was identified as a crosscutting issue within each of the themes. In addition, case studies were recommended as a vehicle for cost-effective technology transfer, and as a means of comparison of predicted and actual field performance. In contrast to the earlier MEND work related to control and limitation of liabilities, there was a shift to recognition of environmental and sustainable development issues.

Since 2003, the MEND Steering Committee has developed an annual work plan to address these key research priorities. Many of these new projects re-examine issues and re-visit sites that were the subject of earlier MEND studies. Advances in technologies and knowledge make it timely to re-examine some of these issues. As well, several of the new projects verify the full-scale application of MEND supported technologies, and investigate their long-term performance. Over the last five years, there has been a shift in some priorities, with a greater interest in cold temperature effects and guidance documents.

Covers for Acidic Drainage Control

A tremendous amount of work has been completed in this area, but there is a need for further research and development to address areas of uncertainty and reduce costs. This is a technically complex area and site-specific factors and conditions add to this complexity, and often necessitate site-specific research. As a result, acidic drainage technologies are not universally applicable. The application of a particular technology to a site may be negated by prohibitive cost or other factors that affect mine waste management.

Long-term monitoring has been started on full-scale applications at a number of sites to assist in confirming the performance of available technologies. Experience in the closure of acid-generating mine waste sites has shown that the prevention of acidic drainage should be a first objective when this is achievable and affordable.

MEND research demonstrated that the oxidation of sulphide minerals can be inhibited by the presence of a water cover, as the water acts as a barrier to the diffusion of oxygen from the atmosphere to the submerged sulphides. Potential disposal options include: 1) the subaqueous disposal of unoxidized sulphidic wastes under a water cover; and 2) the flooding of oxidized wastes.

In Canada, the use of water covers and underwater disposal are being confirmed as the preferred prevention technology for unoxidized sulphide-containing wastes. These aspects were addressed through initial investigations of historically submerged tailings in natural basins with extensive and detailed geochemical investigations.

Water covers have been applied at many sites, but are not universally applicable. Related issues, such as the ability to maintain a water cover over the long term, the integrity of the containment structures, locality and site-specific potential risks due to seismic events, severe storm events, etc., can negate the use of this technology. However, under suitable conditions, the present state of knowledge is sufficient to allow for the responsible design, operation and closure of waste management facilities using water covers for both fresh and oxidized tailings and waste rock.

Dry cover systems are commonly used to decommission waste rock piles and tailings impoundments at sites around the world. The key objective of dry cover systems is to provide a barrier that minimizes the influx of atmospheric oxygen to the mine waste, and limits moisture infiltration. Apart from these functions, dry covers are expected to be resistant to erosion, and provide media for vegetation.

Dry covers can range from a single layer of earthen material to several layers of different material types, including native soils, non-reactive tailings and/or waste rock, geosynthetic materials, and oxygen consuming materials. Multi-layer cover systems utilize the capillary barrier concept to keep one (or more) of its layers near saturation under all climatic conditions. This creates a "blanket" of water over the reactive waste material, which reduces the influx of atmospheric oxygen and subsequent production of acidic drainage.

Case Studies

Case studies, featuring both the successes and the errors, form a large part of the MEND program. Verification of MEND-developed technologies by long-term monitoring of sites will expand the knowledge base and possibly extend application. Case studies also demonstrate practical experiences with different aspects of metal leaching/acid rock drainage (ML/ARD) mitigation and assessment practices at well-characterized sites. Several MEND projects that look at the field performance and sustainability of various aspects of the prediction and mitigation of drainage chemistry are currently underway or recently completed and brief descriptions are provided below.

MEND 2.12.2 ***Assessing the Long-Term Performance of a Shallow Water Cover to Limit Oxidation of Reactive Tailings at Louvicourt Mine*** investigated the long-term performance of the shallow water cover in large test cells by comparing data from the 1996 and 2005 sampling campaigns. This study was initiated nine years after the tailings were submerged, and integrates geochemical, mineralogical and biological data to provide an overall assessment of the long-term performance. The impact of periphyton layers, which developed in the interim, on the performance of shallow-water covers was investigated. Results indicated that development of the overlying biofilm was beneficial in preventing metal release to the overlying water column. Further studies at other Canadian sites with a biofilm are to be investigated under the 2009 work plan.

MEND Case Study Assessments assessed and verified the effectiveness of acidic drainage pollution prevention and control techniques at several sites. Prediction methods, prevention and control techniques, monitoring programs, and closure planning were evaluated. In Phase I of the project, three closed sites were assessed: Dona Lake, Mandy Lake and Heath Steele. Phase II included further field studies at Heath Steele, where a water cover was used as closure technology for the tailings impoundment.

MEND 9.1 ***Case Studies of Metal Leaching/Acid Rock Drainage Assessment and Mitigation in British Columbia*** illustrated site-specific application of ML/ARD mitigation and assessment at three mine sites in British Columbia with significant ML/ARD concerns: Johnny Mountain Mine, Snip Mine and the Sulphurets project. Site specific issues and key design and performance parameters were outlined, along with constraints, information gaps, errors and their management implications.

BHP Rehabilitation Case Studies (in progress) investigated two sites, Mine Poirier (Joutel, Quebec) and East Kemptville Mine (East Kemptville, Nova Scotia). The long-term performance of the geomembrane liner installed at Poirier in 2000 was investigated. The liner has been successful at reducing water infiltration into the tailings pile and limiting oxidation of the tailings, thereby reducing the release of acidic drainage and metals to the environment. Two rehabilitation strategies were implemented on the East Kemptville Mine site. Oxidation of the fine tailings was reduced by an elevated water table, and acidic drainage water produced by the coarse tailings and the mine waste rocks was neutralized through a lime treatment plant. Water handling strategies were also introduced to improve process efficiency.

With the large number of mines opening in Northern Canada, the effect of cold temperature on various technologies is of increasing importance. Oxidation kinetics, permafrost and mine waste management, in cold weather conditions warranted further research.

MEND 1.61.4 ***Covers for Reactive Tailings Located in Permafrost Regions*** gives a brief introduction to permafrost issues and then focuses on covers constructed over reactive tailings in Canadian permafrost regions. Case histories for Nanisivik, Raglan, Lupin and Rankin Inlet are examined, which represent sites with different tailings operations, cover design approaches and physical and climate conditions. **MEND 1.61.5a** ***Northern Soil Covers – Phase I*** (in final draft) reviews cold region phenomena that could impact on soil cover performance, including ground freezing, snow-distribution, limits to revegetation, and identifies research priorities to improve soil cover design and construction methods suitable for cold regions. The objective of **MEND 1.61.5b** ***Northern Soil Covers - Phase II*** **(in progress)** is to link the phenomena found in Phase I with actual northern sites where they occur.

Guidance Documents

MEND 5.10 ***List of Potential Information Requirements in ML/ARD Assessments and Mitigation Work*** listed potential information requirements and factors to consider for ML/ARD work, and serves as a general guide for the mining industry, consultants, regulators, educators and students, and the public interested or involved in mining issues.

The manual, **MEND 2.21.4** ***Design, Construction, and Monitoring of Covers Systems for Waste Rock and Tailings*** incorporates and integrates the best available technology for the design and construction of cover systems over mine wastes. The report contains a summary document and four supporting technical volumes: theory and background; site characterization and numerical analyses of cover performance; field performance monitoring; sustainable performance of cover systems; and case studies. It is intended for use by mining personnel and stakeholders interested in cover systems. **MEND 2.21.5** ***Manual for Macro-Scale Cover Design and Performance Monitoring*** introduces design and monitoring guidelines for mine waste soil cover systems on a macro-scale or watershed scale, and discusses challenges that arise due to increased size and complexity as compared to evaluating cover systems on a micro-scale. Macro-scale cover system evolution follows many of the same guidelines and is governed by the same processes as landform evolution. Challenges and lessons learned in tracking cover system evolution and long-term field performance are illustrated. A number of methods and associated instrumentation for macro-scale monitoring are detailed in the manual and appendix.

Technology Transfer

An integral part of MEND is technology transfer - the distribution of information on developed technologies to the partners and the public. Information is transferred through a number of routes. The MEND web site at **http://mend.nrcan.gc.ca** (currently under construction) is regularly updated with report summaries, a publication list, case studies, newsletters, workshop and conference announcements and links to other relevant initiatives. Workshops are an effective vehicle to transfer information, and MEND hosts one or two workshops each year. The BC-MEND Annual ARD/ML Workshop selects a research theme each year that reflects current practices, new research technologies and relevant developments. Participants expressed a strong interest in the field-test results and case studies, which are always included in these sessions. Themes in recent years were performance of dry covers (2004), prediction of drainage chemistry (2005) and open pits and underground workings (2006), collection and treatment of mine drainage (2007), and most recently, management of tailings and tailings impoundments (2008). Workshops in other parts of Canada focus on issues of regional concern, such as sludge management, tailings disposal, neutral pH drainage, site remediation and case studies on mitigation technologies.

MEND technical reports are available from the MEND Secretariat in paper and/or CD ROM versions. Over 160 of the 200 MEND technical documents (covering 1988-2000) are available on three CD-ROMs. In addition, the workshop proceedings are available in CD-ROM.

Conclusions

MEND continues to be a model of collaboration among industry, different levels of government and NGOs. The MEND program has provided a focus to develop solutions for environmental problems that face the mining industry across Canada and internationally. Through the 20 years of the MEND program, a significant reduction in environmental liability has been achieved. MEND is now recognized world-wide for its contribution to the long-term sustainability of the industry and the environment.

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A BRIEFING ON THE WVDEP, OSMRE AND DHHR SCR-15 STUDY ON THE UNDERGROUND INJECTION OF COAL SLURRY[1]

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Abstract. SCR-15 authorized a comprehensive two-phase study on the potential effects of underground injection of coal slurry on the environment (Phase 1) and human health (Phase 2). A team whose members include personnel from West Virginia Department of Environmental Protection's DMR (Division of Mining and Reclamation) and Division of Water and Waste Management (DWWM), the West Virginia Department of Health and Human Resources-Bureau of Public Health, and Office of Surface Mining Reclamation and Enforcement are conducting the first phase of the study.

An analysis of the chemical composition of coal slurry, including an inventory of organic and inorganic constituents, was conducted at six locations across the State. With input from the environmental and industry groups, six sites were selected from the 13 active coal slurry injection sites in the state. The study sites included are: Southern Minerals, Panther LLC, Marfork Coal Company, Power Mountain, Loadout LLC, and Coresco, LLC.

A detailed hydrogeologic evaluation of the migration of coal slurry and its constituents from injection wells into the ground and surface waters was conducted at four of the six sites. The assessment sites include the coal preparation facilities where the underground injection of coal slurry took place. The sites are Southern Minerals, Panther LLC, Loadout LLC and Power Mountain. All four assessment sites are located in the southern coal fields and have mines which are considered below or mostly below-drainage (mines workings are located below surface drainage features). Water samples collected from surrounding surface and ground water were analyzed for over 250 organic and inorganic chemical constituents. All the sites sampled reflect a "snapshot" of the site-specific hydrologic conditions that surround the slurry injection sites.

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[1]Paper was presented at the 2009 West Virginia Mine Drainage Task Force Symposium, March 31- April 1, 2009, Morgantown, WV.

Status of Acid Mine Drainage Remediation Program in Ohio

*Mitchell E. Farley, ODNR – Division of Mineral Resources Management

Abstract

The Ohio Department of Natural Resources, Division of Mineral Resources Management operates the State's Abandoned Mine Land Program and regulates mine safety and oil and gas, coal and industrial minerals mining. The AML Program has Federal, State, Acid Mine Drainage (AMD) and Emergency units.

The AMD Program is conducted in concert with outside partners, including multiple agencies and watershed groups. It operates out of three district offices across the southeastern portion of the State and employs twenty total staff. The AMD Program concentrates on source control reclamation (mine spoils, coal refuse and stream capturing subsidence) and treatment (dosers and passive systems) as needed. Extensive use of GIS is made through an ARCIMS database and abandoned mine and watershed map servers. Extensive chemical and biological sampling is undertaken to plan and evaluate the performance of projects. Ohio DMRM operates it's own water quality laboratory.

Watershed partners have leveraged 29% (4.5 million dollars) of the almost fifteen (15) million dollars spent on mine drainage abatement to date. Ohio has a watershed coordinator program that enables DMRM to presently place five coordinators in AMD impacted watersheds. Ohio's credible data law provides for the proper training of coordinators and other partners (fish, macroinvertebrate, chemistry and habitat). Ohio continues to prepare hydrologic unit reports and has completed twelve to date. Another nineteen are under consideration.

Ohio DMRM has a close applied research relationship with Ohio University and hosts an annual mining conference there in December every other year.

Issues presently being worked on include the long-term operation and maintenance liabilities associated with treatment and the need for environmental Good Samaritan and real estate disclosure legislation.

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Flooding Conditions in the Meigs Mine Pool Complex

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Abstract

The purpose of this paper is to provide background information and an update of hydrologic information regarding the Meigs Mine pool complex. Mine pool development, water quality, water quantity, and impacts to the local hydrology are briefly covered.

Mining was completed and the mine pool began to fill in 2002. The mine complex is below drainage with the exception of the western edge of the Raccoon mine where the coal seam is just at or near Raccoon Creek. The overburden thickness ranges from 200 to 600 feet. Pumping began from the Meigs 2 pool on January 28, 2008. The Meigs 31 mine has not yet begun pumping to control the mine pool.

Near surface aquifers are impacted by surface tension induced fractures. In areas of low cover the inflow of groundwater to the mine are direct. In most cases, the stream loss may be going into the shallow subsurface, facilitated by fracture dilation. If the strata are friable, the ability of the fractures to heal is diminished as is the case in some streambed dewatering above the Meigs 2 mine.

Recharge into the mines exhibits seasonal variability. Incremental differences in the fill rates are apparent from specific monitoring points. In general, the pool rises and falls in concert over the complex with the exception of the 3rd NE section of Meigs 2. Recharge rates were volumetrically determined for the mine pool complexes.

Since there is a potential for uncontrolled discharges to low-lying stream valleys, maintaining a lower pool elevation through pumping is required. Water quality is expected to improve dramatically with time. Due to the partially unflooded mine pool, the mine pool water quality may require perpetual treatment.

Introduction

As underground mines close, mine pools are becoming commonplace in the Appalachian coal-bearing region. Mine pools form and connect with nearby or adjacent mines to form aquifers that will require pumping in order to avoid uncontrolled discharges to the surface. These discharges have the potential to pollute streams and near-surface aquifers with high sulfate and metal-rich water. The purpose of this paper is to establish background and early to recent flooding conditions of the mines making up the Meigs Mine underground complex.

Background

The Raccoon, Meigs 31, and Meigs 2 mines comprise the complex located in Meigs, Vinton, and a small section in northern Gallia counties of southeastern Ohio near the town of Wilkesville. While mining has not occurred in this complex since 2002, the three no-longer mined complexes remain permitted, and additional permits have been obtained in order to build facilities that will pump and treat the water. The complex is located adjacent to an abandoned underground mine along Raccoon Creek. Mining began in 1972 in the Meigs 2 complex, mining in Meigs 31 started the following year, and then in 1974 mining began in the Raccoon section. The Meigs 1, Meigs 3, and Raccoon were connected during the active mining operation, and are now collectively referred to as Meigs 31. This descriptor will be used throughout the balance of this report.

All three mines exploited the Clarion No. 4 coal seam. Both room and pillar and longwall methods were used. The footprint of the entire mine complex is 23,500 acres (36.7 square miles). Figure 1 map shows the entire complex. The Meigs 31 and Raccoon mines are openly connected, whereas Meigs 2 is separated from them by a solid coal barrier, 1,350 feet wide at its narrowest point.

During mining, the workings were dewatered by pumping water to the surface for treatment. With mining complete, the potential exists for mine pool water to surface and contaminate various tributaries of Leading Creek and Raccoon Creek with metal laden water high in total dissolved solids. This potential discharge would occur in the low-lying stream valleys where vertical fractures from stress relief or from subsidence damage may provide a conduit to the surface.

CONSOL Energy Inc. (CONSOL) will provide for the perpetual treatment of the discharged mine water by building and operating a wastewater treatment plant. A maximum rate of 3000 gpm of contaminated mine water will be pumped from Meigs 2 and travel overland into Meigs 31 where it will mix with the Meigs 31 water. Water will then travel eastward and down dip and be withdrawn from the South Bleeder shaft and treated. In January of 2008, pumping from Meigs 2 began. Currently, Meigs 31 is not yet being pumped.

Physiographical and topographical Setting

The mine complex lies within the non-glaciated portion of the Allegheny Plateau. Surface relief is moderate with rolling and steep sided hills and narrow mature valleys. Over Meigs 31, the land surface elevations range from 640 to 1029 feet m.s.l. with a maximum relief of 400 feet. Over Meigs 2, the topographic elevations range from 590 to 870 feet m.s.l. with a maximum relief of 280 feet. Stream gradients in this region are low to moderate. Land use patterns are primarily hardwood forests and pasture.

Geology

The bedrock geology consists of sedimentary rocks of Pennsylvanian and Permian age. The strata are from the Allegheny and Conemaugh formations. These strata strike north 25.5° east and dip gently to the east-southeast (65.7°) at an average rate of 30 ft/mi. A grabben fault was encountered during mining beneath the mains separating Raccoon Mine from the old Mine 3. Very little limestone is encountered in the Meigs 2 overburden except on the southeast side. However, in the Meigs 31 complex, the Clarion Coal is overlain by the Vanport limestone.

Hydrogeology

The mine complex is entirely below drainage with the exception of the western edge of the Raccoon Mine where the coal seam is just at or near Raccoon Creek (Refer to Figures 2 and 3 topographic maps). The elevation of the Clarion coal ranges from 611 feet m.s.l. at the western edge of the mine declining to 250 feet m.s.l. on the eastern side. The coal thickness is from 4.5 – 6.5 feet and the overburden thickness ranges from 190 to 640 feet over Meigs 31 and 115 to 400 ft m.s.l. over Meigs 2. Above the complex, the lowest topography is at approximately 600 ft m.s.l.

No significant quantities of water were encountered during drilling operations at Meigs 2. However, much water was encountered during mining of low cover areas, especially in the west sides of the mine. The primary water producing zone is 77 to 148 feet below the surface which is at 764 ft m.s.l. The hydraulic conductivity in this zone ranged from impermeable to a high of 5.67×10^{-5} cm/sec. The controlling factor in productivity is due to secondary permeability that exists as joint systems, bedding planes, and natural fractures.

Groundwater flow in this area is almost solely restricted to the interaction between near vertical fractures and bedding planes separations, which is to be expected due to the low primary permeability of the strata. In Appalachian valleys, groundwater flow occurs as vertical infiltration along valley walls via stress-relief fractures and lateral movement along bedding planes fractures (Wyrick and Borchers, 1981). Permeability in this region is thought to decrease with depth by an order of magnitude for each 100 feet (Siplivy, 2004).

Effect of Longwall Mining on the Permeability of the Strata

The longwall method of underground mining includes the excavation of large rectangular coal blocks called panels. The face, where the coal is removed, is generally more than 1,000 feet wide and the length of these panels can be 5,000 feet or more. Longwall mining exhibits relatively predictable surface subsidence features. Total subsidence movement is to a large extent influenced by overburden thickness and lithology.

Kendorski (1993) provides a model that describes types of fracturing above longwall mines, from the mine roof to the ground surface as shown in Figure 4. The average mined seam thickness for the Meigs Mine complex was six (6) feet.

Aquifer dewatering is enhanced by enlargement of existing fractures or opening of new fractures above the zone of caving during a subsidence event. Both represent an increase in permeability and porosity that could result in dewatering aquifers or streams. Dewatering of the aquifer is usually limited to active mining areas. As the strata settles and becomes re-compressed, groundwater levels may rebound as flow paths to the mine become more restricted and less direct. These fractures may heal themselves with time if sufficient amount of clay and shale material are in the strata. On the other hand, if the strata are friable sandstone units with little silts and clays, the ability of the fractures to heal is diminished.

Near surface aquifers are dewatered by surface tension induced fractures. In areas of low cover where vertical subsidence-induced fractures intersect with surface tension fractures and natural stress-relief fractures, water infiltration into the mines may be direct. Wyrick and Borchers (1981)

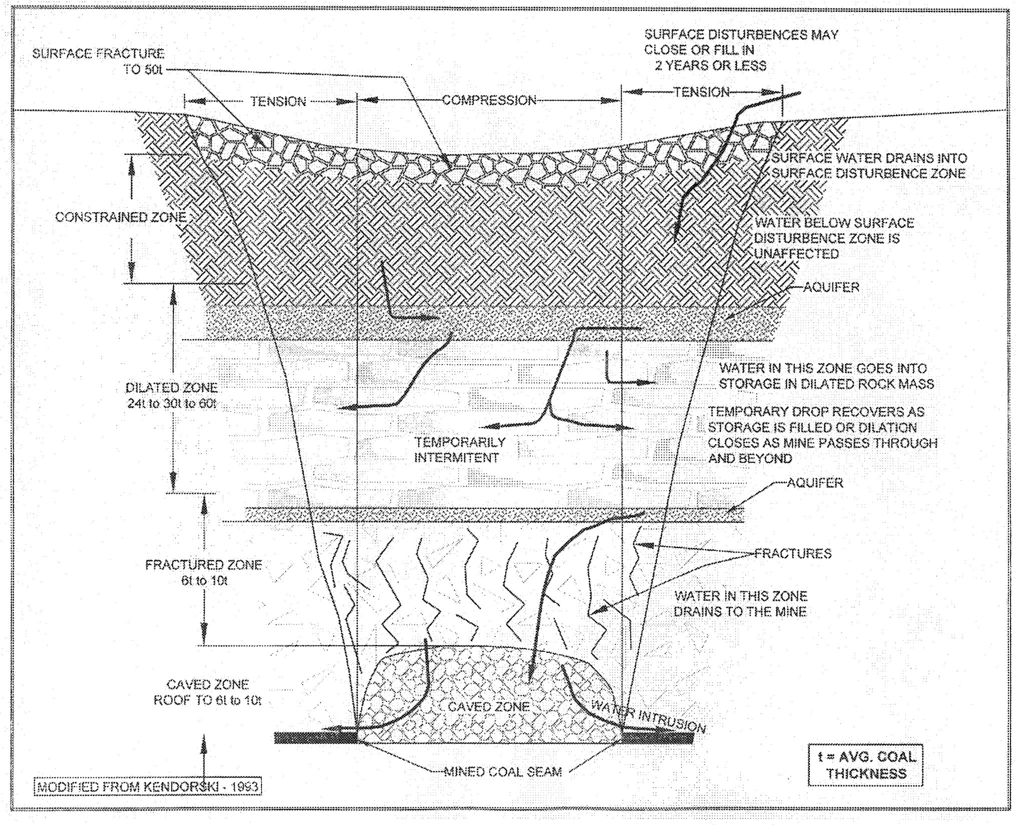


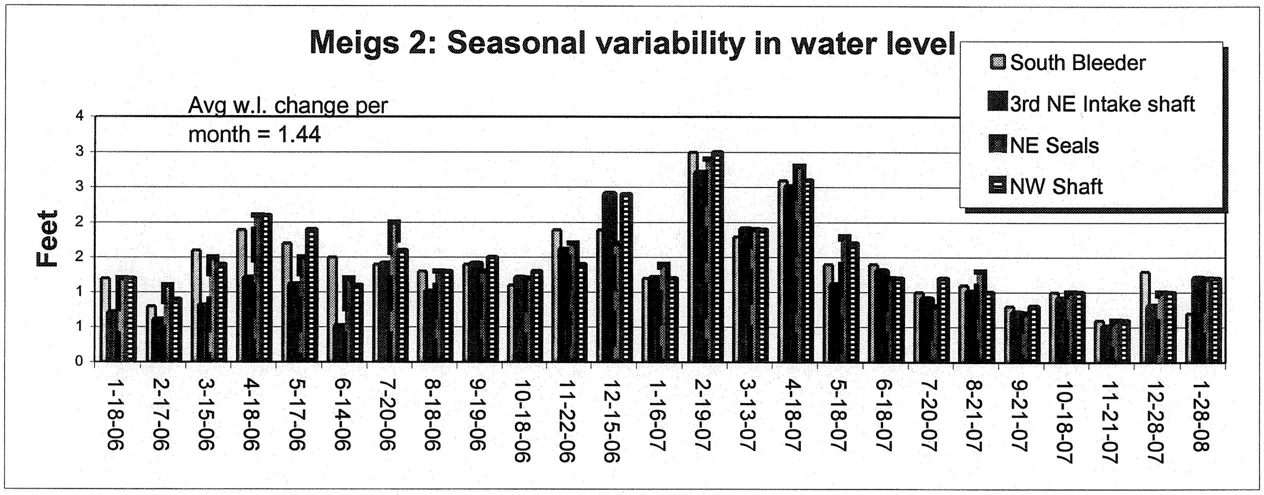
Figure 4. Longwall Subsidence Fracture Model

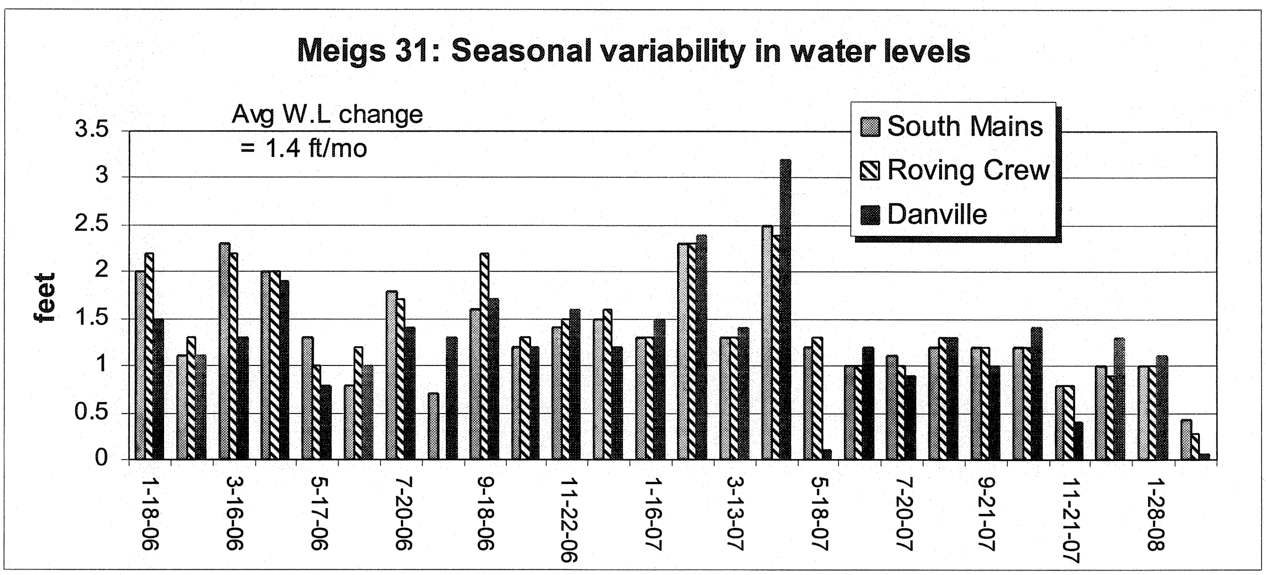
and Ferguson (1974) describe stress relief fractures in the Appalachians that extend to a depth of approximately 150 feet in valley bottoms and sides.

Mine Pool Characteristics

Mines are recharged by vertical infiltration, lateral inflow from adjacent flooded mines and from ground water in the coal itself. Seven mineshafts are accessible for pool level monitoring. The water sampling locations are the South Bleeder over Meigs 2 and the South Mains over Meigs 31. All shafts and monitoring locations are shown on the topographic maps. Recharge into the mines reflects the seasonal climatic precipitation as shown in Figure 5a and 5b. The graphs show a long-term trend of seasonal changes in mine water entering the mine pool. Due to the 1,350 foot barrier separating Meigs 2 from the Meigs 31 and Raccoon Mine complex, the Meigs 2 mine pool acts independently from the Raccoon and Meigs 31 mine pool. The Raccoon and Meigs 31 mines are hydrologically connected and therefore act in concert. Incremental differences in the fill rates from specific monitoring points are apparent.

Prior to pumping out of Meigs 2, the average monthly rate of change from Jan 2006 through January 2008 was 1.44 feet/month. The 3rd NE shaft was slightly slower at 1.2 ft/month. Meigs 31 also had an average monthly rate of change of ~ 1.4 ft/month prior to pumping from Meigs 2 into Meigs 31.





Figures 5a and 5b. Graphs showing the rate of mine pool flooding and seasonal variability

Recharge rate calculations

Different sections of the mine commonly have distinctly different recharge rates. Siplivy (2004) segregated eight recharge areas on the western side of the mine complex; primarily at the Meigs 2. These discrete inflow zones are defined as areas of the mine beneath a stream valley, areas with prominent lineaments, and areas with shallow cover ranging from 115 feet to 220 feet. Recharge rates were determined volumetrically for the Meigs 2 and for Meigs 31 (Raccoon, 1 and 3) sections. Siplivy based recharge rates on mine pool inflow volumes over a 322-day time period. After mining ceased, water levels were monitored in the mine pools. Volume and inflow rate were calculated using mine geometry parameters, in-mine elevations, type of mining, and areas of inundation and gob.

For Meigs 2, with a volume of 1,097,645,880 gallons, the inflow rate was estimated at 2367 gpm over 11,900 acres with a 75% coal recovery rate or 0.266 gpm/acre.

For Meigs 31, with a volume of 837,197,255 gallons, inflow rate was estimated at 1811 gpm over 11,600 acres with a 55% coal recovery rate or 0.284 gpm/acre.

Pumping mine pool to control pool elevation

If Meigs 2 were allowed to fill up, the pool would inundate to the maximum coal elevation of 585 feet m.s.l.; beyond this elevation, recharge will continue to increase the piezometric head of the mine pool above the actual elevation of the coal. As the pool rises to connect with the near-surface water table, a discharge (break-out) would occur at a topographic low at approximately 640 feet m.s.l. in Sisson Run in the northeast corner of Meigs 2. Two class V injection wells will pump water from Meigs 2 into Meigs 31 in order to maintain a safe pool or control elevation of approximately 560 feet m.s.l. With the mine pool held at or below this elevation, a built-in storage capacity will prevent an uncontrolled break-out should the pumps shutdown and/or the treatment system require maintenance. With the water held at or near 560 feet m.s.l., the mine will be 83% flooded (See Figure 6a. Meigs 2 cross-section). As of August 8, 2008, the NE section pool elevation was 568 ft msl; eight feet over the control elevation. This section of the mine pool has continued to act independently from the larger body of the Meigs 2 pool. CONSOL began pumping water out of Meigs 2 into Meigs 31on January 28, 2008 to reverse the rising water level in Meigs 2 and also to control the NE section whose level had surpassed the control elevation.

Similarly for the Meigs Mine 31 complex, the maximum coal elevation is 611 feet m.s.l. on the western side near Raccoon Creek. The Raccoon Mine portal elevation is 630 feet m.s.l. If left uncontrolled, break-out would eventually discharge into the lowest valleys along Raccoon Creek, Parker Run and Malloons Creek at approximately 600 feet m.s.l. The lowest surface elevation over the Raccoon Mine is a tributary to Strongs Run at 640 feet m.s.l. CONSOL would maintain the control pool elevation at 460 feet m.s.l. At this elevation the mine pool would be 64% flooded.

The cross sections in Figures 6a and 6b show the elevation of the coal seam, the estimated maximum pool elevation, and the control elevation for each mine. The location where the coal seam and control elevation cross is known as the "beach area," indicating the percentages of flooding for each pool. Meigs 2 and 31 maps show the surface location of the cross section profile.

Flooding conditions of the Meigs 2 mine pool

Figures 7a and 7b show pool elevation through time representing distinct segments of the mine. The NE Seals and the NW shaft merged with the South Bleeder shaft by early 2005. These two sections now act as one pool evidenced by the identical water levels.

The pool monitored from the 3rd NE Intake shaft remained completely isolated from the rest of the flooded sections on Meigs 2 until August 2004, when the pool elevation rose to a coal elevation of 530 ft m.s.l. which is a topographic high point in-between Meigs 2 and the 3rd NE section.

Upon reaching the coal elevation the water then spilled over into the rest of Meigs 2 through the entry west of the 3rd NE intake shaft. The water levels appeared to be converging until about October 2006 after which time the elevation trends appear to be parallel. The 3rd NE Intake shaft shows water rising at a rate equal to or slightly slower than the rest of Meigs 2 although the elevation of the pool is higher.

Figure 6a Meigs Mine 2 cross section A – A'

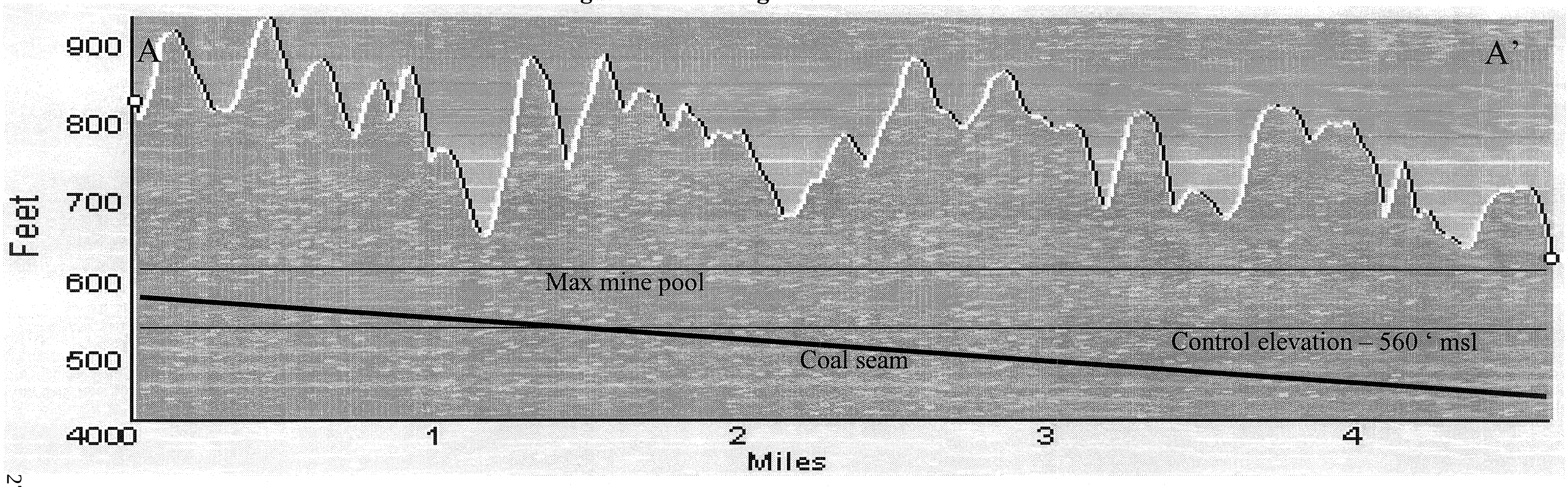
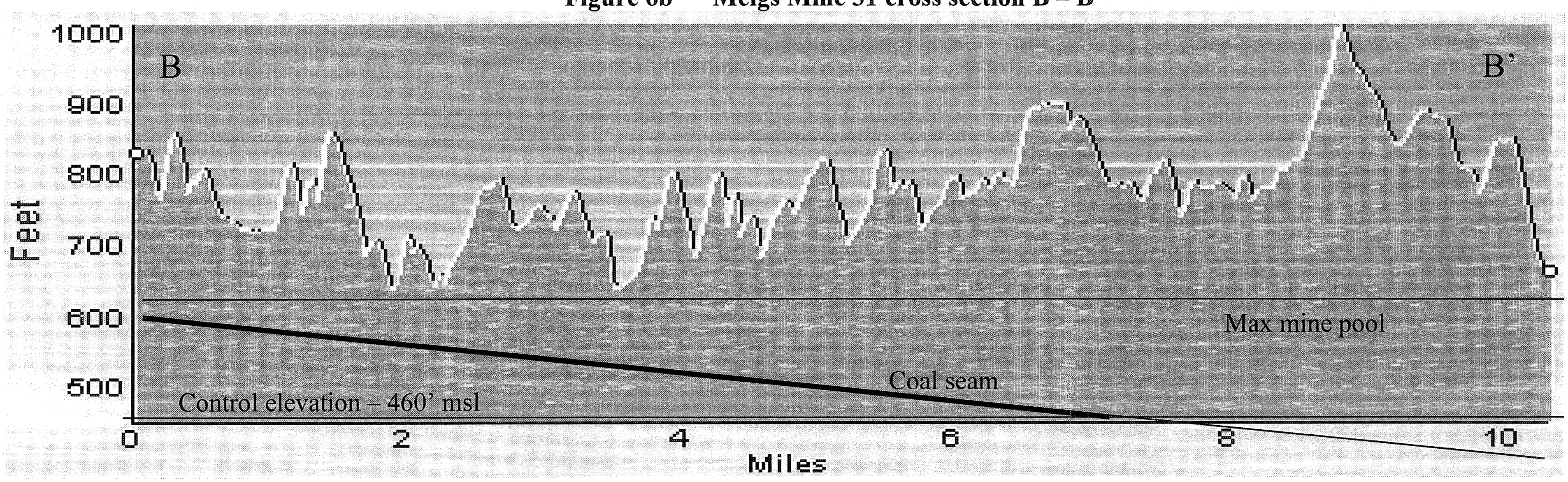


Figure 6b Meigs Mine 31 cross section B – B'



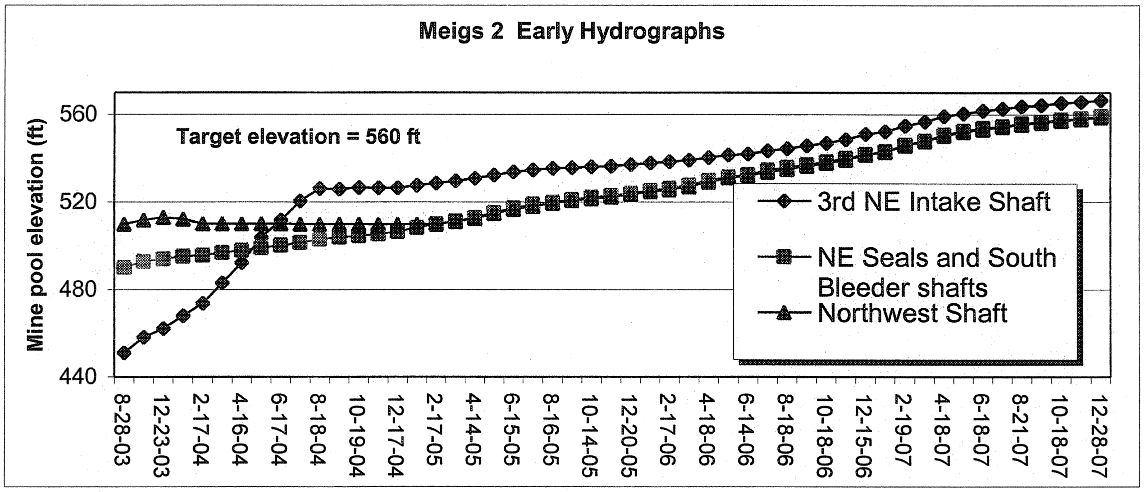


Figure 7a: early flooding conditions

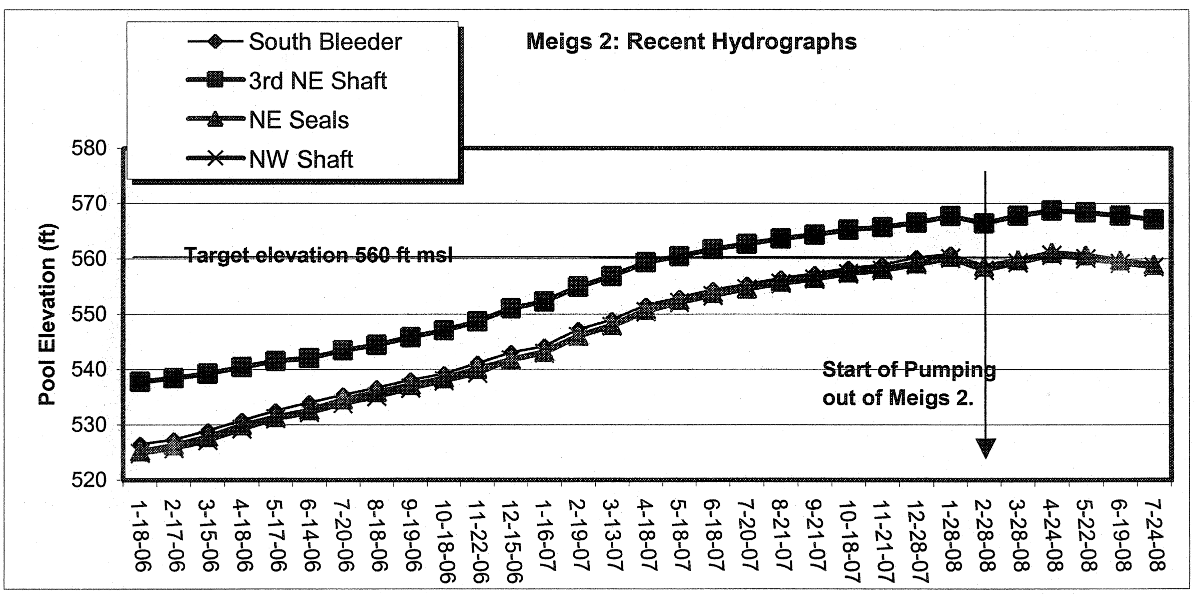


Figure 7b: recent flooding conditions

Figure 7b shows that the 3rd NE section has not converged with the rest of the mine pool. This section of the mine pool maintains a consistent hydrologic head signaling that it may be hydrologically separate from the rest of Meigs 2. However, when Meigs 2 began pumping water from the South Bleeder shaft into Meigs 31 on January 28, 2008 an immediate response was observed at rates of 3000 gpm. The South Bleeder shaft is a little less than six miles from the 3rd NE shaft thus indicating permeable conditions in the mine pool and between the mine pool and the 3rd NE shaft. The Meigs 2 mine pool had exceeded its control elevation in the NE section of the mine and was about 40 feet from topographically low elevations in stream valleys. Near surface aquifers may already have been affected. Most resident's water supplies were replaced with centralized piped water systems after the longwall had impacted private water wells. The NE section of the mine, while still elevated above the rest of the mine pool did exhibit an immediate response to the pumping of the mine pool. As stated earlier, pumping occurs at the most southern part of the Meigs 2 pool from the South Bleeder Shaft.

Graph 7b and 7c show the effect of lowering the Meigs 2 mine pool by pumping from Meigs 2 into Meigs 31. The subsequent increase rate of rise in Meigs 31 is shown in graph 8b. Meigs 2 was experiencing a seasonal decline when pumping from the mine pool began. As pumping began, the rate declined as shown in the graphs for Meigs 2.

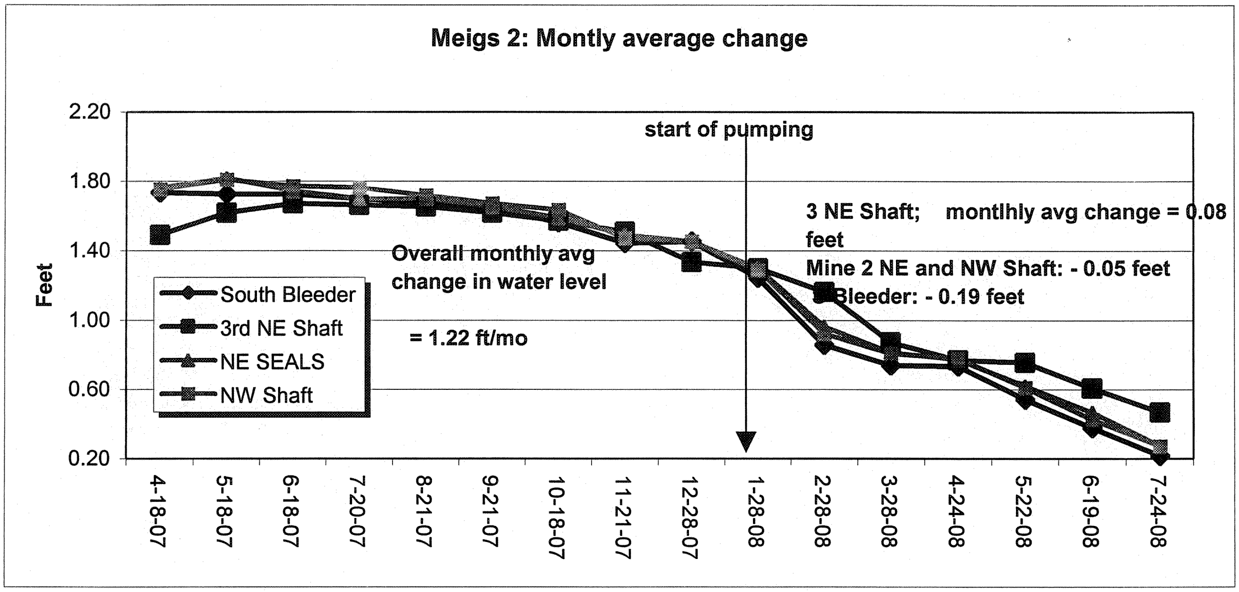


Figure 7c: Effect of pumping on water level in Meigs 2

The South Bleeder shaft shows the largest change in water level as this is where the pumps are located.

Flooding conditions of the Meigs 31 pool

Figures 8a, 8b, and 8c show early and recent flooding conditions for the Meigs 31 mine pool. All three monitoring points show that water levels converged throughout the Meigs 31 mine by mid 2005. The Meigs 31 control elevation of 460 feet m.s.l. was reached in June of 2008. Meigs 31 pool elevation has increased since Jan 28, 2008 when the injectate water from Meigs 2 was first introduced into Meigs 31.

The monthly rate increased from an average 1.4 feet per month to an average 2.9 feet per month. At this rate, a trend analysis indicates the mine pool would reach inundation (~ 600 feet m.s.l.) by the end of 2012 if it were not pumped. Projections for inundation do not account for the change in porosity of the fractured substrata above the mine in or changes in precipitation due to protracted drought or above average rainfall. However, CONSOL anticipates pumping and treating the pool from Meigs 31 by November 2008, therefore, an uncontrolled break out should not become a concern.

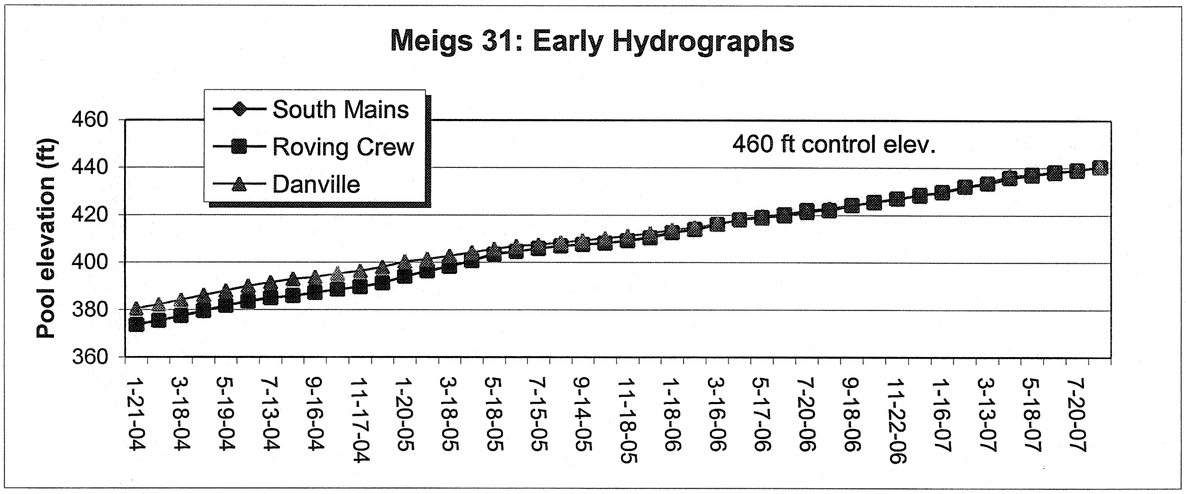


Figure 8a: Early flooding conditions of Meigs 31

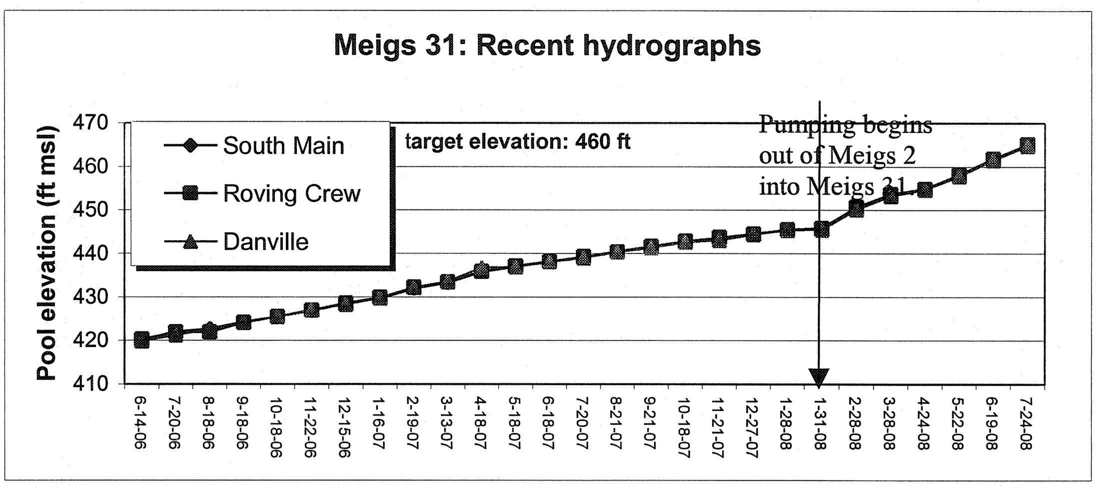


Figure 8b: Recent flooding conditions of Meigs 31

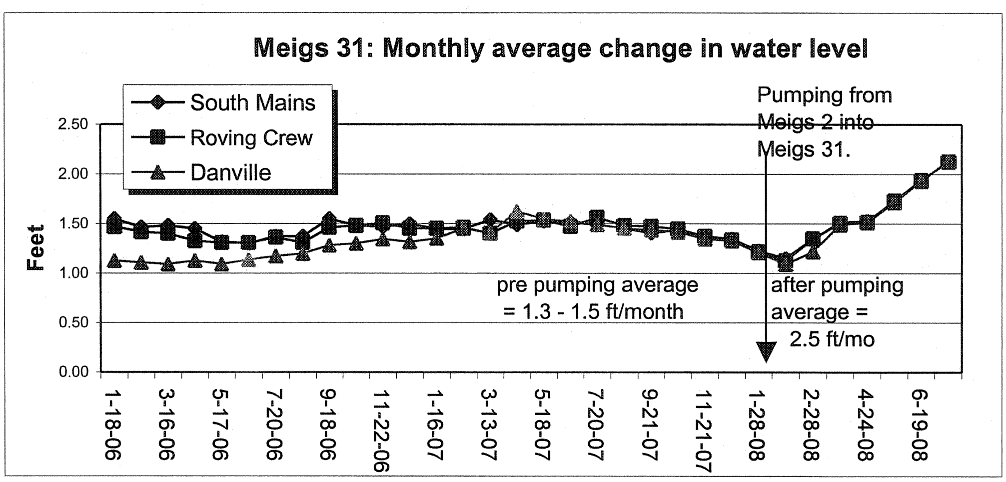


Figure 8c: Monthly average change in water level

Water Quality

During active mining operations, the mine is an ideal environment for pyrite oxidation. Exposed pyrite-rich rocks and coal are constantly ventilated by moist air that facilitates large-scale oxidation. As discussed above, the mine pool will require pumping to control the unchecked discharges. The first pumped water is the frequently of the worst quality because of the flush of concentrated soluble pyrite oxidation products (iron sulfate salts). It is anticipated based on experience with other below-drainage Appalachian mines that water quality will improve dramatically with time. There are several reasons for this improvement.

- Pyrite oxidation ceases in the flooded sections (Watzlaf, 1992).
- After the initial flush, there are less readily available iron sulfates salts to dissolve.
- Alkaline strata in the roof rock in the mine pool will provide some neutralization to the water.
- Dilution and influx of alkalinity will occur from ground water inflows.
- The ground water flow path exhibits some short-circuiting. Areas of rapid transport or flow may exhibit better water quality than areas of restricted water movement.
- Geochemical reactions (e.g., sulfate reduction and cation exchange) can occur along the mine water flow path, thus improving the quality prior to discharge.

The northwest section of Meigs 2 should produce worse water quality due to the presence of pyritic roof rock and the absence of limestone. Limestone is present in the overburden in the southern portion of Meigs 2 and all of Meigs 31. When water first enters the mine, the quality tends to change as it flows slowly through the mine. It may get better or worse depending on where it enters, and the chemistry of the gob through which it flows. Given time, mine water tends to improve in quality as it slowly moves along the flow path. The longer the in-mine residence time, the more opportunity the mine water has to improve through geochemical processes, such as cation exchange and sulfate reduction. Mine water also stratifies with the worst water quality tending to be in the deeper sections.

Water quality from recently flooded deep mines is often more acidic with higher sulfate and metal concentrations than it was while the mine was in operation. A sample collected August 2005 (post-mining) from the South Bleeder shaft in Meigs 2 showed a pH of 6.2, TDS of 15,900 mg/L and iron of 2,700 mg/L. Meigs 31 sampled during the same time from South Mains shaft showed an average pH of 6.6, TDS of 5,106 mg/L, and iron of 90.2 mg/L (Moody and Assoc, Inc. 2006). Siplivy (2004) reported the following water quality. Water is drawn off from near the bottom of the pool.

Meigs Mines 2 and Mine 31 – Pool Water Quality from 2004

	PH	Acidity (Mg/L)	Alkalinity (Mg/L)	Iron (Mg/L)	SO4 (Mg/L)
Meigs No. 2	3 – 5	3000 – 5000	0 – 75	200 – 3000	> 5000
Meigs No. 31	6 – 7	5 – 100	200 – 400	100 – 200	1000 - 3000

The data show the Meigs 2 water quality is significantly worse than Meigs 31. The water in Meigs 31 owes it alkalinity and lower metals to the Vanport Limestone roof rock that is present in the southern part of Meigs 2 and all of the Meigs 31 complex.

Meigs Mines 2 and 31 - Average Pool Water Quality Since Pumping Began from 2008

	pH	Acidity (mg/L)	Alkalinity (mg/L)	Iron (mg/L)	Aluminum (mg/L)	Manganese (mg/L)	Arsenic (mg/L)	SO4 (mg/L)	TDS (mg/L)
Meigs 2	6.2	1021	351	1053	3.3	7.8	0.034	7635	11525
Meigs 31	6.18	912	332	855	0.925	9.1	0.01	6125	10150

Water quality shown in the table above represents water that has been pumped from Meigs 2 into Meigs 31 since the beginning of 2008, but not yet pumped out of Meigs 31. Therefore, Meigs 31 is concentrating all the water and, in a sense, treating in-situ. There appears to be an improvement in water quality out of the Meigs 2 mine. Water from the Meigs 2 pool now has less oxygen and has benefited from initial flushing of the oxidized metals and acidity. A preferential flow path may also benefit the water quality. There is an increase in alkalinity, with less acidity, and a lower iron concentration. The water in Meigs 31 has not yet been pumped, but that part of the mine complex is receiving the worst water from Meigs 2, so it is not unusual that the two waters are beginning to look similar. Pumping from Meigs 31 is planned for January 2009.

Projected future water quality

With pumping of both pools the water quality is expected to improve over time. To the degree that the mine pool does not fully flood, water will continue to become exposed to oxidized pyrite, thus continually yielding acidity and metals to the water in the mine pool.

Projections have been made concerning the long-term water quality from the mine pool complex. Findings from the Pittsburgh seam coal mines in Pennsylvania and West Virginia have demonstrated that for each mine pool volume pumped, there is a corresponding improvement in water quality of approximately 50 percent (CONSOL , personal communication – 2005). A more thorough mixing of mine pool water may result in rapid improvement, however mixing makes prediction more difficult. In addition, partially flooded mines will continue to yield acidity and metals into the mine pool resulting in long-term poor water quality.

Meigs Mine 2: Given the volume and inflow rate for Meigs 2, the average residence time of the mine water after pumping starts (pumping rate – 3100 gpm) is predicted to be approximately 5.2 years. With a 50% improvement with each turnover of the mine pool, it would take approximately 52 years for the iron level to achieve direct discharge standards (< 3.0 mg/L) (CEC, 2005). This projection is speculative due to the partially flooded nature of the mine pool and assumes the rate of iron concentration improvement remains constant. A less optimistic outcome is projected to reduce iron to 600 mg/L after 50 years. However, research by Donovan and others (2000) provides arguments for a more rapid recovery.

Meigs Mine 31: The projected maximum pumping rate for Meigs 31 is 5000 gpm. Given the mine pool volume and inflow rate for Meigs 31, CEC (2005) predicts that the average residence time of the mine water will be 6.6 years. At a 50% improvement rate with each turnover, the mine pool is projected to take 40 years to reach water quality discharge standards for iron. Considering the partially flooded mine pool and incomplete mixing, less optimistic predictions may result in an iron concentration of 35 mg/L after 22 years.

Possible future scenarios

Since mine closure, water is accumulating in the mines and is developing into a "mine pool". The development of these pools and its potential impact to both groundwater and surface water is of great concern for DMRM and CONSOL and has generated the need for permit revisions and modifications. The original permits issued were for operations that were already in existence. The original permits did not address mine pools, surface discharges, or the need for perpetual treatment. CONSOL will be required to create a trust or financial security from which funds can be perpetually used to pay for pump and treat operations. This option is a recent development after the promulgation of House Bill 443 in April of 2007. It allows CONSOL to create an alternative financial security from which the costs of treating underground mine drainage may be funded.

CONSOL will be required to maintain the mine pool at a safe elevation below low-lying valleys, adjacent abandoned underground mines, and near-surface groundwater. CONSOL states that the mine pools will be temporarily maintained by pumping and treating the excess pool water until such time that the mine pool water has improved to discharge without treatment. Specific time frames for this temporary period are varied and speculative. One prediction method gives approximately 52 years for this to occur at which time, through pumping and treating activities, a vast enhancement of the ground-water resources of Meigs and Vinton counties will have been achieved. Once pumping ceases, groundwater resources will be easily available and some streams will flow continually from the mine pool.

The worst scenario is one in which the pool will be perpetually pumped and treated. If pumping and treatment stops, water will freely discharge into streams in violation of state water quality standards contaminating portions of the Leading and Raccoon Creek watersheds and ground-water resources. The first mine water to discharge from Meigs 2 would occur in low-lying stream valleys such as tributaries to Sisson Run. Stream valleys underlain by vertical fractures from stress relief or from subsidence due to longwall mining may provide conduits in which mine water could easily rise to the surface. The first mine water to discharge from Meigs 31 would occur in low-lying stream valley such as Strongs Run at 640 feet m.s.l. and Raccoon Creek at 630 feet m.s.l. Earlier projections for inundation dates will be modified as new data become available and pumping goes into effect for both the Meigs 2 and Meigs 31 mine pools. Meigs 2 pool is currently being pumped into Meigs 31.

Throughout the Appalachian region, mine pools are flooding and resulting in unplanned discharges. Depending on the overburden rock type, the water quality of the discharge can be toxic or benign. Together, the coal industry and state regulatory authorities are addressing these mine pool issues and turning some potential disasters into success stories by turning mine pool water into a usable resource for commercial, aquaculture, and drinking water purposes (Donovan and Leavitt – 2004).

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Stream Mitigation and Ecological Function for Mined Watersheds

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West Virginia University
Division of Forestry and Natural Resources

Managing impacts of large scale surface mines in southern WV is a highly contentious issue. Large scale surface mining results in a complete rearrangement of headwater catchments, and in some cases 50-80% of a watershed's headwater streams are impacted. Recent court cases have questioned the effectiveness of off-site mitigation in replacing headwater functions lost during the mining and reclamation process.

I will present results of recent studies on the localized and watershed scale impacts of mining on aquatic resources in West Virginia. This research attempts to address four critical questions.

1-What ecological functions exist within reclaimed headwater catchments?

2-Are there measurable impacts to aquatic ecosystems downstream, and to what extent does mining interact with other stressors?

3-Are impacts from mining continuous or do they follow a threshold response?

4-Are there management approaches (protection, improved reclamation, off-site mitigation and restoration) that can be used to offset mining related impacts?

Our results indicate that reclaimed headwaters are highly altered but retain numerous important functions, including retention, processing, and downstream transport of organic matter. Nevertheless, negative impacts on water quality and aquatic communities are prevalent, and elevated total dissolved solid (TDS) concentrations may be the most difficult to manage. In many watersheds, mining interacts with other forms of human disturbance, especially residential development, to produce highly impaired conditions. Finally, impacts from mining follow a threshold response; therefore, it should be possible to identify levels of mining below which downstream impacts can be avoided.

In conclusion, effectively managing impacts from surface mining will require an approach that recognizes important ecosystem functions that are retained on reclaimed mines, avoids cumulative impacts from elevated TDS at the watershed scale, and uses strategic off-site mitigation to address complex sources of impairment in mined watersheds.

Methods for the Estimation of Mine Infiltration

Bruce Leavitt
Consulting Hydrogeologist

Abstract

Three existing methods of estimating groundwater inflow into mining operations are reviewed including their origins, methodologies, and limitations. These methods are: the Rule of Thumb method for surface mines; a method proposed by this author in 1996 for Pittsburgh seam underground mines; and a method proposed by McCoy in 2002 for primarily flooded underground mines.

Mine discharge and precipitation data from a Pittsburgh seam mine complex east of Burgettstown, Pennsylvania are used to generate an equation for the estimation of mine water availability under variable precipitation conditions. This equation is based on the percentage of precipitation that arrives at the mine discharge after providing for the re-saturation of the soil.

Two years of daily precipitation and stream flow data generated by the US Geological Survey in the Ballard Fork watershed near Madison, West Virginia were used to generate an infiltration rate for a surface mined site and an unmined site. The effect of mining is to increase the amount of water that infiltrates the mine and eventually discharges from the mine. This increase in available water may support or increase the length of perennial streams within the watershed, or it can be used as part of a stream mitigation program on the mine site.

Introduction

Mine infiltration estimates are frequently used to project the operational and post closure environmental consequences of mining. These consequences can include: changes in the rainfall, runoff, infiltration and evapotranspiration relationship; the rate of mine flooding; the post closure discharge rate; and the mine dewatering requirements. This list of needs is now expanding to include: the ability to project the amount of water available from an underground mine under varying rainfall conditions so that the water can be utilized for other industrial activities such as power plant cooling; and the ability to design intermittent and perennial streams as mitigation for stream segments lost to valley fills. Consequently, a more detailed understanding of mine infiltration is needed to accommodate the greater demands that are being placed on this parameter.

This paper reviews the genesis of the methods of infiltration estimation that are currently in use, evaluates the strength and weaknesses of these methods, and proposes a method which will allow estimation of mine water discharge given variations in the amount of annual precipitation.

Rule of Thumb Method

Prior to 1986 a number of researcher's (Parizek, 1970; Ackenheil & Associates, 1977; Sgambat et al., 1980) have calculated the amount of water that has been produced by mining activity and have converted these data into average recharge data based on the mined area. In 1986, Richard diPretoro completed his Master's Thesis (diPretoro, 1986) on the Premining Prediction of Acid

Potential for Surface Coal Mines in Northern West Virginia. This study looked at 75 surface coal mines in Monongalia and Preston Counties and included reclaimed surface mining operations in the Waynesburg (n=14), Upper (n=31) and Lower Freeport, and the Upper, Middle, and Lower Kittanning coals. Mining of the Pittsburgh seam was excluded because of the prevalence of associated underground mining. Flow and water quality data are based on a single site visit. Mine discharges were observed at least three days after a precipitation event to eliminate the effects of precipitation on the flow rate. The quantity of water flowing from the discharges was measured using a bucket and stopwatch method if the flows could be captured from a culvert. For all other flows, the flow rate was estimated visually to the nearest 10 gallon per minute amount. The author believed this to have an accuracy of ± 30 percent. Based on this analysis, the median flow rate was 0.5 gpm/acre. The range of observations was from 0.02 to 4.35 gpm/acre.

The 1986 diPretoro study is believed to be the source for the Rule of Thumb recharge value of 0.5 gpm/acre. This value has been widely used in permitting decisions for both surface and underground mines alike. This value is easily applied when evaluating proposed mining operations but is unlikely to provide an accurate representation of the actual mine infiltration. There are several reasons for this inaccuracy. The study relied on visual estimates of flow and not measured flow values. The study sites were only visited once which cannot provide a representative sampling of the seasonal variability in the site discharge characteristics. The range in drainage values contributing to the average value of 0.5 gpm/acre is 0.02 to 4.35 gpm/acre. And finally, there are no underground mines in the data set. Because of these problems, reliance on a Rule of Thumb estimate is in all likelihood wrong, particularly when applied to underground mines, or mines outside of the study area or study coal seams.

Leavitt (1997) Method

While working for CONSOL Energy in the 1990's, I realized that the Rule of Thumb infiltration value overestimated the amount of infiltration that was occurring in the Pittsburgh Coal Seam mines that the company operated in southwestern Pennsylvania and northern West Virginia. This overestimation was particularly apparent where the mines had greater overburden thickness in the center of the basin. At that time the Bailey Mine, a longwall operation, was producing less than $1/1000^{th}$ the amount of water predicted by the Rule of Thumb method.

Pumping data were gathered within the company for both longwall and room and pillar full extraction sections. The pumping data consisted of a flow rate derived from the pump operating curve, and pump operation time measured by hour meters attached to each pump. This is an improvement over visual estimation of flow, but it can still lack precision if the pump is worn or is being operated under valve restriction. In both cases, the pump curve flow rate would be greater than the actual pumping rate leading to a potential overestimation of mine discharge.

The area of influence of each pump was identified and the area was measured from the mine maps. These data were plotted against overburden thickness. The overburden thickness was determined by averaging the highest overburden thickness in the source area with the lowest overburden thickness in the source area. Consequently, if the source area included mining to the outcrop, the minimum overburden thickness is zero. This is a crude but easy to determine representation of overburden thickness. Because full extraction underground mines are believed to be highly connected to the near surface hydrology at overburden thicknesses less than 200 feet, a dummy data point was created at 0.50 gpm per acre at this depth based on the Rule of Thumb value. A regression analysis was performed on the data and the following equation was produced.

$$\text{gpm/acre} = 1.117e^{-0.0045H}$$

Where H, in feet, is the average of the maximum and minimum overburden thickness of the mine area being evaluated.

Several caveats must be placed on the use of this relationship. Because this equation is forced to pass through the point 200, 0.50, infiltration estimates at depths less than 200 feet are likely to be overestimated. The equation is based entirely on Pittsburgh seam geology. Consequently, application of this equation in other mine settings has not been verified. All of the mine recharge data used in generating this equation are from operating mines in which maximum vertical hydraulic gradient is achieved. Application of this equation in flooded mines which have a lower hydraulic gradient may yield an overestimation of discharge.

McCoy (2002) Method

In 2002, Kurt J. McCoy published his master thesis entitled "Estimation of Vertical Infiltration into Deep Pittsburgh Coal Mines of WV-PA: A Fluid Mass Balance Approach." In this work, discharge volumes from flooded Pittsburgh seam mines are compared to mine areas to yield infiltration rates expressed in meters per year. The term "meters per year" is a mathematical simplification of cubic meters of water per square meter of mine area per year. In this form, the infiltration rates reported by McCoy can be converted into the more common gallons per minute per acre.

Instead of evaluating overburden thickness directly, McCoy compared the observed infiltration rates to the percent of the mine that is deeper than a specified depth. Three depths were evaluated: A>90 meters (295 ft); A>150 meters (492 ft); and A>210 meters (689 ft). The most significant relationship was found when the mine infiltration rates were plotted against the percent of the mine area that is greater than 150 meters. Figure 1 is reproduced here from the McCoy thesis. Shallow mines which are seasonally influenced and mines which were gaining or loosing water through barrier pillar leakage are excluded from the analysis.

Because of the difference in methods used, a direct comparison between the Leavitt formula and the McCoy formula is difficult. The percent mine area greater than 150 meters is not directly convertible into average overburden thickness. However, 50 percent mine area deeper than 150 meters could be equivalent to an average overburden thickness of 150 meters. Figure 2 shows a plot of the Rule of Thumb method, the Leavitt equation and this point generated from the McCoy relationship.

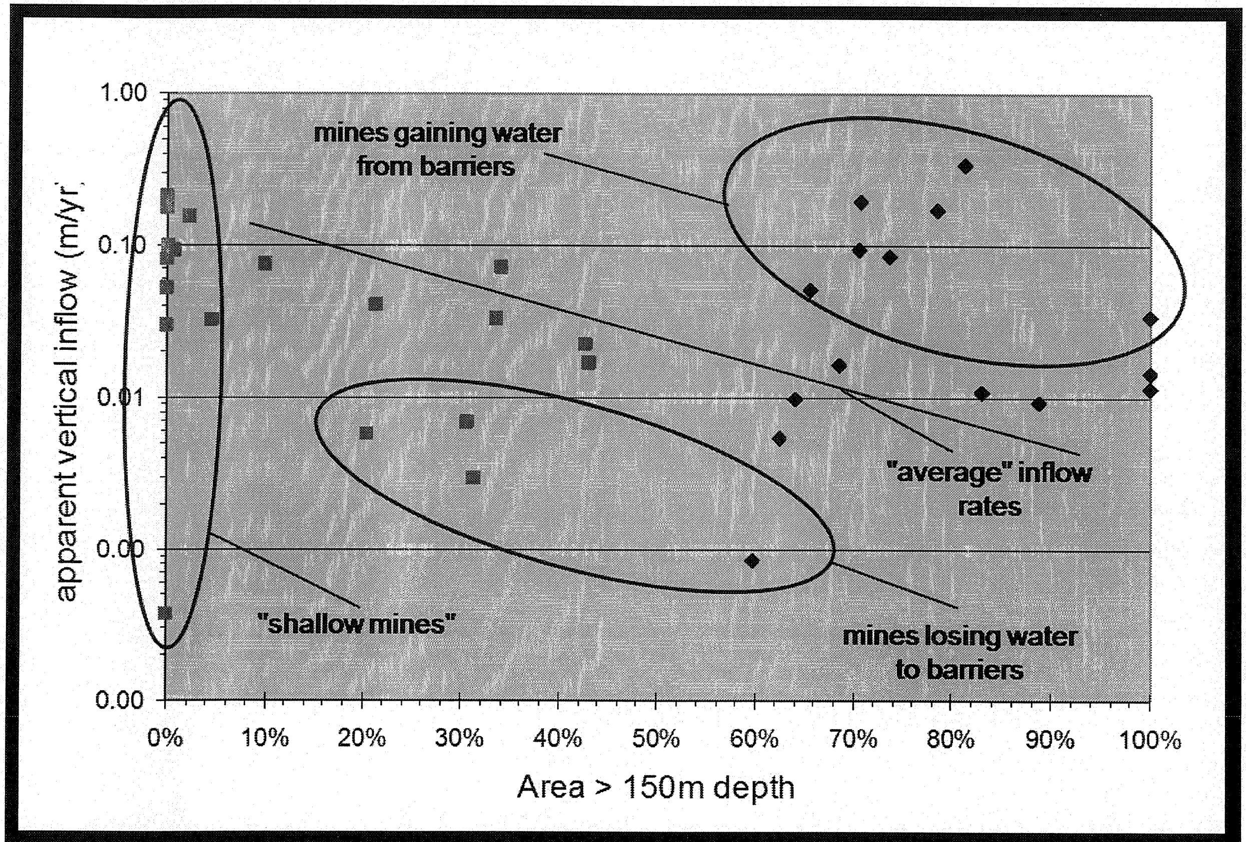

Figure 1. Apparent Vertical Infiltration after McCoy, 2002.

The plot of the McCoy data suggests an infiltration rate almost an order of magnitude lower than that projected by the Leavitt method. There are several possible explanations for this difference. McCoy included a wider selection of mines; the majority of the McCoy mines were flooded compared to unflooded in the Leavitt model; the McCoy mines had a lower percentage of longwall operations; a number of the McCoy mines have been closed for a long time, possibly allowing for healing of mining induced permeability; and the Leavitt model included a number of mines that are classified as "barrier gain dominated" in the McCoy study.

Projecting Mine Water Availability

Underground Mines

The future utilization of water from closed underground mines is dependent on the reliable projection of water availability from these mines. Water infiltration to individual underground mines is not only dependant on mine area, overburden thickness and geology, but also on variations in the annual precipitation. WVU is currently working on a project to evaluate the cost of using mine water for power plant cooling under a grant from the US Department of Energy. For a mine water supply to be useful for power plant cooling, or any other industrial purpose, the amount of water available from the mine must be sufficient in dry years as well as wet years. The following methodology is proposed for estimating mine discharge based on mine discharges records and statistical precipitation data.

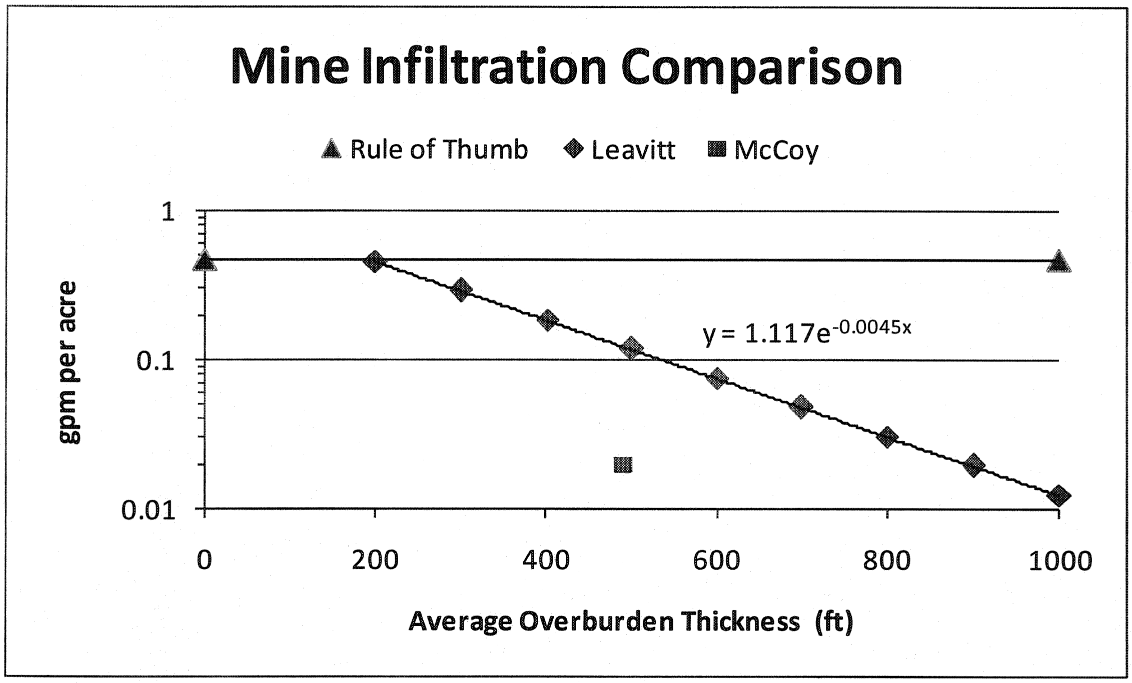

Figure 2. Comparison of mine infiltration methods.

Infiltration to underground coal mines is not uniform throughout the year. During the growing season plants take up water through their roots and transpire it into the atmosphere. Temperatures are higher so water is more readily evaporated. In addition, a portion of the rainfall is intercepted by the plants and is later evaporated without ever reaching the ground. As a result, there is very little deep infiltration during the growing season. At the end of the growing season the soil typically has very little moisture. Before deep infiltration can occur this soil must be re-saturated. Unfortunately, in the Pennsylvania / West Virginia area late fall and early winter are typically low precipitation months therefore the advent of recharge is delayed until enough rain has fallen to fully re-saturate the soil.

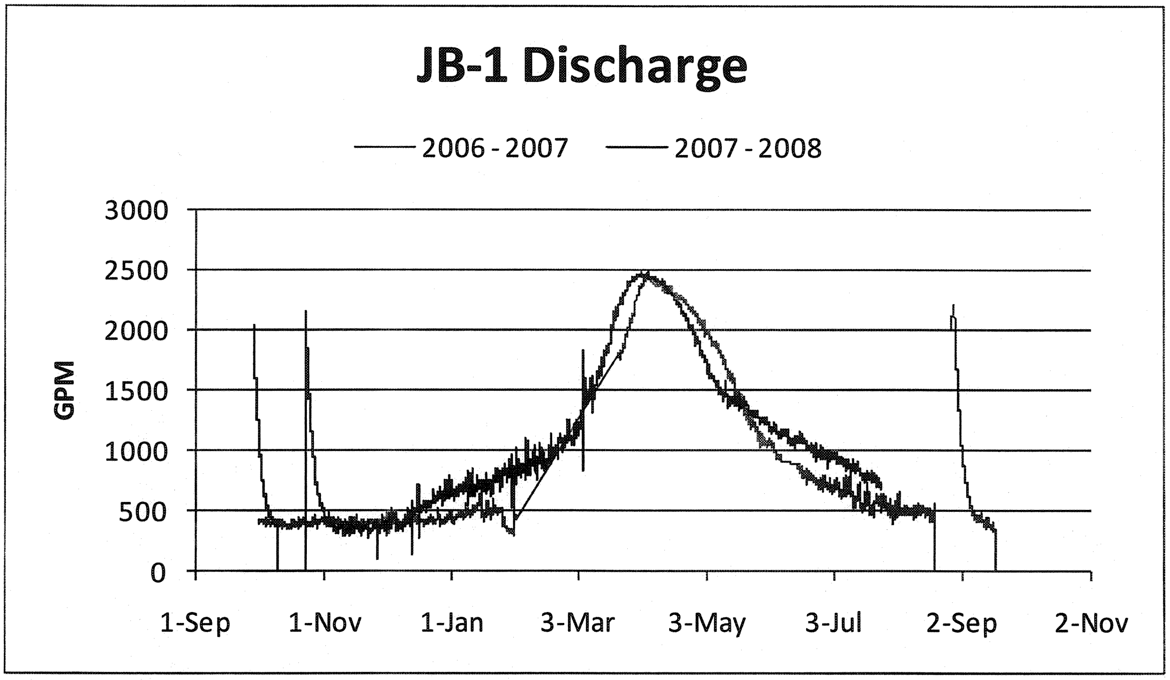

Figure 3. Two year hydrograph of the JB-1 discharge

Figure 3 is a hydrograph of the JB-1 discharge in northern Washington County, Pennsylvania. Mine discharge was initially measured using an H-flume and pressure transducer, but after construction of a passive system in April 2007 the flow was based on a pressure transducer and a rating curve. Note the similarity between the two years. The three spikes in flow, one in late 2006-2007 and two in early 2007-2008 were induced by shutting off the discharge for a period of time causing the water to build up in the mine. In the absence of this testing, the mine discharge would have been at base flow conditions. In the period February to April 2007, no flow data were collected due to the construction of a passive system at the site.

It is clear from the hydrographs that there is little to no summer recharge resulting from summer precipitation. If evapotranspiration limits recharge, then the end of evapotranspiration should mark the point in time when effective recharge is possible. Data from the "Soil Survey of Washington and Greene Counties Pennsylvania" show that a freeze of 28^{o}F occurs on or before October 1 every five out of ten years. For this analysis October 1 has been chosen to represent the beginning of negligible evapotranspiration and hence the beginning of the recharge period. The time between the beginning of the recharge period and the arrival of recharge in the mine represents the amount of water needed to re-saturate the soil. Travel time is believed to be negligible because the initial evidence of recharge would be due to the high conductivity flow paths. In the 2007-2008 water year, the increase in flow began on December 1, 2007. Rainfall records from the Greater Pittsburgh International Airport show that 6.68 inches of precipitation were received between October 1 and December 1. This represents the amount of rainfall needed for re-saturation. It is believed that an equivalent amount of water will eventually be lost once evapotranspiration resumes in the spring.

Groundwater recharge estimates generated by the US Geological Survey for Raccoon Creek, PA indicate that recharge reaches its maximum in March and is essentially over by the end of May. Combining the October 1 date and the May 31 date, there are eight months in which recharge to the mine is possible. The total amount of rainfall received between October 1 and May 31 minus the 6.68 inches needed to re-saturate the soil represents the maximum amount of water potentially available for recharge.

Using the hydrograph data it is possible to calculate the total volume of water emanating from a mine in the course of a year. This represents the total recharge for that mine plus or minus any water diversions within the mine. If the total annual mine discharge is divided by the total precipitation available for recharge then percentage of precipitation that becomes mine recharge can be determined. In the case of the JB-1 discharge that value is 27 percent.

Combining these terms leads to a mine recharge model for the JB-1 discharge in the following form:

$$\text{Recharge}_{\text{inches}} = (\Sigma\ \text{Precipitation}_{(\text{October} - \text{May})} - 6.68\ \text{inches}) * 0.27$$

Because this equation is based on precipitation, it is possible to use monthly rainfall probabilities generated by NOAA to determine the amount of mine water available in average years, and years with a one in ten recurrence interval.

While this equation is specific to the JB-1 discharge, the form of the equation can be applied at other locations where detailed mine discharge data are available and where the mine area can be reliably identified. The data requirements include one year of accurate daily flow and precipitation data. The length of the recharge season can be adapted to local conditions and the amount of water needed to re-saturate the soil can be identified based on the hydrograph response.

Surface Mines

Groundwater discharging from surface mine backfills may be used as a source of water for constructed stream segments that serve as stream mitigation. Estimating the amount and duration of these groundwater discharges is essential to achieving proper stream function in the created stream channel. Current practice would be to rely on the Rule of Thumb value of 0.50 gpm/acre as an estimate of the groundwater resource available from the backfill. This number is an annual average value and does not provide any information about flow duration. In addition, it is based on the visual estimation of flows from three coal seams in northern West Virginia. Since most of the valley fill mining operations that are likely to generate the need for stream mitigation are located in southern West Virginia, a recharge estimate for this area would be very useful.

In 2001 the US Geological Survey reported on precipitation and stream flow response in three watersheds near Madison, WV (Messinger, 2003; Messinger and Paybins, 2003). One watershed known as the unnamed tributary of Ballard Fork has been extensively surface mined. The second watershed is Spring Branch of Ballard Fork, which is unmined. The third watershed is Ballard Fork itself, which has a mixture of mined and unmined areas.

Precipitation was monitored in the study area at four locations between November 1999 and November 2001. Two of these sites were at mountaintop locations, and two were in valleys. Variations in precipitation were noted between the stations and the four daily station rainfall values were averaged to minimize the effect of this variation (Messinger and Paybins 2003).

Three stream gauging stations were established, one each in Spring Branch, Ballard Fork and the unnamed tributary of Ballard Fork. Daily flow data from these three USGS stream gauging stations were downloaded from the USGS web site.

The USGS stream flow data are a combination of direct surface runoff and ground water recharge. Since there is no surface runoff component in mine infiltration, it is necessary to remove this flow component from the data set. Evaluation of the data set showed that for precipitation events less than 0.50 inches per day there was no significant change in the observed stream flow. All precipitation events in the data set, where the one or two day total was 0.50 inches or greater, were identified. In order to remove the surface runoff component, the flow rate on the day preceding the precipitation event was transitioned linearly to the flow rate on the third day following the cessation of the precipitation event. In most cases this was three days. The longest transition was 13 days due to a precipitation event where the 0.50 inch per day criteria was meet eight out of ten days.

Three days is often considered to be sufficient to exclude the effects of surface runoff and some shallow ground water flow. However, a plot of these data in Figure 4 shows that there is still a significant amount of ground water flow to the stream that is in the form of interflow as opposed to deep ground water infiltration. In addition to three days, the same hydrograph smoothing technique was applied at four days and at six days. Both of the longer time periods reduced the flow spikes following the precipitation event. However, on one occasion, six day smoothing resulted in a flow value that was higher than the actual flow value for a period of one day. Consequently, six days may be the practical limit of this method.

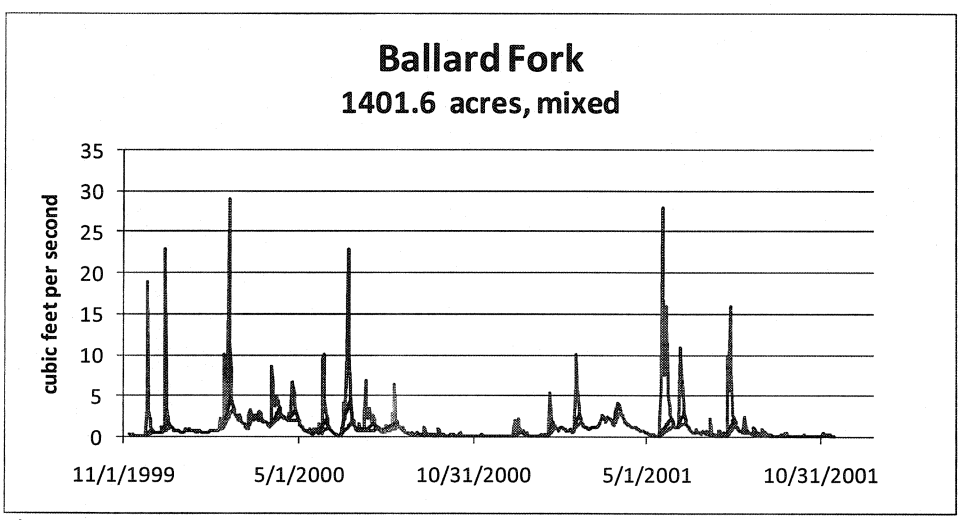

Figure 4a

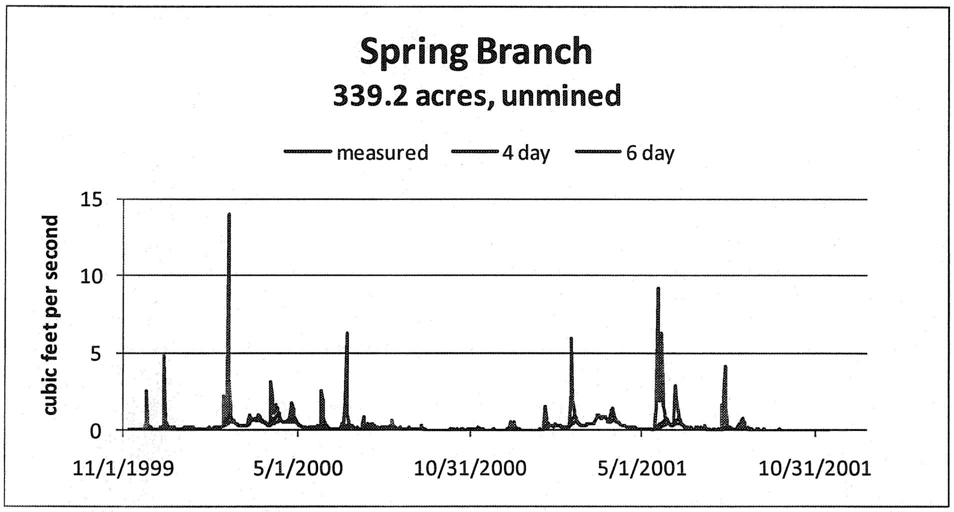

Figure 4b

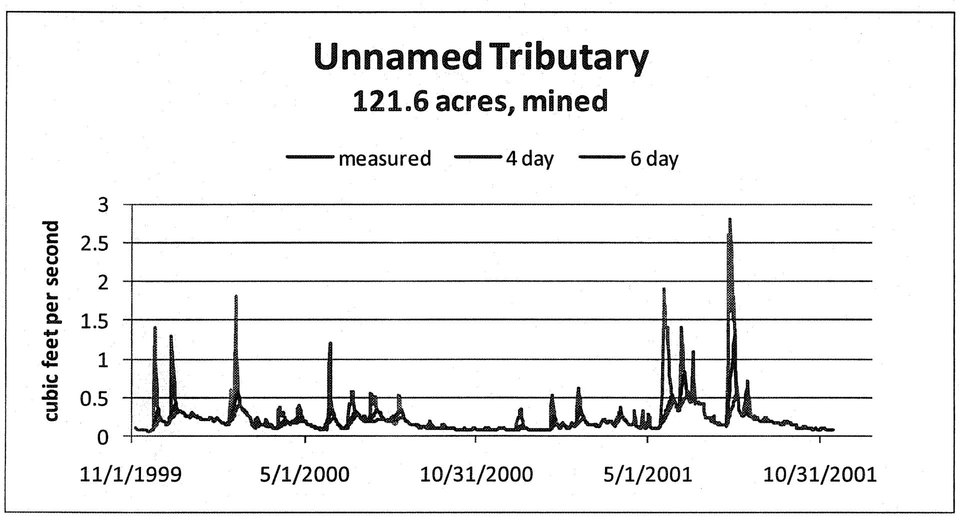

Figure 4c

Based on the precipitation and stream flow data, the annual recharge rate was calculated for these three watersheds. Table 1 and Figure 5 show these data.

Table 1

Average Annual Infiltration Rate in gpm / acre				
	W / runoff	3 - day	4 - day	6 - Day
Mined	0.93	0.84	0.75	0.67
Unmined	0.49	0.30	0.26	0.22
Mixed	0.51	0.33	0.30	0.26

Based on the annual average three-day stream flow value, the mined watershed has 2.8 times the available ground water resource than does the unmined Spring Branch watershed.

These data also allow a comparison of the low flow groundwater discharge rates in the mined and unmined watersheds. On November 15, 1999, Spring Branch had a flow of 0.07 cfs. This is equal to 0.093 gpm / acre. On the same day, the unnamed tributary had a flow of 0.09 cfs, which is equal to 0.332 gpm / acre. Under these low flow conditions, the groundwater discharge from the mined watershed is increased 357 percent over the unmined watershed.

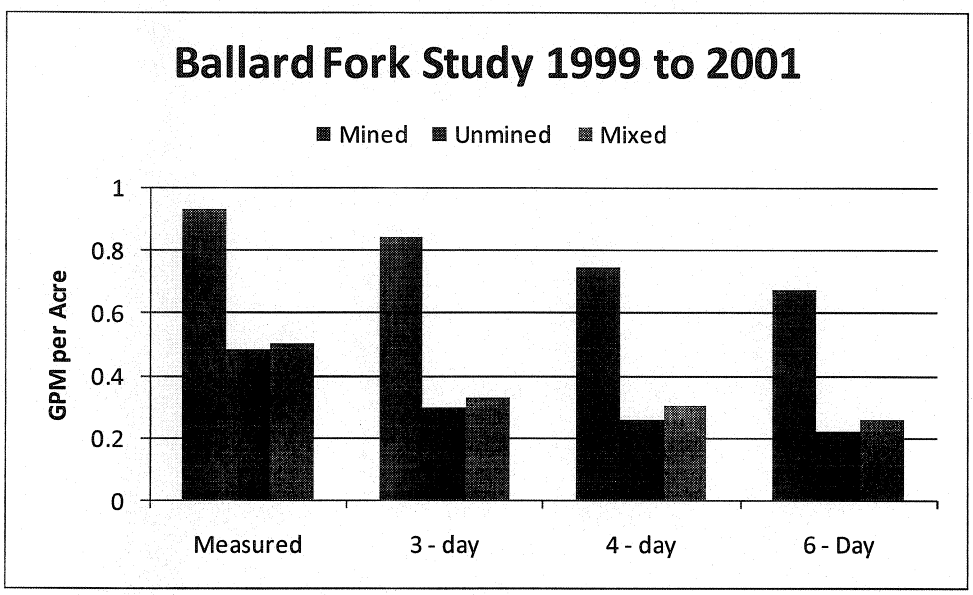

Figure 5. Watershed infiltration rate using three methods to eliminate the effects of runoff.

This increase in groundwater availability has the potential to move the point at which a stream becomes perennial upstream from its position prior to mining. Alternatively, this groundwater discharge from the mine spoil can be used to supply water to constructed stream segments for stream mitigation.

In order to project the amount of groundwater that might be available from a mine spoil aquifer, monthly rainfall was plotted against monthly groundwater discharge per acre. Figure 6 shows this relationship for the three-day data. The three-day data resulted in a regression curve with the highest R^2 value. The data set consists of 25 months of data in which there are three significant outliers. Two of these outliers are months of normal precipitation that were preceded by a month abnormally high precipitation. The third outlier occurred in February of 2000 and was preceded by a month of relatively low precipitation. The reason for this high discharge from such a low rainfall is unknown. Despite this variance, the rest of the data show a correlation between monthly precipitation and groundwater discharge. When the three outliers are removed the curve is lowered and R^2 value increases from 0.227 to 0.474. The resulting equation with the outliers removed is:

$$Q = 0.405e^{0.130P}$$

Where Q is the discharge rate in cubic feet per second, and P is the monthly precipitation in inches.

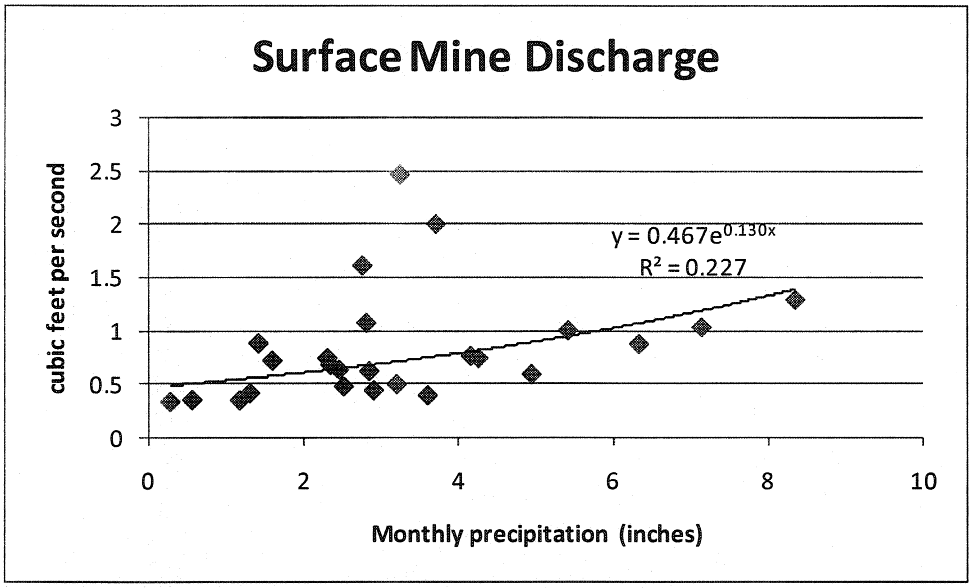

Figure 6. Mine spoil flow vs. monthly precipitation

Using this formula it is possible to substitute historical or statistical precipitation to determine how the spoil aquifer might react under normal to drought conditions. Due to the existence of the outliers, this relationship is not expected to hold under ongoing high precipitation conditions.

Conclusions

The Rule of Thumb method of determining mine infiltration is quick and easy, but it is only a rough approximation. The method is based on a single site visit to 57 mines using dubious methodology. When site specific or even region specific data are available, those data should be favored over the Rule of Thumb. The Rule of Thumb does not include data from locations other than Monongalia and Preston Counties in West Virginia, and even in those counties the Pittsburgh Seam is not included.

The formula presented by Leavitt in 1997 is specific to unflooded Pittsburgh seam mines in Pennsylvania and West Virginia and has not been validated at other locations and other coal seams. The estimate of overburden thickness is crude, relying on an average of the minimum and maximum overburden thickness.

The methodology presented by McCoy (2002) is predictive of infiltration to flooded mines in the Pittsburgh seam that are not receiving or losing water to adjacent mines. His method is based on the percent of the mine that is greater than 150 meters. However, the method has a minimum infiltration rate which may be exceeded by mines that are located under overburden deeper than 150 meters. This approach is not easily converted into the more common gallons per minute per acre value which is used within the industry. One point where conversion is possible suggests that infiltration to flooded mines may be significantly less than infiltration to unflooded mines.

Continuously recorded flow data from an underground mine complex in the Pittsburgh seam has provided a method for projecting mine water discharge under varied precipitation conditions.

The equation that is presented is site specific to this mine complex, but the form of the equation can be applied to other mines where sufficient data are available.

Data from the USGS Ballard Fork study allows a highly reliable estimate of infiltration to the surface mined watershed of 0.847 gpm / acre. Although this is only one site, it is located in a part of West Virginia that has not previously been included in the infiltration analysis. This infiltration rate is significantly higher than in a nearby unmined watershed.

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Restoring the Bennett Branch of the Sinnemahoning

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Since 2004, the Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation has been working with many partners to restore water quality and reclaim abandoned mines in the Bennett Branch of Sinnemahoning Creek. The primary water quality problems in the watershed are the result of uncontrolled and untreated discharges of acid mine drainage (AMD) from abandoned mine lands (AML) that have severely degraded the water quality in the lower 33 miles of the Bennett Branch and many of its tributaries. The primary mission of the Bennett Branch Restoration Project is to develop and implement a detailed mine drainage abatement and abandoned mine reclamation plan with a goal of restoring water quality in the main stem of the Bennett Branch, improving water quality in the AMD impacted tributaries, and maximizing the reclamation of AML throughout the watershed. The restoration work is being pursued in conjunction with the PA Wilds Initiative which advocates economic development and tourism throughout north-central Pennsylvania. Much work is currently underway or has been completed, and much work still needs to be done. This presentation will focus on the background of the Bennett Branch Restoration Project, the restoration efforts to date, and the work planned for the future.

SELENIUM MOBILITY IN COAL AND OVERBURDEN IN CENTRAL APPALACHIA[1]

R.R. Maggard[2]

Abstract: The occurrences of low levels of Selenium (<50 µg/l) are continuing to be the bane of both regulatory and industry in the southern coal fields of West Virginia. This issue was first brought to the attention of the industry as a result of data gathered as part of the Mountaintop Mining Environmental Impact Study in 2002. The current chronic water quality standard in West Virginia of 5 µg/l is considerably less than the values found downstream of some coal mining sites. As a result of these situations, the West Virginia Division of Mining and Reclamation implemented an extremely conservative geochemical sampling and analysis plan with an associated special materials handling plan under the auspices of guidance in January 2008. The author presented concerns about the exact path (mobility) in which the selenium actually becomes part of the water column in a paper presented at this same symposium in 2004. Since that time (5 years), the regulatory agencies have done little to develop a realistic sampling and analytical procedure to determine the actual path of how selenium becomes part of the water column.

Additional key words: Mountaintop Mining, Valley Fill, Geochemical Analysis, Total Sulfur, Pyritic Sulfur, Acid Base Accounting, Neutralization Potential, Potential Acidity, Paste pH, Selenium Mobility, Leaching Procedures

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[1] Paper presented at the 2008 Annual Meeting of the West Virginia Mine Drainage Task Force, Morgantown, WV March 31 – April 1, 2009

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INTRODUCTION

Typically more common contaminants like iron, manganese, and aluminum are more of a concern with coal mine discharges than substances like selenium. After the passage of SMRCA (Surface Mine Reclamation Control Act) the issues of acid mine drainage (AMD) became a primary concern and even led to the formation of the very task force hosting this symposium. A very dedicated and intelligent group of individuals representing practically all the stakeholders have since made great strides in developing methods to both predict, prevent and remediate typical AMD. But the methods to deal with selenium have taken a very different path.

First we did not simply require the analysis of iron for the entire geologic column and simply conclude that the "special handling" of all iron bearing strata would prevent the formation of AMD. The reason for that was simply we knew we would find iron in all of the samples. After careful studies and discussions it was determined that it was the pyritic iron that was most problematic, not all of the iron in the strata. So to develop a more realistic approach to selenium we need to take a different route.

OBJECTIVES

The purpose of this paper is to share the results of several studies to determine the actual mobility of selenium in the strata and which stratagraphic units may be problematic and need special attention. The focus of this analytical work is more concentrated on using the typical acid base analysis in conjunction with selenium analysis and several leaching techniques to better determine the potentially problematic strata in regard to selenium solubility.

METHODOLOGY FOR SELENIUM ANALYSIS

The solid samples (coals, overburdens) were composites collected using methods approved for coals and soils. The samples were prepared for analysis using SW-846 Method 3050B. This is an acid digestion involving nitric acid, hydrogen peroxide and the application of heat. After digestion, the resulting extract is then analyzed for selenium using method SD 7740. This method utilizes Graphite Furnace Atomic Absorption Spectroscopy. The minimum detection level for this procedure is 0.5 mg/kg. Some of the samples were re-analyzed using the Hydride AF method which is described in further detail in the appendix.

METHODOLOGY FOR SELENIUM LEACHABLITY

During previous studies and review of data, several trends were noted.

1. Selenium solubility and occurrences in mine discharges appear to be related to neutral to higher pH with water of moderate to high alkalinity.
2. Selenium has been known to be associated with sulfur in overburden and coal samples.

3. Occasionally, selenium detected in shale samples that exceed the 1 mg/kg established by the WVDEP for special handling do not contain detectable or contain very low levels of pyritic sulfur.

As a result of the above mentioned trends, several methods were developed to determine the circumstances which might facilitate maximum selenium leachability under somewhat natural conditions but in a reproducible and simple expedited procedure.

Procedures

First various samples of a core hole were chosen based on the varying combinations of conditions which exist in the various rock types:

1. Sample #5 was selected with barely detectable pyritic sulfur of 0.01 percent with a net neutralization potential of 4.24 and a paste pH of 7.6 and a selenium value of 2.19 mg/kg by the Hydride AF Procedure,
2. Sample #8 was selected with below detectable value of pyritic sulfur <0.01 percent with a net neutralization potential of 13.73 and a paste pH of 7.7 and a selenium value of 1.02 mg/kg by the Hydride AF Procedure right at the threshold of the WVDEP special handling criteria of 1 mg/kg.
3. Sample #14 was selected with a 0.07 value for pyritic sulfur with a net neutralization potential of 1.86 and a paste pH of 7.6 and a selenium value of 0.75 mg/kg which is below the WVDEP threshold and was analyzed by the Hydride AF Procedure,
4. Sample #12C was selected with a below detectable value of pyritic sulfur <0.01 percent with a net neutralization potential of 0.91 and a paste pH of 6.2 and a selenium value of 4.92 mg/kg. This sample was analyzed by the GFAA Procedure.
5. Sample #16C was selected with an easily detectable value of pyritic sulfur of 0.82 percent with a deficiency of neutralization of 36.74 and a paste pH of 3.4 and a selenium value of 9.46 mg/kg. This sample was analyzed by the GFAA Procedure.

Leaching Method Number One

During this procedure each of the samples were subjected to a one hour exposure to the leaching solution while shaken. The sample size was 2 grams with a 50 ml of leaching solution which ranged from a pH of 2.0 (adjusted H_2SO_4) to a pH of 10.0 (adjusted with CaO).

At the end of one hour of leaching, the resultant extract was measured for pH and analyzed for total selenium, aluminum, iron, manganese, calcium and magnesium.

As you can see by reviewing Table 1 all samples extracted measurable selenium from a low of about 4 µg/l to a high of about 82 µg/l. Some variabilities can be noted. Sample No. 5 had about the same levels as Sample No. 16C which had about 4 times the selenium in the solid sample. Also note that the maximum solubility seemed to occur around a pH of 9. The soluble iron remaining in the extract also seemed to play a role.

Leaching Method Number Two

This method was developed to determine the relationship between sample size and volume of extract.

During this procedure, Sample No. 14 was chosen because it had the lowest measurable value of selenium in the original solid sample (0.75 mg/kg). The sample sizes ranged from 0.5 grams to 50 ml of extract at a pH of 9 (which exhibited the highest numbers in the previous procedure) to 2 grams to 50 ml. We were also concerned about extracted solids contaminating the resultant extract so each run was duplicated using a 0.45 μm filter and a 0.20 μm filter to note any differences.

The values in the extract ranged from about 2 μg/l to a high of about 8 μg/l. The last runs of 2.0 grams to 50 ml with the same sample yielded between 7 and 8 μg/l in the extraction. As you can see in Figure No. 1 the values appear to be practically linear in regards to sample size and extract.

Prevention and Treatment

A last minute procedure was performed just prior to completing this paper which involved the addition of dried AMD sludge to various overburden and coal samples to determine if iron in the AMD sludge could prevent or reduce the mobility of selenium. This idea was proposed by Dr. P. Ziemkiewicz. The results appear promising, using the same leaching procedure previously described with a 10 percent addition of dried AMD sludge by weight reduced soluble selenium levels from 17 to 33 percent. This data is present in Figure 2.

Conclusions

The solubility and mobility of selenium as a result of various coal extraction methods can be highly variable depending on the geochemical characteristics of the parent source rock. The author feels that pyritic sulfur content is important and may play a role in inhibiting the solubility or mobility of selenium in the water column. Others (Lovett and Ziemkiewicz) have previously noted the effects of iron in the system to both be effective in the treatment and possible prevention of selenium being mobilized and discharged from coal extraction sites.

The author feels more efforts need to be made to better understand the mobility issue so more cost effective and practical methods of special handling can be developed and implemented.

Currently additional leaching studies are being conducted by the author to better understand the circumstances of selenium solubility and mobility and its prevention in the Southern Appalachia coalfields.

Acknowledgements

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Table 1. **Argus Energy Leach Study 0810K03**

mg/l

ABA Sample ID	Final pH	Selenium	Aluminum	Iron	Manganese	Calcium	Magnesium
#5, pH 2.0	2.18	0.0173	3.03	20.1	0.337	29.0	10.2
#5, pH 3.0	3.98	0.0181	0.185	2.26	<0.10	14.9	5.23
#5, pH 4.0	8.56	0.0175	<0.10	<0.10	<0.10	1.01	0.411
#5, pH 5.0	8.85	0.0192	<0.10	<0.10	<0.10	0.681	0.290
#5, pH 6.0	9.01	0.0196	<0.10	<0.10	<0.10	0.689	0.278
#5, pH 7.0	8.78	0.0201	<0.10	<0.10	<0.10	0.652	0.289
#5, pH 8.0	8.91	0.0212	<0.10	<0.10	<0.10	0.674	0.292
#5, pH 9.0	9.07	0.0225	<0.10	<0.10	<0.10	0.934	0.388
#5, pH 10.0	9.45	0.0204	<0.10	<0.10	<0.10	1.27	0.515
#8, pH 2.0	2.32	0.0056	6.29	124	5.9	63.9	17.1
#8, pH 3.0	5.32	0.0064	0.147	1.98	0.684	21.0	6.33
#8, pH 4.0	9.30	0.0067	<0.10	<0.10	<0.10	2.98	1.11
#8, pH 5.0	9.70	0.0076	<0.10	<0.10	<0.10	2.61	0.945
#8, pH 6.0	9.67	0.0076	<0.10	<0.10	<0.10	1.98	0.734
#8, pH 7.0	9.73	0.0069	<0.10	<0.10	<0.10	1.73	0.596
#8, pH 8.0	9.59	0.0081	<0.10	<0.10	<0.10	1.76	0.621
#8, pH 9.0	9.50	0.0090	<0.10	<0.10	<0.10	3.25	1.13
#8, pH 10.0	10.0	0.0086	<0.10	<0.10	<0.10	2.18	0.727
#14, pH 2.0	2.01	0.0055	6.66	43.4	0.699	20.9	8.48
#14, pH 3.0	3.74	0.0042	0.320	10.2	0.123	14.2	5.57
#14, pH 4.0	7.30	0.0059	<0.10	<0.10	<0.10	0.990	0.459
#14, pH 5.0	8.37	0.0063	<0.10	<0.10	<0.10	0.655	0.306
#14, pH 6.0	8.48	0.0066	<0.10	<0.10	<0.10	1.04	0.46
#14, pH 7.0	8.45	0.0068	<0.10	<0.10	<0.10	0.707	0.331
#14, pH 8.0	8.45	0.0071	<0.10	<0.10	<0.10	0.789	0.337
#14, pH 9.0	8.71	0.0072	<0.10	<0.10	<0.10	1.14	0.482
#14, pH 10.0	9.34	0.0070	<0.10	<0.10	<0.10	1.21	0.490
#12C, pH 2.0	2.01	0.0241	0.346	3.26	<0.10	3.85	1.08
#12C, pH 3.0	3.04	0.0189	<0.10	1.62	<0.10	3.13	0.889
#12C, pH 4.0	4.60	0.0136	<0.10	0.285	<0.10	1.69	0.553
#12C, pH 5.0	5.03	0.0136	<0.10	<0.10	<0.10	1.34	0.440
#12C, pH 6.0	5.24	0.0136	<0.10	<0.10	<0.10	1.23	0.405
#12C, pH 7.0	5.04	0.0141	<0.10	<0.10	<0.10	1.62	0.509
#12C, pH 8.0	5.23	0.0136	<0.10	<0.10	<0.10	1.57	0.416
#12C, pH 9.0	5.91	0.0155	<0.10	<0.10	<0.10	1.68	0.436
#12C, pH 10.0	6.54	0.0140	<0.10	<0.10	<0.10	2.63	0.547
#16C, pH 2.0	1.99	0.0818	2.65	95.7	<0.10	2.32	0.691
#16C, pH 3.0	2.93	0.0390	2.27	85.7	<0.10	2.20	0.641
#16C, pH 4.0	3.35	0.0262	2.31	85.8	<0.10	2.27	0.672
#16C, pH 5.0	3.38	0.0270	2.27	83.9	<0.10	2.23	0.659
#16C, pH 6.0	3.32	0.0267	2.24	82.0	<0.10	2.30	0.653
#16C, pH 7.0	3.37	0.0274	2.25	81.9	<0.10	2.42	0.651
#16C, pH 8.0	3.38	0.0263	2.27	82.8	<0.10	2.61	0.669
#16C, pH 9.0	3.40	0.0129	2.17	78.5	<0.10	3.19	0.646
#16C, pH 10.0	3.41	0.0251	2.26	82.5	<0.10	4.46	0.705
Blank, pH 2.0	-	<0.0002	<0.10	<0.10	<0.10	<0.10	<0.10
Blank, pH 3.0	-	<0.0002	<0.10	<0.10	<0.10	<0.10	<0.10
Blank, pH 4.0	-	<0.0002	<0.10	<0.10	<0.10	<0.10	<0.10
Blank, pH 5.0	-	<0.0002	<0.10	<0.10	<0.10	<0.10	<0.10
Blank, pH 6.0	-	<0.0002	<0.10	<0.10	<0.10	<0.10	<0.10
Blank, pH 7.0	-	<0.0002	<0.10	<0.10	<0.10	0.202	<0.10
Blank, pH 8.0	-	<0.0002	<0.10	<0.10	<0.10	0.363	<0.10
Blank, pH 9.0	-	<0.0002	<0.10	0.123	<0.10	1.09	<0.10
Blank, pH 10.0	-	<0.0002	<0.10	<0.10	<0.10	2.29	<0.10

Se analyzed on 11-11-08 by method SW7742
Other metals analyzed 11-7-08 by method SW6010B,
Extraction solutions prepared using H2SO4 and hydrated lime.
Samples extracted for 1 hour and then filtered through 0.45 um filter.
Extraction ratio: 2 g sample / 50 mL extractant

Table 2. **Extractable Selenium Study**

Sample ID	Extractant pH	Sample to Extractant Ratio	Filter Size (um)	Selenium Concentration mg/L
Blank	9	NA	0.45	0.0002
Blank	9	NA	0.20	<0.0002
14	9	0.5 g to 50 mL	0.45	0.0024
14	9	0.5 g to 50 mL	0.20	0.0023
14	9	1.0 g to 50 mL	0.45	0.0044
14	9	1.0 g to 50 mL	0.20	0.0044
14	9	2.0 g to 50 mL	0.45	0.0083
14	9	2.0 g to 50 mL	0.20	0.0079

Se analyzed on 12-16-08 by method SW7742
Extractant solution prepared using hydrated lime.
Samples extracted by tumbling for 1 hour.

Figure 1,

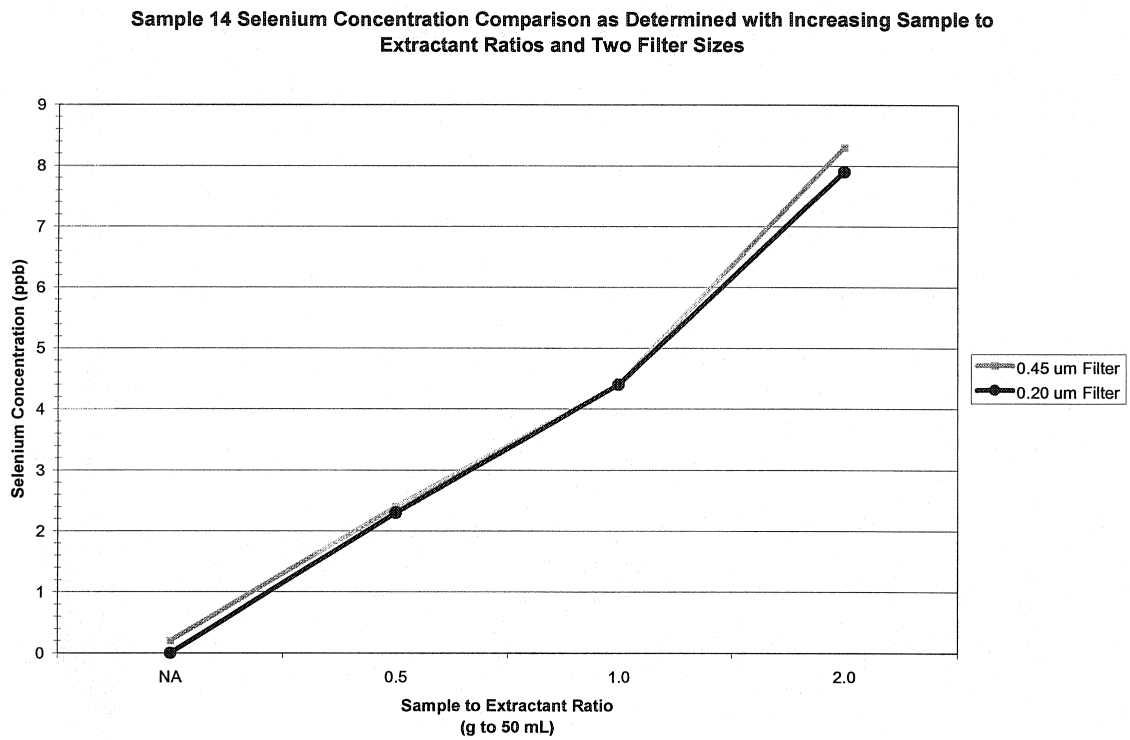
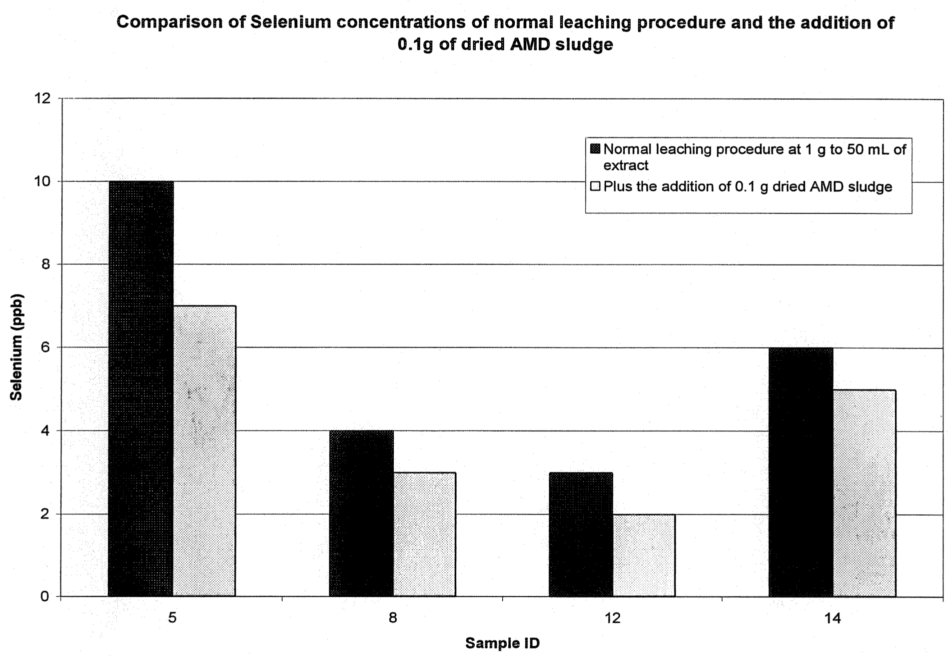


Figure 2



GFAA vs Hydride AF

GFAA (Graphite Furnace Atomic Absorption spectroscopy) is one of a few analytical techniques that is utilized to analyze for metals, such as selenium, in a variety of sample types. This instrumentation for this method utilizes an electrically heated graphite tube furnace to provide the atomization energy required for absorbance based measurements. This technique generally provides relatively low reporting capability for a variety of sample types. Analytical bias, both positive and negative, can be an issue, particularly for complex matrices. Prior to analysis, samples must be subjected to an appropriate digestion, typically involving the use of nitric acid and, for some samples, hydrogen peroxide.

Another technique for measuring selenium in a variety of sample types is hydride generation atomic fluorescence (HGAF). This technique is very similar to method SW7742 (hydride generation atomic absorption) with the minor exception that a fluorescence detector is used in place of an absorbance based detector. Just as with the GFAA technique, samples must first be digested before the instrumental based quantifying analysis can take place. This digestion usually takes place in two steps; the first step involves a typical nitric acid digestion designed to solubilize selenium. The second step requires heat and high concentrations of hydrochloric acid in order to convert (reduce) all selenium to the Se+4 oxidation state. Selenium in this state is then measured and quantified by the HGAF technique. This method provides very low reporting capability for selenium and is relatively robust in handling and overcoming matrix interferences which can cause analytical bias in many types of environmental samples.

It has been REIC's experience that the HGAF technique provides superior low level reporting capability for selenium and is generally more robust at handling the complex matrices encountered in mining related samples.

Argus Energy WV, LLC

Acid-Base Account ~

Site: Core ARG-WV-05-50
Date: December 18, 2005
REIC Job #: 0512292

Calcium Carbonate Equivalent in Tons/1000Tons of Material

SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	COLOR	REACTION with HCL	% SULFUR * = Pyritic	POTENTIAL ACIDITY	NEUTRALIZATION POTENTIAL	NET NEUTRALIZER DEFICIENCY	NET NEUTRALIZER EXCESS	PASTE pH	GFAA 1st Run SELENIUM (mg/kg)	GFAA 2nd Run SELENIUM (mg/kg)	GFAA 3rd Run SELENIUM (mg/kg)	Hydride 4th Run SELENIUM (mg/kg)	GFAA Average SELENIUM (mg/kg)
-	0.00-23.00	23.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	23.00-26.00	3.00	MS	10YR7/6	0	<0.01	0.31	19.09		18.78	7.3	0.68	0.30	0.36	1.05	0.45
2	26.00-29.00	3.00	SH	10YR7/1	0	<0.01	0.31	16.57		16.26	7.7	0.72	0.42	0.70	0.95	0.61
3	29.00-32.00	3.00	SH	10YR7/1	0	<0.01	0.31	13.39		13.08	7.8	1.06	0.84	0.98	1.55	0.96
4	32.00-35.00	3.00	SH	10YR7/1	0	<0.01	0.31	6.62		6.31	7.7	1.26	1.42	1.48	2.59	1.39
5	35.00-38.00	3.00	SH	10YR7/1	0	0.01	0.31	4.55		4.24	7.6	0.90	1.82	2.24	2.19	1.65
6	38.00-41.00	3.00	SH	10YR7/1	0	<0.01	0.31	14.17		13.86	7.6	1.06	0.48	0.46	0.71	0.67
7	41.00-44.00	3.00	SH	10YR7/1	0	0.01	0.31	13.51		13.20	7.7	1.12	0.44	0.78	0.96	0.78
8	44.00-47.00	3.00	SH	10YR7/1	0	<0.01	0.31	14.04		13.73	7.7	1.02	0.46	0.86	1.02	0.78
9	47.00-50.00	3.00	SH	10YR7/1	0	0.04	1.25	13.94		12.69	7.6	0.84	0.24	0.36	0.45	0.48
10	50.00-53.00	3.00	SH	10YR7/1	0	0.05	1.56	14.80		13.24	7.7	0.78	0.58	0.74	1.16	0.70
11	53.00-56.00	3.00	SH	10YR7/2	0	0.09	2.81	6.47		3.66	7.7	0.84	0.60	0.84	1.55	0.76
12	56.00-59.00	3.00	SH	10YR7/1	0	0.21	6.56	13.56		7.00	7.7	1.58	0.80	0.76	1.32	1.05
13	59.0062.00	3.00	SH	10YR7/1	0	0.30	9.38	9.15	0.23		7.4	1.66	1.24	1.56	1.99	1.49
14	62.00-65.00	3.00	SS/SH	10YR7/1	0	0.07	2.19	4.05		1.86	7.6	0.40	0.46	0.56	0.75	0.47
15	65.00-68.15	3.15	SS/SH	10YR7/1	0	0.14*	4.38	2.10	2.28		7.7	0.22				0.22
16	68.15-73.00	4.85	SS	10YR8/1	1	0.25	7.81	7.84		0.02	7.6	0.20				0.20
17	73.00-77.00	4.00	SS	10YR8/1	1	0.11	3.44	17.79		14.35	8.0	<0.20				
18	77.00-79.50	2.50	SS	10YR8/1	1	0.11	3.44	11.20		7.76	7.6	<0.20				
19	79.50-79.90	0.40	SH	10YR5/2	0	0.55*	17.19	0.51	16.68		5.9	0.70			0.63	0.70
20	79.90-83.90	4.00	SS	10YR8/1	0	0.17	5.31	10.00		4.69	7.3	<0.20				
21	83.90-84.20	0.30	COAL	10YR3/1	0	2.43*	75.94	-20.04	95.98		2.6	-				
22	84.20-86.10	1.90	SS	10YR6/2	0	0.23*	7.19	2.61	4.58		5.5	0.22				0.22
-	86.10-93.00	6.90	COAL	-	-	-	-	-	-	-	-					
23	93.00-95.35	2.35	MS	10YR6/2	0	0.01	0.31	3.06		2.75	7.2	0.70				0.70
24	95.35-98.65	3.30	SH	10YR5/2	0	<0.01	0.31	9.95		9.64	7.1	0.36				0.36
25	98.65-103.00	4.35	SS	10YR8/1	0	0.04	1.25	6.65		5.40	7.0	<0.20				
26	103.00-105.85	2.85	SS	10YR8/1	0	0.05	1.56	1.42	0.14		6.0	<0.20				
-	105.85-117.25	11.40	COAL	-	-	-	-	-	-	-	-					
27	117.25-119.20	1.95	SH	10YR7/2	0	0.06	1.88	3.44		1.56	7.0	0.38				0.38
28	119.20-120.45	1.25	SS	10YR8/1	0	0.02	0.63	2.68		2.06	5.8	0.30				0.30
29	120.45-123.00	2.55	SH	10YR6/1	0	0.06	1.88	5.66		3.79	7.2	0.22				0.22

Argus Energy WV, LLC

Acid-Base Account ~

Site: Core ARG-WV-05-50

Date: January 12, 2006

REIC Job #: 0601059

Calcium Carbonate Equivalent in Tons/1000Tons of Material

SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	COLOR	REACTION with HCL	% SULFUR * = Pyritic	POTENTIAL ACIDITY	NEUTRALIZATION POTENTIAL	NET NEUTRALIZERS DEFICIENCY	NET NEUTRALIZERS EXCESS	PASTE pH
1	84.30-85.30	1.00	SS	10YR7/2	0	1.31*	40.94	11.47	29.47		4.8
2	85.30-87.50	2.20	COAL	10YR2/1	0	2.30*	71.88	-13.13	85.01		2.8
3	87.50-87.71	0.21	SH	10YR4/1	0	0.10*	3.13	1.92	1.21		6.1
4	87.81-87.92	0.21	COAL	10YR3/1	0	0.13*	4.06	1.92	2.14		6.5
5	87.92-89.72	1.80	COAL	10YR2/1	0	0.20*	6.25	1.70	4.55		6.3
6	89.72-90.20	0.48	SH	10YR5/1	0	0.02*	0.63	3.21		2.58	6.1
7	90.20-91.33	1.13	COAL	10YR2/1	0	0.08*	2.50	0.28	2.22		5.3
8	91.33-92.10	0.77	MS	10YR6/1	0	0.02	0.63	2.68		2.05	6.9
9	104.80-105.00	0.20	SS	10YR7/1	0	0.11*	3.44	-1.03	4.47		5.7
10	105.00-105.18	0.18	COAL	10YR2/1	0	0.09*	2.81	-0.53	3.34		5.5
11	105.18-105.52	0.34	Carbolith	10YR3/1	0	0.11	3.44	3.31	0.13		6.8
12	105.52-106.95	1.43	COAL	10YR2/1	0	<0.01*	0.31	1.22		0.91	6.2
13	106.95-107.12	0.17	Carbolith	10YR3/1	0	0.03*	0.94	2.20		1.26	6.9
14	107.12-109.00	1.88	COAL	10YR2/1	0	0.03*	0.94	0.94	0.00		6.5
15	109.00-109.30	0.30	SH	10YR4/1	0	0.05*	1.56	2.45		0.89	7.1
16	109.30-109.94	0.64	COAL	10YR2/1	0	0.82*	25.63	-11.11	36.74		3.4
17	109.94-111.17	1.23	SH	10YR7/1	0	0.09*	2.81	0.28	2.53		6.4
18	111.17-112.61	1.44	COAL	10YR2/1	0	0.10*	3.13	-0.93	4.06		6.0
19	112.61-113.12	0.51	SH	10YR2/1	0	0.04*	1.25	2.00		0.75	7.0
20	113.12-113.27	0.15	COAL	10YR3/2	0	0.03*	0.94	-11.38	12.32		5.3

~As Referenced in EPA manual: EPA-600/2-78-054; Field and Laboratory Methods Applicable to Overburden and Minesoils.

Research, Environmental and Industrial Consultants INC.

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APPROVED

T.A. Keeney, Research Soil Scientist

Argus Energy WV, LLC

Site: Core ARG-WV-05-50
Date: January 11, 2006
REIC Job #: 0601059

Selenium Data Summary Table

SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	SELENIUM (mg/kg)
1	84.30-85.30	1.00	SS	0.42*
2	85.30-87.50	2.20	COAL	2.82
3	87.50-87.71	0.21	SH	0.82
4	87.81-87.92	0.21	COAL	1.06
5	87.92-89.72	1.80	COAL	1.54
6	89.72-90.20	0.48	SH	0.54
7	90.20-91.33	1.13	COAL	0.30
8	91.33-92.10	0.77	MS	0.42
9	104.80-105.00	0.20	SS	<0.20
10	105.00-105.18	0.18	COAL	5.22
11	105.18-105.52	0.34	Carbolith	2.18
12	105.52-106.95	1.43	COAL	4.92
13	106.95-107.12	0.17	Carbolith	5.88
14	107.12-109.00	1.88	COAL	7.02
15	109.00-109.30	0.30	SH	2.20
16	109.30-109.94	0.64	COAL	9.46
17	109.94-111.17	1.23	SH	1.48
18	111.17-112.61	1.44	COAL	3.86
19	112.61-113.12	0.51	SH	2.46
20	113.12-113.27	0.15	COAL	7.92

Selenium Method: SW7740

Selenium MDL: 0.20 mg/kg

PQL: 1.00 mg/kg

* - The matrix spike exceeded method control limits due to matrix interference.

Approved: ______________________ ____________

Ivan W. Leef - Inorganic Lab Manager Date

Approved: ______________________ ____________

T.A. Keeney - Research Soil Scientist Date

Analysis and Speciation of Selenium in Environmental and Biological Samples

Jason Unrine
University of Kentucky, Department of Plant and Soil Sciences, Lexington, KY 40546

Selenium (Se) is both an essential nutrient and a toxicant. It is one of the few environmental toxicants that have been linked to widespread adverse effects in the environment. Environmental consequences of Se pollution include local extirpation of fish and bird populations and, in a few cases, severe effects on fish community structure. There are a variety of sources of environmental Se, both geogenic and anthropogenic. Selenium concentrations are highest in organic rich sedimentary deposits such as some shales, coal and oil. Characteristic toxic effects often observed in individual animals include decreased reproductive success, largely due to teratogenesis. Biotransformation and partitioning of Se to particulate phases in aquatic systems control its efficient food chain transfer. These characteristics necessitate measurement in a variety of environmental samples for site specific risk assessments including source materials, water, sediment, algae, macrophytes, suspended particulates and animal tissue. A variety of techniques for selenium analysis are available that range in sophistication, availability and cost. This presentation will provide an overview of the strengths and limitations of various analytical techniques by sample matrix. Both total Se measurements and Se speciation measurements will be covered. Hyphenated analytical techniques for Se speciation will be highlighted.

Linkages between Acid and Metal Load Reductions from AMD Attenuation to Ecological Recovery in Little Raccoon Creek, Ohio.

Ben McCament[1], Jen Bowman[1], Kelly Capuzzi[2], Mitch Farley[3], Brett Laverty[4]

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2. Ohio Environmental Protection Agency, Southeast District, Logan, Ohio
3. Ohio Department of Natural Resources – Division of Mineral Resource Management, Athens, Ohio
4. North Carolina Department of Environmental and Natural Resources, Asheville, NC Formerly Vinton Soil & Water Conservation District, McCarthur, Ohio

Abstract

Acidic mine drainage (AMD) from pre-law coal mines wiped out aquatic communities in the lower 24 miles of Little Raccoon Creek in the mid 1900's. Data collected in the 1950's by the Ohio Division of Wildlife, showed non-existent or sparse fish populations due to high levels of acidity and metals related to AMD. With the enactment of SMCRA in 1977, environmental controls on coal mining reduced additional AMD loads. However, biological data collected in 1984 and 1985 by Ohio EPA still showed highly impaired aquatic ecosystems and high acid loads. Water quality improvements began to occur in the 1990's with AMD loads decreasing due to natural attenuation of abandoned surface mine spoil and reclamation efforts by state and federal agencies. In response, 1999 data showed aquatic organisms beginning to re-populate Little Raccoon Creek in areas where they had not existed for many decades.

With the inception of the Raccoon Creek Partnership in the late 1990's, AMD projects were implemented with the purpose of restoring the ecological integrity of Little Raccoon Creek. To date, a total of six large-scale AMD treatment projects have been implemented, and acid loads have been reduced by 4,065 pounds per day. Aquatic life recovery has been most notable in the lower 13 river miles, where net-alkalinity, total iron, and total aluminum water quality criteria are met. Between river miles 13 – 24 where the majority of AMD sources originate, biological improvement has occurred but is far from attaining Ohio EPA criteria for warm-water habitat. Chemical and habitat data show high total aluminum and iron concentrations in this reach, which is likely preventing full ecological recovery through direct toxicity to organisms and by flocculants impairing substrate habitat. Reducing metal concentrations must be an integral part of future AMD treatment projects to enhance biological communities in Little Raccoon Creek.

This paper was originally presented at the 2008 USEPA/NGWA Remediation of Abandoned Mine lands Conference, Oct 2-3, 2008, Denver, CO.

Introduction

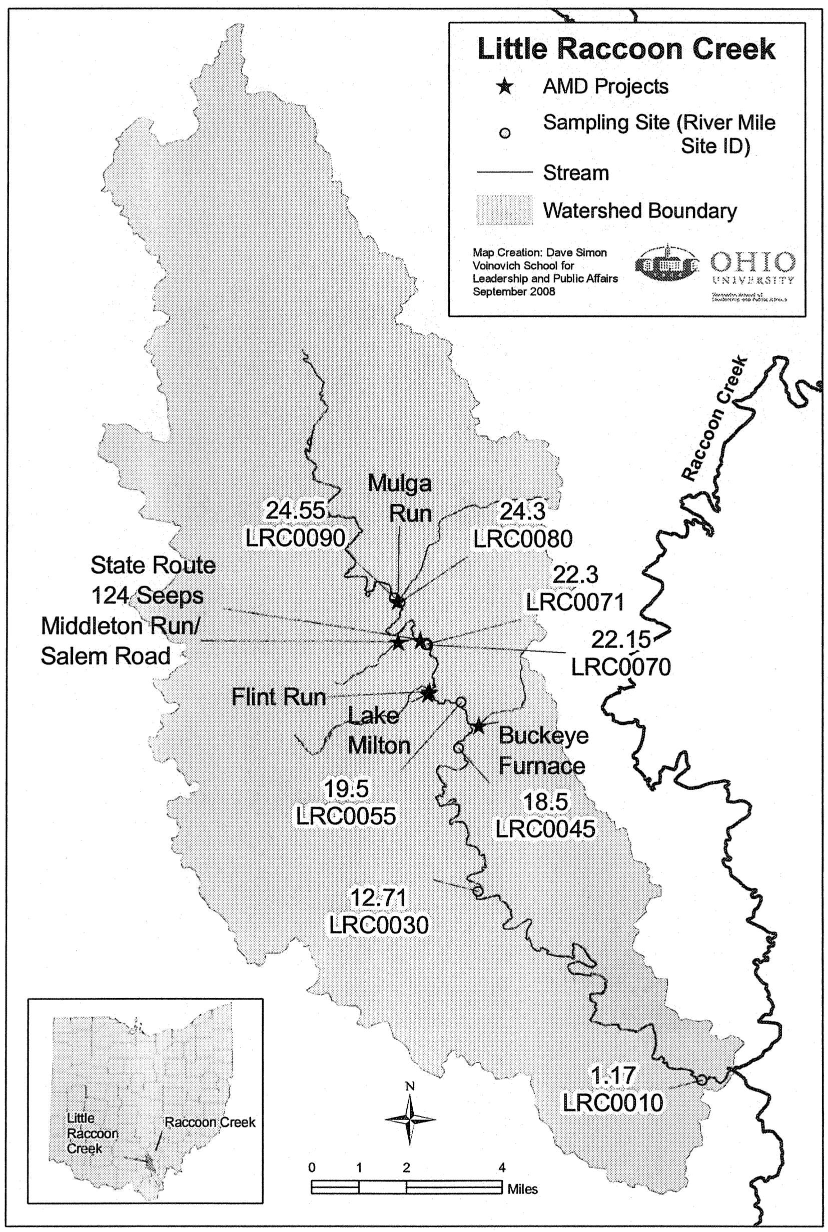
The eastern coal region extends through parts of Alabama, Virginia, Tennessee, Kentucky, West Virginia, Ohio, Pennsylvania, and Maryland. Rich deposits of coal have been mined in this region for the last 150 years but adequate environmental controls over mining practices have only been in place for the last 30 years. The final legacy of unregulated coal mining has been described as “environmental devastation” and “economic abandonment” in the eastern coalfields (Comp 2000). Thousands of miles of streams and rivers are adversely affected by acid mine drainage (AMD) emanating from a multitude of abandoned strip mines and underground mines. The United States Environmental Protection Agency conducted a biological study of the northern Appalachian Region in 1995 and found more than 5,100 miles of streams affected by acid mine drainage (USEPA 1995).

The coalfields of Ohio are located on the northern boundary of the eastern coal region and extend over 12,340 square miles in the eastern and southeastern part of the state. To provide a measure of the magnitude of the problem, 3.4 billion tons of coal was mined in Ohio from 1800 to 1993 (Crowell 1995). The brunt of acid mine drainage generation in the Ohio coalfields have been and continue to be born by the Hocking River and the Raccoon Creek Watersheds (USEPA 1995). The Raccoon Creek Watershed drains 683 square miles in southeast Ohio and discharges into the Ohio River near Gallipolis, Ohio. The largest tributary in the watershed is Little Raccoon Creek, which is 38 miles long and drains 157 square miles of Vinton, Jackson, and Gallia Counties (Map 1).

The Little Raccoon Creek basin has been extensively timbered and mined for iron and coal since the latter part of the 19^{th} century. As a result, sedimentation and acid mine drainage have proven detrimental to the health of Little Raccoon Creek. The decline of coal mining, the passage of time, and the enactment of SMCRA have improved the quality of Little Raccoon Creek, but much work still remains.

The Raccoon Creek partnership (RCP) was formed in 1996 to address abandoned coal mines and associated acid mine drainage issues in the Raccoon Creek Watershed. This core partnership consists of elements from Ohio Department of Natural Resources Division of Mineral Resource Management, Division of Wildlife, Division of Soil and Water Conservation, Ohio Environmental Protection Agency, Ohio University’s Voinovich School of Leadership and Public Affairs, the Vinton Soil & Water Conservation District, and others, to fulfill their mission: “to work toward conservation, stewardship, and restoration of the watershed for a healthier stream and community.” In 2007, the RCP incorporated and became a nonprofit (501(c)(3)) organization. The partnership funds projects through a number of grant sources including the Ohio EPA 319 clean water program, Ohio Abandoned Mine Land Fund, and the OSM Appalachian Clean Streams Initiative.

Map 1: Little Raccoon Creek



Geology

Southeast Ohio is underlain by sedimentary rocks of Pennsylvanian and Permian-age (250-150 mya) that dip to the southeast at 30-40 feet per mile (DeLong 1957). The Allegheny Formation underlies the majority of the Little Raccoon Creek Watershed and contains all of the economically important coal seams in the basin. The Allegheny coal beds include the following seams in order of decreasing age: the Brookville coal (no. 4), the Clarion coal (no. 4a), the lower Kittanning coal (no. 5), middle Kittanning coal (no. 6), the lower Freeport (no. 6a), and the upper Freeport coal (no. 7). The Allegheny Formation is mainly comprised of shale and clay, followed by sandstone (40%), a small amount of bituminous coal, and a lower percentage of carbonate material (Stout 1916, Sedam 1991). This lack of carbonate material and the presence of high sulfur coal (1% - 4%) make this basin particularly vulnerable to the effects of acid mine drainage (Childress 1985). Little Raccoon Creek is located within the unglaciated Western Allegheny Plateau Ecoregion and although the landscape topography is steep, the gradient of Little Raccoon Creek is about 4.2 feet per mile.

Mining History

Coal production in Jackson County peaked in the years surrounding 1903 with over 2.4 million tons shipped in that year alone. After 1910, coal mining steadily declined until the rise of strip mining methods in the 1950's. Strip mining has increased in recent years but has yet to reach the total output achieved in the early part of the last century. A total of 93.2 million tons of coal was mined in the county between 1820 and 1993, of which 65% (60.3 million tons) was mined by underground mining methods and 35% (32.9 million tons) by surface mining methods (Crowell 1995).

A large portion of the historical mining in Ohio occurred without any state or federal regulation governing the actual mining or post-mining condition of the affected lands. Ohio's first mining and reclamation law was passed in 1948 but required very little of coal operators. The state required a monetary performance bond of $100/acre, limited grading of spoil material, and some tree plantings on the disturbed area. However, pit floors and high walls were allowed to remain. In 1965, the Ohio General Assembly (OGA) revised the requirements commonly referred to as A-law. Under the revised law, operators were required to post a performance bond of $300/acre, grade spoil piles, burial of the pit floor, and the establishment of vegetation (trees, shrubs, legumes, or grasses) on the spoil banks and last cut excavations. In 1972, the OGA created a more stringent mining and reclamation standard commonly referred to as B-law. The B-laws required a yearly license, a variable rate performance bond, elimination of all high walls, burial of pit floors, restoration of the original land contour, replacement of topsoil, the establishment of vegetation, and the prevention of pollution to the waters of the state. In 1975, the OGA updated the law to allow for 5-year permits instead of year licenses. All other reclamation requirements remained the same under the new law commonly referred to a C-law. In 1977, the United States Congress passed the Surface Mining Control and reclamation Act (SMCRA), which was largely modeled after Ohio's 1972 B-law requirements. The passage of SMCRA essentially created a nationwide standard for reclamation and created the Office of Surface Mining as a regulatory agency. The OGA adopted the new standards in 1981 but little changed with the exception of an addition of sediment retention ponds, a detailed pollution prevention plan, a performance bond of $2500 per acre, and the collection of coal severance tax.

Underground drift mining was the dominant method for mining above-drainage coal in Ohio until the end of World War II, but was quickly replaced by strip mining methods as post-war technology provided mining companies with larger and more powerful equipment (Crowell 1995). Surface mining methods utilize high explosives, stripping shovels, loading shovels, and large draglines to remove overburden and expose the underlying coal. The stripping method removes 100% of the coal as compared to underground methods, which, at best, removes only 50% - 70% of the mineable reserves (Morrow 1956). The drawback is the complete disruption of surface drainage patterns and groundwater pathways.

According to the USGS mine map series, the Little Raccoon Creek basin has approximately 9,800 acres of underground mines and 9,000 acres of surface mines.

Methodology

Data utilized for this analysis consists of chemical, physical, and biological data collected from three sources: Ohio Environmental Protection Agency (OEPA), U.S. Geological Survey (USGS), and the Raccoon Creek Partnership (RCP). The historical data, pre 1990's, was collected by OEPA and USGS. The more recent data was collected by all sources but primarily by RCP.

Chemical data

The RCP collected chemical water quality data along mainstem long-term monitoring stations at a minimum of two events per year. Short-term monitoring stations established near restoration project discharges were monitored more frequently, between two and twelve sampling events per year. Chemical grab samples were collected and sent to OEPA's certified ODNR Division of Mineral Resources Management laboratory in Cambridge Ohio for Group I analysis. Group I water quality analysis includes pH, specific conductivity, acidity, alkalinity, hardness, aluminum, iron, manganese, sulfate, calcium, magnesium, total dissolved solids, and total suspended solids. Field parameters including dissolved oxygen, pH, conductivity, and temperature were measured either with a multi-probe Hydrolab Quanta datasonde or a YSI 600 XLM meter. USGS and OEPA collected both field and laboratory samples following their respective agency's standard procedures (OEPA, 2003 and USGS, 1999).

Biological data

Biological data was collected by both OEPA and USGS. Fish (IBI & Miwb) and macroivertebrate (ICI) data were collected and analyzed using Ohio EPA protocols outlined in Volume II: Users Manual for the Biological Assessment of Ohio's Surface Waters (Ohio EPA 1987, 1989, & 2006) and Volume III: Standardized Biological Field Sampling and Laboratory Methods for Assessing Fish and Macroinvertebrate Communities (Ohio EPA 1987, 1989, 2006). Additional family-level macroinvertebrate sampling was conducted following the Macroinvertebrate Aggregated Index for Streams (MAIS) methodology (Smith & Voshel, 1997).

Physical data

Qualitative Habitat Evaluation Index (QHEI) data were collected in the same reach as the fish sampling sites. QHEI sampling followed standard Ohio EPA protocols (Rankin 1989, Ohio EPA 2006). Instantaneous discharge measurements were recorded by the RCP, OEPA, and USGS at the time chemical water samples were collected using either a pygmy meter, AA meter, and/or cutthroat Baski flume following standard procedures (USGS, 1982 and 1984 and Kilpatrick, 1983).

Raccoon Creek Watershed Project

Priority Subwatersheds

There are 22 major tributaries or subwatersheds that comprise the bulk of the Little Raccoon Creek drainage basin. Continuous water quality monitoring by the Raccoon Creek partners over the last ten years has narrowed the acid mine drainage focus to six subwatersheds that are contributing significantly to the degradation of Little Raccoon Creek. These basins include Flint Run, Buffer Run, Middleton Run, Mulga Run, and SR 124 tributary (Map 1). In addition to the severity of the water quality is the fact that all six tributaries discharge along an 11.5-mile section of Little Raccoon Creek in Jackson County (RM 13.0 – RM 24.5). The post-surface mining condition of the affected lands in the Little Raccoon Creek basin include thousands of acres of unreclaimed surface mining lands with exposed high walls, exposed pit floors, toxic piles of overburden, closed contour impoundments, acidic-water filled pits, and large valley-fills used to dispose of rejected coal refuse. All underground mining occurs above drainage with many underground mines discharging acid mine drainage into the basin.

Acid Sources and Load Reductions

The Raccoon Creek Partnership has implemented 6 AMD treatment projects in the Little Raccoon Creek Watershed since 1999. Table 1, shows the name of the project, brief treatment description and year completed. Further project details such as treatment, costs, design, and construction companies are on the NPS website at www.watersheddata.com under Reports/Raccoon Creek.

Table 1: Completed AMD Projects in the Little Raccoon Creek Watershed

AMD Project Name	Brief Description of Treatment	Year Completed	Total Cost	Acidity Load Reduction lbs/day (% load reduction)	Metal Load Reduction lbs/day (% load reduction)
Buckeye Furnace (Buffer Run)	Reclamation, Successive Alkaline Producing System (SAPS)	1999	$1,090,530	1549 (76%)	236 (53%)
SR124 Seeps project	Reclamation, Open Limestone Channels (OLC)	2001	$315,490	82 (55%)	13 (50%)
Mulga Run	2 Steel Slag Leach Beds (SLB), Wetland Enhancement	2004	$440,783	10 (100%)	177 (57%)
Middleton Run (* accumulative three discharges at Salem Road)	Reclamation, OLC, Steel Slag Channel, Limestone Leach Bed (LLB)	2005	$687,913	334 (90%)	46 (73%)
Flint Run East	Reclamation, SLB, LLB, SAPS, OLC, Wetland Enhancement	2006	$1,456,106	803 (99%)	109 (33%)
Lake Milton	SAPS, SLB	2007	$961,536	1287 (99%)	102 (93%)

Results

Historical Water Quality Trends

Water quality data in Little Raccoon Creek date back to the early 1950's with the first study conducted by the Ohio Division of Wildlife (Ohio DOW 1954). Monitoring began again in Little Raccoon Creek in the early 1970's with a few samples and began in earnest in the late 1970's. As an overall analysis of historical water quality, Little

Raccoon Creek has displayed two trends: (a) chemical water quality and aquatic communities throughout much of the mainstem have been degraded by mining pollution (AMD and metals) with the lower 24 miles being the most impacted, and (b) the water quality with relation to mining pollution has improved dramatically over the past three decades and as a result, the aquatic ecology has improved.

Data collected in Little Raccoon Creek from the early 1970's to the present document decreased levels of total acidity, higher concentrations of total alkalinity, and higher pH. This is best represented in the lower reaches of Little Raccoon Creek at sampling sites at river mile 1.17 and river mile 12.71 (Figures 1 - 4), where the most historical data exists. Early data from the late 1970's to early 1980's indicate a time period where pH was lowest and total acidity concentrations were highest throughout Little Raccoon Creek. Total acidity ranged from 0 – 140 mg/l and pH ranged from 3 to just below 6 during this early time period. Data at additional sites, although sparse, indicate that pH was lowest in the lower 18.5 river miles but was impaired to some degree at all sites measured downstream of river mile 24.55. The majority of mining occurred in the basin downstream of river mile 24.55 and this sampling site has maintained a net 30 mg/l total alkalinity concentration since first sampled in the mid 1980's. Data collection in the mid and late 1990's by both Ohio EPA and USGS showed a noticeable increase in pH and decrease in total acidity (increase in total alkalinity) at river mile 1.17 and 12.71. Total alkalinity also improved slightly at river mile 19.5 but remained fairly constant at river mile 22.15 and sites upstream.

Aquatic biology data follow the same trend as the chemical data with improved conditions over the past three decades. Biological data collected in 1984 (includes six fish sites (IBI) and three macroinvertebrate sites (ICI) by Ohio EPA) show extremely impaired aquatic communities, but improve in the 1990's, and by 2002- 2007 drastically improve at most sites (Figure 5). The lower section of Little Raccoon Creek was essentially devoid of aquatic communities in 1984 and the entire stream was impaired even upstream of major AMD sources. As a general trend, IBI scores are highest upstream of river mile 24 and lowest at river mile 11 and 1.17. Both of the lower sites scored a 12 for the metric, which is the lowest possible score and only two fish species were documented. None of the sites met established criteria for the Warm Water Habitat (WWH) use designation for the state of Ohio. ICI scores showed similar conditions with all scored below 20 out of a possible 60 and river mile 11 receiving the lowest score. IBI and ICI scores increased significantly from 1984 to 1995. The IBI at river mile 24.55 improved only slightly from a 32 in 1984 to 36 in 1995, however the IBI dramatically increased from a 12 in 1984 to a 37 in 1995 at river mile 11.0. ICI scores improved at all sites as well in 1995 with the best scores above river mile 24. All fish and macroinvertebrate index scores remained below WWH criteria in 1995. Most recent IBI data (2005 – 2007) shows full recovery of fish to meet WWH criteria at river mile 12.7 and 1.17. ICI scores from 1999 shows similar results with the lower 13 river miles attaining WWH criteria.

Figure 1: Little Raccoon Creek pH Data at RM 1.17

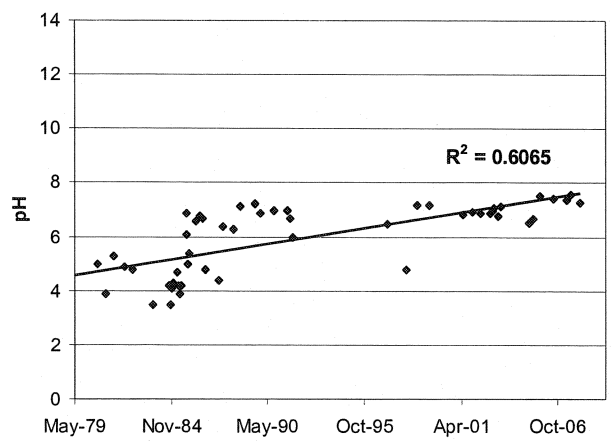


Figure 2: Little Raccoon Creek pH Data at RM 12.71

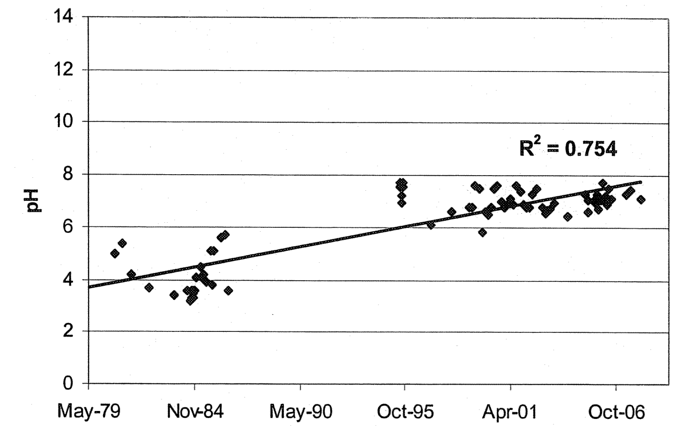


Figure 3: Little Raccoon Creek Total Acidity & Alkalinity at RM 1.17

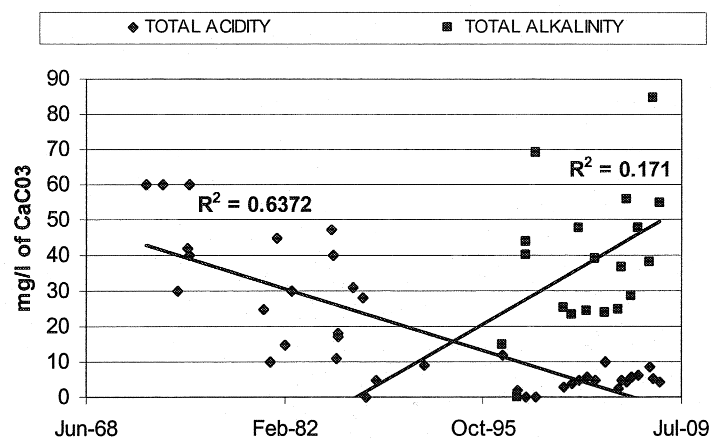


Figure 4: Little Raccoon Creek Total Acidity & Alkalinity at RM 12.71

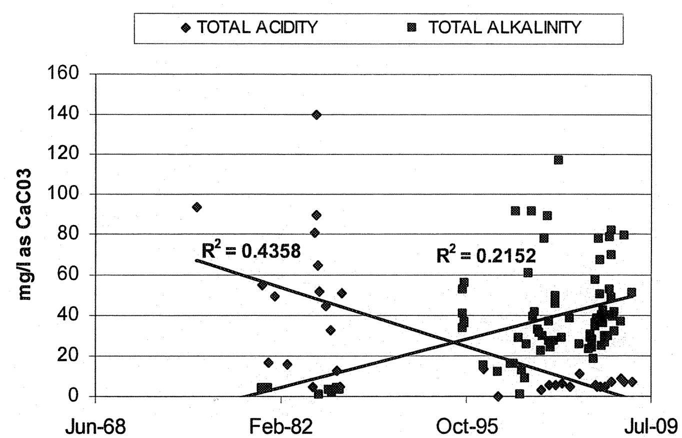
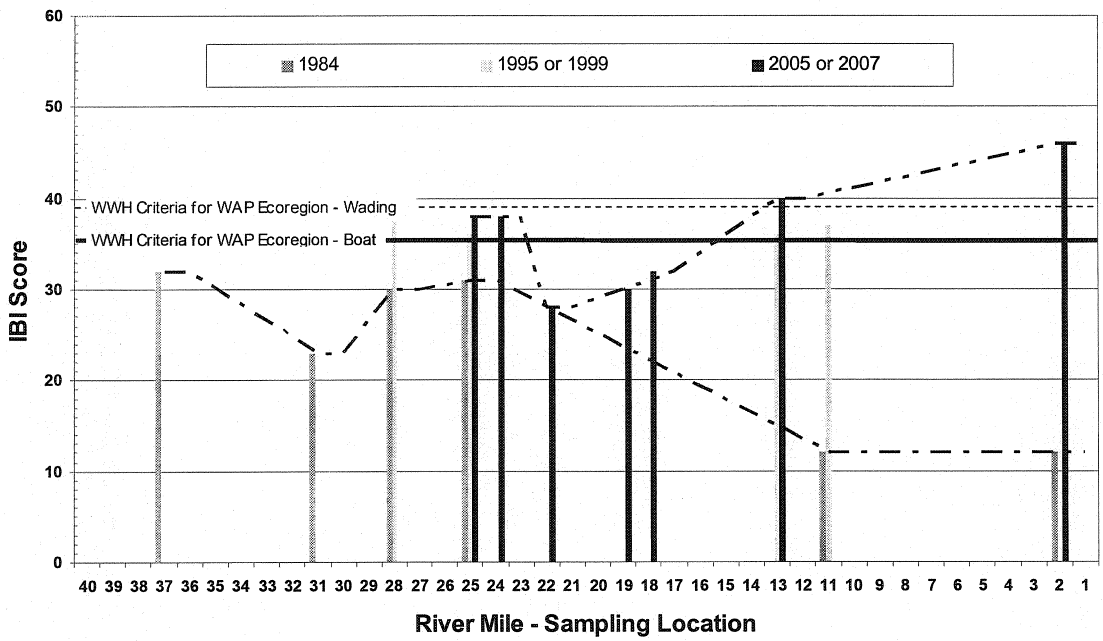


Figure 5. IBI Scores in Little Raccoon Creek: 1984 - 2007

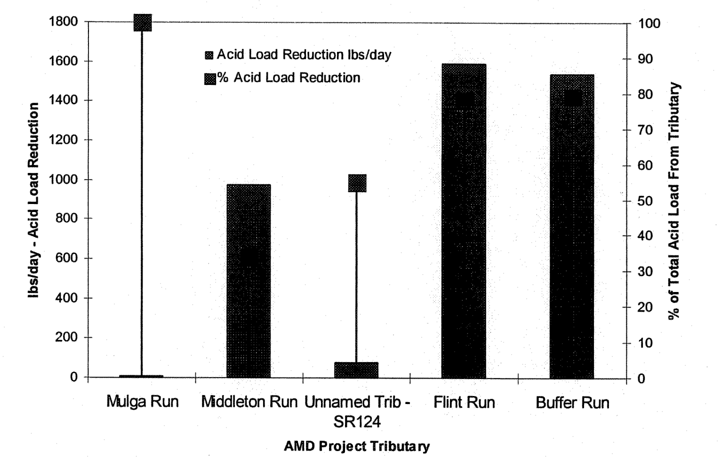


Improving water quality in Little Raccoon Creek over the past three decades is a direct result of several factors within the watershed including: federal and state mining regulation laws, reclamation of abandoned mine lands in the watershed, re-mining (resulting in reclamation of abandoned sites), and AMD treatment projects by the Raccoon Creek Partnership. The federal mining regulation law (SMCRA 1977) limited new sources of AMD from 1977 forward, while state and federal agencies began reclaiming abandoned mine sites in the watershed in the early 1980's. This reclamation typically consisted of regrading and re-vegetating the site to reduce erosion. Many sites were planted with trees, as well, as part of the reforestation program. In addition to state and federal agency efforts, some mining companies re-mined areas where economic beds of coal were left and reclaimed the abandoned mines as part of the process. One particular site is the Broken Aro tipple site located in the Flint Run subwatershed. Mead Paper Company bought the site to test its paper mill sludge as a soil medium for reclaiming abandoned surface mine sites. Mead applied the sludge to the 140 acre tipple site and re-vegetated the site. Although this reclamation was not designed to treat AMD it did improve water quality and reduce acid loads from the site.

Current Water Quality

Little Raccoon Creek long-term monitoring efforts have been underway since 2000 with the first basin-wide study to evaluate and prioritize AMD projects in the watershed (Laverty, 2000). As AMD implementation projects were developed and implemented by the Raccoon Creek Partnership, additional long term stations were developed and frequency of chemical sampling increased to two – four times per year. A total of six AMD treatment or abatement projects have been constructed since 1999 in the basin, with the most recent completed in 2007. These six projects occur in 5 tributaries to Little Raccoon Creek: Mulga Run, Middleton Run, Flint Run (2 projects), SR124 tributary (unnamed tributary to Little Raccoon Creek), and Buffer Run. Acid load reductions total over 4,000 lbs/day (730 tons/year) based on data collected at the mouth of each tributary where AMD treatment projects were sited (Figure 6). Acid load reductions were calculated using a regression for pre and post data normalized based on the mean annual daily discharge for the site (Stoertz, 2004).

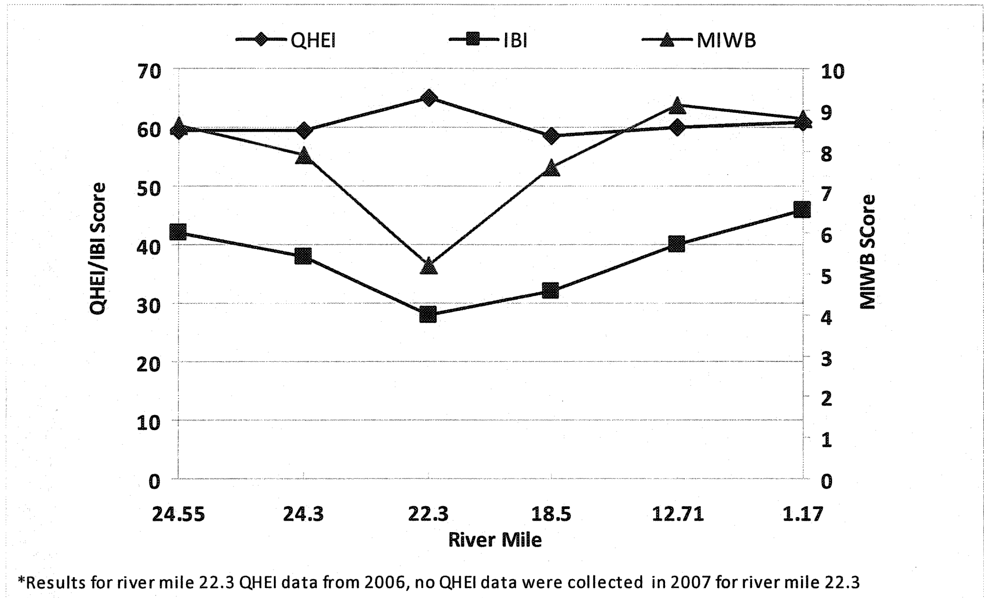
Figure 6: AMD Load Reduction in Little Raccoon Creek Watershed



The ultimate goal of AMD treatment and acid reduction projects is to restore the ecological integrity of Little Raccoon Creek. Attainment status of surface waters in Ohio is based on biological criteria and thus is the end result for restoration efforts. Although natural attenuation, reclamation, and AMD treatment projects mentioned above have significantly improved water quality in Little Raccoon Creek, the stream has not fully recovered. Downstream of RM 12.7 and upstream of RM 24.4 biological criteria attain and have proven that restoration is possible in the stream. However, Little Raccoon Creek does not meet biological criteria for fish from RM 22.2 to RM 18.7 based on IBI (40 – Boat) or Miwb (8.3) scores (Figure 7). This corresponds with the region where mining was heavy and AMD sources are abundant. Habitat data does not appear to be the limiting factor in fish community recovery in Little Raccoon Creek with Qualitative Habitat Evaluation Index (QHEI) scores at or above the statewide criteria for warm-water habitat of 60. Macroinvertebrate data correlate with the fish data, with MAIS scores falling mostly within the "poor" category, with the exception of RM 18.7 which scores "good" in 2007 (Johnson pers. communications 2008).

Current (2005 – 2008) chemical water quality data in Little Raccoon Creek indicate adequate buffering capacity exists throughout the stream (RM 24.55 – 1.17) to support warm-water habitat biota. Net-alkalinity concentrations decrease at each downstream site for most sampling events as AMD tributaries enter Little Raccoon Creek between RM 24.55 and RM 12.71, but concentrations remain above 20 mg/l at all times from 2005 – 2008 (Figure 8), which is a target concentration established by Ohio EPA for the TMDL for the adjacent Upper Basin of Raccoon Creek TMDL (Ohio EPA 2003). Analysis for the TMDL for the Upper Basin of Raccoon Creek demonstrated that sites that maintained a net alkalinity concentration of 20 mg/l maintained high pH values and typically met Ohio EPA biological criteria for warm-water habitat. This analysis holds true in relation to pH in Little Raccoon Creek with pH (lab measured) readings above 6.5 at all sites for all sampling events (Figure 9).

Figure 7: 2007 Little Raccoon Creek
Fish and Habitat Data



Heavy metals such as iron, aluminum, and manganese are often associated with mine drainage in the Raccoon Creek basin based on the local geology. Total manganese data from 2005 – 2008 in Little Raccoon Creek indicate low and fairly stable concentrations below the 2.0 mg/l drinking water standard established by U.S. EPA. A water quality standard or criteria for the protection of aquatic life does not exist for total manganese. Only 10% of the Little Raccoon Creek sites exceeded the drinking water standard. Total iron concentrations are higher and more variable in Little Raccoon Creek (Figure 10). Iron concentrations spike at RM 19.5 and 18.5, downstream of the Flint Run and Buffer Run AMD tributaries, but continue to decrease further downstream in Little Raccoon Creek. Total iron exceeds the U.S. EPA concentration maximum criteria (cmc) at all sampling stations during at least one sampling event but far exceed the criteria at RM 19.5 and 18.5. These two sites do not attain Ohio EPA WWH criteria for fish and macroinvertebrates, which may be related to the high iron concentrations. However, Ohio EPA does not have an established criteria concentration for the protection of aquatic life for total iron.

Aluminum concentrations occur in Little Raccoon Creek at levels that would impair aquatic life according to U.S. EPA criteria for continuous and maximum concentration criteria (0.087 and 0.75 mg/l respectively (Figure 11)). All sites exceed the criteria continuous concentration (ccc). The four sampling sites that are attaining WWH criteria scores for fish (and have "good" macroinvertebrate community rankings) have maximum concentrations of total aluminum below 0.4 mg/l for all but one event, RM 1.17 at 0.62 mg/l on 3/7/05. These four sites do not exceed the U.S. EPA cmc of 0.75 mg/l during any single measurement from 2005 – 2008. This data indicates that total aluminum concentrations are elevated in Little Raccoon Creek between river mile 19.5 and 22.3 and are likely a limiting factor for complete biological recovery in the stream in this section.

Figure 8: Net-alkalinity Concentration in Little Raccoon Creek: 2005 – 2008

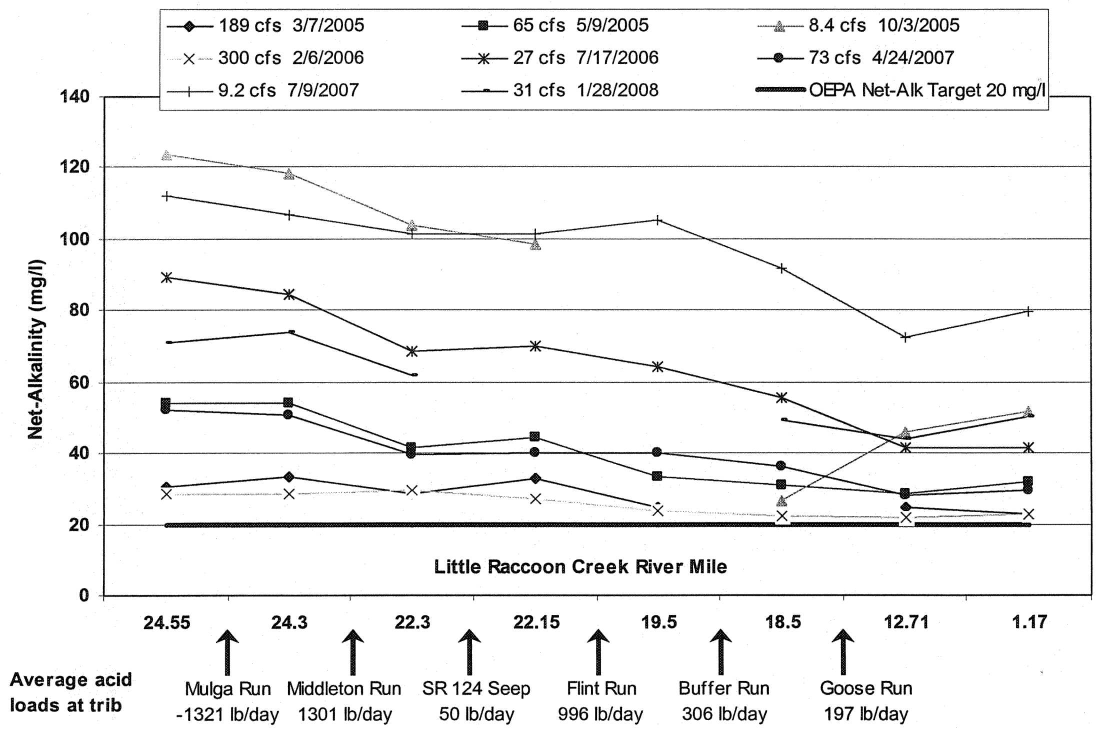


Figure 9: Lab pH Readings in Little Raccoon Creek: 2005 – 2008

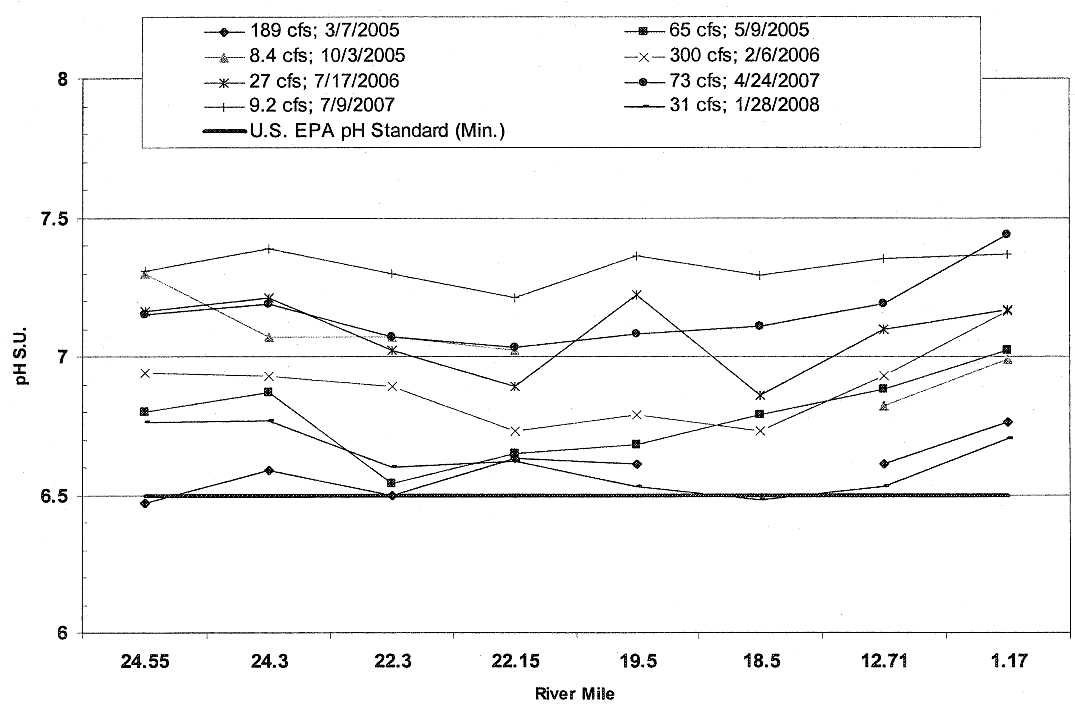


Figure 10: Total Iron Concentrations in Little Raccoon Creek: 2005 - 2008

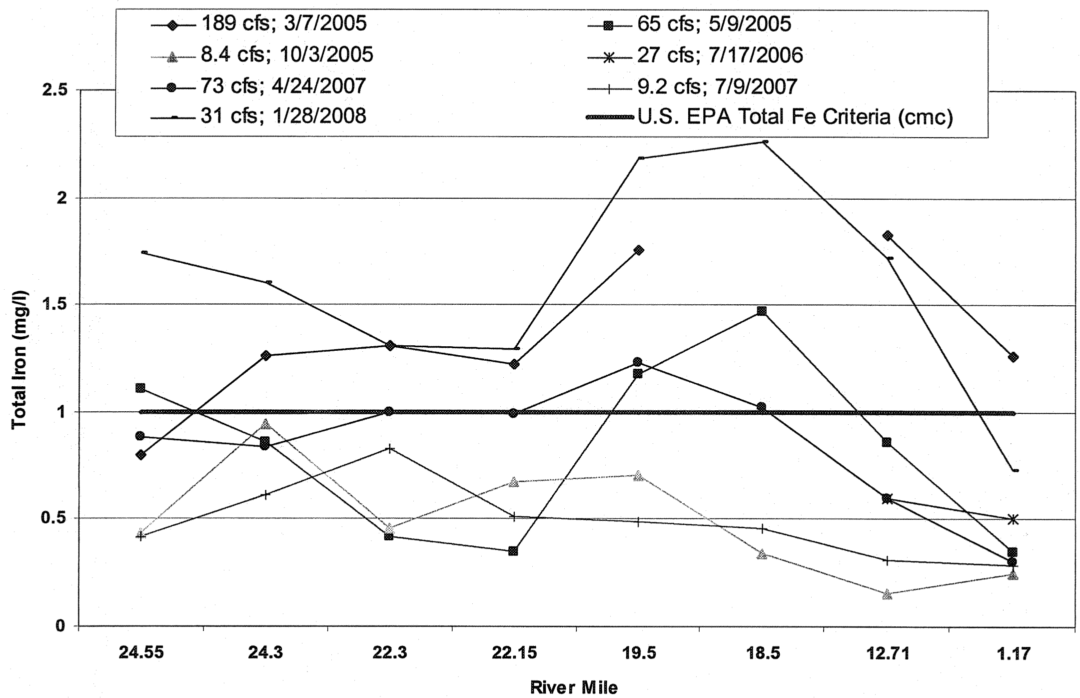
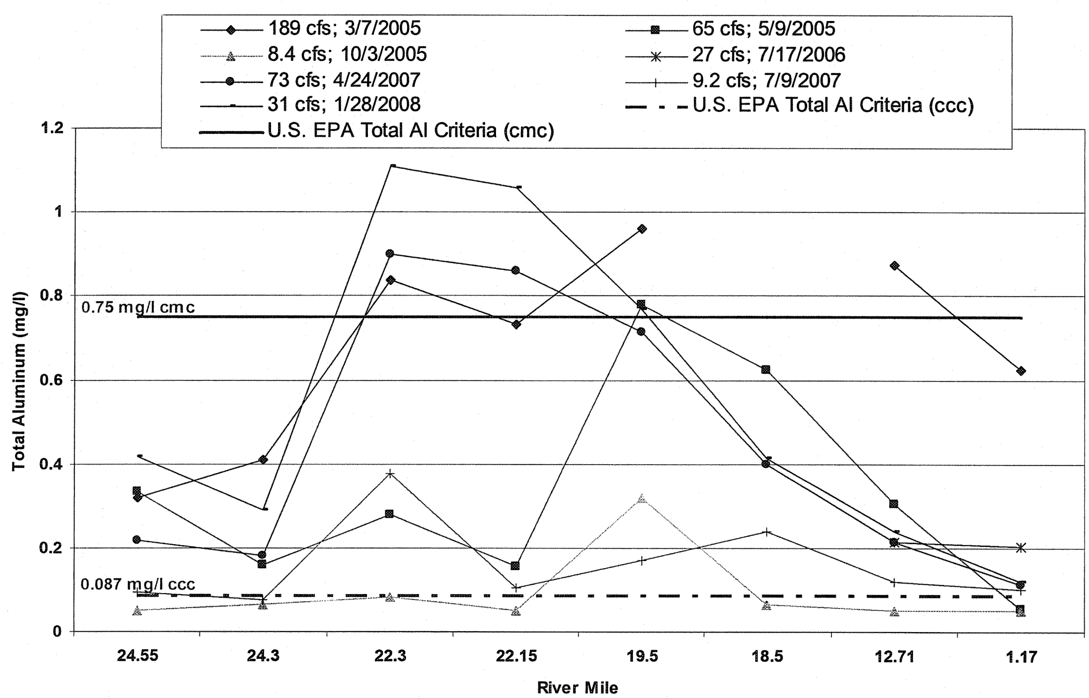


Figure 11: Total Aluminum Concentrations in Little Raccoon Creek: 2005 - 2008



Conclusions

Over the past three decades water quality has improved in Little Raccoon Creek as a direct result of several factors within the watershed including: federal and state mining regulation laws, reclamation of abandoned mine lands in the watershed, re-mining (resulting in reclamation of abandoned sites), and AMD treatment projects by the Raccoon Creek Partnership. Chemical water quality such as, alkalinity and pH, have improved through the entire mainstem of Little Raccoon Creek and are meeting target and standards set forth by Ohio EPA and US EPA. However biological recovery has not been fully met through the entire mainstem of Little Raccoon Creek. Between river miles 24.3 and 18.5, the biological community does not meet warm water habitat. Further investigation of the chemical water quality reveal that metals such as, iron and aluminum; fail to meet chemical water quality standards during all sampling events within this six-mile section of stream.

In order to fully restore biological integrity in the mid-section of Little Raccoon Creek, river mile 24.3 to 18.5, future restoration efforts need to focus on iron and aluminum metal reduction and retention. Of these two metals, aluminum exhibits a more toxic effect on biology than iron at these concentrations.

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Datashed: An Online Tool for Passive Treatment System Monitoring and Maintenance[1]

Shaun Busler[2], Peter Drake[3], Bruce Golden[4], Cliff Denholm[2], Tim Danehy[2], Tom Grote[2], and Margaret Dunn[2]

Abstract: Datashed is a user-friendly, interactive, GIS enabled online database developed by Stream Restoration Inc. to assist watershed groups, academic institutions, private industry and government agencies in the operation and maintenance of passive treatment systems. Using primarily open-source technology, Datashed provides a cost-effective and reliable solution to the management of data associated with environmental efforts. Specific, individualized functions can easily be added using common programming languages. One of these functions, called i-Map, is a Geographic Information System (GIS) that spatially connects the data stored within Datashed. Both anonymous and authorized users can easily upload, download, and print data from any standards-compliant web browser without the use of additional plug-ins or software.

Additional Keywords: database, open source, internet, Geographic Information System (GIS), operation and maintenance, AMD, mine drainage

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[1]Paper presented at the 2009 West Virginia Mine Drainage Task Force Symposium, Morgantown, WV, March 31 – April 1, 2009.

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[4]Bruce Golden is the Regional Coordinator for the Western Pennsylvania Coalition of Abandoned Mine Reclamation, Greensburg, PA.

Introduction

For more than a decade, organizations have been installing passive systems to treat abandoned mine drainage throughout the Commonwealth of Pennsylvania. Through these activities, watersheds are being restored. According to an inventory of mine drainage treatment projects compiled by the Office of Surface Mining (OSM), over 280 systems exist within Pennsylvania. Many of these restoration projects, however, must be maintained properly in order to have a lasting impact. To prevent streams from reverting to their polluted condition, these projects must continue to function.

Volunteers, non-profit organizations, and government agencies have spent numerous hours collecting valuable water quality data in order to determine the effectiveness of these treatment systems. Dependent upon the organization, this data has a variety of end uses. Some groups enter this data into a computer database and use the data for reports, newsletters, etc. Other groups do not have a database and only keep paper records. Many times, government agencies store their data in proprietary databases behind firewalls for security. As a result, the availability of this data to the general public and to researchers is limited.

History

Stream Restoration Incorporated (SRI) has assisted numerous watershed groups throughout Pennsylvania with assessment, restoration, and protection projects. These efforts have included all necessary reports, studies, designs and construction oversight for the installation of over 30 passive treatment systems throughout Pennsylvania having a combined total of more than 200 components. With this experience, SRI understands the necessity of properly maintaining passive treatment systems and the need to make water quality data available to others.

In 2002, SRI began the development of the Datashed (www.datashed.org) web system to aid in the operation, maintenance, and monitoring of these passive systems. Work began on Datashed under a small United States Geologic Survey (USGS) grant to SRI to assist interns from Grove City College in monitoring passive treatment systems in the headwaters of the Slippery Rock Creek watershed. A small company, 241 Computer Services, offered to donate much of their time to create a simple interface for these interns to upload water quality data through the Internet and to provide downloadable information, such as schematics and inspection sheets, on the passive treatment systems. As funding was not readily available for Datashed, work was completed in small increments over time. Additional partners have contributed to Datashed since its inception and include: Western Pennsylvania Coalition for Abandoned Mine Reclamation (WPCAMR), BioMost, Inc., PA Department of Environmental Protection, US Environmental Protection Agency, Greene County Watershed Alliance, Indiana County Conservation District, Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR), Slippery Rock Watershed Coalition, and others. The enhancements to Datashed have been increased with contributions from these project partners.

Features

As funding was limited, SRI decided to use Free and Open Source Software (FOSS) where available to reduce costs while increasing the longevity, security, reliability and stability of the web site. Commercial software would have cost hundreds of thousands of dollars to meet the requirements. The FOSS alternatives have met these requirements and reduced initial and recurring maintenance costs of the software. The current configuration of Datashed uses PHP, MySQL, Mapserver, Apache, and MediaWiki as well as a host of open source functional libraries. Datashed currently offers the following capabilities:

- Instant, 24/7 access to important documents such as Operation & Maintenance Plans, inspection sheets, directions to project sites, topographic maps, and aerial photos
- Password-protected data submissions (i.e., field data)
- i-Map, an interactive GIS map depicting all known passive treatment systems at abandoned mine sites in Pennsylvania and other datasets
- Multi-parameter project searches
- Printable monitoring reports and predefined graphs
- Public access to *all* water sampling data
- Wiki

Downloads:

One of the primary functions of Datashed is to offer access to materials that will allow organizations, especially volunteer-based programs, to easily monitor their passive systems. Datashed provides downloadable operation and maintenance plans, site schematics, aerial photos, as-built drawings, etc. In addition, Datashed uses Virtual Earth Web Services to allow users to view and print directions to the passive system based on their address.

Water Quality Data:

The data stored within Datashed can be viewed and downloaded from the web by anyone in several different formats. The data is found by searching for the passive system or stream within a multi-parameter query or by searching i-Map. Once the site is found, data can be viewed in dynamically-generated reports or downloaded as a CSV (comma separated value) file, which is easily opened in Excel, Access or other tools to allow further calculations and data manipulations.

No data may be uploaded to Datashed without first having an account. Users must type in their password before being able to access the data submission interface. Passwords protect Datashed from potential vandalism and false data entries and provide a traceable path to the source of the data. Data can be uploaded in several ways. For new organizations using Datashed, a tool has been developed to import large datasets in an electronic format. This tool assists in matching the fields within the organizations dataset to fields within Datashed. This tool also checks the data to ensure the data is within appropriate ranges (i,e., pH is between 0 and 14). Once an organization has imported the historic dataset, the organization could continue to use the import tool or they could use an interface where they simply type the data into an online form. For organizations that would like a comprehensive assessment of their passive treatment system, operation and maintenance forms can be created. Information, such as erosion, berm

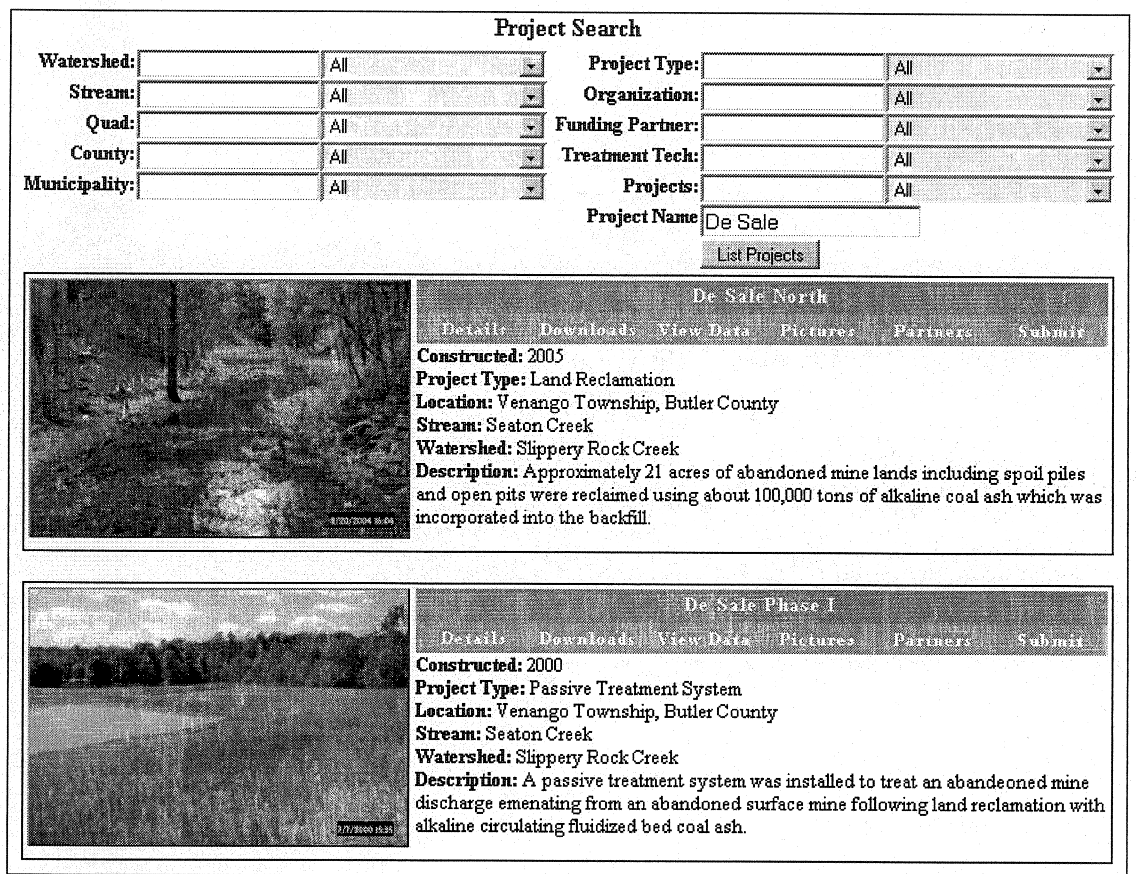

Figure 1: Project searches can be based on multiple parameters and by name.

stability, valve operability, etc., can be entered into an online form. In addition to water quality and operation and maintenance data, users may upload photos.

Once the data has been uploaded to Datashed, the data can be viewed or downloaded as stated previously. In addition, dynamically-generated graphs are available. These graphs use the most up-to-date information stored within Datashed at the moment they are generated. As new data is uploaded to Datashed, these graphs are updated to reflect these changes.

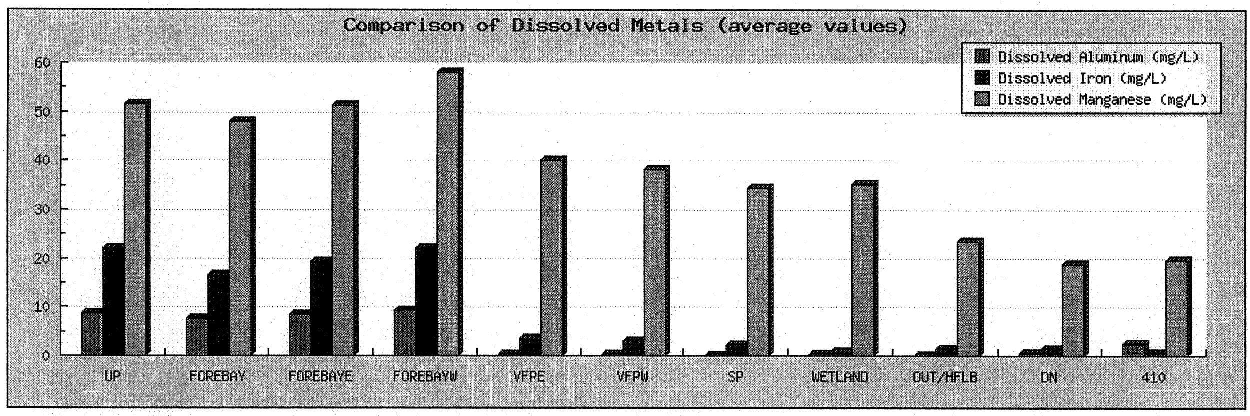

Figure 2: Example dynamically generated graph.

i-Map - Geographic Information System (GIS):
An innovative GIS application called i-Map has been developed to spatially connect the data stored in Datashed. The spatial component of Datashed is run utilizing MapServer, a robust, free and open source GIS software originally developed by the University of Minnesota ForNet project in cooperation with NASA and the Minnesota Department of Natural Resources (DNR). A wide variety of government agencies, non-profit organizations, businesses, and academia are actively involved in using and developing this software such as the US Army Corp of Engineers, Minnesota DNR, USDA Forest Service, and Canada Center for Remote Sensing and Natural Resources Canada. A custom-designed JavaScript/HTML interface allows users to easily find sampling points and directs users to additional content on the site. Each passive system can be queried for average water quality data. Terrabytes of additional geographic data are made available using Web Mapping Services (WMS), such as NASA's Landsat 7 satellite and USGS topographic maps, and on-the-fly projections. Not only can i-Map be a WMS client, i-Map can serve spatial data to other internet and desktop applications. In addition, customized GIS maps can be generated from parameters stored within the database, such as the topographic maps found in the download section of Datashed.

FACTS:
Funding AMD Chemistry for Treatment Systems (FACTS) is a program of WPCAMR offering funding for chemical analyses to watershed organizations in Pennsylvania. In cooperation with WPCAMR, many new features have been incorporated to Datashed to create a powerful data management system and repository for data collected for the FACTS program. FACTS standardizes the process of establishing a sampling schedule and coordinates the analysis of water samples with the watershed organization and participating laboratories.

Wiki:
A wiki is a collection of web pages that is edited by users. Datashed uses wikis in several different ways. Administrators of Datashed are capable of adding and modifying content within the Help pages without having to learn HTML or other programming languages, which also prevents accidents with the code. In addition, any organization using Datashed can use the Community Wiki to generate content that may be useful to other organizations, such as instructions on how to use different types of field sampling equipment.

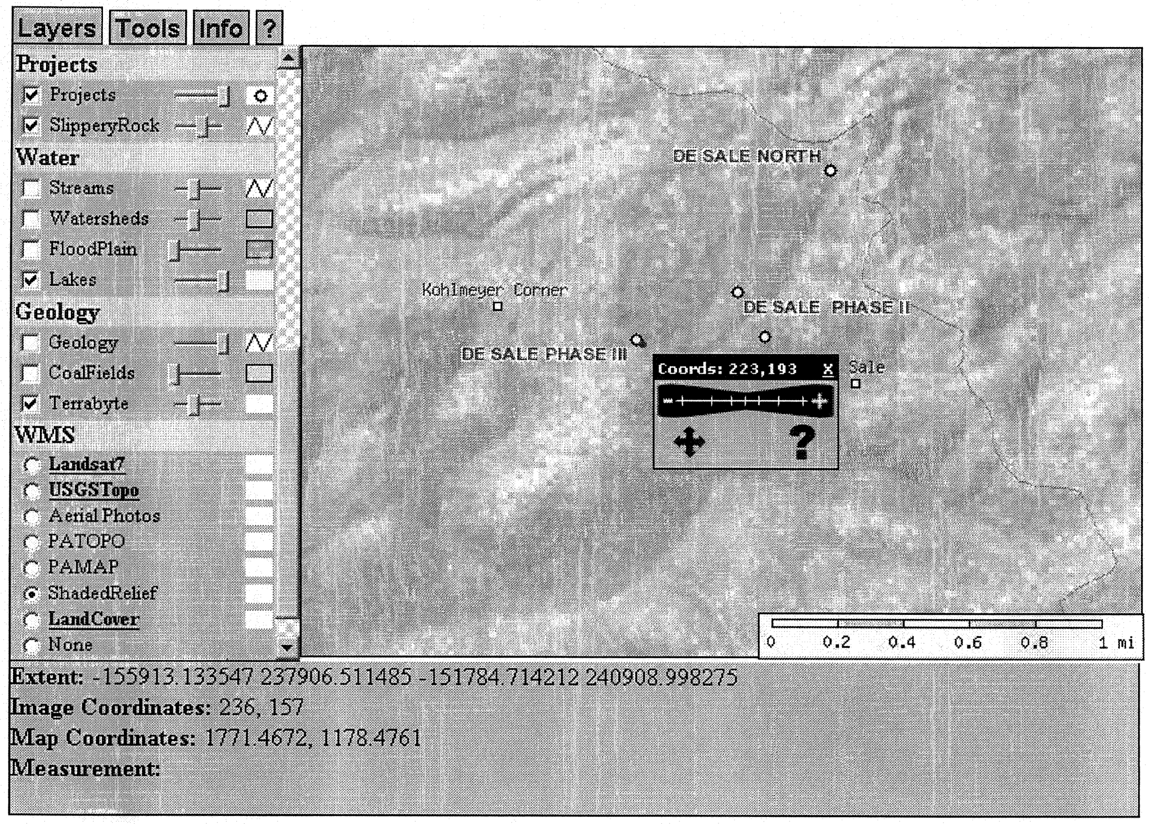

Figure 3: Screenshot of i-Map, the GIS component of Datashed.

Future Upgrades

Datashed is a work in progress. Additional features are being added to meet the needs of the project partners. Below is a list of a few of the more prominent feature requests:

1. Tutorials on using Datashed.
2. Allow the user to define custom graphs and reports based on date, location, etc.
3. Modeling of passive treatment systems to determine the effectiveness of the system and when maintenance may be needed.
4. Management interface to add, modify, transfer, or delete data.
5. Develop online tools to calculate flows (multiple methods) and loading, unit conversions (ex. gallons to liters), etc.

Conclusion

It is the goal of SRI for local groups to be actively involved in the operation, maintenance, and monitoring of treatment systems. Datashed has begun to help us achieve this goal. Although a work in progress, many features are currently available to store and distribute data on passive systems. Please send us any comments or suggestions to make the site even better!

THE EFFECTS OF SPECIFIC CONDUCTANCE OF WATER ON THE BENTHIC MACROINVERTEBRATE COMMUNITY DOWNSTREAM OF COAL MINING ACTIVITIES[1]

R.R. Maggard[2]

ABSTRACT

Regulatory agencies have been attempting to connect moderate (500 μs/cm) to high (>1000 μs/cm) specific conductance to the impairment of benthic macroinvertebrate communities and in turn to the impairment of receiving streams in regard to narrative water quality standards. The focus of these agencies has been to place the blame for these issues on Mountaintop Coal Mining and the associated construction of valley fills. Numerous studies have been issued from various regulatory agencies that employ a multitude of statistics and present various charts and tables, and yet lack the very detailed information in regard to actual land use activities needed in order to draw accurate and objective conclusions. A study conducted in southern West Virginia in four adjacent watersheds resulted in data conflicting with that of Pond et al. (2008). Specific conductivity was unrelated to the benthic macroinvertebrate communities present downstream of varying types of mine water discharge. Streams receiving mine water discharge yielded greater benthic community populations and diversity in comparison to the control stream receiving no mine water discharge.

KEY WORDS: Bioassessment, Mountaintop Coal Mining, Underground Coal Mining, Macroinvertebrate, Specific Conductance, West Virginia Stream Condition Index (WVSCI), Valley Fills Genus-Level Index of Most Probable Stream Status (GLIMPSS), Ephemeroptera, Sulfates, Calcium, Magnesium

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[1] Paper was presented at the West Virginia Mine Drainage Task Force Symposium, March 31-April 1, 2009.

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Editor's note: Due the number and length of tables in this paper, they were not included in the proceedings. They are available on the http//wvmdtaskforce.com website.

INTRODUCTION

The most recent study to present the arguments in regard to benthic impairment related to specific conductance and its relationship to mining activities was Pond et al. (2008). As presented in the Pond et al. report, mining impacts were categorized into three levels of disturbance as determined by specific conductance (Low <500 µs/cm, Medium 500-1000 µs/cm, High >1000 µs/cm) and its relationship with SO_4. However, it is stated within the Pond et al. report that "within the mined site data set, we found no evidence that MMI's (multimetric indices) were significantly correlated with the number of valley fills upstream or distance from the fill ($p>0.05$), but these indicators appeared to be related to our inexact estimates of the amount of mining in the watershed."

This author will present data based on exact information in regard to the degree of mining related disturbance in the watershed. Estimation of mining related disturbance based upon predetermined conductance or sulfate values will not be utilized.

METHODOLOGY

Various past studies have repetitively analyzed the same data with little regard to its accuracy and its correlation to the following: the type of mining, the targeted seam being mined, the size and stage of construction of valley fills, and the reclamation status of the operation. Little effort has been made to analyze the functional shift that sediment control ponds may cause in the benthic community.

The study sites have been evaluated regarding their land uses that may have contributed to elevated conductivities in order to investigate relationships between land use and conductivity. This report will present data collected in four (4) adjacent watersheds located in southern West Virginia near the town of Kiahsville in Wayne County: Big Branch, Tomblin Branch, Vance Branch, and Rocky Branch. These sites are located on tributaries of Trough Fork and are discussed in greater detail below (refer to FIGURE 1).

Site Descriptions

Big Branch

The Big Branch watershed contains 165 acres and was selected as a study site due to the negligible amount of surface disturbance present throughout the watershed. Big Branch discharges high conductivity water due to an indiscrete seepage through a 200-foot-wide outcrop barrier as a result of a flooded underground mine. The underground mine was sealed in 2000 and targeted the 5-Block coal seam. The Big Branch site allows the evaluation of water chemistry changes in the absence of sediment pond construction, valley fill construction, and other miscellaneous land clearing activities typically associated with mountaintop mining.

Tomblin Branch

The Tomblin Branch watershed contains 295 acres and was selected as a reference site because it receives no discharge from flooded underground mines or from surface mining activity, its location (across the hollow from Big Branch), and the negligible amount of surface disturbance present throughout the watershed.

Rocky Branch

The Rocky Branch watershed contains 129 acres and was selected as a study site because of its similarity to Big Branch. Rocky Branch contains an underground mine that has flooded and is now sealed. Seepage on the down-dip outcrop is contributing to the base flow of Rocky Branch.

Vance Branch

The Vance Branch watershed contains 404 acres and was selected as a study site because it contains a typical surface mine with two valley fills and four sediment ponds. The surface mine has been reclaimed since 2000 and had 275 acres of disturbance. The surface mine targeted the 5-Block coal seam.

Methods of Investigation

The four sites listed above were evaluated for benthic macroinvertebrates, aquatic habitat, and water chemistry. A modified EPA Field operations and methods manual for measuring the ecological condition of wadeable streams (EPA/620/R-94/004F) and EPA Rapid bioassessment protocols for use in streams and wadeable rivers (EPA 841-B-99-002) were followed in the collection of the benthic macroinvertebrate specimens, water chemistry, and habitat evaluations. Measurements for flow, physical water quality, and chemical water quality were collected at each site. Benthic macroinvertebrate samples were collected, and the physical habitat of each site was evaluated. To date, five sampling events have been conducted at the Big Branch and the Tomblin Branch sites: Fall 2007, Spring 2008, Summer 2008, Fall 2008, and Winter 2009. Only two sampling events have been conducted at the Rocky Branch and Vance Branch sites: Fall 2008 and Winter 2009. The individual methodologies are described below.

Water Chemistry

Because water quality is an important factor in determining the viability of an aquatic habitat, chemical water quality parameters were analyzed multiple times for each site. The following chemical water quality parameters were analyzed by REI Consultants, Inc.: acidity, alkalinity, total hardness, nitrate/nitrite, chloride, sulfate, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), total phosphorus, dissolved organic carbon, total aluminum, dissolved aluminum, antimony, arsenic, beryllium, cadmium, calcium, chromium, copper, total iron, dissolved iron, lead, total manganese, dissolved manganese, magnesium, mercury, nickel, potassium, selenium, silver, sodium, thallium, and zinc.

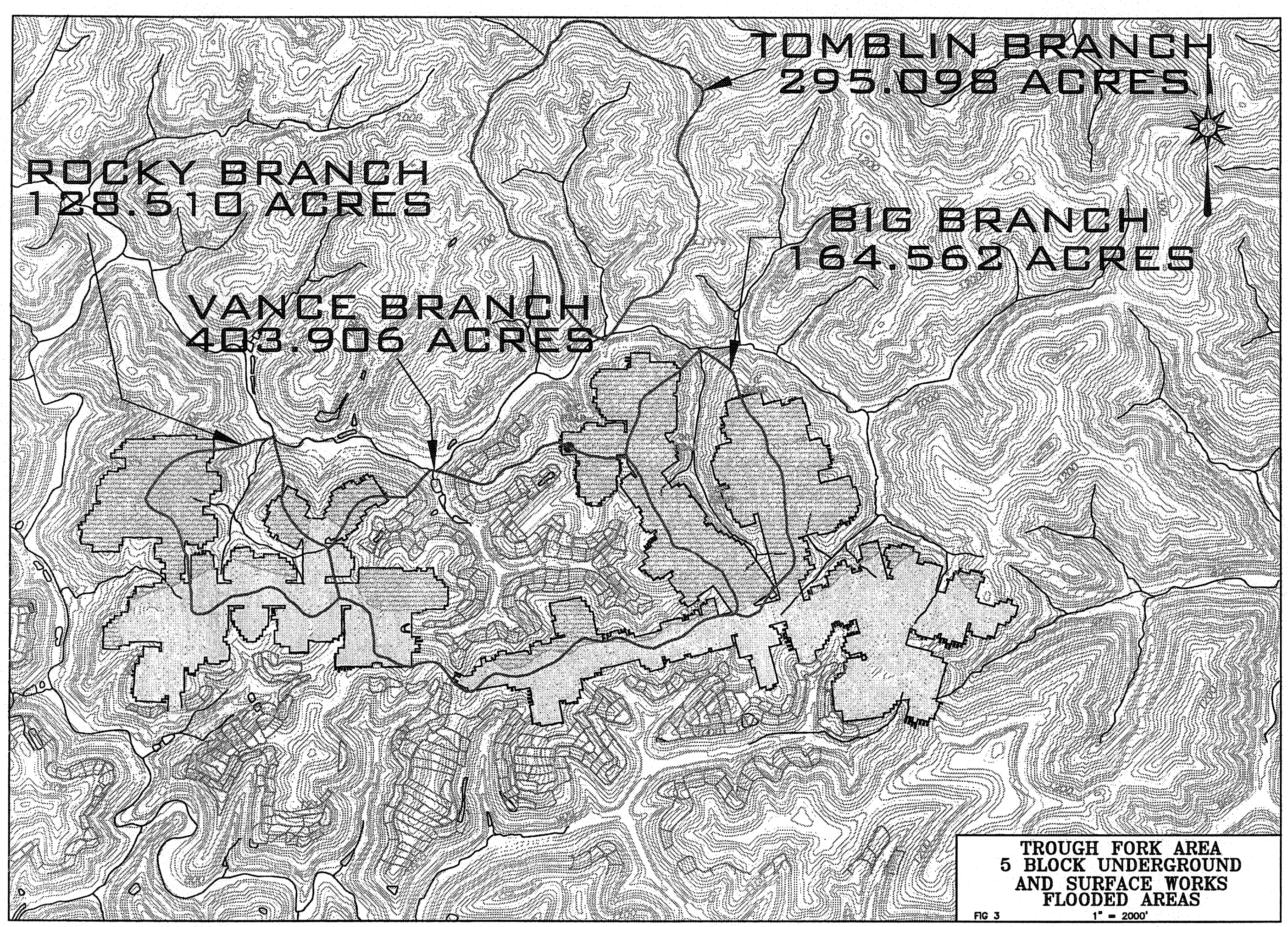

FIGURE 1 – Study watersheds illustrating location of surface mine and flooded underground mines

Physical Water Quality

REI also analyzed physical water quality parameters at each site, including water temperature, Dissolved Oxygen (DO), pH, and conductivity (measured with a Hydrolab™ Minisonde multi-parameter probe). Flow was measured with a Marsh-McBirney™ Model 2000 portable flow meter. Stream widths, depths, and velocities were measured, and the resulting average discharge was reported for each station.

Habitat Assessment

Habitat was assessed by REI Consultants, Inc. and rated on ten parameters in three categories using a modified version of the EPA Rapid bioassessment protocols for use in streams and wadeable rivers (EPA 841-B-99-002) in accordance with the "Programmatic Environmental Impact Statement (A Survey of the Condition of Streams in the Primary Region of Mountain Top Removal/ Valley Fill Coal Mining - March 1999, U.S. EPA, Region III).

Benthic Macroinvertebrate Collection

A modified EPA Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers (EPA 841-B-99-002) was followed in the collection of the benthic macroinvertebrate specimens. At each station, macroinvertebrate collections were made via a 0.1 m^2 Surber sampler and a 0.25 m^2 "D-Frame" kick-net sampler. Both samplers were fitted with a 500-Φm mesh size net. Three quantitative replicates samples were collected in a riffle area by Surber sampling. Four semi-quantitative "D-Frame" kick-net samples were composited from a riffle/run area to equal 1-m^2 sampling area.

Samples were placed in 1-liter plastic containers, preserved in 35% formalin, and returned to the laboratory for processing. Samples were then picked under microscope, and detrital material was discarded only after a second check to insure that no macroinvertebrates had been missed. All macroinvertebrates were identified to lowest practical taxonomic level and enumerated.

Several benthic macroinvertebrate metrics were then calculated for the station. The WV-SCI score was calculated using the 200 organism method. The kick sample from each station was spread onto a gridded sieve. Grids were selected at random and picked under dissecting scopes, until 200 insects (+/- 10%) were obtained. Those insects were then identified to the lowest practical taxonomic level, and this data was used to calculate the WV-SCI score. Any remaining grids were then picked to determine the number of insects in the total kick sample. The insects were then identified and added to the original 200. The Surber samples were picked completely, and all insects were identified. These insect counts were then added to those taken from the kick sample in order to obtain the total station abundance. All metrics, excluding the WV-SCI score, were then calculated from the total station abundance.

Benthic Macroinvertebrate Metrics

REI Consultants, Inc. calculated several benthic macroinvertebrate measurements for each of the sampling stations. Twelve (12) individual metrics were calculated and are as follows: Taxa richness; Modified Hilsenhoff Biotic Index; Ratio of Scraper and Filtering Collector Functional Feeding Groups; Ratio of Ephemeroptera, Plecoptera, Trichoptera (EPT) and Chironomidae Abundances; Percent Contribution of Mayflies; Percent Contribution of Dominant Family; EPT Index; Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected; Simpson's Diversity Index; Shannon-Wiener Diversity Index; Shannon-Wiener Evenness; and the West Virginia Stream Condition Index (WV-SCI).

<table>
<tr><th>Range</th><th>Rank</th><th></th></tr>
<tr><td>78 to 100</td><td>"Very Good"</td><td rowspan="3">Not Impaired</td></tr>
<tr><td>68 to 78</td><td>"Good"</td></tr>
<tr><td>60 to 68</td><td>"Gray Zone"</td></tr>
<tr><td>45 to 60</td><td>"Slightly Impaired"</td><td rowspan="3">Impaired</td></tr>
<tr><td>22 to 45</td><td>"Moderately Impaired"</td></tr>
<tr><td>0 to 22</td><td>"Severely Impaired"</td></tr>
</table>

These metrics are described in greater detail in Kirk and Johnston 2009[3].

RESULTS[4]

Physical Descriptions and Habitat Evaluations

Big Branch

This station is located on Big Branch, an undisturbed tributary of Trough Fork which receives underground mine drainage. The benthic sampling station is located at approximately 38° 02' 24.9" latitude and 82° 13' 08.1" longitude. Coarse Particulate Organic Matter (CPOM) was moderate and Large Woody Debris (LWD) has usually been sparse. This station is located in a forested area, and has a shaded canopy of mixed tree species. The substrate has been comprised recently of approximately 5% sand, 75% gravel, and 20% cobbles. This substrate composition would provide sub-optimal to optimal aquatic habitat.

Physical water quality measurements from the five sampling events are as follows: stream flow ranged from a very low 0.0525 to a moderate 0.26 ft^3/s; water temperature ranged from 0.2 to 18.8°C; pH ranged from near-neutral 7.09 to a somewhat alkaline 7.77; Dissolved Oxygen (DO) ranged from 8.39 to 13.6 mg/1; and conductivity ranged from a moderately high 543 to a high of 1,550 µs (TABLE 1A[5]).

[3] Kirk E. and Johnston R.. 2009. A summary of the benthic macroinvertebrate and water chemistry of Big Branch, Tomblin Branch, Rocky Branch, and Vance Branch. Conducted for Argus Energy WV, LLC by REI Consultants, Incorporated.

[4] Kirk E. and Johnston R.. 2009. A summary of the benthic macroinvertebrate and water chemistry of Big Branch, Tomblin Branch, Rocky Branch, and Vance Branch. Conducted for Argus Energy WV, LLC by REI Consultants, Incorporated.

[5] Because of the length and number of tables in this report, the tables are not included in the proceedings, but are available at the http//wvmdtaskforce.com website.

This station generally receives marginal to sub-optimal substrate and available cover (primary) ratings, sub-optimal to optimal channel morphology (secondary) ratings, and sub-optimal to optimal riparian and bank structure (tertiary) ratings. Primary limitations of the habitat at this survey site include: "Epifaunal Substrate and Available Cover", "Velocity-Depth Regime", and "Channel Flow Status". This station has scored from a 136 to a 156 (mean = 146) out of a possible 200 (TABLE 3A), and would generally provide sub-optimal aquatic habitat.

Tomblin Branch

This station is located on Tomblin Branch, an undisturbed, reference tributary of Trough Fork, which receives no supplemental flow from mining drainages. The benthic sampling station is located at approximately 38° 02' 39.6" latitude and 82° 13' 28.6" longitude. Coarse Particulate Organic Matter (CPOM) has usually been moderate, and Large Woody Debris (LWD) has been sparse. This station is located in a forested area, near a road and a residence, and has a partly-shaded canopy of mixed tree species. The substrate has been comprised of approximately 5% sand, 54% gravel, 40% cobble, and 1% boulder. This substrate composition would provide sub-optimal to optimal aquatic habitat.

Physical water quality measurements for the five sampling events are as follows: stream flow ranged from "no-flow" to a moderate 0.441 ft^3/s; water temperature ranged from 0.7 to 21.2° C; pH ranged from an acidic 5.93 to a slightly acidic 6.72; Dissolved Oxygen (DO) ranged from a limiting 1.4 during the no-flow event of Fall 2008 to a 14.7 mg/1 in the Winter 2009; and conductivity ranged widely from a very low 49 to a moderate 470 µs (TABLE 1B).

This station generally receives marginal to sub-optimal substrate and available cover (primary) ratings, sub-optimal to optimal channel morphology (secondary) ratings, and poor to sub-optimal riparian and bank structure (tertiary) ratings. However, during the Fall 2008 sampling event, stream flow was virtually non-existent, and the flow-related parameters such as "Velocity-Depth Regime", "Channel Flow Status", and "Frequency of Riffles" suffered considerably. During the Winter 2009 sampling event, stream flow increased considerably, but some of the variables such as "Embeddedness", "Bank Vegetation Protection", and "Riparian Zone Width" still limit this reference site. This station has scored from a 68 to a 127 (mean = 109) out of a possible 200 (TABLE 3B), and would generally provide marginal to sub-optimal aquatic habitat. Although this station is a reference site, it is limited some seasons by the available stream flow, and the lack of stream flow precludes some deeper, faster habitat types from occurring within the sampling reach.

Rocky Branch

This station is located on Rocky Branch, an undisturbed tributary of Trough Fork which receives underground mine drainage. The benthic sampling station is located at approximately 38° 02' 16.2" latitude and 82° 14' 37.3" longitude. Coarse Particulate Organic Matter (CPOM) has been moderate, and Large Woody Debris (LWD) was recorded lately as being moderate. This station is located in a forested area, and has a shaded canopy of mixed tree species. The substrate was recently visually assessed to comprise approximately 15% sand, 15% gravel, 60% cobble, and 10% boulder. This substrate composition would provide sub-optimal to optimal aquatic habitat, but the amount of sand could become limiting at times.

Physical water quality measurements from the two seasonal sampling events are as follows: stream flow has been very low and ranged from 0.018 to 0.079 ft^3/s; water temperature ranged from 0.2 during the Winter 2009 to 10.8°C in Fall 2008; pH was slightly alkaline in Fall 2008 with 7.58 to acidic in Winter 2009 with 6.45; Dissolved Oxygen (DO) ranged from 11.8 to 15.4 mg/1; and conductivity ranged from a fairly high 663 in Winter 2009 to a very high 1,650 µs in Fall 2008 (TABLE 1C).

This station received sub-optimal substrate and available cover (primary) ratings, marginal to optimal channel morphology (secondary) ratings, and marginal to optimal riparian and bank structure (tertiary) ratings. Primary limitations of the habitat at this survey site have included: "Epifaunal Substrate and Available Cover", "Embeddedness", "Channel Flow Status", and "Bank Vegetation Protection". This station scored a 132 in Fall 2008 and a 139 in Winter 2009 out of a possible 200 (TABLE 3C), and would generally provide sub-optimal aquatic habitat.

<u>Vance Branch</u>

This station is located on Vance Branch, a heavily mining-influenced tributary of Trough Fork which contains fills and sediment control structures (ponds), and receives all of its downstream flow through the ponds. The benthic sampling station is located at approximately 38° 02' 11.0" latitude and 82° 14' 03.1" longitude. Coarse Particulate Organic Matter (CPOM) has been moderate, and Large Woody Debris (LWD) was recently recorded as moderate. This station is located in a forested area, and has a shaded canopy of mixed tree species. The substrate was recorded as being comprised of approximately 1% sand, 19% gravel, 20% cobble, and 60% boulder. This substrate composition would provide sub-optimal aquatic habitat, due to the very large proportion of boulders, and less than optimal amount of cobbles.

Physical water quality measurements from the two sampling events are as follows: stream flow was a moderate 0.268 in Fall 2008 and a desirable 1.331 ft^3/s in Winter 2009; water temperature ranged from a 4.1 to 16.8°C; pH was a somewhat alkaline 7.54 to 7.91; Dissolved Oxygen (DO) ranged from 10.2 to 13.1 mg/1; and conductivity was a very high 2,090 to 2,100 µs (TABLE 1C). Because this site is located downstream from the existing fills and sediment ponds, stream flow is more substantial (and perennial), water temperatures are warmer, and conductivity is higher.

This station has received marginal to sub-optimal substrate and available cover (primary) ratings, marginal to optimal channel morphology (secondary) ratings, and sub-optimal to optimal riparian and bank structure (tertiary) ratings. Primary limitations of the habitat at this survey site include: "Epifaunal Substrate and Available Cover", "Velocity-Depth Regime", and "Channel Alteration". This station scored tightly between a 134 and a 139 out of a possible 200 (TABLE 3D), and would generally provide sub-optimal aquatic habitat. A lack of deeper pools, somewhat embedded substrate, and the "altered" channel all limit this site, even though stream flow is adequate.

Physical and Chemical Water Quality Analysis

Water quality is a very important factor in determining the viability of the aquatic habitat. Although stream flow, substrate, and stream geomorphology are also important, water quality can be the most limiting function of a stream ecosystem. Heinen (1996) and Jenkins et al. (1995) address the ranges of some chemical water quality constituents within West Virginia watersheds.

Water Quality Parameter	Range for Freshwater Organisms	Source
pH	6 to 9	Stumm and Morgan 1996
Acidity	not available	
Alkalinity	10 to 400 mg/L	Jenkins et al. 1995
Calcium	4 to 160 mg/L	Heinen 1996
Chloride	< 230 mg/L	CSR 46 WVDEP
Conductivity	not available	
TDS	not available	
Sulfate	< 850 mg/L	Jenkins et al. 1995
Iron	< 1 mg/L	Jenkins et al. 1995
Magnesium	< 28 mg/L	Heinen 1996
Manganese	< 1.0 mg/L	Heinen 1996; Jenkins et al. 1995
Selenium	< 0.005 mg/L	US EPA 1986
Aluminum	< 0.750 mg/L	CSR 47 WVDEP
Hardness	10 to 400 mg/L	Heinen 1996

Big Branch

Physical and chemical water quality was analyzed seasonally on Big Branch. Physical water quality on Big Branch has generally shown adequate stream flow, desirable dissolved oxygen, near-neutral to alkaline pH levels, and moderately-high to highly elevated conductivity (TABLE 1A). Chemical water quality at this station has revealed some minor acidity, but adequate levels of alkalinity to offset any impacts from the acidity. Modest levels of TDS, sulfate, and hardness exist, but these are not surprising since the stream obtains underground mine drainage at all times into its stream flow (TABLE 2A). These levels are well within acceptable ranges for freshwater organisms. Trace amounts of nitrate/nitrite, iron, manganese, and aluminum persist, but these levels are also well within acceptable ranges. Magnesium appears to be the only metal constituent which exceeds recommended levels. Levels of conductivity are considered to be quite high, although recommended criteria have not been established. The levels of many of the parameters were highest during the Fall 2008 when stream flow was at its lowest level. This is not surprising, since it would be at this timeframe that the proportion of mine waters to natural stream waters would be at its highest level, and therefore comprise a considerable amount of the flow. Overall water quality was considered fairly desirable at this station located on Big Branch with the exception of the conductivity, hardness, and magnesium.

<u>Tomblin Branch</u>

Physical and chemical water quality was also analyzed seasonally on Tomblin Branch. Physical water quality on Tomblin Branch has generally shown adequate dissolved oxygen and low conductivity levels, but because this watershed is relatively undisturbed, stream flows are more "natural" in flow, and are therefore, very low in the summer months, and can become non-flowing within very dry fall seasons (TABLE 1B). Additionally, when low-flow conditions are present, dissolved oxygen levels can plummet within the few standing puddles of water (TABLE 1B). Stream pH levels were generally lower than those observed on Big Branch, and were limiting during the Spring 2008 and Winter 2009 sampling events. Very little alkalinity was present at these two timeframes, and although acidity was low, it exceeded the alkalinity present, resulting in net-acidic waters. The reason for this is likely due to a recent "flushing" of tannins and acid-bearing materials into the stream from precipitation events. The winter snow melts and spring rains can flush large amounts of tannic acids into the streams, and those systems with low natural alkalinity are more susceptible to acid problems. The streams with mining influences such as fills, and especially those with sediment ponds in their headwaters, can also have smoother flow regimes rather than the very sporadic flows of undisturbed headwater streams. Conductivity in Tomblin Branch is quite low, with the exception of the no-flow event of Fall 2008, where water quality samples were collected from a standing puddle. Chemical water quality at this station has revealed some minor acidity, but adequate levels of alkalinity (TABLE 2B). Levels of acidity in Tomblin Branch were higher than those of Big Branch; levels of alkalinity in Tomblin Branch were lower than those of Big Branch. This results in Tomblin Branch having a considerably lower pH level. Low levels of hardness, nitrate/nitrite, sulfate, chloride, and almost all metals were observed in Tombin Branch during all sampling events except for the Fall 2008 event. The no-flow conditions during that sampling season undoubtedly resulted in a concentration of the chemical constituents (TABLE 2B). Other than the low pH during Spring 2008 (5.93) and the limiting DO level of Fall 2008, most other variables were well within acceptable ranges for freshwater organisms. Because the water quality of Tomblin Branch is quite desirable for benthic organisms during normal to higher flow levels, it appears that the amount of water present within Tomblin Branch itself may be the most limiting variable.

<u>Rocky Branch</u>

Physical and chemical water quality has been analyzed only twice on Rocky Branch; during the Fall 2008 and during the Winter 2009. Physical water quality on Rocky Branch showed some very low, but adequate stream flows, desirable dissolved oxygen, somewhat acidic to somewhat alkaline pH levels, and widely-ranging, but elevated conductivity (TABLE 1C). Chemical water quality at this station revealed some minor acidity, but an adequate level of alkalinity. During the Fall 2008 sampling event, the very low flows resulted in fairly high levels of hardness, TDS, sulfate, and magnesium (TABLE 2C), but these are not too surprising since the stream receives some seepage from a 5-Block underground mine that produces acidic water when pumped during active mining. Almost all metals such as aluminum, iron, manganese, and selenium are quite low, and are well within acceptable ranges for freshwater organisms. During the higher flows of the Winter 2009 sampling event, most parameters such as hardness, nitrate/nitrite, sulfate, TSS, TDS, aluminum, calcium, manganese, magnesium, and sodium were considerably lower than the Fall 2008 event. A few parameters such as iron, selenium, chloride, and DOC were very similar between the two events. The combination of a few parameters at or just above limiting levels such as hardness, sulfate, TDS, conductivity, and magnesium may be limiting however to the aquatic fauna of Rocky Branch when flows are drastically low. Overall, water quality was considered much more desirable during the Winter 2009 at Rocky Branch compared to the Fall 2008. The increased proportion of natural waters to mine waters helps in diluting some of the elevated levels of potentially limiting constituents.

Vance Branch

Physical and chemical water quality has been analyzed only twice on Vance Branch; during the Fall 2008 and the Winter 2009 sampling events. Physical water quality on Vance Branch had showed an adequate to desirable stream flow, desirable dissolved oxygen levels, somewhat alkaline pH levels, and highly elevated conductivity levels (TABLE 1C). Chemical water quality at this station revealed little to some acidity, and adequate levels of alkalinity. High levels of hardness, TDS, sulfate, and magnesium existed during both the Fall 2008 and the Winter 2009 sampling events (TABLE 2C). These elevated levels are due to surface mining in the 5-Block coal seam, and the mine waters are actively being treated for iron and manganese. Almost all metals such as aluminum, iron, lead, zinc, and selenium are quite low, and are well within acceptable ranges for freshwater organisms. There was a high level of manganese during the Winter 2009 sampling event, but this was not observed during the Fall 2008 event. The combination of a few parameters at, or just above limiting levels such as hardness, sulfate, TDS, conductivity, and magnesium may be limiting to the aquatic fauna of Vance Branch. Overall, water quality was considered somewhat undesirable at this station on Vance Branch due to the elevated levels of a few key constituents.

Benthic Macroinvertebrate Results

Big Branch

Benthic samples were collected at Big Branch in Fall 2007, Spring 2008, Summer 2008, Fall 2008, and Winter 2009. The total abundance of benthic macroinvertebrates at this site ranged from 470 individuals in Winter 2009 to 2,383 individuals in Fall 2008 representing from 28 to 43 taxa (TABLE 4A). Benthic communities were fairly well balanced with similar proportions of sensitive, facultative, and tolerant individuals, even during the drought periods of Fall 2008 and mid-Winter 2009. Wide varieties are large abundances of mayflies, stoneflies, and caddisflies were collected with the exception of mayflies during the Summer and Fall 2008 surveys (TABLES 4A & 5A). It would be during these lower-flow seasons that the proportion of mine waters would be highest compared to the "natural" waters in the stream from precipitation events or groundwater. The percentages of shredders within the stream at all sampling events was high, and ranged from 20.9% to 61.7% (TABLE 5A). The WV-SCI as calculated from the 200-bug count sample, was usually quite good, and ranged from 62.8 to 86.4 (TABLE 5A). The WV-SCI score was even high during the Winter 2009 event with a score of 83.8 (TABLE 5A). The lower score during the Summer 2008 was not so much a reflection of low flows as it was likely due to a seasonal difference with most of the mayflies emerging from the stream by this timeframe. Overall, the five separate benthic sampling events on Big Branch resulted in desirable outcomes, even though a large proportion of the streamflow in Big Branch can be attributed to down dip outcrop seepage which consists of high conductivity, high hardness, and at times, elevated levels of magnesium.

Tomblin Branch

Benthic samples were collected at Tomblin Branch in Fall 2007, Spring 2008, Summer 2008, Fall 2008, and Winter 2009. The total abundance of benthic macroinvertebrates at this site ranged from 187 to 505 individuals representing from 7 to 34 taxa (TABLE 4B). Benthic communities were facultative/tolerant in Fall 2007; were more sensitive in Spring 2008; and were very tolerant during the Summer 2008 and Fall 2008 surveys (TABLE 4B). The community was split in Winter 2009 with relatively large proportions of sensitive and tolerant individuals, but not many facultative ones. With Tomblin Branch being entirely dependent upon precipitation events, low-flow periods such as summer and the drought conditions of Fall 2008 dramatically affect the benthic and fisheries communities inhabiting these streams. With the Spring 2008 season having the highest flows on Tomblin Branch (TABLE 1B), the stream contained a very sensitive benthic community consisting of a wide variety of taxa. Total station abundance was low, but the EPT index (number of EPT taxa present) was 17 (TABLE 5B). The Winter 2009 sample contained flows not much more than during the Summer 2008, and therefore, the resulting number of individuals and WV-SCI were very comparable (TABLES 4B & 5B). For the Fall 2007, Summer 2008, Fall 2008, and Winter 2009, due to the low and limiting stream flows, mayflies were completely absent, stoneflies were very sparse, and caddisflies were almost non-existent (TABLE 4B). The percentages of shredders within the stream ranged dramatically from 2.5% during the Fall 2008 to 30.1% during the best flow season of Spring 2008 (TABLE 5B). The WV-SCI as calculated from the 200-bug count sample, was poor, and the stream would be considered as "impaired" 4 out of the 5 sampling seasons, even though this is an undisturbed reference stream. During the Spring 2008, when flows were at their highest, the WV-SCI was very desirable with a 91.4 (TABLE 5B). Overall, four out of the five separate benthic sampling events on Tomblin Branch resulted in poor outcomes, with the stream being undoubtedly very dependent upon streamflow. Water chemistry was usually desirable, but the low-flows were definitely the limiting factor affecting Tomblin Branch. No other water chemistry parameter was at levels limiting to sensitive aquatic fauna.

Rocky Branch

Benthic samples were collected, to date, at Rocky Branch only in the Fall 2008 and Winter 2009. The total abundance of benthic macroinvertebrates at this site has been low with 90 individuals in Winter 2009 to 377 individuals in Fall 2008. Diversity has been desirable with

20 and 28 taxa, respectively (TABLE 4C). The benthic community was fairly well balanced in Fall 2008 with similar proportions of sensitive, facultative, and tolerant individuals. In Winter 2009, the site was actually fairly sensitive. A modest variety of stoneflies and caddisflies were collected in Fall 2008; mayflies were absent (TABLE 4C). However, in Winter 2009 when flows were much higher, mayflies were back (13.3%) and the number of EPT taxa increased to 9 of the 20 taxa present (TABLES 4C & 5C). The percentage of shredders within the stream was high both events with over 30.0%, and the station was considered to be quite diverse given that total station abundance was low. The WV-SCI as calculated from the 200-bug count sample has not been overly desirable, with scores of 61.5 and 64.8, but these scores are not too poor considering that the first was within a very serious drought, and the second was within the mid-winter. The Fall 2008 season was influenced heavily by the drought, and water chemistry was limiting. However, because stream flows were supplemented by outcrop seepage, the stream remained perennial, and the WV-SCI score was actually higher than those of undisturbed reference stream, Tomblin Branch. Rocky Branch has scored higher than Tomblin Branch during the Fall 2008 and Winter 2009 surveys (TABLES 5B & 5C). As stated previously, Rocky Branch is limited by water quality parameters such as hardness, sulfate, TDS, conductivity, and magnesium, but maintains perennial flow. Overall, it will be interesting to see how well Rocky Branch does during other sampling events compared to the reference stream and other mining-influenced streams.

Vance Branch

To date, benthic samples were collected at Vance Branch only in the Fall 2008 and in Winter 2009. The total abundance of benthic macroinvertebrates at this site has been moderately high with 499 and 467 individuals, respectively. However, diversity has been considered low with 13 and 12 taxa, respectively (TABLE 4D). The benthic community was quite facultative in Fall 2008 with 96.6% of the individuals collected being considered facultative. In Winter 2009 the community shifted towards a less facultative and more tolerant community. A large number but low variety of caddisflies have been collected; mayflies and stoneflies were absent during both the Fall 2008 and Winter 2009 seasons, with the exception of a single stonefly individual (TABLE 4D). The percentage of shredders within the stream has been quote low with 3.4 and 4.3%, and diversity indices such as Simpson's and Shannon-Wiener considered the stream to be poorly diversified (TABLE 5D). The WV-SCI as calculated from the 200-bug count sample has not been very desirable with scores of 44.2 and 48.8, but again, the Fall 2008 season was within a very substantial drought, and water chemistry was limiting. Likewise, winter months do not normally produce very healthy benthic communities. However, as with Rocky Branch, because stream flows at this sampling point are below existing sediment ponds, the stream remains perennial, and the WV-SCI scores were actually higher than those of the undisturbed reference stream, Tomblin Branch. Tomblin Branch during the same timeframe had a Fall 2008 WV-SCI score of 25.2 and a Winter 2009 WV-SCI score of 33.7 (TABLE 5B), compared to the Vance Branch scores of 44.2 and 48.8 during the same periods (TABLES 5B & 5D).

DISCUSSION[5]

An optimal benthic macroinvertebrate community is characterized by a high relative abundance of pollution sensitive and facultative individuals, high species diversity, and the presence of all functional feeding groups. The quality of the benthic macroinvertebrate community is dependent on water quality, physical habitat characteristics, riparian vegetation, and amount of human disturbance. Optimal physical water quality is characterized by good stream flow all year, neutral pH values, and dissolved oxygen levels >5 mg/L. Good chemical water quality should indicate low levels of total and dissolved metals, low dissolved and suspended solids, and residual buffering capacity.

A substrate containing a large percentage of cobble sized particles, with minimal embeddedness and sediment deposition would provide an optimal physical habitat. Good bank stability, stream side cover comprising native vegetation, and a riparian buffer zone between the stream and human impacts are necessary to provide appropriate nutrient cycling and minimize erosion.

This study had several interesting observations made:

- Tomblin Branch, the undisturbed reference stream, rated very healthy during periods when stream flow was adequate (WV-SCI of 91.4), but has rated poorly when its biggest limiting factor (the stream flow) was low (WV-SCI scores of 54.0, 36.9, 25.2, and 33.7).

- Big Branch, a stream which receives perennial down-dip outcrop seepage, but has no physical mining disturbances, scored fairly well throughout various seasons, and only appeared to lose some of its good WV-SCI rating during the Summer 2008 survey when mayflies would be normally absent. This site scored well even in mid-Winter 2009 when the site scored an WV-SCI of 83.8. The desirable results have occurred even though water chemistry variables such as conductivity, TDS, sulfates, and (at times) magnesium, were elevated, and led to the observation that "sometimes mine water is better than little or no water."

- Rocky Branch, a perennial stream which also receives some of its flow from outcrop seepage from a separate 5-Block underground mine that produced acidic water when pumped during active mining, scored moderately-well, and contained some mayflies, stoneflies, and caddisflies. Both Rocky Branch and Big Branch are physically undisturbed watersheds but Rocky Branch has poorer water quality with higher levels of conductivity, magnesium, TDS, and several metals. Nevertheless, Rocky Branch has had better WV-SCI scores (61.5 and 64.8) during the same timeframe as Tomblin Branch (25.2 and 33.7), and again contributed to the statement that "at times, mine water may be better than little to no water."

[5] Kirk E. and Johnston R.. 2009. A summary of the benthic macroinvertebrate and water chemistry of Big Branch, Tomblin Branch, Rocky Branch, and Vance Branch. Conducted for Argus Energy WV, LLC by REI Consultants, Incorporated.

- Vance Branch, a perennial stream located directly downstream of fills and sediment ponds, and in a heavily surfaced mined watershed, contained a moderate number of individuals, but undoubtedly, the poorer water quality and the disturbances to the watershed have affected this stream noticeably. Taxa richness is low and mayflies and stoneflies are basically absent. It is not anticipated that Vance Branch would rate considerably better in the Spring, as water quality and habitat would not greatly improve, but it is notable that Vance Branch (WV-SCI scores of 44.2 and 48.8) scored better than the reference stream, Tomblin Branch (WV-SCI scores of 25.2 and 33.7), during the same timeframe.

- A graphical comparison between stream flows and the calculated WV-SCI score did not reveal a good correlation (FIGURE 2). However, the amount of volumetric flow for one stream may be more beneficial to one stream than another. For instance, 100 gallons per minute flowing in a 3 feet wide stream may be adequate for fish migration, but not be enough to wet the cobbles on a channel twenty feet wide. Although Big Branch, Tomblin Branch, Rocky Branch, and Vance Branch were quite similar in size, it is difficult to compare numerical flows between the streams. Further, differences in water chemistry also played a major role in the WV-SCI scores of each stream; only Tomblin Branch with its very desirable water chemistry, was limited by the amount (or lack thereof) of stream flow.

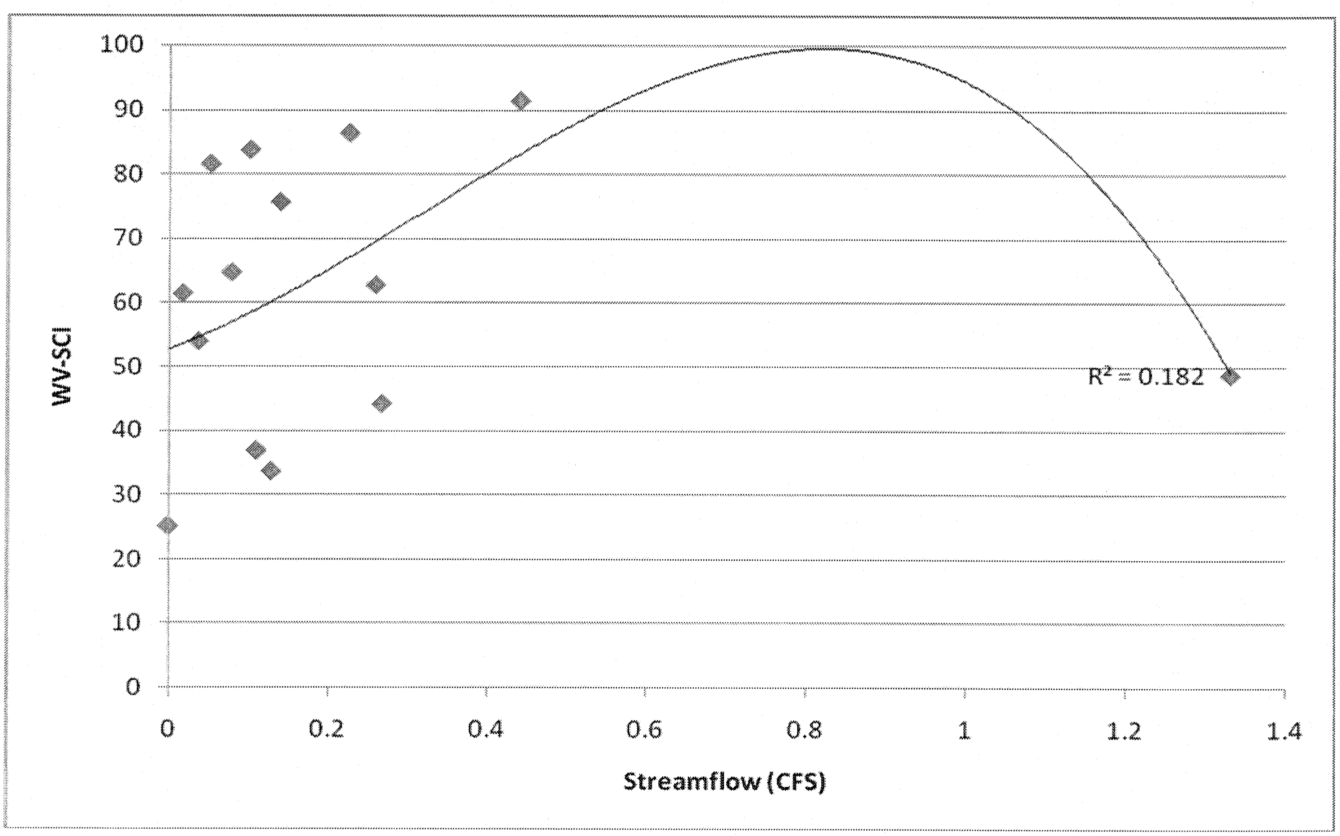

FIGURE 2. Chart showing relationship of streamflow to WV-SCI score for Big Branch, Tomblin Branch, Rocky Branch, and Vance Branch. All sampling dates shown. REI Consultants, Inc.

CONCLUSIONS

A comparison of the data presented in this study to that of the data presented by Pond et al. (2008) raises several questions. These questions are discussed below.

Question 1:

Big Branch exhibits high specific conductivity with no mountaintop mining or valley fill construction. However, Big Branch continued to have a Mayfly community. Is it possible that the reductions in Mayflies observed by Pond et al. (2008) are not attributed to high conductivity but the effects of sediment ponds or changes in vegetation? If this is so, sediment ponds and vegetation shifts are temporary effects of surface mining that are more easily remediated if deemed necessary.

Question 2:

Briefly reviewing the data collected from Vance Branch a dramatic increase of filter feeders can be seen. Filter feeders would be the expected benthic community present immediately downstream of an impounding structure such as a sediment pond. Are large populations of Mayflies expected to be found below such structures?

In light of this information, the author recommends that the regulatory agencies reconsider the issue of biological impairment and the methods currently utilized to measure its severity. Improving the quality of aquatic resources requires a close examination of success stories-as well as alleged failures-and the collaboration of all agencies and individuals involved.

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FIGURE 3. EPA Habitat

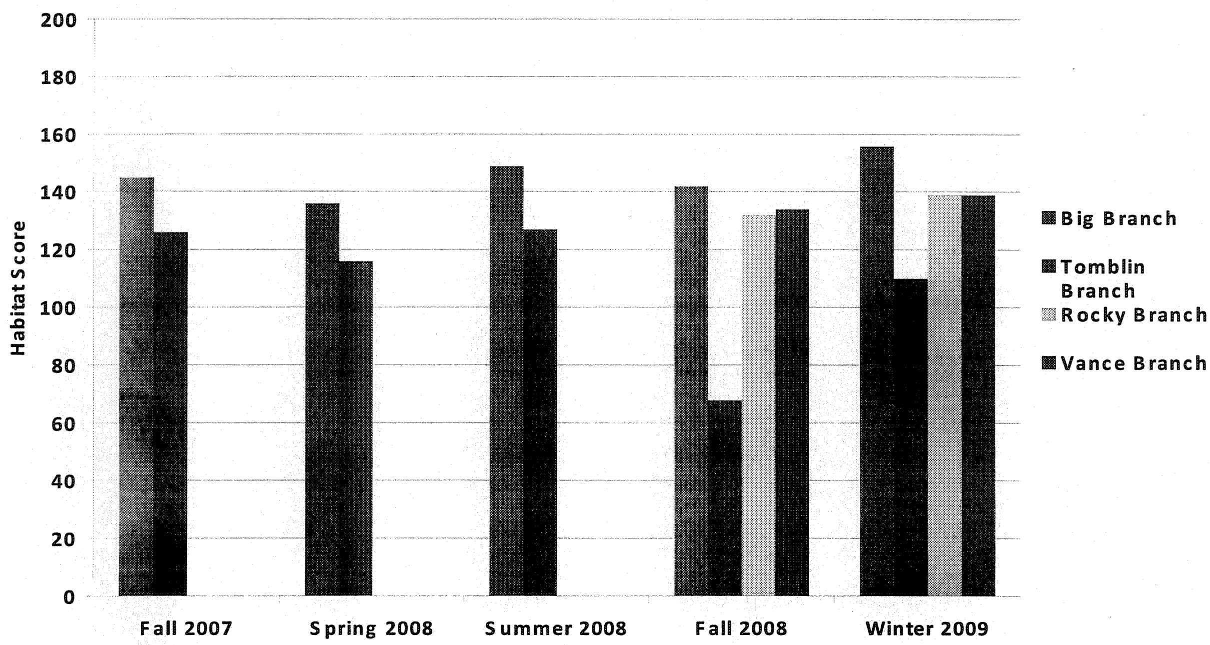

FIGURE 4. % EPT of Total Abundance

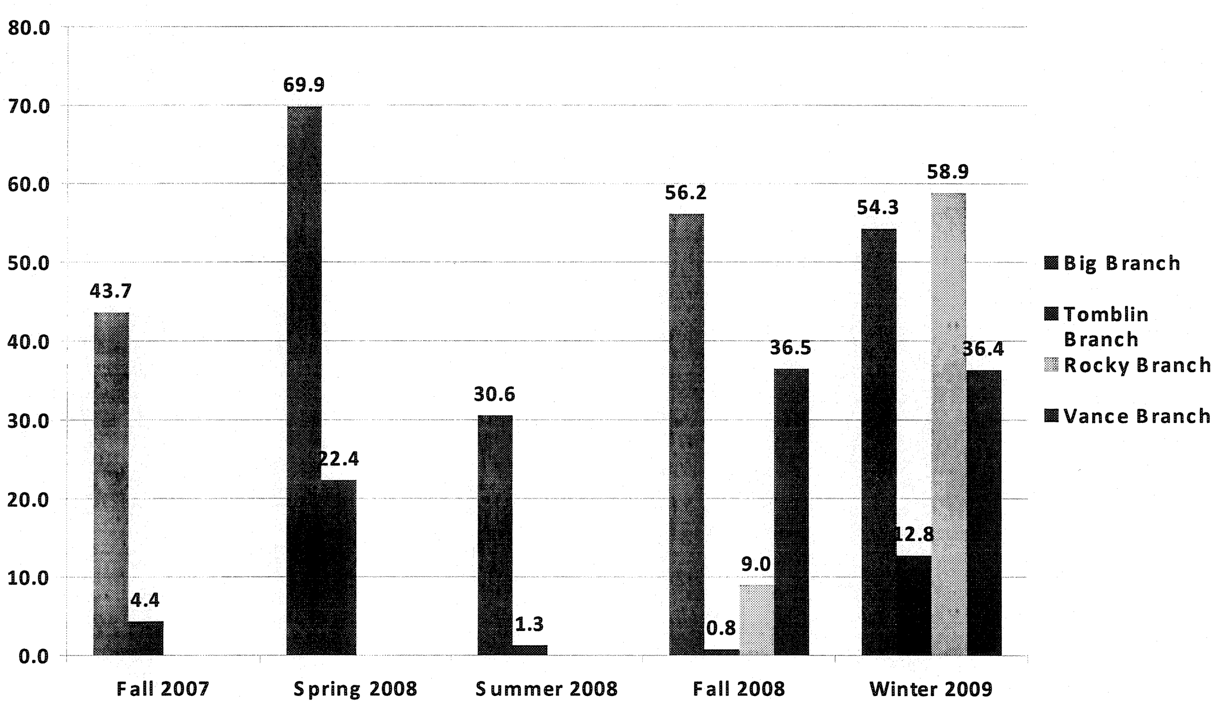

FIGURE 5. % Shredders

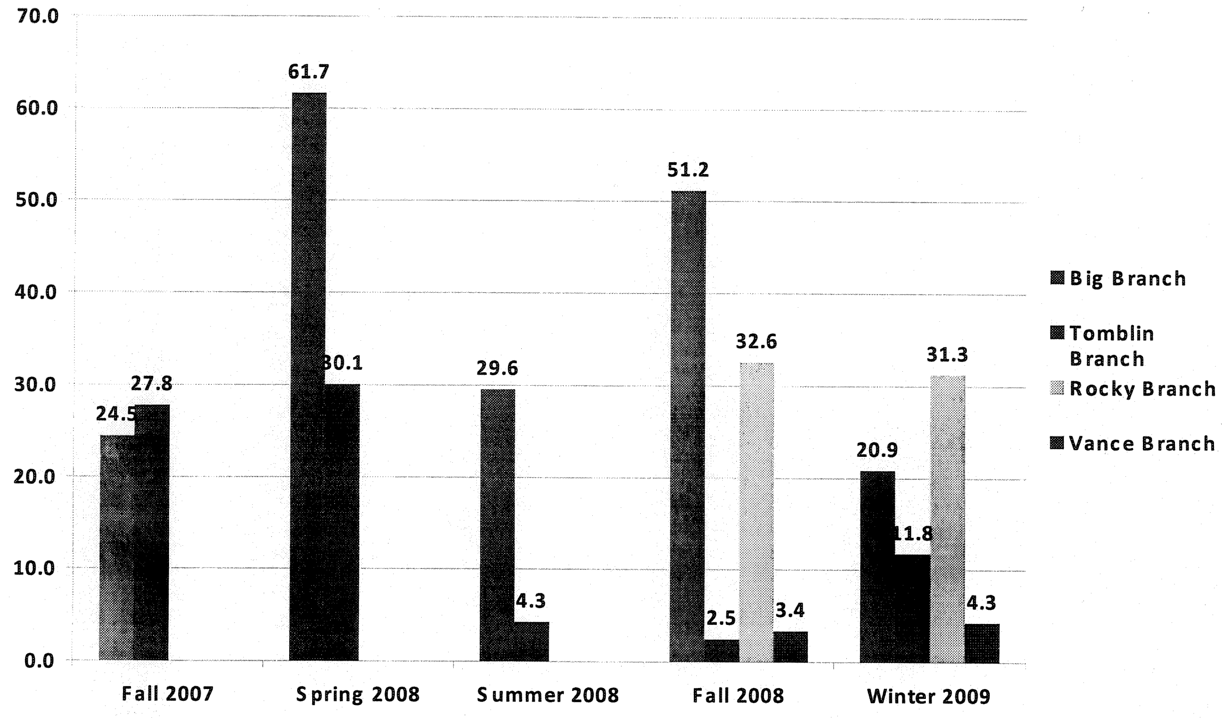

FIGURE 6. % Collector/Filterers

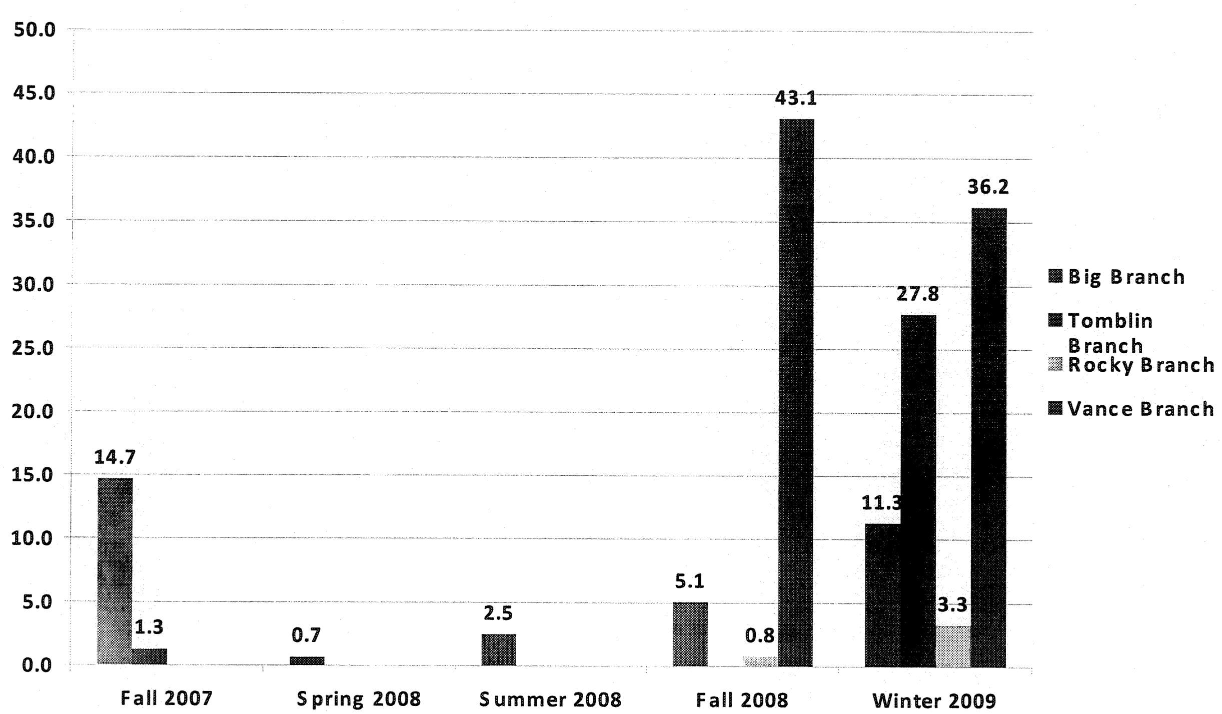

FIGURE 7. # Stonefly Individuals

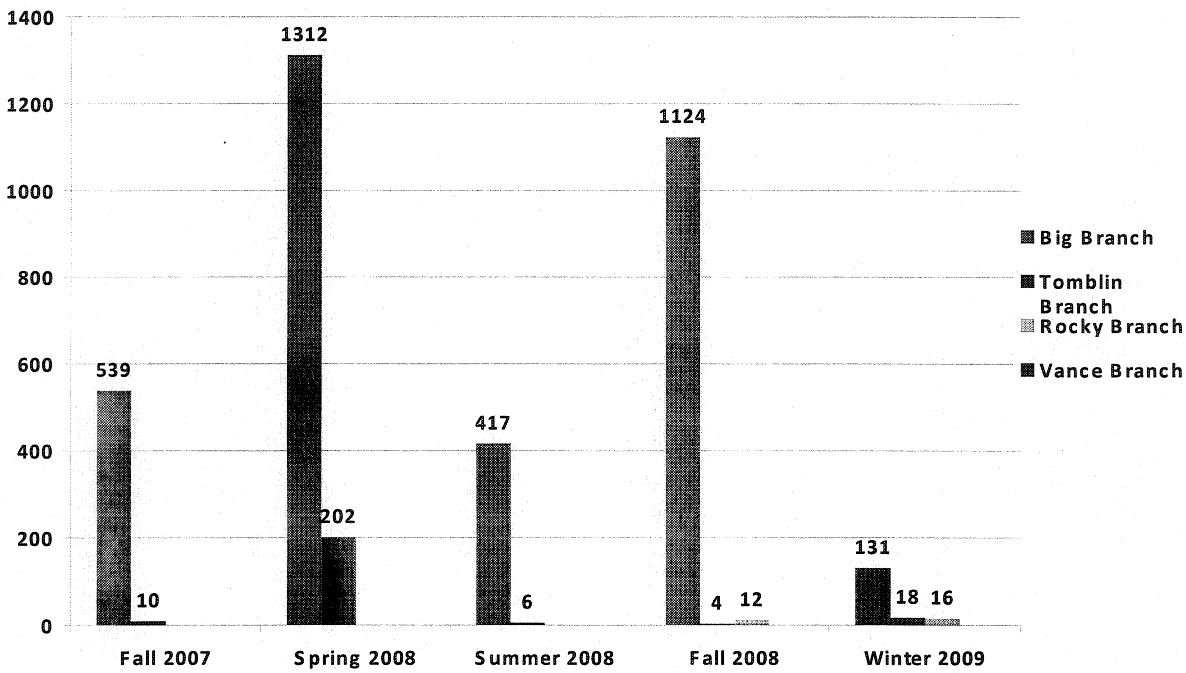

FIGURE 8. # Stonefly Genera

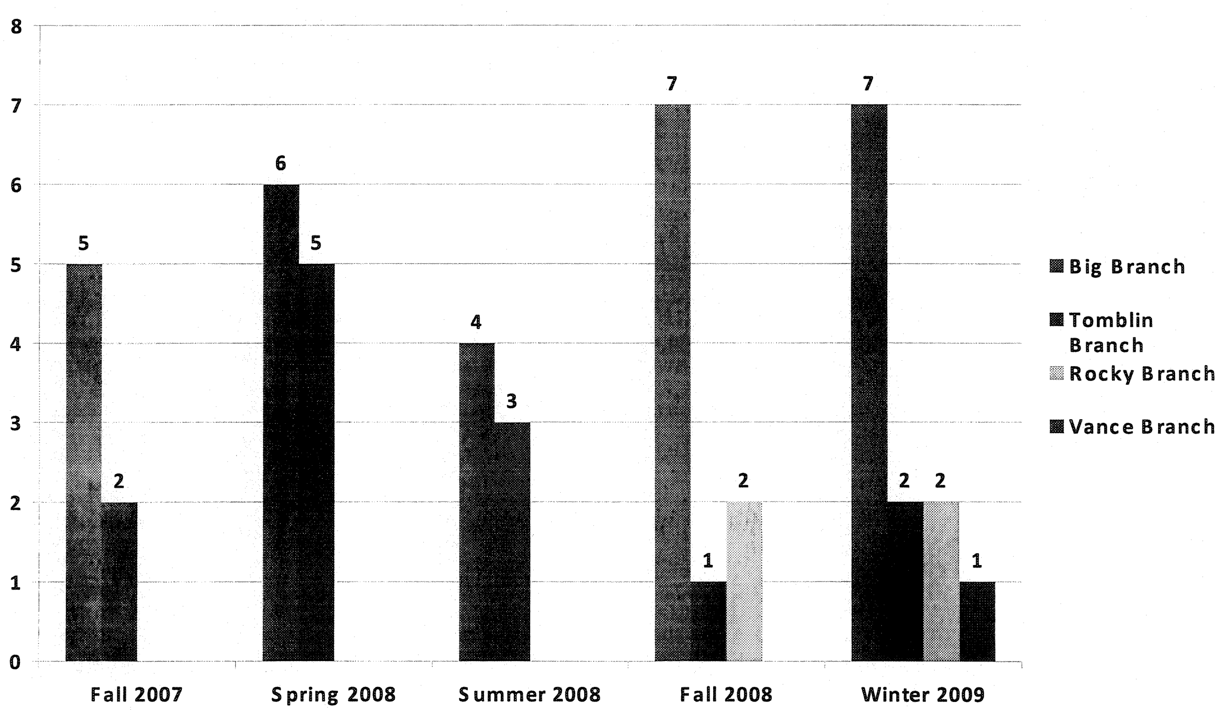

FIGURE 9. # Mayfly Individuals

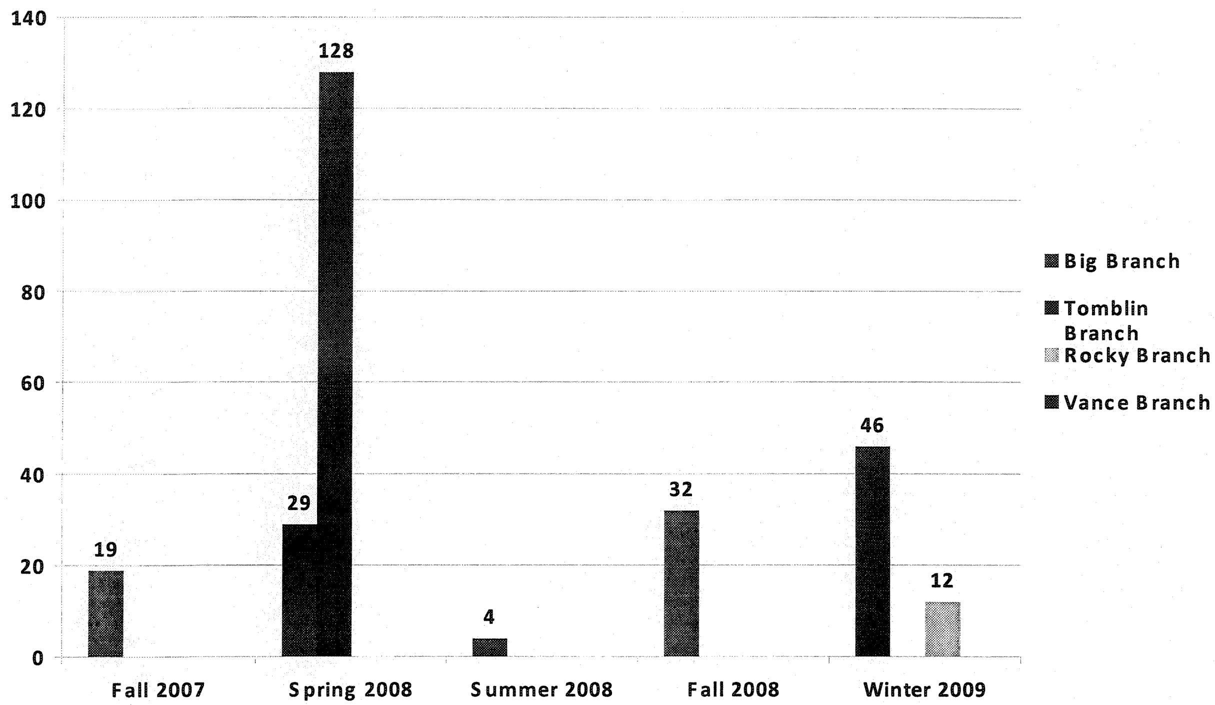

FIGURE 10. # Mayfly Genera

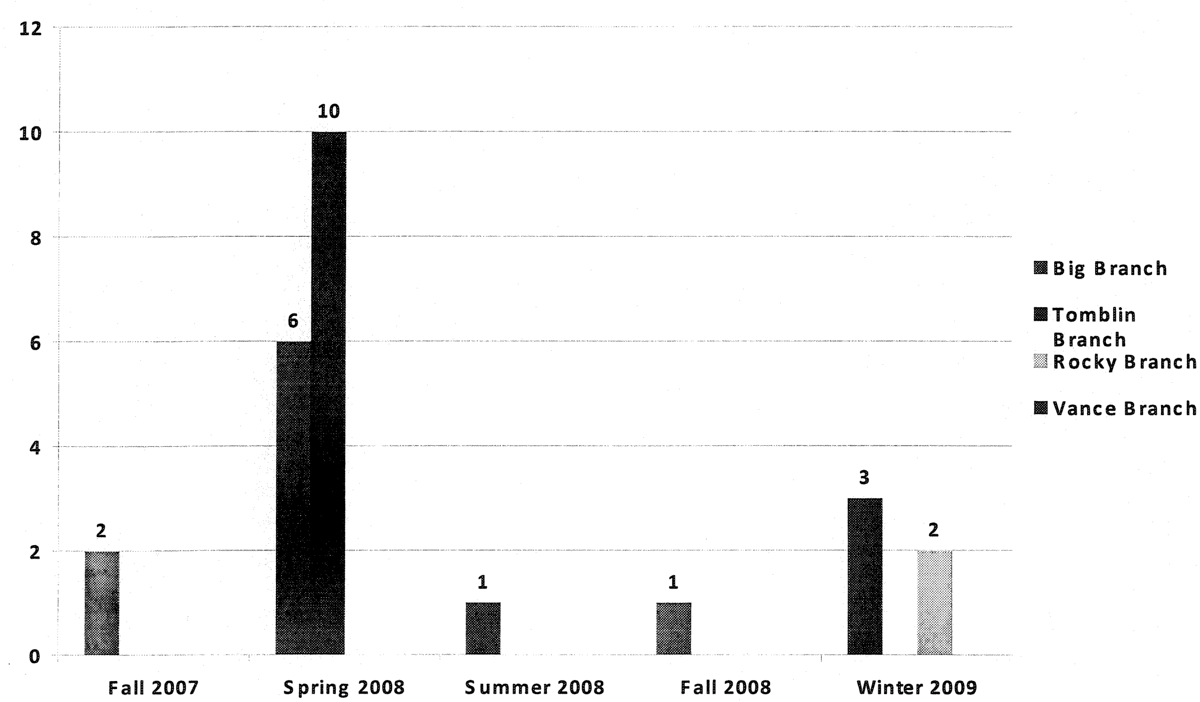

FIGURE 11. % Mayflies

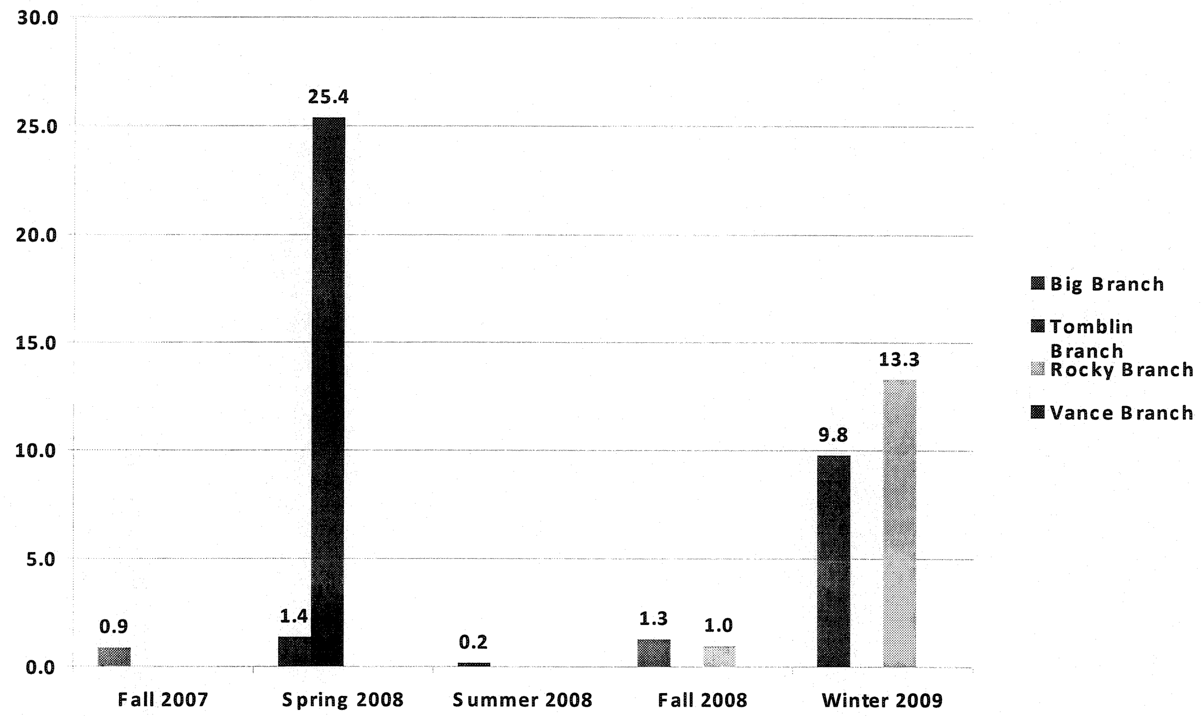

FIGURE 12. WV-SCI

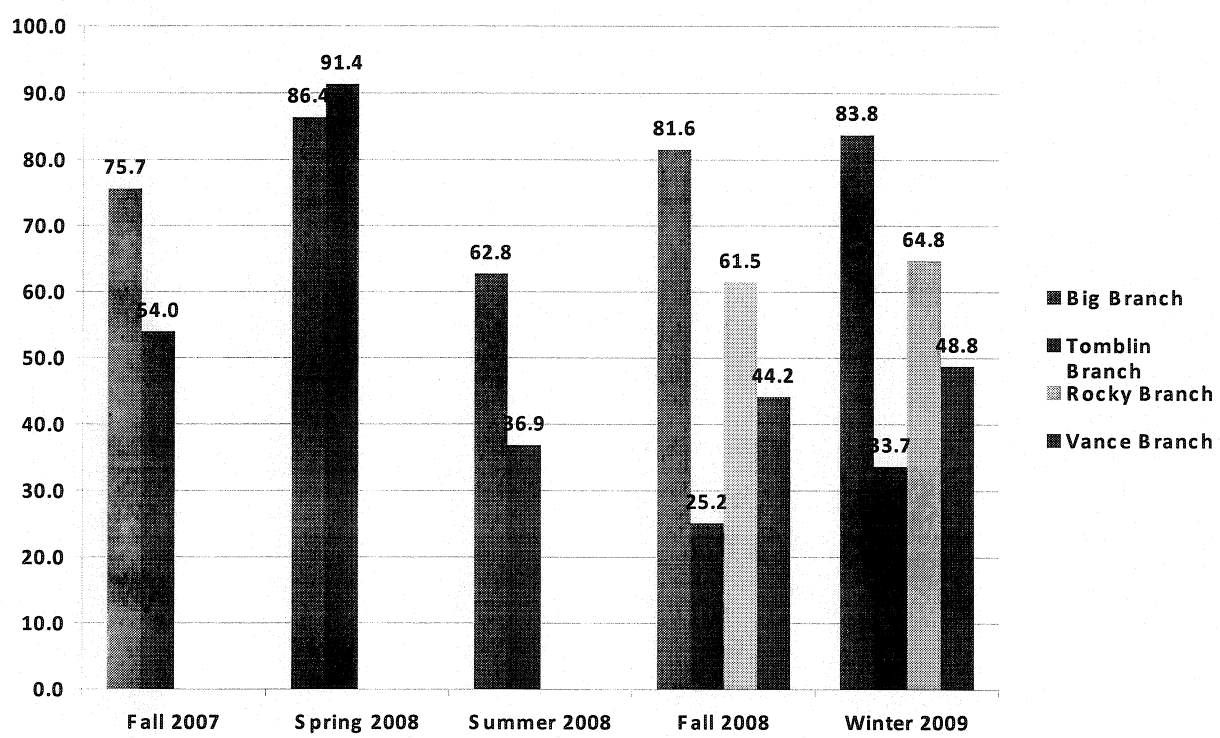

FIGURE 13. % Sensitive Individuals

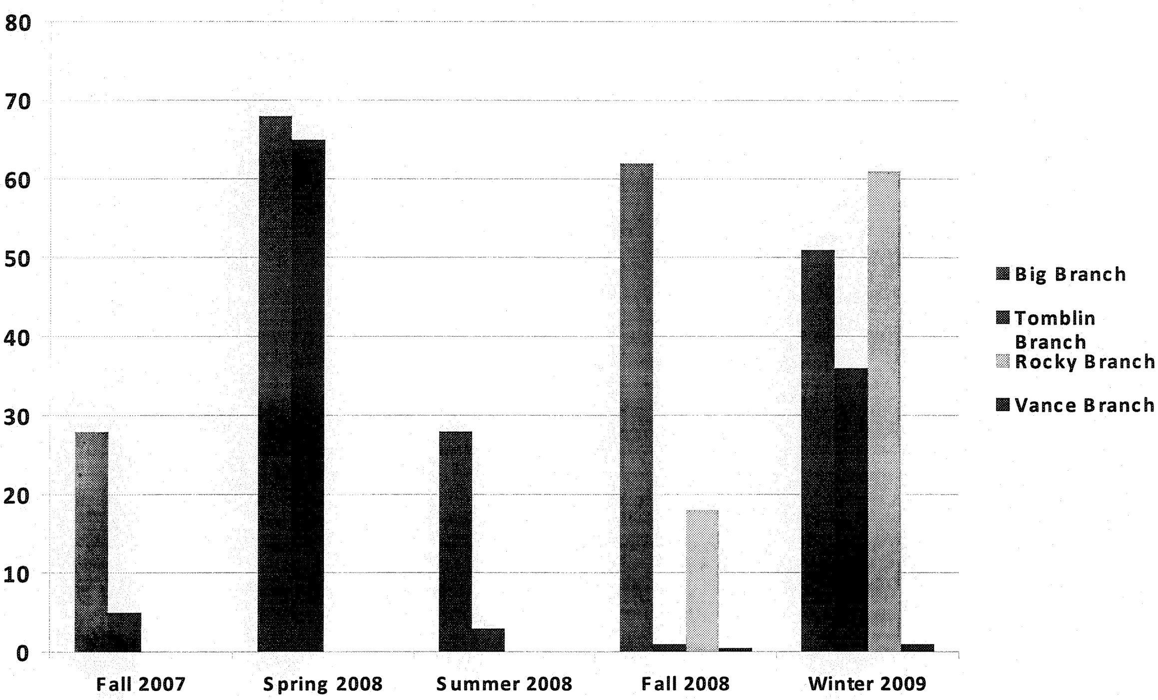

FIGURE 14. Conductivity (us)

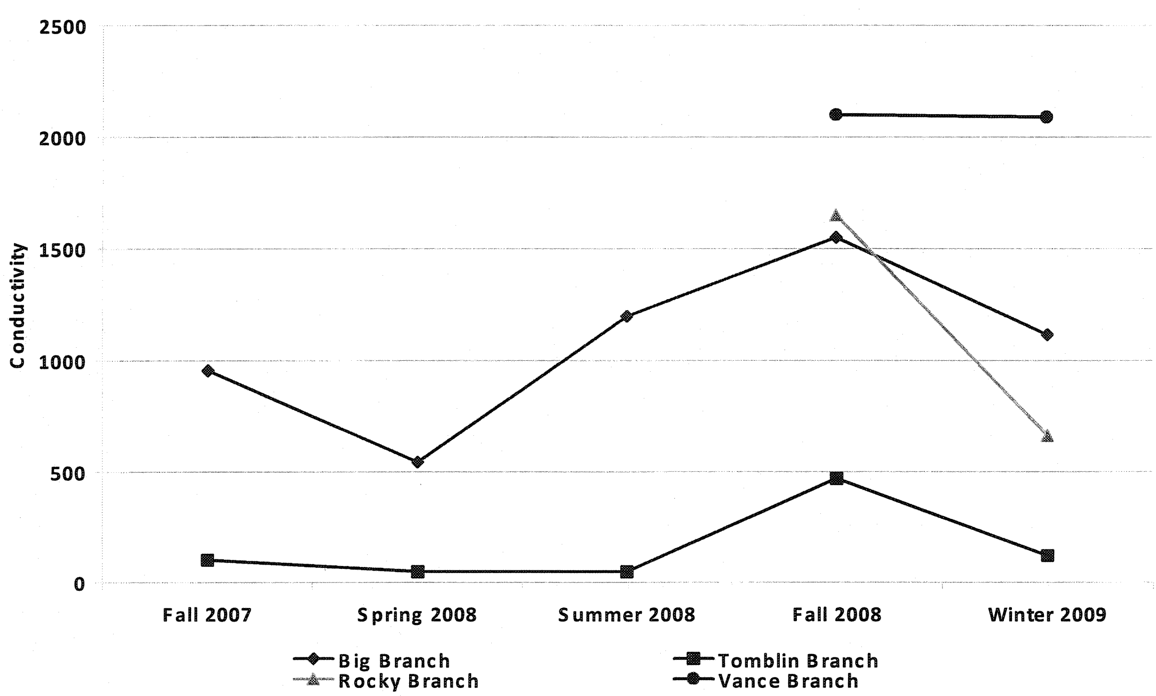

FIGURE 15. # of Taxa

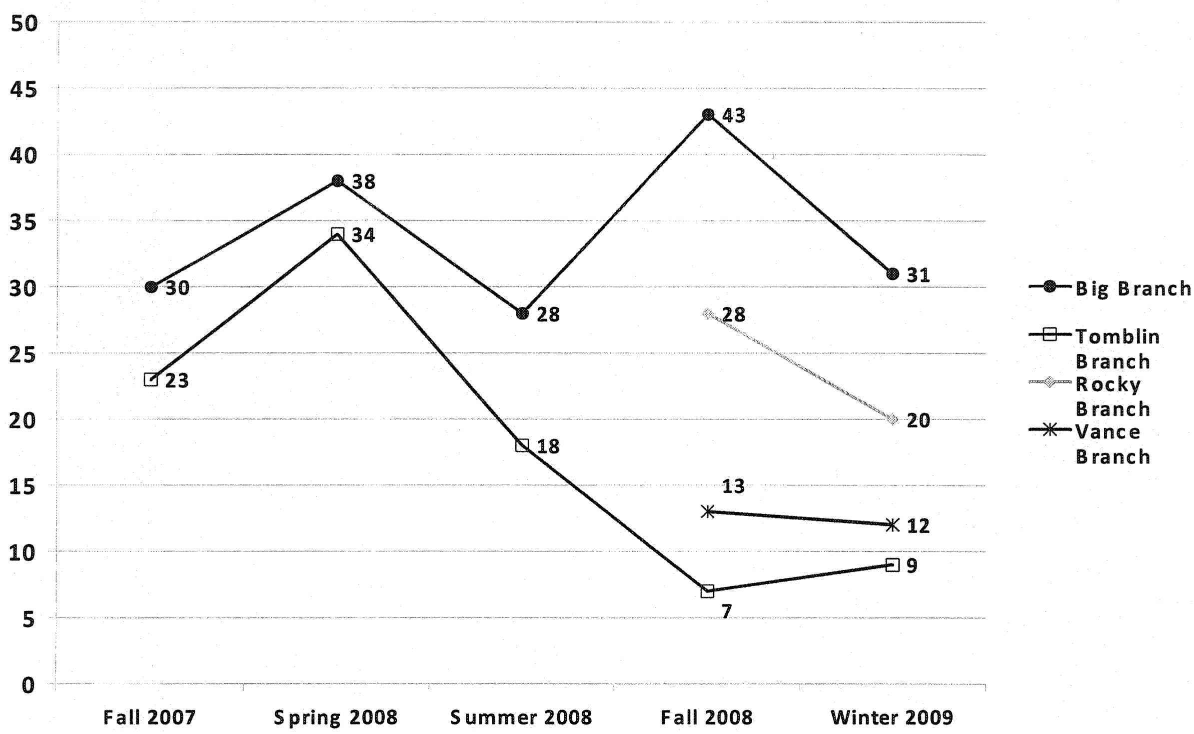

TABLE 1A. Seasonal physical water quality for Big Branch. Argus Energy-WV, LLC.

PARAMETER	Big Branch				
	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
Flow (ft^3/s)	0.140	0.227	0.26	0.0525	0.102
Temperature (°C)	12.2	4.6	18.8	10.5	0.2
DO (mg/l)	9.30	13.6	8.39	11.2	15.5
pH (SU units)	7.69	7.09	7.77	7.74	7.13
Conductivity (µs)	955	543	1,196	1,550	1,114

TABLE 1B. Seasonal physical water quality for Tomblin Branch. Argus Energy-WV, LLC.

PARAMETER	Tomblin Branch				
	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
Flow (ft^3/s)	0.038	0.441	0.11	None	0.129
Temperature (°C)	12.8	5.0	21.2	10.3	0.7
DO (mg/l)	9.30	13.0	6.87	1.4	14.7
pH (SU units)	6.47	5.93	6.39	6.72	6.20
Conductivity (µs)	102	49	49	470	122

TABLE 1C. Seasonal physical water quality for Rocky Branch. Argus Energy-WV, LLC.

PARAMETER	Rocky Branch	
	Fall 2008	Winter 2009
Flow (ft^3/s)	0.018	0.079
Temperature (°C)	10.8	0.2
DO (mg/l)	11.8	15.4
pH (SU units)	7.58	6.45
Conductivity (µs)	1,650	663

TABLE 1D. Seasonal physical water quality for Vance Branch. Argus Energy-WV, LLC.

PARAMETER	Vance Branch	
	Fall 2008	Winter 2009
Flow (ft^3/s)	0.268	1.331
Temperature (°C)	16.8	4.1
DO (mg/l)	10.2	13.1
pH (SU units)	7.91	7.54
Conductivity (µs)	2,100	2,090

TABLE 2A. Seasonal chemical water quality for Big Branch. Argus Energy-WV, LLC.

PARAMETER	Big Branch				
	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
Acidity (mg/l)	5.4	6.6	2.5	2.2	6.8
Alkalinity (mg/l)	108	51.6	166	181	129
Total Hardness (mg/l)	146	191	657	720	564
Nitrate/Nitrite (mg/l)	0.59	0.15	0.46	< 0.030	0.41
Chloride (mg/l)	3.49	2.73	10.0	5.62	3.94
Sulfate (mg/l)	344	148	495	602	346
TSS (mg/l)	2	2	14	3	4
TDS (mg/l)	591	279	486	971	722
Total Phosphorous (mg/l)	<0.020	<0.020	<0.020	0.03	0.02
Diss. Organic Carbon	4.07	1.41	2.14	1.86	2.12
Dissolved Aluminum	0.151	<0.0050	<0.100	0.355	<0.0300
Total Aluminum (mg/l)	0.154	0.014	<0.100	0.312	<0.0300
Antimony (mg/l)	<0.00040	<0.00040	<0.0010	<0.00040	<0.00040
Arsenic (mg/l)	<0.00200	<0.00200	<0.0100	<0.00200	<0.00200
Beryllium (mg/l)	<0.00020	<0.00020	<0.0010	<0.00020	<0.00020
Cadmium (mg/l)	<0.00020	<0.00020	<0.0010	<0.00020	<0.00020
Calcium (mg/l)	35.90	48.6	171	181	147
Chromium (mg/l)	<0.00100	<0.00100	<0.0050	<0.00100	<0.00100
Copper (mg/l)	0.0017	0.0032	<0.0050	0.0019	<0.00100
Dissolved Iron (mg/l)	<0.0200	<0.0200	0.187	<0.0200	0.139
Total Iron (mg/l)	0.020	0.047	0.193	<0.0200	0.207
Lead (mg/l)	0.0003	<0.00020	<0.0010	<0.00020	<0.00020
Diss. Manganese (mg/l)	0.012	0.028	0.081	0.009	0.033
Total Manganese (mg/l)	0.014	0.031	0.082	0.013	0.050
Magnesium (mg/l)	13.60	16.90	55.7	65.3	47.9
Mercury (mg/l)	<0.00010	<0.00010	<0.0010	<0.00010	<0.00010
Nickel (mg/l)	0.0067	0.0029	<0.0100	0.0053	0.0035
Potassium (mg/l)	3.07	3.61	12.1	14.2	9.79
Selenium (mg/l)	<0.00100	<0.00100	<0.0100	0.0016	<0.00100
Silver (mg/l)	<0.00100	<0.00100	<0.0020	0.0015	<0.00100
Sodium (mg/l)	4.010	5.48	18.2	19.9	16.5
Thallium (mg/l)	<0.00020	<0.00020	<0.0010	<0.00020	<0.00020
Zinc (mg/l)	0.0212	0.0052	<0.0100	<0.00300	<0.00300

TABLE 2B. Seasonal chemical water quality for Tomblin Branch. Argus Energy-WV, LLC.

	Tomblin Branch				
PARAMETER	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
Acidity (mg/l)	4.0	1.8	5.0	35.5	3.3
Alkalinity (mg/l)	6.5	4.2	15.9	144	4.0
Total Hardness (mg/l)	15.3	18	52.9	83.7	40.4
Nitrate/Nitrite (mg/l)	0.74	0.05	0.20	NA*	0.21
Chloride (mg/l)	1.04	1.59	12.1	24.6	4.00
Sulfate (mg/l)	42.5	17.2	29.0	22.7	35.2
TSS (mg/l)	1	16	16	49	4
TDS (mg/l)	85	36	109	223	78
Total Phosphorous (mg/l)	<0.020	0.02	<0.020	0.04	0.02
Diss. Organic Carbon	5.19	1.41	2.67	13.0	1.97
Dissolved Aluminum	<0.0200	0.032	<0.100	0.242	<0.0300
Total Aluminum (mg/l)	<0.0200	0.083	<0.100	0.388	0.054
Antimony (mg/l)	<0.00040	<0.00040	<0.0010	<0.00040	<0.00040
Arsenic (mg/l)	<0.00200	<0.00200	<0.0100	<0.00200	<0.00200
Beryllium (mg/l)	<0.00020	<0.00020	<0.0010	<0.00020	<0.00020
Cadmium (mg/l)	<0.00020	<0.00020	<0.0010	<0.00020	<0.00020
Calcium (mg/l)	2.95	3.46	11.6	25.3	8.74
Chromium (mg/l)	<0.00100	<0.00100	<0.0050	0.0015	<0.00100
Copper (mg/l)	0.0016	0.0019	<0.0050	0.0068	<0.00100
Dissolved Iron (mg/l)	0.025	0.04	0.212	0.472	0.020
Total Iron (mg/l)	0.035	0.073	0.315	1.45	0.066
Lead (mg/l)	0.0003	0.0003	<0.0010	0.0028	<0.00020
Diss. Manganese (mg/l)	0.006	0.002	0.096	0.720	0.017
Total Manganese (mg/l)	0.006	0.006	0.099	0.759	0.018
Magnesium (mg/l)	1.93	2.26	5.79	5.02	4.51
Mercury (mg/l)	<0.00010	<0.00010	<0.0010	<0.00010	<0.00010
Nickel (mg/l)	0.0034	0.0025	<0.0100	0.0095	0.0033
Potassium (mg/l)	1.20	0.969	2.80	9.54	1.46
Selenium (mg/l)	<0.00100	<0.00100	<0.0100	0.0017	<0.00100
Silver (mg/l)	<0.00100	<0.00100	<0.0020	0.0015	<0.00100
Sodium (mg/l)	0.484	1.11	3.93	47.1	1.20
Thallium (mg/l)	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Zinc (mg/l)	0.0153	0.0105	0.0124	0.0240	0.0080

* NA = Nitrate/Nitrite value not available due to instrument malfunction.

TABLE 2C. Seasonal chemical water quality for stations located on Rocky Branch. Argus Energy-WV, LLC.

PARAMETER	Rocky Branch	
	Fall 2008	Winter 2009
Acidity (mg/l)	3.9	5.0
Alkalinity (mg/l)	79.5	27.6
Total Hardness (mg/l)	778	287
Nitrate/Nitrite (mg/l)	NA*	0.18
Chloride (mg/l)	4.74	5.06
Sulfate (mg/l)	748	262
TSS (mg/l)	17	3
TDS (mg/l)	1,110	424
Total Phosphorous (mg/l)	0.04	0.02
Dissolved Organic Carbon (mg/l)	1.98	1.94
Dissolved Aluminum (mg/l)	0.317	<0.0300
Total Aluminum (mg/l)	0.322	0.045
Antimony (mg/l)	<0.00040	<0.00040
Arsenic (mg/l)	<0.00200	<0.00200
Beryllium (mg/l)	<0.00020	<0.00020
Cadmium (mg/l)	<0.00020	<0.00020
Calcium (mg/l)	185	69.1
Chromium (mg/l)	<0.00100	<0.00100
Copper (mg/l)	0.0021	<0.00100
Dissolved Iron (mg/l)	0.061	<0.0200
Total Iron (mg/l)	0.031	0.043
Lead (mg/l)	<0.00020	<0.00020
Dissolved Manganese (mg/l)	0.068	0.007
Total Manganese (mg/l)	0.041	0.007
Magnesium (mg/l)	76.7	27.7
Mercury (mg/l)	<0.00010	<0.00010
Nickel (mg/l)	0.0070	0.0032
Potassium (mg/l)	11.3	4.11
Selenium (mg/l)	0.0016	0.0017
Silver (mg/l)	0.0015	<0.00100
Sodium (mg/l)	16.8	7.72
Thallium (mg/l)	<0.00020	<0.00020
Zinc (mg/l)	0.0032	0.0092

* NA = Nitrate/Nitrite value not available due to instrument malfunction.

TABLE 2D. Seasonal chemical water quality for stations located on Vance Branch. Argus Energy-WV, LLC.

PARAMETER	Vance Branch Fall 2008	Vance Branch Winter 2009
Acidity (mg/l)	<1.0	9.3
Alkalinity (mg/l)	51.0	171
Total Hardness (mg/l)	1,020	1,170
Nitrate/Nitrite (mg/l)	0.03	0.26
Chloride (mg/l)	16.8	10.2
Sulfate (mg/l)	1,030	883
TSS (mg/l)	4	4
TDS (mg/l)	1,510	1,620
Total Phosphorous (mg/l)	0.02	0.03
Dissolved Organic Carbon (mg/l)	1.95	2.04
Dissolved Aluminum (mg/l)	0.343	<0.0300
Total Aluminum (mg/l)	0.344	<0.0300
Antimony (mg/l)	<0.00040	<0.00040
Arsenic (mg/l)	<0.00200	<0.00200
Beryllium (mg/l)	<0.00020	<0.00020
Cadmium (mg/l)	<0.00020	<0.00020
Calcium (mg/l)	236	253
Chromium (mg/l)	<0.00100	<0.00100
Copper (mg/l)	0.0027	<0.00100
Dissolved Iron (mg/l)	<0.0200	0.423
Total Iron (mg/l)	0.119	0.423
Lead (mg/l)	<0.00020	<0.00020
Dissolved Manganese (mg/l)	<0.0030	5.63
Total Manganese (mg/l)	0.892	5.56
Magnesium (mg/l)	104	132
Mercury (mg/l)	<0.00010	<0.00010
Nickel (mg/l)	0.0229	0.0715
Potassium (mg/l)	13.3	13.4
Selenium (mg/l)	0.0016	0.0014
Silver (mg/l)	0.0014	<0.00100
Sodium (mg/l)	13.7	13.6
Thallium (mg/l)	<0.00020	<0.00020
Zinc (mg/l)	0.0508	0.0130

TABLE 3A. Seasonal high gradient habitat scores for stations located Big Branch. Argus Energy-WV, LLC.,

	Big Branch				
	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
Primary – Substrate and Available Cover					
1. Epifaunal Substrate and Available Cover (0-20)					
	11	11	13	13	15
2. Embeddedness (0-20)					
	14	10	17	13	14
3. Velocity-Depth Regime (0-20)					
	14	10	10	9	14
Secondary – Channel Morphology					
4. Sediment Deposition (0-20)					
	15	12	16	17	17
5. Channel Flow Status (0-20)					
	15	15	14	9	16
6. Channel Alteration (0-20)					
	18	16	16	17	17
7. Frequency of Riffles (0-20)					
	14	16	16	15	14
Tertiary – Riparian and Bank Structure					
8. Bank Stability (0-10)					
Left Bank	6	5	7	8	8
Right Bank	6	7	6	9	9
9. Bank Vegetative Protection (0-10)					
Left Bank	7	8	8	6	6
Right Bank	7	8	8	6	6
10. Riparian Zone Width (0-10)					
Left Bank	9	9	9	10	10
Right Bank	9	9	9	10	10
Total Score	145	136	149	142	156

Note: The scoring for each category	Optimal	Sub-optimal	Marginal	Poor
Primary	16-20	11-15	6-10	0-5
Secondary	16-20	11-15	6-10	0-5
Tertiary	9-10	6-8	3-5	0-2

TABLE 3B. Seasonal high gradient habitat scores for stations located Tomblin Branch. Argus Energy-WV, LLC.,

	Tomblin Branch				
	Fall 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2009
<u>Primary – Substrate and Available Cover</u>					
1. Epifaunal Substrate and Available Cover (0-20)	12	11	13	7	14
2. Embeddedness (0-20)	13	13	11	8	8
3. Velocity-Depth Regime (0-20)	10	10	10	2	13
<u>Secondary – Channel Morphology</u>					
4. Sediment Deposition (0-20)	14	11	16	14	14
5. Channel Flow Status (0-20)	15	16	15	1	13
6. Channel Alteration (0-20)	18	15	16	11	11
7. Frequency of Riffles (0-20)	14	15	16	1	13
<u>Tertiary – Riparian and Bank Structure</u>					
8. Bank Stability (0-10)					
Left Bank	6	4	7	5	5
Right Bank	6	7	7	5	5
9. Bank Vegetative Protection (0-10)					
Left Bank	4	5	6	4	4
Right Bank	4	5	6	4	4
10. Riparian Zone Width (0-10)					
Left Bank	5	2	2	3	3
Right Bank	5	2	2	3	3
Total Score	126	116	127	68	110

Note: The scoring for each category	Optimal	Sub-optimal	Marginal	Poor
Primary	16-20	11-15	6-10	0-5
Secondary	16-20	11-15	6-10	0-5
Tertiary	9-10	6-8	3-5	0-2

TABLE 3C. Seasonal high gradient habitat scores for stations located Rocky Branch. Argus Energy-WV, LLC.,

	Rocky Branch	
	Fall 2008	Winter 2009
<u>Primary – Substrate and Available Cover</u>		
1. Epifaunal Substrate and Available Cover (0-20)	13	13
2. Embeddedness (0-20)	13	13
3. Velocity-Depth Regime (0-20)	14	14
<u>Secondary – Channel Morphology</u>		
4. Sediment Deposition (0-20)	14	14
5. Channel Flow Status (0-20)	9	16
6. Channel Alteration (0-20)	17	17
7. Frequency of Riffles (0-20)	14	14
<u>Tertiary – Riparian and Bank Structure</u>		
8. Bank Stability (0-10)		
Left Bank	7	7
Right Bank	5	5
9. Bank Vegetative Protection (0-10)		
Left Bank	4	4
Right Bank	4	4
10. Riparian Zone Width (0-10)		
Left Bank	9	9
Right Bank	9	9
Total Score	132	139

Note: The scoring for each category	Optimal	Sub-optimal	Marginal	Poor
Primary	16-20	11-15	6-10	0-5
Secondary	16-20	11-15	6-10	0-5
Tertiary	9-10	6-8	3-5	0-2

TABLE 3D. Seasonal high gradient habitat scores for stations located Vance Branch. Argus Energy-WV, LLC.,

	Vance Branch	
	Fall 2008	Winter 2009
<u>Primary – Substrate and Available Cover</u>		
1. Epifaunal Substrate and Available Cover (0-20)	8	8
2. Embeddedness (0-20)	12	12
3. Velocity-Depth Regime (0-20)	10	10
<u>Secondary – Channel Morphology</u>		
4. Sediment Deposition (0-20)	17	17
5. Channel Flow Status (0-20)	14	19
6. Channel Alteration (0-20)	9	9
7. Frequency of Riffles (0-20)	18	18
<u>Tertiary – Riparian and Bank Structure</u>		
8. Bank Stability (0-10)		
Left Bank	8	8
Right Bank	8	8
9. Bank Vegetative Protection (0-10)		
Left Bank	9	9
Right Bank	9	9
10. Riparian Zone Width (0-10)		
Left Bank	5	5
Right Bank	7	7
Total Score	134	139

Note: The scoring for each category	Optimal	Sub-optimal	Marginal	Poor
Primary	16-20	11-15	6-10	0-5
Secondary	16-20	11-15	6-10	0-5
Tertiary	9-10	6-8	3-5	0-2

Status of PA's AMD Set Aside Program

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Comprehensive legislation reauthorizing the Abandoned Mine Land (AML) program under Title IV of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) was signed into law on December 20, 2006. The legislation made many changes to SMCRA. Among the most significant is an allowable thirty percent (30%) set aside for acid mine drainage (AMD) abatement projects, up from a previous maximum of ten percent (10%). This, along with other changes that will result in a substantial increase in AML funding to states and tribes, will provide significantly more funding for restoration of AMD-impaired streams, up to $400 million in Pennsylvania by 2021. The Pennsylvania Department of Environmental Protection (DEP) has taken several actions to involve the public in decision-making and to ensure effective spending of these funds.

The DEP, in conjunction with their Citizens Advisory Council and the Mining and Reclamation Advisory Board, held ten public town hall meetings in the coal regions of Pennsylvania in May, June and September of 2007. The Department followed up with focus group meetings as a second part of its public outreach efforts. A joint DEP and Office of Surface Mining (OSM) workgroup was then established to develop the set aside program implementation guidelines for Title IV funded mine drainage treatment and abatement projects. The main objective of the workgroup is to develop guidelines that ensure the efficient and effective expenditure of AMD set aside funding that achieves comprehensive, measurable restoration of watersheds impacted by abandoned coal mine drainage in accordance with the requirements of SMCRA.

The magnitude of the mine drainage problem in Pennsylvania greatly exceeds the funding expected. Estimates to correct the entire AMD problem exceed $5 billion in capital costs alone. While Pennsylvania could potentially focus up to $400 million toward AMD problems over the next 15 years, many, and in fact a majority, of mine drainage problems will not be addressed through the AML program alone during this time period. As a result of this reality, DEP will be implementing a process that evaluates the "worth" of restoring specific watersheds and includes a cost-benefit analysis. Along with implementation guidelines, score sheets and over-arching goals are being developed. Work is being prioritized and will include the development of Qualifying Hydrologic Units that will meet the requirements specified in the reauthorized SMCRA. The new guidelines will be in place by July, 2009.

GE's ABMet® Selenium Removal System

Jill Sonstegard
GE Water & Process Technologies

Removal of dissolved selenium in its oxidized forms has proven to be a formidable challenge for conventional water treatment systems. Although historically proven, natural in-situ reduction of selenate/selenite in wetland systems requires a lengthy contact time and allows the contaminants to remain in the local ecosystem. A novel approach to natural remediation technology is the utilization of fixed-bed bioreactors which exploit site-specific, naturally occurring, non-pathogenic microbes in an optimized, self contained system. These systems have been designed to remove selenium in less than a 2 hour hydraulic retention time while sequestering the contaminants in a minimal sludge volume for later disposal. The self-perpetuating microbial bio-catalysts require only a nominal carbon supplement and power supply, thereby resulting in a very low operating and maintenance cost. In addition to selenium removal, other contaminants such as nitrate and trace metals can be co-precipitated, further increasing the overall benefit/value of the system. Please visit the GE display at the reception and poster session for more information

Monitoring With Remote Equipment

Mark Trimble, CPG
Vibra-Tech

More and more, requirements for various types of monitoring are stretching companies to their limits. At some point, all of the monitoring requirements can become unmanageable.

A common first-step for someone with monitoring requirements is to handle everything in-house. Then, as monitoring requirements increase, it is realized that too much time and effort is being expended by company employees, and that their official duties are being interfered with. Furthermore, monitoring results might be called into question when they are collected by the company that is being regulated.

A common second-step, once monitoring requirements become overwhelming, is to enter into monitoring service agreements with various service providers. That might, initially, seem to free-up company employees to concentrate on their official duties. However, coordinating monitoring programs and consultants, collecting and reviewing results, preparing and presenting results to regulators, and storing the results, soon requires company employees to get deeply involved again. At that point, they are once again taken away from their official duties.

A mining company, for example, might use several of their own employees to travel their properties regularly to check on rain gauges. They might contract with someone to travel all day, from monitoring well to monitoring well, to measure static levels. They might contract with another company to monitor blast vibration. They might contract with other, individual consultants for weather stations, pieziometers, inclinometers, strain gauges, and the list goes on.

Simple and reliable monitoring equipment of various types, mated with proven collection and transmitting equipment, can be installed in the most remote locations. Hundreds of monitors can be fielded, serviced, and operated by a single consultant. Monitoring installations, powered by solar energy, and communicated with via earth-orbiting satellites, can be left unattended for very long periods of time, and used to meet numerous monitoring requirements. Remote monitors can be used for something as simple as rainfall, to something as exotic as photoelectric sensors that alert to light sources entering a cavern system that is off limits to the public.

Data from these remote monitoring installations can be posted to a web page. Company employees can access the password protected web page to view results. As an example, wind direction for a specific time, on a day three months prior, can be displayed on demand. Or, rainfall, in 15 minute increments, for a particular day last week can be displayed. Even a static level in a monitoring well, in real-time, can be displayed. These installations can also be used in conjunction with alarms, such as a flashing light, or a dial-out, to indicate some preselected level or value has been reached.

Battelle Develops VEP to Remediate Acid Mine Drainage

A breakthrough process collects AMD, purifies the water, removes the pyrites, and recycles the extractant at minimum expense in a rather small footprint

BY STEVE FISCOR, EDITOR-IN-CHIEF

The Battelle VEP test facility in Pennsylvania treats AMD at a rate of 30 gpm.

The engineering and science firm Battelle has developed a breakthrough technology to efficiently remove sulfate ions and metal cations from acid mine drainage (AMD). This technology is based on a novel adaptation of liquid-to-liquid extraction, cool kinetic efficiencies, and some inherent chemical engineering principles. This is the first cost-effective method to purify AMD from metals and sulfate without generating a waste stream. It produces purified water and recyclable products, such as potassium sulfate and iron sulfate, which has other uses, such as fertilizer. Other remediation technologies exist, but all of them create a waste stream that has to be land-filled. Battelle's innovation could potentially save thousands of miles of waterways from discharge from abandoned mines and help other mines in regions where scarce water resources are tainted naturally.

In 15 months, the Battelle team converted a concept into a practical demonstration plant, located at an AMD site near St. Michaels, Pa. The project was funded by Battelle, Winner Global, and the Pennsylvania Department of Environmental Protection. This first stage demo of this technology involved treating and processing the acid mine water at 30 gallons per minute (gpm) over six weeks. "Fast kinetics" enabled a small equipment footprint. Using automation and inexpensive consumables, the plant successfully treated the AMD at a relatively low cost (including energy consumption). Upon analyzing the field results, the plan is to now scale up the demonstration plant to 500 gpm—eventually scaling up to 5,000 gpm.

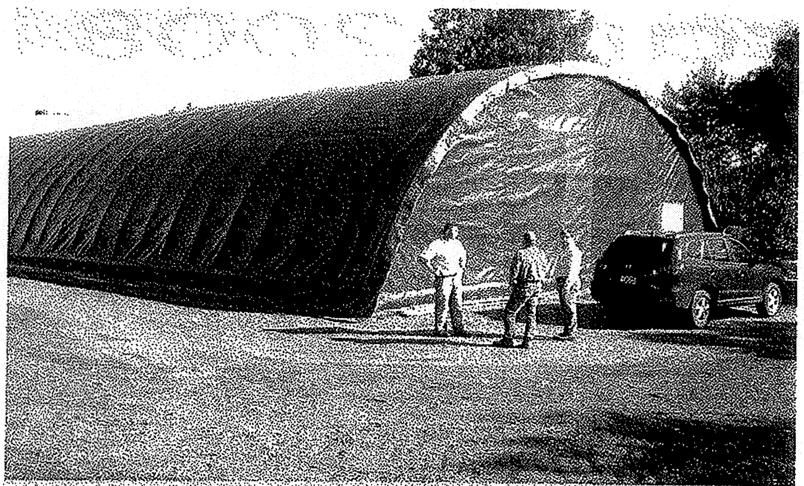
The VEP process offers mining companies numerous positive environmental and economic advantages. The purified water can be subsequently treated to make it potable. There are minimal pollutants released as the extraction process economically recycles the metals and minerals. This treatment process can be adapted to extract other types of metals and minerals, such as selenium, arsenic, aluminum, iron, cobalt, and nickel.

In Pennsylvania alone, there are more than 4,600 miles of waterways impaired with AMD. Battelle's VEP is poised to offer coal-producing states and mining companies an effective, affordable treatment of their most polluted AMD discharges that will not produce a residual sludge. This system can potentially restore miles of polluted streams and rivers, thereby rejuvenating currently impaired environments and economies.

They Said It Couldn't Be Done; Battelle Did Not Listen

Winner Global approached Battelle and asked if they thought their chemical engineering team could develop a method to address AMD. In particular, the objectives were to have a technology that could not only remove iron, but also sulfates, and not generate a secondary waste stream. "Lime treatment [gypsum], for example, generates piles of waste and they wanted to avoid that," said Mike von Fahnestock, program manager, chemical, environmental, material operations department for Battelle. "They also wanted the process to be scalable, cost effective, and technologically feasible."

Battelle submitted a proposal with a few concept and ideas. The Commonwealth of Pennsylvania provided matching funds to do the work. "We were able



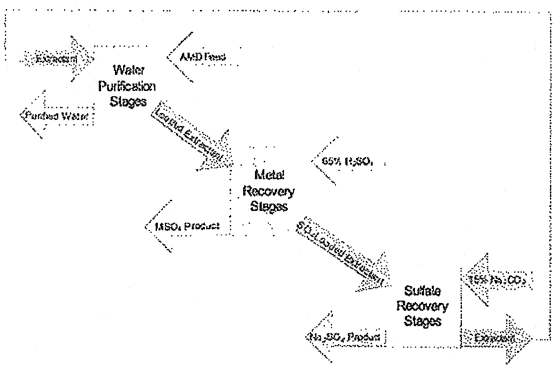
Fast Kinetics and unique chemistry keep the footprint small on this 30 gpm demonstration facility in St. Michaels, Pa.

to leverage some existing liquid-to-liquid extraction technologies," von Fahnestock said. "Battelle had designed some technology for the Air Force to remove chromium from industrial waste water from a shaft plating processes and thought they could adapt that process to AMD and remove sulfate. This was non-obvious because the solvent extraction industry specifically said that sulfate could not be removed cost effectively with scalability using solvent extraction. We overcame that hurdle with the some innovative chemistry."

The proposed concept incorporated four phases. The scientists started with some batch tests and equilibrium studies. Then they improved increased the research to a bench-scale test that continuously operated with actual AMD from several different locations. "We gained some very good results," von Fahnestock said. "From that design, we adapted the solvent extraction technology into a 30-gpm pilot system and took it to St. Michaels. The test facility operated for three months. We demonstrated excellent sulfate removal, iron removal, and scalability."

"We took the VEP from an idea to test tubes in a 200 ml/min lab bench test to a 30-gpm pilot where we range tested from 10 gpm to 30 gpm," von Fahnestock said. "[The VEP] had different flow rates, excellent repeatable sulfate removal, good iron removal. We met secondary drinking water standards for sulfate removal. We found we could maintain the desired pH." As far as economics, the researchers found that the VEP process could be cost competitive with other techniques for removing sulfates, such as bio treatment, reverse osmosis, and lime treatment, especially considering the secondary waste stream.

"We have demonstrated the process successfully and we are working out a license agreement with Winner Global to take this technology forward commercially," von Fahnestock said. "The next target is to go for a 500 gpm plant and we believe we could easily scale it up to 5,000 gpm."

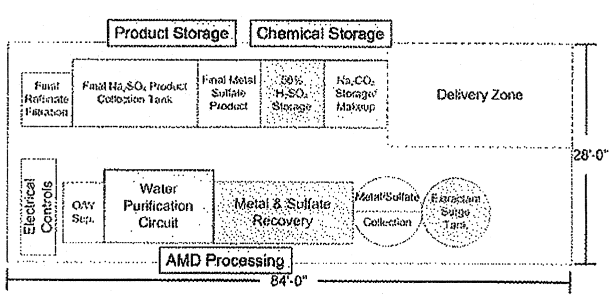


The VEP has three phases: extraction, metals recovery, and sulfate recovery.

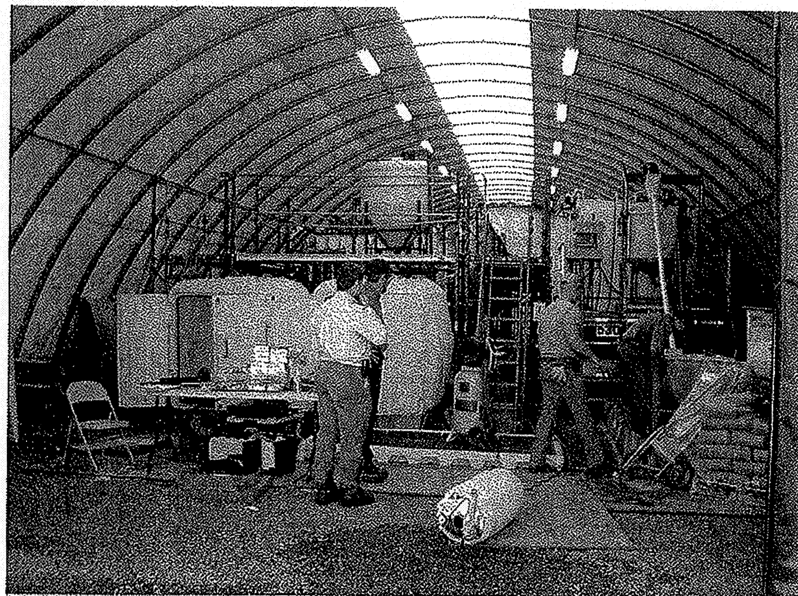
How the VEP Process Works

To avoid generating a waste stream, the contaminants are removed in four extraction stages and process regenerates the extractant. The extractant is expensive and inorganic, so discharging it is not an option. The loaded contaminants (metals, sulfates, etc.) are stripped in these four stages. In the metals recovery stage, the metals make contact with sulfuric acid to generate a product. In the case or iron, the product would be ferrous or ferric sulfate.

The VEP has three phases: extraction, metals recovery, and sulfate recovery. "From a chemical engineering standpoint, during solvent extraction processes, you reach a certain equilibrium state and that's all you get," von Fahnestock said. "By running a few tests, we were able to calculate how many extraction boxes were needed to accomplish the level of sulfate removal desired. If we started with 2,000, and we wanted the result to be less than 250, we calculated that we needed four extraction sections or boxes. Each box is a mixer that mixes the inorganic extractant with the water, and a second part to the box, a weir, serves as a separator."



A schematic (plan view) shows how the stations are arranged.



The St. Michaels facility is scalable, but holds capital expenses to a minimum.

Fast Kinetics Enable a Small Foot Print?

"The traditional solvent extraction literature says that you can not economically pull sulfate out of the stream," von Fahnestock said. "That's because the kinetics—or the rate at which the sulfate would be removed from the water pulled into the extractant and subsequently recovered—would be too slow. We adapted the chemistry and process design to overcome that. We can have a contact time of 60 to 90 seconds to remove the iron and sulfate and whatever else is in there. If the residence time was one to two hours, the plant would have to 60 to 120 times larger in size. When that would be scaled up, the capital costs and land costs would be enormously cost prohibitive."

By purifying all of the water first and discharging it, the process does not have to carry that water through to the back end of the plant. "We only need to add enough chemicals to stoichiometrically remove the contaminants that are loaded on the extractant. So we don't have to acidify or build-up the pH on all of the water," said von Fahnestock. "As much as 98% of the water has been discharged before anything is added. All the process is dealing with is extractant and some minor water that caries through the process. The extractant can be recharged and recycled. The extractant is designed to make a very clean split with the water so that extractant is not entrained. That can be polished off with a filter."

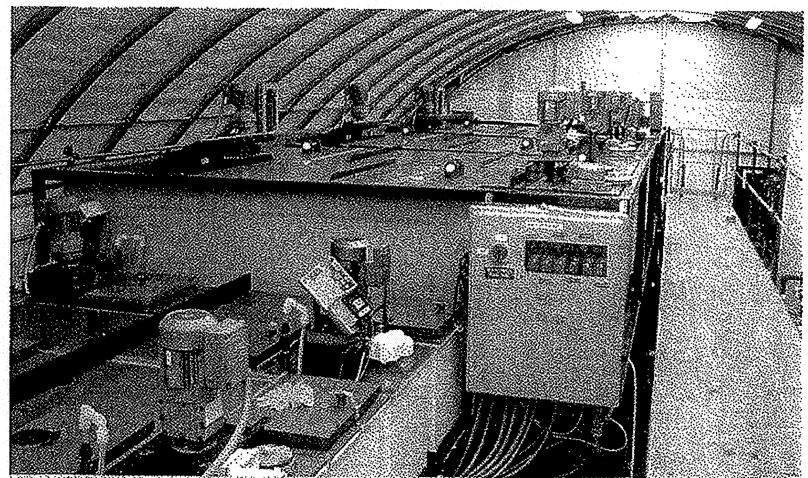
Similar to oil and water, the process allows chemistry to work its natural course. The mixture wants to split apart and it overflows the weir. "After five to seven minutes of residence time, the inorganic, which is lighter than water, overflows a weir in one direction," von Fahnestock said. "That process would be repeated four times by the extractors before the mixture moves through a couple of metal strippers, and four sulfate recovery strippers." At the St. Michaels demonstration plant, the process used two trailers. One had the extractors and strippers and the other had the chemical feed tanks and product storage tanks.

The net result was that the VEP process was able to produce purified water to less than 250 mg sulfate. It removed the iron and it can remove aluminum if necessary. "In the recovery stage, we recover the iron as iron sulfate as a concentrated liquid," von Fahnestock said. "It can be used as a water conditioner or it can be dried and used as a fertilizer. It has value. The process yields potassium or sodium sulfate depending on which process is used. Potassium carbonate would generate potassium sulfate."

The product is useful, but by no means, would not cover the costs of the process. "No, it's not a money making process by itself, but it avoids waste disposal costs and it offsets operating cost through product recovery," von Fahnestock said. "The purified water itself would have value. Because it's low in sulfate, it will not corrode or scale equipment. Or it could be fed to a municipal plant or it could be used to restore a water shed with pure water rather than polluted water."

Costs are estimated at $6 per 1,000 gallons for total life cycle cost. "We performed an economic assessment and it's around $6 and we have done enough testing that we think that's a pretty good number," von Fahnestock said. "It's not $20 and it's not $2. Lime is about $1.50. Reverse osmosis can be as much as $30.

"Solvent extraction is certainly nothing new to mining, so why not leverage what's already out there," von Fahnestock said.



Metal and sulfate strippers need only 60 to 90 seconds of contact.

"This is just a different way of doing solvent extraction."

The stakeholders are obviously excited about VEP's potential and its future commercial scale up. "It's not a silver bullet," von Fahnestock said. "We think it's a perfect technology for a heavily contaminated sites with high sulfate problems and lots of iron. The passive systems handle the easy stuff and this process can clean up the difficult sites. At St. Michaels, that point source was responsible for one-third of the pollution in the Conemaugh River. If you could eliminate that with one system, it would have a magnifying benefit downstream."

CHEMSTREAM
CHEMICAL FEED

ENVIRONMENTAL WATER TREATMENT

WHO WE ARE: Chemstream, Inc. Is headquartered in the North Star Industrial Park in Stoystown, Somerset County, Pennsylvania. We have a chemical blending facility that is capable of custom blending caustic soda, dust suppressants, flocculants, and coagulants.

WHAT WE DO: With combined experience of over 100 years, Chemstream has the ability of adjusting pH, and removing dissolved solids and suspended solids for acid mine drainage, active mine discharge and storm water. We get the job done quickly, and get your water in compliance positively and economically.

HOW WE DO IT: Chemstream has patented water-powered chemical metering, and gravity-powered aeration systems that allow chemical treatment to be controlled and economical. In addition, Chemstream has electric pumps, and pond baffles. We also provide hands-on, on-site SERVICE.

1 Wheel-Treater — **Water-powered chemical injector Rugged and dependable stainless steel construction.**

2 Vario-Ject — **110/90V DC variable speed chemical injector pump. (Gear, peristaltic, or piston.)**

3 Aero-Troff — **Aeration Troughs with new Aero-Edge Technology. One, two, and four foot widths, in a modular design with the disposable "Aero-Edge"**

4 Pond Partition — **Sturdy pond baffles/curtains. Custom lengths, three and five foot widths. There's heat bonding of UV inhibited materials.**

5 ChemSolution — **Specialized chemicals for removal of dissolved and suspended solids. Unique additives enhance performance.**

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Chemstream, Inc. 166 Commerce Drive Stoystown, PA 15563 Office: (814) 629-7118 Mobile (814) 442-2118

INAP's Global Acid Rock Drainage Guide Workshop

April 1, 2009, Morgantown, WVa

The GARD Guide

The development of the Global Acid Rock Drainage (GARD) Guide is sponsored by the International Network for Acid Prevention (INAP) with the support of the Global Alliance. The GARD Guide was created through the contributions of many individuals and organizations. A team lead by Golder Associates prepared a draft of the Guide. INAP established broad-based Steering and Advisory Committees to direct preparation of this document. INAP also received input from several other contributors, peer reviewers, workshop participants and interested stakeholders. INAP gratefully acknowledges all of this assistance.

The draft GARD Guide is now available for review on the web at:

http://www480.pair.com/aturner/gardwiki/index.php/Main_Page

Participants are invited to access the Guide and to provide comments to INAP via:

Mr. Gilles Tremblay/Ms. Charlene Hogan
GARD Guide Secreteriate
gtrembla@nrcan.gc.ca
chogan@NRCan.gc.ca

Sections on the management of ARD from coal mines are being drafted by Dr. Robert Kleinmann and Dr. Paul Ziemkiewicz and will be inserted into the GARD Guide at a later date. Partial drafts of the material will be sent to the attendees of the workshop prior to the meeting. Attendees are invited to provide comments to INAP during the workshop or at the e-mail addresses given above.

An updated version of the GARD Guide will be produced in May 2009, uploaded to INAP's website and formally launched at the 8th ICARD conference to be held June 23-26, 2009 in Sweden.

Workshop Agenda

1. Introductions – Terry Chatwin/Keith Ferguson
2. Review of Workshop Topics – Breakout Groups – All
3. Report to Plenary – All
4. Open Question and Answer Session – All

Workshop Topics

Attendees at the workshop will break into groups and will be assigned one of following topics extracted from the draft GARD Guide for review. All comments received will be considered in updating the Guide.

1. Chapter 5 Prediction

1.A Proposed Prediction Program Flow Chart

Figure 1 represents an idealized, generic overview of a comprehensive ARD/ML prediction program. The program as presented applies to a project that advances from exploration through to mine closure. However, in the case of operating or closed sites, only certain components of this program might be of relevance and the program would be adapted.

The flow chart assumes that ARD/ML prediction activities are performed at every stage of a project. These activities are coupled with other project planning activities, and the level of detail of ARD/ML characterization activities is determined by the stage of the project. Data are accumulated as the project proceeds so that the appropriate information needed to support engineering design is available when needed.

The chart includes feedback loops. If new information becomes available during any one of the stages of the ML/ARD program (e.g., a change in mine plan, unexpected monitoring results), re-evaluation of earlier stages may be required. These types of iterations are omitted from the flow chart for clarity.

Questions for Discussion:

1) Does Figure 1 apply to ARD prediction for coal mines? If not what changes are required?
2) Is it applicable to a broad range of cases or does it require additional qualifiers or detail in the Figure or accompanying text?
3) Does it imply too broad a program so it is not appropriate for “simple” prediction cases?

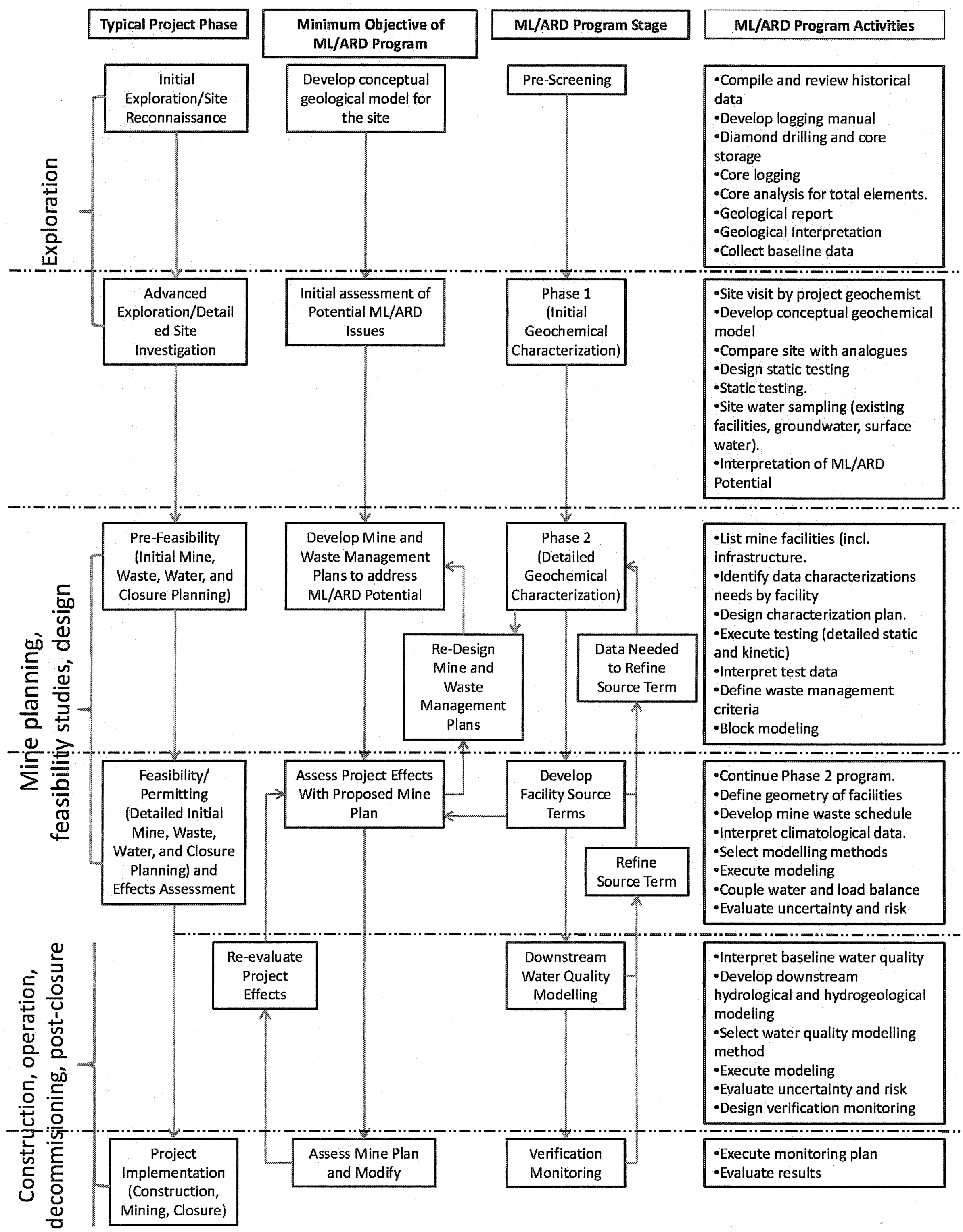

Figure 1 Generic Prediction Flow Chart

1.B Screening and Evaluation Criteria

Use of screening and evaluation criteria generally is required to assess whether results from geochemical characterization studies represent a potential impact or risk to a receiving environment at a mine site. These criteria can be based on professional and empirical experience, guidance documents, as well as regulations promulgated for the express purpose of protecting the environment.

Screening and evaluation criteria are commonly used at mine sites for the purpose of water and mine waste management. The latter involves identification of potentially acid generating (PAG) and non acid generating (NAG) waste. PAG material is either acidic or predicted to become net acidic in the future. A material will become net acidic if the rate of acid neutralization is unable to keep pace with the rate of acid generation. This inability to maintain neutral conditions may be due to a decrease in the rate of acid neutralization and/or an increase in the rate of acid generation. NAG material is predicted to generate near-neutral or alkaline drainage in the future. Materials will be net neutral or alkaline if the rate of acid neutralization keeps pace with the generation of acidity (Price, 2009).

Site-specific, operational parameters and threshold values are established for waste classification (i.e., PAG vs. NAG) based on regulatory requirements, literature and the geochemical test program. Examples of commonly-used operational parameters for waste rock management include the sulphur content, paste pH, NNP, NPR, NCV, NAG value or NAG pH and metal content.

Professional and empirical experience may be an acceptable basis for establishing a screening or evaluation criterion. For instance, if a quantitative relationship can be reliably established between ARD potential and sulphur content, a sulphur cutoff can be determined for the purpose of segregating between PAG and non-PAG waste rock. Similarly, if a relationship between metal leachability and metal content is identified, a metal concentration cutoff can be established to discriminate between material that will or will not affect receiving water quality. Sometimes a combination of methods is needed to classify problematic material, such as paste pH and NPR.

Guidance documents are available that provide screening criteria for evaluation of geochemical test results, in particular those related to prediction of ARD potential: ABA and NAG (e.g., Price, 1997, AMIRA, 2002). These criteria generally are related to specific values for NNP, NPR, NAG pH and NCV, and can be used to classify mine wastes and geologic materials in terms of their ARD potential. Special care is required when dealing with mining wastes that exhibit both low sulphur contents and low NP because small changes in analytical results can dramatically affect the calculated NPR and hence the mine waste classification. Therefore, the screening process should generally consider use of multiple criteria and tests, such as those based on NNP and NAG as well.

Figure 2**Error! Reference source not found.** is the Australian AMIRA (2002) decision tree for the determination of acid generation potential. Through use of a combination of results from ABA and NAG testing as well as professional judgment, samples are categorized into a number of classes with a range of ARD potentials. Another example of guidelines, and widely used throughout North America, is based on NPR values as shown in Table 1 (adapted from Price, 2009):

Table 1 Initial Screening Criteria for ABA Results

Potential for ARD	Initial Screening Criteria	Interpretation
Likely	NPR <1	Likely acid generating, unless sulphide minerals are non-reactive.
Possible (uncertain)	1<NPR<2	Possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides.
Non acid generating	NPR>2	Not potentially acid generating unless significant preferential exposure of sulphides along fractures planes, or extremely reactive sulphides in combination with insufficiently reactive NP.

In Europe, an NPR value of 3 is conservatively assumed to be the threshold between potential acid generating and non acid generating mine waste. However, use of a lower ratio is acceptable if it can be proven based on site-specific information that such a value is sufficiently protective. As with all screening criteria, the onus in on the proponent to prove that these criteria are appropriate and defensible based on site-specific considerations.

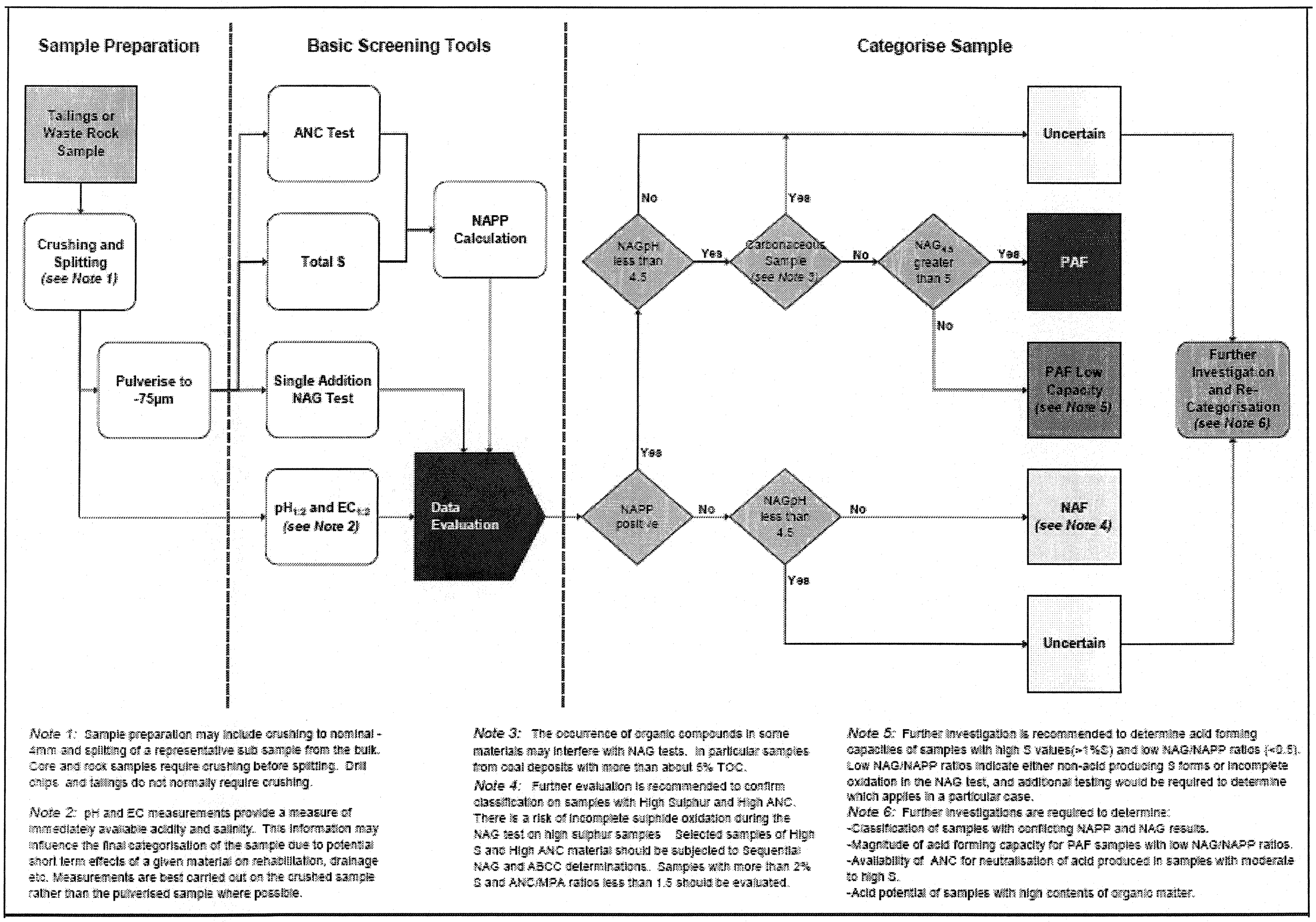

Figure 2 ARD Screening Decision Tree (AMIRA 2002)

Questions for Discussion:

1) Does Figure 2 apply to coal mines? If not how might it be adjusted?
2) Is Table 1 used and applicable for coal mines? If not what screening and evaluation criteria are appropriate?
3) What further guidance could be provided on interpretation of prediction test results for coal mines?

2. Chapter 6 Prevention and Mitigation

2.A Demonstration of Prevention and Mitigation Approaches

Specific evaluation of methods for prevention and mitigation of ARD requires a clear definition of objectives and purpose. The specific environmental technologies and options that will work best will be site specific, often governed by climatic considerations. The applicability of several methods is summarized in Table 2. Some methods have been demonstrated to be effective at many sites around the world while others have had limited demonstration.

Water covers are a proven performer from a geochemical perspective but are sustainable only in climates with a positive water balance (i.e. precipitation > evaporation). In climates with a suitable water balance, geotechnical and long-term hazards with respect to stability, extreme storms and floods, spillways, erosion and other natural hazards such as seismic events must be considered.

In pit disposal and mine backfill might be preferred in some situations but this method of disposal usually only becomes available after or well into the mine operating phase.

In many cases more than one approach or method will be required, for example sulphide separation combined with water covers, elevated water table and barrier covers may prove to be the best combined system for a given tailings impoundment.

Table 2 Summary of Prevention and Mitigative Measures and Climate Considerations

Oxygen Limiting	
Widely Demonstration	**Limited Demonstration**
- Submergence (all climates except B) - Water Covers (A, C, D) - Saturated Soil Cover (A, C, D) - In Pit Disposal (all climates) - Mine Backfilling (all climates)	- Oxygen Consuming Cover (all climates) - Elevated Water Table (A,C, D)
Water Limiting	
Widely Demonstrated	**Limited Demonstration**
- Diversion (all climates) - Store and Release Covers (B) - Membrane Covers (all climates)	- Low Permeability covers in Wet Climates (A, C, D)

Geochemical	
Widely Demonstrated	**Limited Demonstration**
- Segregation (all climates) - Avoidance (all climates) - Desulphurization (all climates)	- Alkaline Covers (all climates) - Passivation (all climates) - Intimate Blending (all climates)

LEGEND: (Climate Classification by Köppen system)

(A) Tropical Humid
(B) Dry
(C) Temperate Mild Mid-Latitude
(D) Continental Severe Mid-Latitude
(E) Polar
(H) Highland

Questions for Discussion:

1) Does Table 2 capture approaches to ARD prevention for coal mines?
2) What other overall guidance is available for ARD prevention for coal mines?

2.B Selective Handling for Coal Mine Waste

The following is extracted from the draft coal mining addendum for the GARD Guide:

Potentially acid-forming overburden should be selectively handled to reduce the rate of pyrite oxidation (Perry et al. 1998; Skousen and Ziemkiewicz 1996). Typically, it is placed on a pad of non-reactive rock so that it is elevated above any fluctuating water level in the pit. The material should be compacted and treated with alkaline material to neutralize the acid-producing potential, and then capped with a layer of low permeability material and covered with non-acid-producing material and topsoiled to reduce water and air movement into the acid rock (Figure 3).

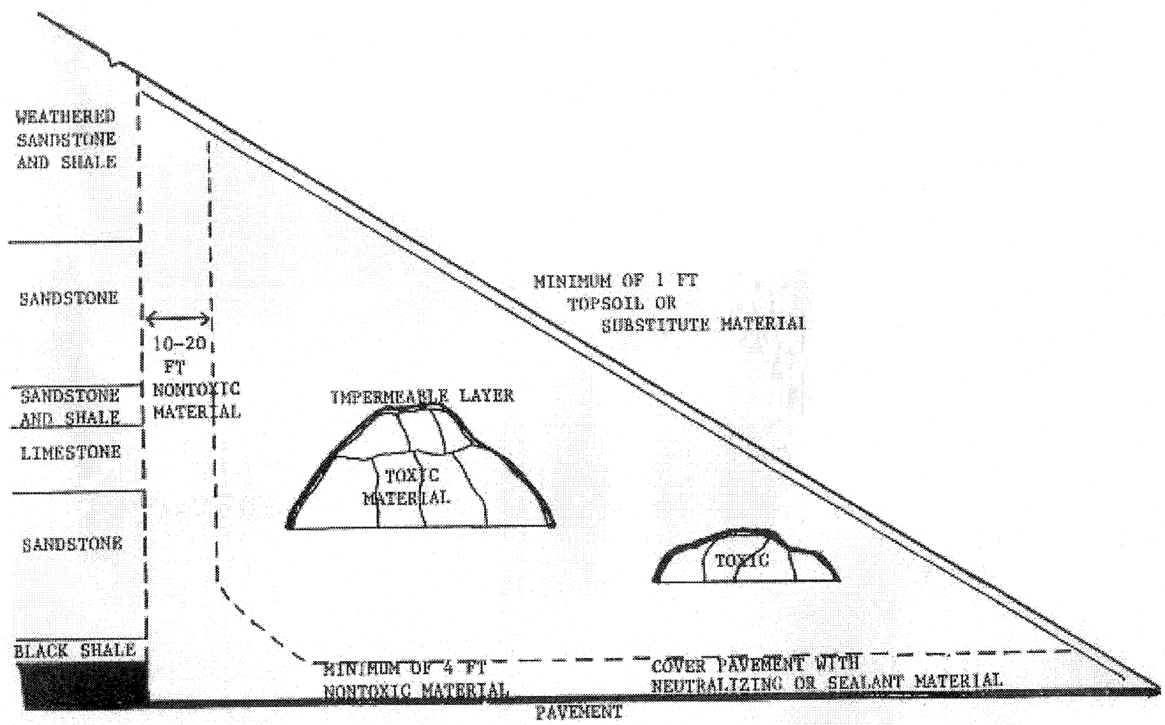

Figure 3. During construction of the backfill, toxic material should be placed off the pit floor, compacted, treated with neutralizing material, and capped with an impermeable layer to reduce air and water contact (from Skousen et al., 1987).

Questions for Discussion:

1) Does Figure 3 reflect the approach to selective handling of waste for open cast coal mines?
2) Are there any other elements for selective handling that you would add or is there a separate figure you would propose?
3) Can you identify some public domain papers that describe the development and implementation of ARD management plans for coal mines?

3. Chapter 9 Management and Performance Assessment

The development, implementation and assessment of the ARD management plan will typically follow the sequence of steps illustrated in the flow chart in Figure 4.

Characterization is the starting point for the development of an ARD management plan. This includes consideration of the bio-physical setting, regulatory and legal registry, community and corporate requirements and financial considerations. Clear goals and objectives are then established for the management plan. These might include the prevention of the development of acidic seeps and runoff or the meeting of specific water quality criteria. Characterization and prediction programs identify the potential magnitude of the ARD issue and provide the basis for the selection and design of appropriate ARD prevention and mitigation technologies. The design process includes an iterative series of steps in which ARD control technologies are assessed and then combined into a robust system of management and controls (ARD management plan) for the specific site. The initial mine design is used to develop the ARD management plan needed for an environmental assessment (EA). The final design is usually developed in parallel with project permitting.

The ARD management plan identifies materials and wastes for special management. Risk assessment and management are included in the plan to refine strategies and implementation steps. To be effective, the ARD management plan must be fully integrated with the mine plan. Operational controls such as Standard Operating Procedures (SOP's), Key Performance Indicators (KPI's) and Quality Assurance/Quality Control (QA/QC) programs are established to guide the implementation. Roles, responsibilities and accountabilities for mine operating staff to implement the ARD management plan are identified. Data management, analysis and reporting schemes are developed to track progress of the plan.

In the next step, montioring is conducted to assess the field performance compared to the design goals and objectives of the management plan. Assumptions made in the characterization and prediction programs and design of the prevention/mitigation plan are tested and revised or validated. "Learnings" from monitoring and assessment are assessed and incorporated into the plan as part of continuous improvement. Accountability for implementing the management plan is checked to ensure that those responsible are fully adhering to elements of the plan. Internal and external reviews or audits are often conducted of performance, management systems and technical components to provide additional perspectives on the implementation of the ARD management plan. Review by site and corporate management of the entire plan is necessary to ensure it continues to adhere to site and corporate policies. Further risk assessment and management is conducted at this stage to assess the effects of changing conditions or plan deviations. Finally results are assessed against the goals. If the goals are met, performance assessment and monitoring continues throughout the mine life with periodic re-checks against the goals. If the goals are not met, then re-design and re-evaluation of the management plan and performance assessment and monitoring systems for ARD prevention/mitigation are required. This additional work might also include further characterization and prediction assessments.

Questions for Discussion:

1) Does Figure 4 reflect the approach to develop and implement an ARD management plan for coal mines?
2) Are there any other elements of the ARD management plan or Performance Assessment or Monitoring that should be added to the relevant boxes?
3) Can you list key considerations in integrating ARD management into mine operating plans?
4) Can you identify some public domain papers that describe the development and implementation of ARD management plans for coal mines?

Figure 4 Development of ARD Management Plan Flow Chart