Proceedings of

COAL COMBUSTION BY-PRODUCTS AND WESTERN COAL MINES: A TECHNICAL INTERACTIVE FORUM

Held at
Denver Marriott West Hotel
Golden, Colorado
April 16-18, 2002

SOUTHERN ILLINOIS UNIVERSITY
Carbondale

Edited by:
Kimery C. Vories
Dianne Throgmorton

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FOREWORD

Beginning in May of 1994, the Office of Surface Mining (OSM) has taken an active role in encouraging and promoting technological advances, research, and technology transfer related to the use and disposal of coal combustion by-products (CCBs) at mine sites. The primary activities and accomplishments of OSM in this area have been the establishment of a multi-interest group steering committee that has (1) conducted national technical interactive forums on "The Use and Disposal of Coal Combustion By-Products at Coal Mines" in October of 1996 at Southern Illinois University and in April of 2000 at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia, and now "Coal Combustion By-Products and Western Coal Mines" in April of 2002; (2) edited, published, and distributed hundreds of copies of the forum proceedings; (3) provided technical assistance to the American Society for Testing Methods (ASTM) on draft guidance for CCBs on mine sites; and (4) developed and managed an Internet Website dedicated to providing a user friendly guide to CCB literature, organizations, EPA rule making, and educational events.

OSM has signed a Memorandum of Understanding with the NETL to collaborate on CCB research and issues. OSM staff also serve on the (1) national steering committee of the Combustion By-Products Recycling Consortium in order to assist in directing CCB research efforts; and (2) technical program committee for the biennial International Ash Symposium conducted by the University of Kentucky Center for Applied Energy Research. OSM staff has presented technical papers related to CCB placement on Surface Mining Control and Reclamation Act (SMCRA) mine sites at numerous technical conferences.

OSM staff are currently working with the U.S. Environmental Protection Agency to investigate whether or not additional Federal regulations are necessary to protect the public and environment when CCBs are placed at the mine site. OSM also is contributing to the effort by the Interstate Mining Compact Commission and member States on developing a State consensus on how best to regulate CCB placement at both SMCRA and non-SMCRA mine sites.

The purpose of the April 2002 forum was to provide an organized format for discussion of issues concerning the use and disposal of CCBs at coal mines and specific western region applications; an easily understood, state-of-the-art summary talk by knowledgeable speakers; a published post forum proceedings that summarizes the presentations and participant discussions and recommendations; and access to the discussions for all interested participants.

Based on the results of the above efforts, OSM will assess the outcomes of the forum and CCB activities and make recommendations for potential revisions to OSM policy and plans for enhancement of additional technology transfer events. I would like to sincerely thank the steering committee, invited speakers, and participants for their time and efforts in making this program a success.

Kimery C. Vories
CCB Steering Committee Chairperson

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RETIREMENT AND FAREWELL

Dr. Rustu Kalyoncu is a commodities specialist with the Minerals Management Team of the U.S. Geological Survey in Reston, Virginia. He has extensive research and professional experience in the areas of refractory dissolution, portland cement kiln and hydration chemistry, nano particle technology, coal combustion products, graphite, and iron and steel slags. He holds a B.S. and M.S. in Ceramic Engineering and a Ph.D. in Materials Science from Alfred University, a MBA/M.S. in Business Administration and Research Management from the University of Dayton, and a J.D. from the University of Alabama.

Dr. Rustu Kalyoncu has been a valued member of the CCB Steering Committee since our first forum in 1996. By the time this proceedings is published, he will have retired from the U.S. Geological Survey. In gratitude for his distinguished service to the committee and his contribution to the field of advancing the science for re-cycling of coal combustion by-products, the CCB Steering Committee would like to pass on his last words of wisdom before departing to his new career.

WORDS OF WISDOM
FROM
DR. RUSTU KALYONCU

NOTHING THAT IS WORTH DOING
IS ACCOMPLISHED IN OUR OWN LIFETIME
THEREFORE, WE CAN ONLY BE SAVED BY HOPE.

NOTHING THAT IS TRUE
OR BEAUTIFUL OR GOOD
MAKES COMPLETE SENSE TO US
IN THE IMMEDIATE CONTEXT OF HISTORY
THEREFORE, WE MUST BE SAVED BY FAITH.

NOTHING THAT WE DO,
HOWEVER VIRTUOUS,
CAN BE ACCOMPLISHED ALONE
THEREFORE, WE MUST WORK TOGETHER.

WHAT IS A TECHNICAL INTERACTIVE FORUM?

Kimery C. Vories
USDI Office of Surface Mining
Alton, Illinois

I would like to set the stage for what our expectations should be for this event. This is the third in a series of technical interactive forums cosponsored by OSM on aspects of Coal Combustion By-Product (CCB) placement at mine sites. The goal of the first two forums in 1996 and 2000 was to establish a national state of the art on CCB placement at coal mine sites. This forum was designed to look at the issue from the perspective of the Western United States in addition to changes at the national level. The CCB Steering Committee began planning for this event more than a year ago in February of 2001. Copies of proceedings of these earlier forums are available on OSM's technology transfer CD and at the CCB Information Network Website at www.mcrcc.osmre.gov/ccb.

The steering committee has worked hard to provide you with the opportunity for a free, frank, and open discussion on the state of the art in CCB placement at coal mine sites that is both professional and productive. Our rationale for the format of the technical interactive forum is that, unlike other professional symposia, we measure the success of the event on the ability of the participants to question, comment, challenge, and provide information in addition to that provided by the speakers. We anticipate that, by the end of the event, a consensus will emerge concerning the topics presented and discussed and that the final proceedings will truly represent the state of the art in CCB placement at coal mine sites.

Therefore, one of the main purposes of this event is to bring as much scientific light and technical experience as possible to bear on this topic. It has been my personal experience that the most progress I have seen toward making advances in technical fields like this has come when we have been able to work as a team of professionals toward a consensus on:

- the facts related to the topic, and
- the state of the science in terms of our most workable options and alternatives.

During the course of these discussions, we have the opportunity to talk about technical, regional, and local issues, while examining new and existing methods for finding solutions, identifying problems, and resolving controversies. The forum gives us the opportunity to:

- share our experiences and expertise concerning CCB placement at coal mines,
- outline our reasons for taking specific actions, and
- give a rationale for our actions concerning testing, permitting, water monitoring, material handling, reclamation, and protection of the environment concerning CCB placement at coal mines.

A basic assumption of the interactive forum is that no person present has all the answers or understands all of the issues. It also is assumed that some of these issues, solutions, and concerns may be very site, regional, or CCB type specific.

The purpose of the forum is to:

- present you with the best possible ideas and knowledge during each of the sessions, and
- promote the opportunity for questions and discussion by you the participants.

Our purpose is to empower you the participants with better knowledge, new contacts, and new opportunities for problem solving and issue resolution.

The format of the forum strives to improve the efficiency of the discussion by providing:

- a copy of the abstract and biography for each speaker that you may want to read before hand in order to improve your familiarity with the subject matter and the background of the speaker.

We are recording the talks and discussions for later inclusion in the post forum publication so that you do not have to worry about taking notes. For this reason, we will require that all participants speak into a microphone during the discussions. In order for us to make the most efficient use of time and ensure that you the participants have the opportunity to provide questions and comments, we require our session chairpersons to strictly keep to the time

schedule. A ***green light*** will be displayed at the beginning of the talk. A ***yellow light*** will be displayed for the last 5 minutes of the talk. A ***dim red light*** will be displayed for 30 seconds followed by a ***blinking red light*** that will signal that the talk is over and the speaker has 5 minutes for questions.

In the post forum publication, issues raised during the discussions will be organized based on similar topic areas and will not identify individual names. All registrants will receive one copy of this proceedings. This publication will be very similar to the proceedings of earlier forums conducted by OSM, which are available for your viewing at the OSM exhibit.

It is important to remember that there are four separate opportunities for you the participants to be heard:

- 5 minutes will be provided for questions at the end of each speaker's talk.
- 20 minutes of participant discussion is provided at the end of each topic session. The chairperson will recognize participants that wish to speak, and they will be requested to identify themselves and speak into one of the portable microphones so that everyone can hear the question.
- At the end of the forum, an open discussion will be conducted on where we should go from here.
- And finally, a blue forum evaluation form has been provided in your folder. This will help us to evaluate how well we did our job and recommend improvements for future forums or workshops. Please take the time to fill out the blue evaluation form as the forum progresses and provide any additional comments or ideas. These should be turned in at the registration desk at the end of the forum.

One of the reasons for providing refreshments during the breaks and lunch is to keep people from wandering off and missing the next session. In addition, the breaks and lunch provide a better atmosphere and opportunity for you to meet with and discuss concerns with the speakers or other participants. Please take advantage of the opportunity at break time to visit the exhibits and posters in the break area. When the meeting adjourns today, all participants are invited to a social reception where refreshments will be provided.

Finally, the steering committee and I would like to thank all of the speakers who have been so gracious to help us with this effort and whose only reward has been the virtue of the effort. I also would like to thank each of you the participants for your willingness to participate and work with us on this important issue. Thank you.

COAL COMBUSTION BY-PRODUCTS STEERING COMMITTEE RECOMMENDATIONS

Future Forum Topics and Planning

1. The next forum should be the spring of 2004 in order to follow the EPA proposed rule concerning CCB placement on mine sites.
2. Should consider conducting a CCB and mining forum every two years.
3. Would like to see an entire forum on mercury issues related to CCBs.
4. Need a forum or workshop that would focus on developing recommendations for the use of better leaching methods.
5. Need to have perspective of attorneys in the field.
6. Would like to have more information on new or expanding uses.
7. Should include more talks from an international perspective.
8. More information on the range of methods used by States to regulate CCB placement.
9. Would like to see fewer case studies and more on hydrology and regulatory direction.
10. Would like to see more case studies.
11. Would like to see State permitting case studies with a panel discussion.
12. Need case studies from citizen groups trying to improve watersheds.

Future Forum Talks

1. Next forum should include an update on progress of the Interstate Mining Compact Commission on State direction for regulatory changes.
2. Would like to see more information on how generation of electricity impacts CCB production and quality.
3. More information on CCBs used in reclamation of AML mine sites.
4. Need to develop an environmental damage case study.
5. Clarify the role of CERCLA in connection with CCB placement.
6. Clarify the relationship in mine permits of overburden analysis and characterization/acid-base accounting/toxic-forming materials/PHC-CHIA analysis/CCB placement planning.

Improvement of Forum Format

1. The pace of the talks was very aggressive. Would like to see more time for discussion.
2. The first session had too much on commercial ash use.
3. More effort to try to find credible speakers from the environmental community.
4. Like forums that start and end at noon.
5. Investigate better ways to encourage participants that receive complimentary registrations to stay for the entire event.
6. More effort to secure an appropriate keynote speaker.
7. Need to improve the setup for the use of overheads.
8. Future forums should try to have a good field trip opportunity.
9. Should improve the focus of case study presentations.
10. Sessions should provide a better progression of speakers.
11. Need to get more involvement by States and coal companies.

COAL MINING AND RECLAMATION WITH COAL COMBUSTION BY-PRODUCTS: AN OVERVIEW

Kimery C. Vories
Office of Surface Mining (OSM)
Alton, Illinois

Abstract

The use and disposal of Coal Combustion By-Products (CCBs) (i.e., fly ash, bottom ash, flue gas desulfuratization material, and fluidized bed combustion material) at coal mines has become an area of intense interest, research, activity, and controversy during the last decade. The U.S. Department of Interior, Office of Surface Mining (OSM) was created in 1977 as part of the Surface Mining Control and Reclamation Act to provide minimum levels of protection concerning public health, safety, and the environment and balance this with the need for a viable U.S. coal supply. Since May of 1994, OSM has taken an active role in encouraging and promoting technological advances, research, and technology transfer related to the use and disposal of those material residues remaining after the combustion of coal to produce electric power. Currently, less than 2 percent of the CCBs that are produced in the United States are placed back at the mine site where they originated. Most of the uses to date have been extensively researched and indicate that the placement of these materials on the mine site usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards and, secondarily, as non-toxic fill within the spoil area prior to grading and final reclamation. Beneficial uses are as (1) a seal to contain acid forming materials and prevent the formation of acid mine drainage; (2) an agricultural supplement to create productive artificial soils on abandoned mine lands where native soils are not available; (3) a flowable fill that seals and stabilizes abandoned underground mines to prevent subsidence and the production of acid mine drainage; (4) a construction material for dams or other earthlike materials where such materials are needed as a compact and durable base; and (5) a non-toxic, earthlike fill material for final pits and within the spoil area. Although the recycling of these materials into useful products has attracted a great deal of interest as a raw material for basic construction products, there also has been a growing controversy from environmental groups that believe the use of these materials places an unacceptable risk on public health and environmental quality. This paper will attempt to provide an overview of how the dynamics of the efforts to increase the recycling and use of these materials and counter efforts to place all of these materials in perpetually sealed and monitored landfills has played out within the microcosm of the coal mining and reclamation community.

A Brief History of OSM CCB Technology Transfer Initiatives

The CCB Steering Committee

In May of 1994, OSM solicited recommendations for technical studies and applied research topics from the States, industry, and public interest groups. A wide variety of responses to this outreach identified CCBs as a priority topic for consideration by OSM. OSM initiated a survey in September of 1995 to determine interest in holding a national technical interactive forum on the topic of CCBs. Based on the results of this survey, OSM organized a multi-interest group steering committee in February of 1996 to plan for and implement a wide range of technology development and transfer events and products to advance the application of good science wherever CCB placement occurred on surface coal mine sites. The steering committee is composed of recognized experts related to all aspects of CCBs from universities, appropriate State and Federal agencies, coal industry, electric utilities, and the CCB recycling industry.

CCBS Associated with Coal Mining–Interactive Forum

In October of 1996, OSM cosponsored its first technical interactive forum related to CCBs. In cooperation with the

Mining Engineering Department at Southern Illinois University at Carbondale, OSM produced a post-forum proceedings (Chugh, 1996)[1] that includes a series of 28 papers summarizing topics related to coal combustion by-products and their application at surface coal mines nationwide. Topics include activities related to beneficial use and disposal. The papers are presented by university researchers, State regulatory personnel, industry experts, consultants, and citizen interest groups. The papers are presented in the categories of:

1. Coal Combustion By-Product Characterization;
2. Site Characterization;
3. Regulatory Requirements;
4. Designing/Engineering/Planning;
5. Environment: Land and Water;
6. Monitoring and Evaluation; and
7. Case Studies.

An edited discussion section provides a summary of the issues raised, different perspectives, and controversies brought out during the forum. Subject category workgroups at the forum outlined the remaining issues needing further work and attention. At the conclusion of the forum, the CCB Steering Committee met and identified the following five items as the most important needs identified by the 1996 forum:

1. a guidance document for the use and disposal of CCB materials within the coal mining environment;
2. acceptable monitoring procedures for evaluating the interaction of groundwater at CCB disposal sites;
3. development of formal education and training opportunities on various aspects of CCB handling;
4. additional forums, workshops, or symposia to address various aspects of CCB handling that have not yet been sufficiently addressed; and
5. development of better methods for communicating aspects of CCB handling to the public.

The CCB Steering Committee made the following recommendations to its sponsoring organization management:

1. The highest priority and energies of the sponsoring organizations should be to pursue the development of a "State of the Science Resource Manual" on the evaluation and handling of CCB materials on the mine site for use or disposal.
2. There should be a follow up forum to address concerns raised by the work groups on aspects of CCB evaluation and handling that were not sufficiently addressed by the forum.

Summary of OSM Director Comments on CCBs and Mining at the 1996 CCB Forum[2]

The following remarks summarize relevant comments concerning the disposal or use of CCB materials on the mine site made by then Acting Director of OSM, Kathrine Henry (Henry, 1996).

OSM supports those efforts to recycle coal combustion by-products into commercial items for use on or off the mine site. Despite everything that's been done to create economically viable products for those residues, however, only about one-quarter of them are used in that way. The remainder of the coal combustion by-products still has to be stockpiled or disposed of, *somewhere*. Interest in coal mines as potential disposal facilities or markets for new products produced from coal combustion by-products has gone up with the dramatic cost increases and mounting difficulties involved in handling those residues on site at coal fired power plants.

In 1993, the Environmental Protection Agency issued its final regulatory determination that coal combustion by-products were deemed nonhazardous and were to be regulated by the individual States under Subtitle D of the Resource Conservation and Recovery Act when disposed of as a solid waste. As a result, the States have been challenged to develop appropriate strategies for integrating the concerns of State solid waste programs with SMCRA programs when disposal occurs on permitted State primacy coal mine sites.

When the use or disposal of coal combustion by-products happens at surface coal mines, State coal mining regulators are involved to the extent that SMCRA requires:

1. the mine operator to ensure that all toxic materials are treated, buried, and compacted, or otherwise disposed of, in a manner designed to prevent contamination of the ground or surface water;
2. making sure the proposed land use does not present any actual or probable threat of water pollution; and
3. ensuring the permit application contains a detailed description of the measures to be taken during mining and

reclamation to assure the protection of the quality and quantity of surface and groundwater systems, both on and off-sites, from adverse effects of the mining and reclamation process; also, to assure that rights of present users of such water are protected.

Any disposal of coal combustion by-products at mine sites must be in accordance with those standards and with applicable solid waste disposal requirements. The States differ in their regulatory requirements for disposal of coal combustion by-products as solid waste. Trace element concentrations in coal combustion by-products vary according to where the coal was mined. Chemical and physical characteristics differ by region, as do mine site conditions. Accordingly, regulatory programs to allow use or disposal must be designed to handle those differences. At OSM, we are supportive of State efforts to develop appropriate methods and criteria. We will do what we can to help on request.

Currently, the debate over use or disposal of coal combustion by-products at coal mines centers on the potential for the materials to release toxins back into the environment. We recognize that improved knowledge of the risks and benefits associated with the disposal and use of coal combustion by-products is badly needed, as is a greater acceptance of that knowledge by regulators and the public. The more we know, the more options we have.

CCB Information Network Website

In March of 1997, the USDI Office of Surface Mining invited resource agencies and organizations that are working with or have access to significant information on CCBs to participate as a voluntary steering committee that would develop a system for making this information accessible to potential users in the coal mining community. The steering committee developed a website that can be accessed directly at http://www.mcrcc.osmre.gov/ccb/ that contains:

1. a user friendly guide, including abstracts, of existing scientific and technical literature;
2. sources and location of CCB literature;
3. access to the OSM library for copies of significant literature for loan to potential users;
4. definitions of basic terminology;
5. name and phone numbers of State CCB contacts;
6. information and access to upcoming CCB special events;
7. copies of CCB Forum Proceedings from 1996 and 2000;
8. a chronology of relevant dates and events related to rule making by the U.S. EPA; and
9. access to related websites that contain information on active researchers and research programs.

The Use and Disposal of CCBs at Coal Mines: A Technical Interactive Forum[3]

Many of the questions and concerns raised at the 1996 Interactive Forum, however, remained. In response to these additional concerns, the CCB Steering Committee resolved to conduct an additional technical interactive forum in the year 2000 to address the more important concerns and new developments related to coal mining and CCBs that were either identified at the 1996 forum or since that time.

The purpose of this technical interactive forum on April 12-13, 2000 at the facilities of the U.S. DOE National Energy Technology Laboratory in Morgantown, West Virginia was to provide:

1. an organized format for discussion of issues concerning the use and disposal of CCBs at coal mines;
2. an easily understood, state of the art summary talk by knowledgeable speakers;
3. a published proceedings that summarizes the presentations and participant discussions;
4. access to the discussions for all interested participants at the forum;
5. opportunity for poster presentations on CCB projects and research;
6. opportunity for exhibits of CCB use, technology, services, and equipment; and
7. optional technical CCB workshops and field trips.

The 22 talks covered four topics in the following categories:

1. CCB Basics;
2. Regulatory;
3. Beneficial Uses at the Mine Site; and

4. Hydrology.

At the conclusion of the forum, the participants recommended that the steering committee focus on the following initiatives for future actions:
1. provide assistance to the U.S. EPA on documentation of mine related damage cases;
2. provide assistance to the American Society for Testing Materials on development of improved standard testing methods for CCBs on mine sites;
3. conduct region specific technical forums; and
4. enhance educational and Internet opportunities on CCB issues and information.

CCBs And Western Coal Mines: A Technical Interactive Forum

On April 16-18, 2002, OSM cosponsored the third in a series of forums on issues related to CCBs and mining in Golden Colorado. This forum addressed regional applications of CCBs at mine sites in the arid and semi-arid Western United States as well as issues related to proposed rule changes by the U.S. Environmental Protection agency.

The major topics for discussion at the forum were:
1. CCB Basics,
2. Testing and Terminology,
3. Western Mining Applications/Case Studies,
4. Environmental Impacts to Groundwater, and
5. Regulatory Direction.

Memorandum of Understanding (MOU) Between OSM and The National Energy Technology Laboratory (NETL)

On February 10, 1999, OSM signed an MOU with NETL to collaborate on coal mining related and environmental issues. They agreed to cooperate in three principal areas:
1. Technical Services and Equipment Utilization;
2. Technical Expertise; and
3. Information Exchange.

Areas of mutual interest potentially related to CCBs included:
1. mine drainage prevention, elimination, and treatment;
2. remining/reprocessing coal waste;
3. coal combustion by-product disposal; and
4. preservation of the hydrologic balance.

Combustion By-Products Recycling Consortium: National Steering Committee

OSM staff participates with NETL on the National Steering Committee for the Combustion By-Products Recycling Consortium that is attempting to develop technologies for use by the coal utilities and their suppliers that will assist in solving problems related to the handling of by-products from their clean coal processes. The main strategy of the consortium is to:
1. characterize product streams from flue gas desulfurization materials and low nitrous oxide burners;
2. develop a list of potential market opportunities and disposal options; and
3. develop and implement research and demonstration programs around identified priority topics.

Of the 18 research projects awarded funding in 1999 ($1.2 million over two years), eight projects are applicable to the placement of CCBs on coal mine sites. In 2000, 17 research projects were funded for $1.8 million over a 2-year period. Six of these projects concern environmental aspects of CCBs at coal mines. CBRC announced a third request for proposals that were due September 5, 2001.

International Ash Utilization Symposium: Technical Steering Committee

OSM staff serves on the technical program committee planning for the above events that took place October 18-20, 1999 and October 22-24, 2001 in Lexington, Kentucky, and the current event October 20-22, 2003. The biennial event covers all aspects of coal combustion by-product utilization. The program includes recent research findings in more than a dozen topical areas. The OSM staff encourage the presentation of technical papers, assistance in panel presentations, and serve as a session co-chair in the areas of mining, underground injection, government programs, and treatment of acid forming materials.

ASTM Standard Guide for the Use of Coal Combustion Products (CCPs) For Surface Mine Reclamation

Since June of 2000, the OSM staff and the CCB Steering Committee have been actively participating with the American Society for Testing Materials (ASTM) in the development of (1) a standard guide for technical methods to be used in evaluating CCBs for use or disposal at mine sites; and (2) standardized definitions of terms related to CCBs. Committee members are actively reviewing and commenting on draft guidance documents being prepared by ASTM. The OSM staff have provided information to ASTM on how the Surface Mining Control and Reclamation Act is utilized to regulate the placement of CCBs on surface coal mines.

Symposium Outreach to Professionals in Coal Mining and Reclamation

Beginning in 2001, OSM staff began an initiative to communicate the OSM perspective on CCB and coal mining issues to other professionals working in areas related to coal mining and reclamation by presenting papers at related national and international symposia including:

1. 14th American Coal Ash Association International Symposium on Management and Use of Coal Combustion Products, San Antonio, Texas
2. 2001 U.S. Department of the Interior Conference on the Environment, Albuquerque, New Mexico
3. 11th International Conference on Coal Science, San Francisco, California
4. 2001 International Ash Utilization Symposium, University of Kentucky, Lexington, Kentucky
5. 18th International Pittsburgh Coal Conference, Newcastle, New South Wales, Australia
6. April 2002, CCBs and Western Coal Mines: A Technical Interactive Forum, Golden, Colorado
7. 15th American Coal Ash Association International Symposium on Building Partnerships for Sustainability, St. Petersburg, Florida

A Brief History of U.S. Environmental Protection Agency (EPA) Rule Making on CCBs Related to their Use and Disposal on Mine Sites.

U.S. Congress Passes Solid Waste Disposal Act Amendments

In October of 1980, Congress temporarily exempts from regulation, under Subtitle C of the Resource Conservation and Recovery Act (RCRA), certain large volume fossil fuel wastes (FFW), and then directs the U.S. EPA to conduct a detailed and comprehensive study of fossil fuel wastes based on eight study factors.

U.S. EPA Exempts Four of the Large Volume CCBs from Hazardous Waste Regulation

On August 9, 1993, the U.S. EPA made a regulatory determination that the four large volume FFWs do not warrant regulation as hazardous under Subtitle C of RCRA. EPA commits to a schedule to complete the report to congress for the remaining wastes.

U.S. EPA Proposed Hazardous Waste Determination

On April 28, 1999, EPA published its Notice of Availability for the EPA's Report to Congress on Fossil Fuel Combustion Wastes not previously studied including oil, natural gas, and certain coal combustion wastes. EPA purposed to determine whether the remaining fossil fuel combustion wastes should retain their exemption from hazardous waste regulations. Of potential concern to the mining community, EPA stated that "The Agency currently has insufficient information on managing fossil fuel combustion wastes in surface and underground mines in order to

assess the potential for risks associated with this practice, whether for disposal or beneficial uses such as mine reclamation." During the comment period, OSM provided extensive input on the requirements of the Surface Mining Control and Reclamation Act as well as pertinent research results related to the use of CCBs at mine sites.

In March of 2000, the U.S. EPA provided OSM with a draft final rule that would list all CCBs as hazardous when disposed or placed in a landfill including when placed on a mine sites regulated under SMCRA.

In response, OSM provided letters from its Director as well as from the Assistant Secretary of the Interior in support of the position that listing of CCBs at mine sites under Subtitle C (Hazardous Waste) under RCRA was not warranted based on the following observations:

- EPA wrongly proposes to place the burden for the determination of toxicity for these materials on the receiver (the mine) rather than on the producer of the materials (usually a power plant). This is inconsistent with the "polluter pays" principle, and it takes responsibility out of the hands of those who are in the best position to make toxicity determinations based on knowledge of the composition of the materials in the first place.
- The EPA requirements for groundwater monitoring and liners of mine filling sites are likely to produce conflicts with the Surface Mining Control and Reclamation Act (SMCRA) bond release and liability requirements for reclamation.
- The EPA conclusions concerning the use and disposal of Coal Combustion By-Products (CCBs) on SMCRA mining sites are not adequately supported by scientific data. First of all, none of the scientific data upon which EPA bases its conclusions specifically addresses the potential for CCB toxicity on mine sites. EPA examples of toxicity are exclusively on electric power plant associated disposal sites. EPA ignores the preponderance of scientific data from university research, the Department of Energy (DOE), and the Electric Power Research Institute that shows that less than 1 percent of tested CCBs show any potential generation of hazardous leachates. EPA further ignores university research showing that coal mine spoil tends to absorb any potential leachate from CCB disposal.
- EPA makes no distinctions that recognize the vastly different circumstances under which CCBs are handled. The risks associated with CCBs can vary dramatically depending on the environmental setting of the mine, the region of the country where it is located, and differing geology and climate. For example, there are drastic differences in alkalinity and acidity problems depending on whether the mining is in the Eastern or the Western United States. There are also considerable differences depending on the regulatory requirements and mining practices of coal versus non-coal mining, surface versus underground mining, and active versus abandoned mine reclamation. DOE and Interior (USGS) have the capability to address some of these research questions, but more time is needed than EPA is allowing.
- EPA proposes no method for testing and certification that any CCB is nonhazardous and exempt from regulation as a waste. In other words, EPA is going from a policy of blanket exemption from RCRA to blanket inclusion in RCRA, regardless of site-specific analyses.
- The EPA decision will have a negative impact on the current national effort to recycle these materials into beneficial economic uses on the mine site. This is counter to EPA's emphasis on recycling as a means of minimizing the need for waste disposal. It also exacerbates the existing dilemma of inadequate availability of landfill facilities.
- The EPA decision will have a negative impact on the beneficial environmental uses of this material for control of acid mine drainage, reclamation of abandoned mine sites, and subsidence control. Beneficial uses include filling voids in underground mines, shoring up underground mines to reduce the likelihood of surface subsidence, and amending soils to improve revegetation at mine sites.
- The EPA decision does not recognize the potential for the existing SMCRA programs to regulate and oversee the use and disposal of CCBs on coal mine sites. Rather than exploring ways to provide the needed environmental assurances within the existing regulatory regime of SMCRA, EPA proposes to introduce a RCRA-based mechanism on top of existing SMCRA-based regulation at mine sites.
- The EPA decision does nothing to address EPA's stated concerns about the lack of uniform minimum State standards for disposal of these materials. In essence, it would impose a more costly regulatory mechanism without removing the risk that some States would ineffectively implement the new requirements.
- There is no indication that EPA's imminent determination is being subject to the scrutiny one would ordinarily expect for decisions of this environmental magnitude under the National Environmental Policy Act. Because of the degree to which the effects on the quality of the human environment are likely to be highly controversial, EPA needs to more fully analyze the impacts before making a decision including, if necessary, performing an

environmental impact statement.

- The current EPA decision is a radical departure from the direction EPA stated in the public record of its report to Congress on April 28, 1999. Concerned Federal agencies, including OSM, Energy, and Agriculture, only learned of this new direction on March 6, 2000, and have had insufficient time for review and interagency discussion of the impacts of the determination.
- Other Interior bureaus that will be impacted by this decision have not been included in the interagency briefings. OSM has been informed by the Bureau of Land Management that at least seven or eight Federal coal mine leases dispose of CCBs at mine sites in New Mexico, Colorado, Wyoming, and North Dakota. OSM is aware of at least one mine on the Navajo Nation in Arizona that disposes of CCBs on the mine site, which would involve the Bureau of Indian Affairs, and the Navajo Nation.

U.S. EPA Proposed Solid Waste Regulations for CCBs at Coal Mines

In its decision on May 22, 2000, the U.S. EPA determined that national regulations under Subtitle D (Solid Waste) of the Resource Conservation and Recovery Act (RCRA) [and/or possible modifications to regulations under the Surface Mining Control and Reclamation Act (SMCRA)] were warranted when these wastes are used to fill surface or underground mines. EPA believes this is necessary so that CCBs will be consistently managed across all waste scenarios.

On September 14, 2000, EPA met with OSM to initiate a dialog between the two agencies concerning EPA rule making for CCBs used as fill at surface and underground mine sites. During the course of this discussion, EPA informed OSM that EPA expects to have a proposed rule out under Subtitle D of RCRA (Solid Waste) in 2003 and a final rule by 2004.

EPA has also invited OSM staff on a series of joint tours of mines sites where CCBs are being used as fill. To date, tours have taken place in the anthracite mining districts in Pennsylvania and in Northern West Virginia where fluidized bed combustion ash is being returned to the mine site to support reclamation and as a seal for acid forming materials. Tours also have been conducted in the States of Indiana, Illinois, New Mexico, and North Dakota. Additional tours are anticipated in other States during 2002.

Additional Federal Regulation at SMCRA Mine Sites: Arguments For and Against

EPA Concerns

Concerns that EPA staff have expressed to OSM as to why they feel EPA regulation under RCRA may be necessary are:

- EPA has found a small number (less than 12 from about 1000 monitoring wells at CCB disposal sites nationwide) of unlined solid waste disposal facilities at electric utilities where leachates from the facility have been determined to contain elements at levels of toxicity determined to be detrimental to public health and/or the environment.[4] Although they have not found any such examples at mine sites, they feel that the similarities between these utility disposal sites and mine sites where CCBs are placed as fill warrant similar regulation.
- Groundwater monitoring at SMCRA mine sites may be inadequately designed to detect toxicity.
- Bonding of SMCRA mine sites (a minimum of 5-10 years after reclamation and revegetation has been completed) may be of insufficient duration to detect toxicity.

OSM Concerns

Concerns OSM has expressed to EPA as to why additional EPA rule making for mine sites may not be warranted include:

- OSM believes that the SMCRA regulations already provide at least as much protection of the public health and environment as anything as yet proposed by EPA. The extensive mining and reclamation designs, environmental investigations, leachate testing, requirements to protect or replace drinking water sources, performance bonding, and post reclamation water monitoring requirements of SMCRA make mine sites significantly more protective of the environment than what is found at electric utility ash disposal sites where toxic leachate has occurred and, therefore, are not similar to them.

- It is not valid to compare utility CCB disposal sites where toxic leachate has occurred with SMCRA mine sites as they differ significantly in terms of regulatory requirements, geology, geography, hydrology, characteristics of CCBs used as fill, and reclamation practices. Electric utility disposal sites where toxic leachates have occurred are typically characterized by:
  (1) geographic placement in a floodplain;
  (2) a geologic setting of alluvial sand and gravel usually close to a river;
  (3) groundwater that is plentiful and of high quality;
  (4) all types of CCB materials are placed in these facilities in a wet slurry without any chemical characterization of the material;
  (5) reclamation is accomplished with a shallow layer of fill over the area and revegetated; and
  (6) the Clean Water Act usually covers the area during operation and State solid waste regulations at disposal (Figure 1).

  CCB placement at mine sites typically is characterized by:
  (1) a geographic placement in an upland position;
  (2) a geologic setting of bedrock sandstone, shale, and limestone underlain by an impermeable fire clay below the lowest coal seam that was mined;
  (3) groundwater is limited and of poor quality;
  (4) only those CCBs that are leachate tested and approved in the SMCRA permit are allowed for placement on the mine site;
  (5) reclamation is accomplished with a deep layer of spoil over the area followed by topsoil and then revegetated; and
  (6) at all phases, the placement is regulated by the environmental protection permitting and performance standards of SMCRA, which include the requirements of the Clean Water Act and applicable State Solid Waste program requirements (Figure 2).

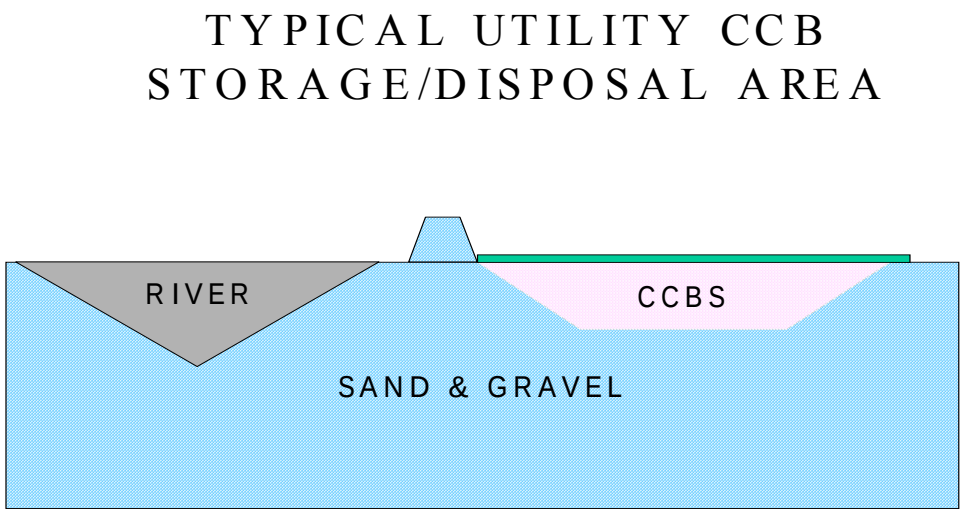

Figure 1. Typical cross-section of an electric utility disposal sites where toxic leachate has occurred.

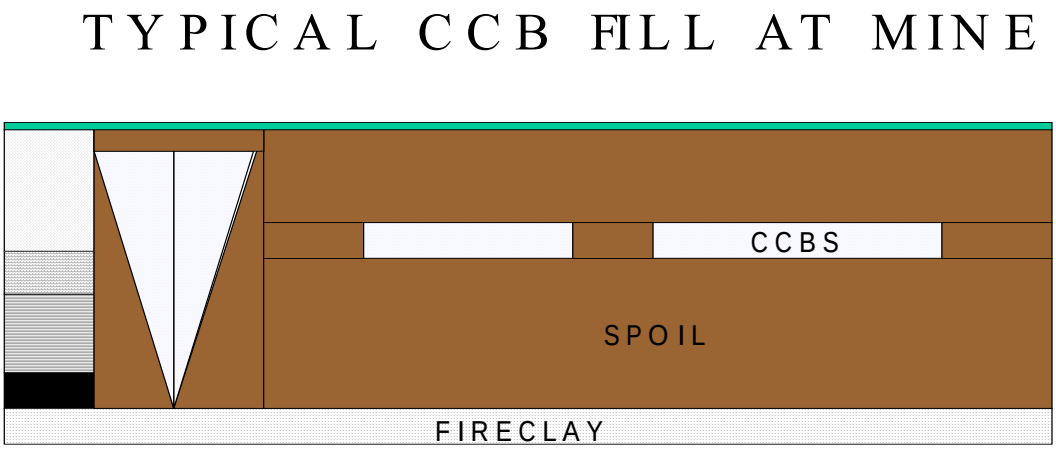

Figure 2. Typical cross-section of CCB placement at a reclaimed coal mine site.

- EPA has yet to bring forward any data or scientific evidence that CCBs placed at mine sites under SMCRA have resulted in any toxicity that would pose a threat to public health or the environment.
- The SMCRA performance bond lasts as long as is necessary to determine that the environmental performance requirements of the SMCRA program and the applicable permit have been met. The release of the bond is not determined by time, but by environmental performance.
- SMCRA permits, unlike utility disposal sites where toxic leachate has occurred, must include detailed information on potential pollutants of ground and surface water, a detailed hydrologic protection plan, and a ground and surface water monitoring plan.
- SMCRA water quality performance standards require that disturbances to the hydrologic balance be minimized by protecting ground and surface water from pollutants and include requirements for the replacement of water supplies impacted by contamination and require water monitoring based on probable impacts.
- There has been extensive research over the last 20+ years related to effects of CCB placement at mine sites where it is used:
  (1) as nontoxic mine fill;
  (2) for subsidence control;
  (3) as seals for acid forming materials;
  (4) for the reduction of acid mine drainage;
  (5) as a soil substitute; and
  (6) for reclamation of abandoned mine lands where existing soil material is not available.

Recent studies by the U.S. Geologic Survey[5] have successfully utilized magnesium to calcium ratios and sulfur-isotope ratios as tracers on pressurized fluidized bed combustion (PFBC) by-product placed in an abandoned coal mine to mitigate the effects of acid mine drainage. The study demonstrates that the application has been environmentally beneficial in dramatically decreasing the effects of acid mine drainage, and that any remaining trace elements in the groundwater are due to acid mine drainage and not leachate from the PFBC.

To date, all of this research has indicated that the use of CCBs at mine sites is beneficial to public health and the environment in most cases and at a minimum has no negative effect on public health or the environment.

Conclusion

OSM staff has been extensively involved with the development and distribution of technical information related to the beneficial placement of CCBs at coal mine sites since 1995. Because of the complexity of the issues involved and the importance of protection of public health and the environment during surface coal mining and reclamation, OSM is very supportive of additional research into the potential environmental effects of CCB placement at coal mine sites. Any additional Federal regulation of CCB placement at SMCRA mine sites, however, should only be based on sound scientific evidence that the existing regulatory framework is not adequate.

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Kimery Vories has been a Natural Resource Specialist with the Office of Surface Mining since 1987. He is chairperson of several multi-agency, multi-interest group steering committees that hold forums, publish proceedings, and manage Internet websites on mining and reclamation issues related to the technical aspects of Coal Combustion By-Products, Prime Farmland Reclamation, Reforestation, and Bat Conservation. He has been professionally employed in coal mining and reclamation since 1979 with 37 related professional publications. He serves on: (1) the National Steering Committee for the Combustion By-Products Recycling Consortium; and (2) the Technical Program Committee of the International Ash Utilization Symposium at the University of Kentucky. He holds a BA and MA in Biology/Geology from Western State College of Colorado with an additional 3 years Post MA Graduate work in Ecology and Reclamation at the University of Massachusetts and Colorado State University.

Session 1

Coal Combustion By-Products: The Basics

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Coal Combustion Products—Production and Uses
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Physical and Chemical Characteristics of CCB
Ann Kim, U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, Pennsylvania

Western Region Fly Ash Survey
Gretchen K. Hoffman, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

ASTM Standards to Support Mine Applications of CCBs
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Coal Combustion Residues and Mercury Control
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COAL COMBUSTION PRODUCTS—PRODUCTION AND USES

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Abstract

The first research on fly ash was reported in the Proceedings of the American Concrete Institute in 1937, which introduced the term "fly ash" to the literature. The Chicago Fly Ash Company, formed in 1946, was the first to market fly ash as a construction material for manufacturing concrete pipe. The U.S. Bureau of Reclamation used fly ash on a large scale in the construction of the Hungry Horse Dam in Montana in 1949. Six other dams were constructed during the 1950s using fly ash concrete. Initial markets for fly ash were as a portland cement extender and as an enhancer of the qualities of concrete to meet new postwar requirements.

Burning coal generates more than half the electricity in the United States. As a result, more than 100 million metric tons of CCPs are generated by the electric utilities, almost one-third of which is used in a number of applications. CCPs are used primarily in cement and concrete, structural fills, waste stabilization, road base/subbase, wallboard, and mining applications. Innovative high-volume applications are being developed. In 2000, CCPs were used as a raw material in numerous products ranging from wallboard to bowling balls.

Coal Combustion Products

The working definition for solid materials resulting from the combustion of coal has been evolving. Environmental regulators first used the term coal combustion wastes. Later, the term coal combustion by-products gained popularity. Lately, coal combustion products (CCPs) has become a household term for those in the power industry, the ash marketers, and most users of these materials. The solids included in CCPs are fly ash, bottom ash, boiler slags, and flue gas desulfurization (FGD) material. Fly ash is the fine fraction of the CCPs that is carried out of the boiler by the flue gases. Almost all fly ash is captured by dust collecting systems such as electrostatic precipitators. Bottom ash is defined as the large ash particles that accumulate at the bottom of the boiler. Boiler slag is the molten inorganic material that is collected at the bottom of the boilers and discharged into a water-filled pit where it is quenched and removed as glassy particles resembling sand. Fly ash represents a major component (58%) of CCPs produced, followed by FGD material (24%), bottom ash (15.5%), and boiler slag (2.5%). Among the major CCP components, fly ash and FGD materials boast the highest use rate, about 32%, of the amount produced.

Electricity accounts for more than one-third of the primary energy used in the United States. More than one-half of the Nation's electricity is generated by burning coal. Coal burning, combined with pollution control technologies, generates large quantities of CCPs. During 2000, about 860 million metric tons (MT) of coal were burned and about 98 MT of CCPs were generated by the electric utilities.

In addition to the ash, sulfur in flue gases emitted from fossil-fuel-burning electricity generating plants is also a concern for the environment. The majority of electric power utilities, especially in the eastern and midwestern states, use high sulfur bituminous coal. Increased use of high sulfur coal has contributed to an acid rain problem in North America. To address this problem, the U.S. Congress passed the Clean Air Act Amendments of l990 (CAAA 90) (Public Law 101-549) with stringent restrictions on sulfur oxides emissions. The sulfur dioxide (SO_2) reduction provisions of the CAAA, which are being implemented in a two-phase plan to be completed by 2010, forced the electric utilities to find ways of reducing SO_2 emissions. A number of utilities have switched to alternative fuels, such as low sulfur coal or fuel oil, as partial or temporary solutions to the problem. The significant number of electric utilities still using high sulfur coal have installed flue gas desulfurization (FGD) units.

FGD units remove SO_2 from flue gas, but in doing so generate large quantities of FGD material, which is a mixture of gypsum (hydrous calcium sulfate), calcium sulfite ($CaSO_3$), fly ash, and unreacted reagents. A number of power plants convert the $CaSO_3$ to calcium sulfate by forced oxidation and take appropriate measures to reduce the other impurities in the FGD material to produce synthetic gypsum that exceeds the specification for wallboard manufacture. Wallboard plants, recently constructed adjacent to such electric utilities, use the FGD gypsum from

those electric utilities. The FGD material adds to the accumulation of already high levels of CCPs. About 23 MT of FGD material was produced in 2000 with about 4.5 MT (20%) used mostly for wallboard manufacture. FGD issues affect, directly or indirectly, coal, gypsum, lime, limestone, and soda ash producers. Increased commercial use of FGD products represents an economic opportunity for high sulfur coal producers and the sorbent industry (especially lime and limestone). Today, synthetic gypsum competes directly with natural mined gypsum as raw material for wallboard manufacture. The value of CCPs is well established by research and commercial practice in the United States and abroad. As engineering materials, these products can add value while helping conserve the Nation's natural resources.

Production

A small, steady increase in CCP production rates through 2000 is apparent (Table 1). In 1999, it was predicted that fly ash, bottom ash, and boiler slag production could be expected to remain flat in the near future, as no significant increase in the use of coal was planned for electric power generation. An unexpected jump in petroleum prices, however, may well change the Nation's energy equation in favor of increased coal use. An increase in ash generation can be expected with increased coal burning. The commencement of phase two of the CAAA in January 2000 is expected to contribute to a significant increase in synthetic gypsum generation in the years ahead. The energy policies of the new administration, which call for increased use of fossil fuels, especially the use of coal in electric power generation, gives an additional reason to anticipate increases in the generation of CCPs. Tables 2 through 4 show the domestic production and consumption data for 2000. Table 2 lists the total quantities of CCPs (dry and ponded), whereas tables 3 and 4 summarize the dry and ponded CCP data, respectively.

Figure 1 depicts various geographic regions for which CCP data are presented. Graphic representation of CCP data is shown in figures 2 through 9. Figures 2 and 3 show historical CCP production and use data, respectively. Total CCP production and use data for 2000 are presented in Figure 4. Figure 5 depicts production by CCP type and region. Figures 6 through 9 show leading uses for fly ash, bottom ash, boiler slag, and FGD material, respectively.

Consumption

The components of CCPs have different uses because they have distinct chemical and physical properties; each one is suitable for a particular application. CCPs are used in cement and concrete, mine backfill, agriculture, blasting grit, and roofing applications. Other current uses include waste stabilization, road base/subbase, and wallboard production (synthetic gypsum). Potential FGD gypsum uses also include applications in subsidence and acid mine drainage control and as fillers and extenders.

Total CCP use in 2000 decreased by 4.7% to 28.59 MT from 30.00 MT in 1999. Fly ash, bottom ash, and boiler slag all showed slight decreases in use, whereas FGD material recorded an 8.7% increase over the 1999 figure (Table 1). Domestic CCP consumption data from 1996 to 2000 are summarized in Figure 3. Figures 6 through 9 summarize the use data for individual CCP types. Among the CCPs, fly ash was used in the largest quantities and found the widest range of applications, with about 60% of annual consumption used in various structural applications. Use in cement and concrete production tops the list of leading fly ash applications with more than 50%, followed by structural fills and waste stabilization (Figure 6).

Structural fill and road base/subbase applications are major bottom ash uses. About 65% of bottom ash is used in road base/subbase, structural fill, and snow and ice control (Figure 7). Minor uses include concrete, mining applications, and cement clinker raw feed. Bottom ash also can be used as fine aggregate in asphalt paving mixtures. Some bottom ash is sufficiently well graded that pavements containing bottom ash alone can meet gradation requirements. Bottom ash containing pyrites or porous particles is not suitable for use in hot mix asphalt mixtures, where strict gradation requirements exist. It is used more commonly in cold-mix emulsified asphalt mixtures, where gradation requirements and durability are not as critical as in hot mix surface mixtures.

Owing to its considerable abrasive properties, boiler slag is used almost exclusively in the manufacture of blasting grit. Use as roofing granules also is a significant market area. Blasting grit and roofing granules make up almost 95% of boiler slag applications (Figure 8). Boiler slag also can be used as fine aggregate, especially in hot mix asphalt owing to its superior hardness, affinity for asphalt, and dust-free surface, which aids in asphalt adhesion and resistance to stripping. Since boiler slag exhibits a uniform particle size, it is commonly blended with other aggregates for use in asphalt mixtures.

Wallboard manufacture (75% of the total), concrete, mining applications, and structural fill accounts for the bulk of FGD product uses (Figure 9). Structural fill and concrete accounts for a majority of other uses of FGD material. Agricultural uses account for only 1.6% of total FGD material use; however, potential FGD material use in agriculture exceeds even its use in wallboard manufacture.

World Review

Partial world production and consumption data were compiled in 1999. Data were obtained from major European and Asian countries, including India, China, and Russia. Table 5 summarizes partial world CCP statistics. Republic of Korea—not in table—produced 400 million tons of CCPs in 1999. It is believed to be the largest quantity generated by a single country. In the table, data from 13 European Union countries are combined under the European Coal Combustion Products Association (ECOBA). ECOBA member countries are Belgium, France, Germany, Greece, Ireland, the Netherlands, Poland, Portugal, Spain, and the United Kingdom. ECOBA members account for more than 90% of CCP production in Europe.

In 1999, the ECOBA beneficially used 56% (31 MT) of the 55.5 MT of the CCPs that its member countries generated compared with about 30% use in the United States. More than 18 MT of the 37 MT of fly ash produced was used (48% use rate). A slightly smaller fraction (44%) of bottom ash, 100% of boiler slag, and 87% of synthetic gypsum produced found beneficial uses (Table 5). Raw material shortages and favorable State regulations account for the higher use rates of CCPs in Europe. As in the United States, ECOBA members used CCPs in a number of applications, with concrete leading the way at 37%, followed by portland cement manufacture with 31% and road construction with 21%; other uses made up the remainder (11%).

Among the individual countries contacted, Canada, India, Israel, Japan, and South Africa reported partial CCP production and use data. Canada used about 1.9 MT (27%) of 7 MT of CCPs produced, whereas coal-burning electric utilities in India generated about 90 MT of CCPs in 1999, of which about 13% (11.7 MT) was used. The remainder was disposed of in wet ponds. In Japan, 1999 figures were 9.1 MT and 7.65 MT for production and use, respectively. These figures translate into 84% use rate for Japan. The high disposal costs of CCPs in Japan ($100 per metric ton) make alternative uses economically viable (Mark Early, Barlow Junker Pty Ltd., oral commun., 2001). Large volume CCP use in India, China, and the Republic of Korea is an environmental and economic necessity owing to the planned increase in coal-fired power plants to meet future electricity needs and the high ash contents of coal burned. Current burning of coal containing 40% to 45% mineral matter generates 90 million metric tons per year (MT/yr) of CCPs in India, most of which is disposed of in wet ponds in the vicinity of the plants. The situation in the Republic of Korea is even more serious owing to the fact that the Republic of Korea burns more coal for electricity production than any other country in the world. Korean coal also contains high fractions of mineral matter, which results in the generation of CCP quantities four times that of the United States (Ji-Young Ryu, Korea Electric Power Corporation, oral communication, 2001).

Current State of Research and Technology

Research and development activities have focused on improving FGD processes and finding new applications for CCPs, especially the FGD product. Japanese and West European researchers have led much of the research and development efforts in new FGD technologies. Electric utilities in these countries have no room for the disposal of the products from the current FGD processes and are forced to find better solutions to flue gas emission problems. Research efforts emphasize the development of technology that requires less space for installation and yields smaller quantities of products than the well-established methods using lime or limestone as sorbents. Research and development efforts in FGD have been directed, for the most part, toward either decreasing the quantities of the reaction products or increasing their economic value to upgrade them from waste products to resources.

Consol Energy Corporation is successfully manufacturing aggregates from CCPs using a pelletization process it developed (Aggregates Manager, 2000). Fly ash and synthetic gypsum are combined by disk pelletization with moderate-temperature curing to form aggregates. If commercialized, such manufactured aggregates may eventually play an important role in the 2-billion-ton-per-year aggregates market.

In order to reduce nitrogen oxides emissions to meet the requirements of the CAAA 90 restrictions on nitrogen oxide (NO_x) emissions, many electric utilities installed no-NO_x burners. No-NO_x burners, however, lead to a

significant increase in the unburned carbon content of fly ash, in certain cases exceeding 10%. High carbon content renders fly ash unsuitable for cement and concrete applications that account for the bulk of fly ash use. Excess unburned carbon in concrete-containing fly ash cement reduces the freeze-thaw resistance of concrete by capturing the air entraining agents that are used to modify the porosity of the concrete. Researchers at The Pennsylvania State University have developed a method to economically separate unburned coal from fly ash (Skillings Mining Review, 1999). It appears that the unburned carbon separated from the fly ash is suitable for manufacturing activated carbon, which is used in water treatment and gas purification processes. These carbon products have a significant market with 350,000 metric tons per year sold. The unburned carbon, separated from fly ash, does not need cleaning or grinding, nor does it need heating to remove volatiles. While anthracite, which is currently used as the precursor in the manufacture of activated carbon, sells for about $50 per metric ton, the unburned-carbon in fly ash can be separated at $10 to $15 per metric ton and the clean fly ash can be sold to concrete or cement producers.

Reports of research and development results during the past two decades indicate that an increase in the development of uses for CCPs will happen in small steps. At the 14th International Symposium on Management and Use of Coal Combustion Products, held in San Antonio, Texas in January 2001, researchers from industry, academia, and Federal and State governments made presentations that covered a range of topics from characterization to applications of CCPs in landfills, agriculture, mine backfilling, acid mine abatement, manufacture of building blocks, and recovery of high value rare-earth metals. The proceedings of the 14th symposium contain 82 papers, presented in 13 sessions (American Coal Ash Association, 2001).

Barriers to Utilization

There are a number of technical, economic, institutional, and legal barriers to the use of large quantities of CCPs. Technical and economic barriers are not mutually exclusive in that technological advancements usually result in economic feasibility. Principal technical barriers include issues related to CCP production, specifications and standards, materials characterization, product demonstration and commercialization, and user-related factors.

Economic barriers to increased CCP use can be key among all factors affecting by-product use. With proper economic incentives, other barriers to increased use of CCPs can be overcome. For coal-burning electric utilities, the revenues from the sale of CCPs are often insignificant. The high cost of transporting the low unit-value CCPs and competition from locally available natural materials pose two of the most important economic barriers.

Among the institutional and legal barriers are the lack of knowledge of potential ash uses, sporadic data on environmental and health effects, compositional inconsistencies in the products, belief that other raw materials are readily available, lack of State guidelines, and viewpoint of the industry that EPA regulations and procurement guidelines are too complicated and rigid rather than being general guidelines for use.

An American Society for Testing and Materials subcommittee under the Committee E-50 on Environmental Assessment, on which the U.S. Geological Survey (USGS) is represented, was recently formed to address the question of standards and definitions of coal and CCP-related terms. Subcommittee members evaluated the latest draft of the definitions document. Recommendations were submitted to the committee for action in 2001. This draft calls for the change of CCPs to coal combustion by-products (CCBs) to iterate the ideal definition of a product, which is the principal reason for a process. It is argued that coal is burned to produce energy, not ash. Therefore, energy is the product of coal burning processes; anything else is a by-product.

Concerned industry and government representatives, scientists, and engineers have formed a number of national and international organizations to address the removal of barriers to use of CCPs. Some of the most prominent are the American Coal Ash Association (ACAA), the recently formed Coal Ash Resources Research Consortium (CARRC), the Center for Applied Energy Research (CAER), the Coal Combustion By-Products Recycling Consortium (CBRC), the Coal Combustion By-Product Information Network Steering Committee (CCBINSC), and a number of State organizations.

Future Outlook

Two principal factors that will affect the size of the coal market and, therefore, quantities of CCPs generated are market deregulation and emissions regulations. Market deregulation will encourage electric utilities to search for the lowest cost fuel, and that will probably be coal. On the other hand, there is the need to comply with phase two of

the CAAA '90. Phase two of the CAAA '90, implemented in January 2000, capped power plant SO_2 emissions nationally at 7.72 MT/yr. As of January 2000, there were about 10 MT of SO_2 allowances available for sale to noncompliant plants. The allowances were accrued during phase one of the CAAA '90. Quick disappearance of these allowances will force utilities to switch to clean fuels or to retrofit power plants with FGD units. Increases in the production of fly ash and bottom ash will be proportional to the increase in coal use for electric power production. However, there may be a significant rise in the FGD material owing to the implementation of phase two of the CAAA '90. Currently, U.S. electric power generators that support FGD units represent little more than 10,000 MW of generating capacity, which is 1.2% of total U.S. generating capacity. Generating capacity currently under construction that will support FGD units represents another 10,000 MW. In addition, FGD units are planned for another 13,000 MW of capacity that are proposed for future construction. When operational, these generators are expected to more than triple the quantity of FGD material to about 75 MT/yr from the current level of 24 MT/yr. Continued installation of FGD units, combined with the potential effect of future EPA rule making, presents a formidable challenge to electric utilities and CCP-user industries.

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TABLE 1
HISTORIC COAL COMBUSTION PRODUCT PRODUCTION AND USE

[In thousand metric tons. Source: American Coal Ash Association]

	1996	1997	1998	1999	2000
Fly ash:					
Production	53,900	54,700	57,200	56,900	57,100
Use	14,700	17,500	19,200	18,900	18,200
Percent use	27.50	32.10	33.60	33.20	31.90
Bottom ash:					
Production	14,600	15,400	15,200	15,300	15,400
Use	4,430	4,600	4,760	4,930	4,480
Percent use	30.40	30.20	31.30	32.10	29.10
Boiler slag:					
Production	2,360	2,490	2,710	2,620	2,440
Use	2,170	2,340	2,170	2,150	2,110
Percent use	92.30	94.10	80.10	81.80	87.00
FGD material: 1/					
Production	21,700	22,800	22,700	22,300	23,300
Use	1,500	1,980	2,260	4,030	4,380
Percent use	6.96	8.67	10.00	18.10	18.80
Total CCPs:					
Production	92,400	95,400	97,800	97,100	98,200
Use	22,800	26,500	28,400	30,000	28,600
Percent use	24.90	27.80	29.00	30.80	29.10

1/ FGD flue gas desulfurization.

TABLE 2
TOTAL COAL COMBUSTION PRODUCT PRODUCTION AND USE, 2000 1/

[In thousand metric tons. Source: American Coal Ash Association. NA, not available; --, zero]

	Fly ash	Bottom ash	Boiler slag	FGD material 2/	Total CCPs
Production	57,100	15,400	2,440	23,300	98,200
Use:					
Agriculture	13	4	--	69	86
Blasting grit-roofing granules	--	133	1,900	--	2,030
Cement clinker raw feed	1,030	158	--	--	1,190
Concrete-grout	9,600	381	(3/)	318	10,300
Flowable fill	632	10	16	30	688
Mineral filler	108	93	11	(3/)	212
Mining applications	1,050	333	--	166	1,550
Roadbase-subbase	1,100	759	(3/)	85	1,940
Snow and ice control	3	755	53	--	811
Soil modification	102	25	--	--	127
Structural fills	2,370	1,230	32	496	4,130
Wallboard	--	--	--	3,020	3,020
Waste stabilization-solidification	1,800	32	--	19	1,850
Other	413	571	89	173	1,250
Total	18,200	4,480	2,100	4,380	29,200
Individual use percentage	31.90	29.10	87.00	19.00	NA
Cumulative use percentage	31.90	31.30	33.10	32.80	NA

1/ FGD flue gas desulfurization.
2/ Less than 1/2 unit.

TABLE 3
DRY COAL COMBUSTION PRODUCT PRODUCTION AND USE, 2000

[In thousand metric tons. Source: American Coal Ash Association. NA, not available; --, zero]

	Fly ash	Bottom ash	Boiler slag	FGD material 1/	Total CCPs
Production	42,600	9,420	756	18,400	71,200
Use:					
Agriculture	13	4	--	66	93
Blasting grit-roofing granules	--	102	610	--	712
Cement clinker raw feed	818	142	--	--	960
Concrete-grout	9,240	276	--	317	9,830
Flowable fill	274	10	--	1	285
Mineral filler	106	51	11	(2/)	168
Mining applications	682	258	--	164	1,100
Roadbase-subbase	1,070	508	--	85	1,660
Snow and ice control	3	489	12	--	504
Soil modification	71	22	--	--	93
Structural fills	2,320	483	32	496	3,330
Wallboard	--	--	--	2,160	2,160
Waste stabilization-solidification	1,800	27	--	19	1,850
Other	68	336	28	170	602
Total	16,500	2,710	693	3,480	23,400
Individual use percentage	38.60	28.70	91.70	18.80	29.10
Cumulative use percentage	38.60	36.80	37.60	29.70	NA

1/ Total CCPs include categories I and II, dry and ponded respectively.
2/ FGD flue gas desulfurization.
3/ Less than 1/2 unit.

TABLE 4
PONDED COAL COMBUSTION PRODUCT PRODUCTION AND USE, 2000

[In thousand metric tons. Source: American Coal Ash Association. NA, not available; --, zero]

	Fly ash	Bottom ash	Boiler slag	FGD material 1/	Total CCPs
Production	14,500	5,920	1,680	4,900	27,000
Use:					
Agriculture	--	--	--	3	3
Blasting grit/roofing granules	--	31	1,290	--	1,320
Cement clinker raw feed	211	15	--	--	226
Concrete-grout	362	105	(2/)	1	468
Flowable fill	358	(2/)	16	29	403
Mineral filler	2	42	--	--	44
Mining applications	363	75	--	2	440
Roadbase-subbase	30	251	(2/)	--	281
Snow and ice control	--	266	41	--	307
Soil modification	30	4	--	--	34
Structural fills	51	743	(2/)	--	794
Wallboard	--	--	--	857	857
Waste stabilization-solidification	--	5	--	--	5
Other	346	235	61	3	645
Total	1,750	1,770	1,410	895	5,830
Individual use percentage	12.10	29.90	84.10	18.30	NA
Cumulative use percentage	12.10	17.30	22.40	21.60	NA

1/ FGD flue gas desulfurization.
2/ Less than 1/2 unit.

Table 5. World Production and Consumption of Coal Combustion Products in 2001

(Thousand metric tons)

Country or association	Fly ash	Bottom ash	Boiler slag	Fluidized bed combustion ashes	Other	Spray dryer absorbent product	Flue gas desulfurization gypsum	Total	Percentage of use
European Coal Combustion Products Association:									
Production	38,959	5,578	2,350	1,015	277	460	10,639	59,300	XX
Consumption:									
Cement raw material	4,421	165	--	29	--	--	--	4,615	7.8
Blended cement	1,999	--	--	1	--	--	--	2,000	3.4
Concrete addition	5,973	--	156	--	--	--	--	6,129	10.3
Aerated concrete blocks	745	62	--	--	--	--	--	807	1.4
Nonaerated concrete blocks	343	970	--	--	--	--	--	1,313	2.2
Lightweight aggregate	14	52	--	--	--	2	--	68	0.1
Bricks and ceramics	68	5	--	--	10	--	--	83	0.1
Grouting	389	--	--	--	--	--	--	389	0.7
Asphalt filler	202	--	168	--	--	--	--	370	0.6
Subgrade stabilization	251	68	--	--	--	--	--	319	0.5
Pavement base course	414	218	1,216	38	--	--	--	1,886	3.2
General engineering fill	1,290	542	--	182	37	25	--	2,076	3.5
Structural fill	1,237	141	--	--	--	--	--	1,378	2.3
Soil amendment	175	--	--	58	--	78	--	311	0.5
Infill	577	--	--	357	--	244	--	1,178	2.0
Blasting grit	--	22	720	--	--	--	--	742	1.3
Plant nutrition	30	--	--	--	--	28	--	58	0.1
Set retarder for cement	--	--	--	--	--	--	793	793	1.3
Projection plaster	--	--	--	--	--	--	778	778	1.3
Plaster boards	--	--	--	--	--	--	4,499	4,499	7.6
Gypsum blocks	--	--	--	--	--	--	245	245	0.4
Self-leveling floor screeds	--	--	--	--	--	--	1,329	1,329	2.2
Other	84	5	90	15	230	26	10	460	0.8
Total	18,212	2,250	2,350	680	277	403	7,654	31,826	53.7
Landfill, reclamation, restoration	17,032	2,619		182		33	733	20,599	34.7
Temporary stockpile	2,340	95					1,306	3,741	6.3
Disposal	2,069	614		153		24	948	3,808	6.4
Utilization rate	89.00	87.00	100.00	85.00	100.00	95.00	79.00	XX	XX
Canada:									
Production	5,500	1,800	NA	NA	NA	NA	500	7,800	XX
Consumption	1,100	200	NA	NA	NA	NA	500	1,800	23.0
India:									
Production	NA	NA	NA	NA	NA	NA	NA	94,000	XX
Consumption	NA	NA	NA	NA	NA	NA	NA	12,500	13.0
Israel:									
Production	NA	NA	NA	NA	NA	NA	NA	1,320	XX
Consumption	NA	NA	NA	NA	NA	NA	NA	1,290	98.0
Japan:									
Production	7,000	1,400	NA	NA	NA	NA	1,700	10,100	XX
Consumption	6,000	1,000	NA	NA	NA	NA	1,500	8,500	84.0
Korea, Republic of:									
Production	NA	NA	NA	NA	NA	NA	NA	300,000	XX
Consumption	NA	NA	NA	NA	NA	NA	NA	15,000	5.0
South Africa:									
Production	2,000	NA	NA	NA	NA	NA	NA	2,000	XX
Consumption	NA	NA	NA	NA	NA	NA	NA	NA	NA
Turkey:									
Production	NA	NA	NA	NA	NA	NA	NA	20,000	XX
Consumption	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA Not available. XX Not applicable. -- Zero.

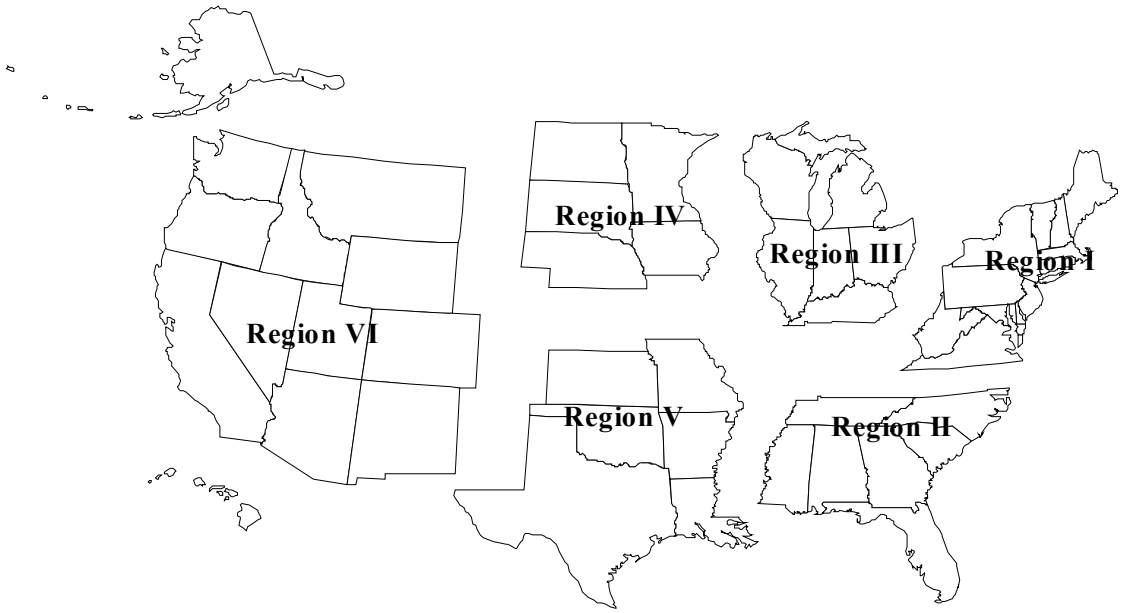

Figure 1. ACAA Regions of the United States

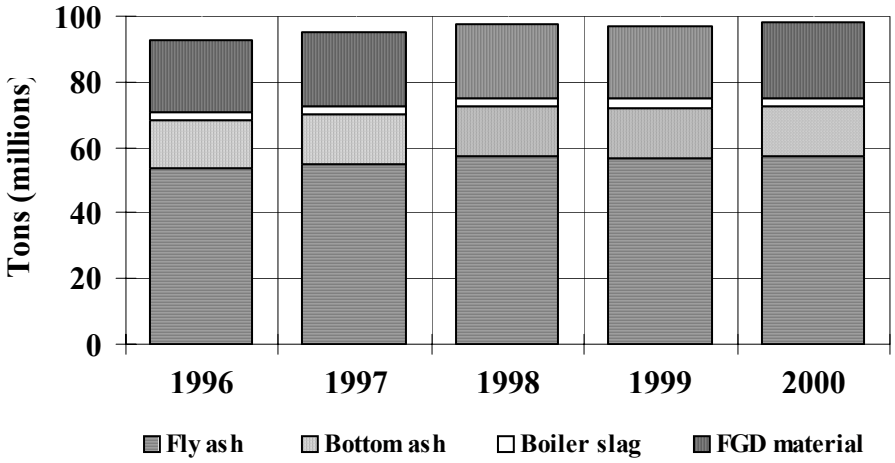

Figure 2. Historic Coal Combustion Product Production Data 1996-2000 (Source ACAA)

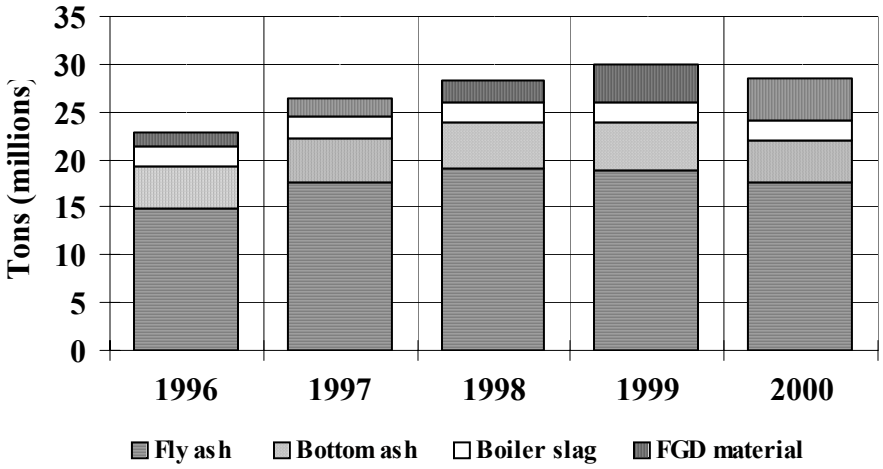

Figure 3. Historic Coal Combustion Product Use Date 1996-2000 (Source ACAA)

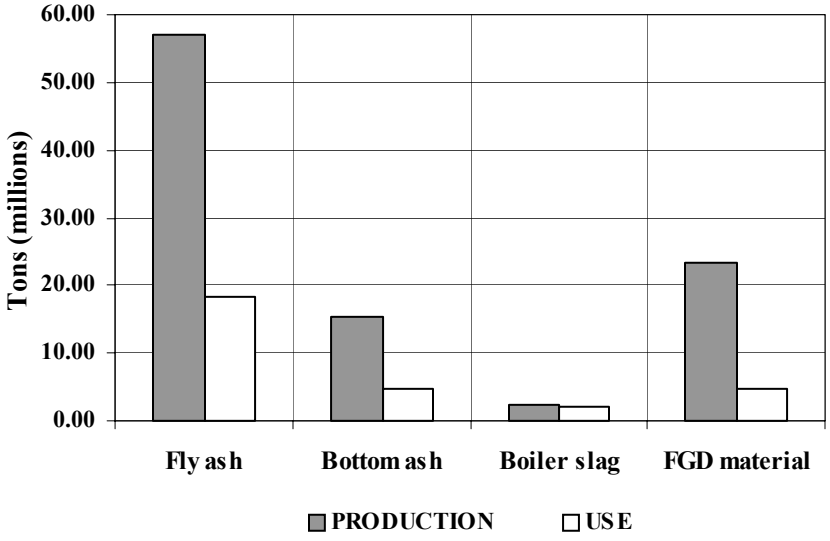

Figure 4. CCP Production and Use for the United States 2000. (Source ACAA)

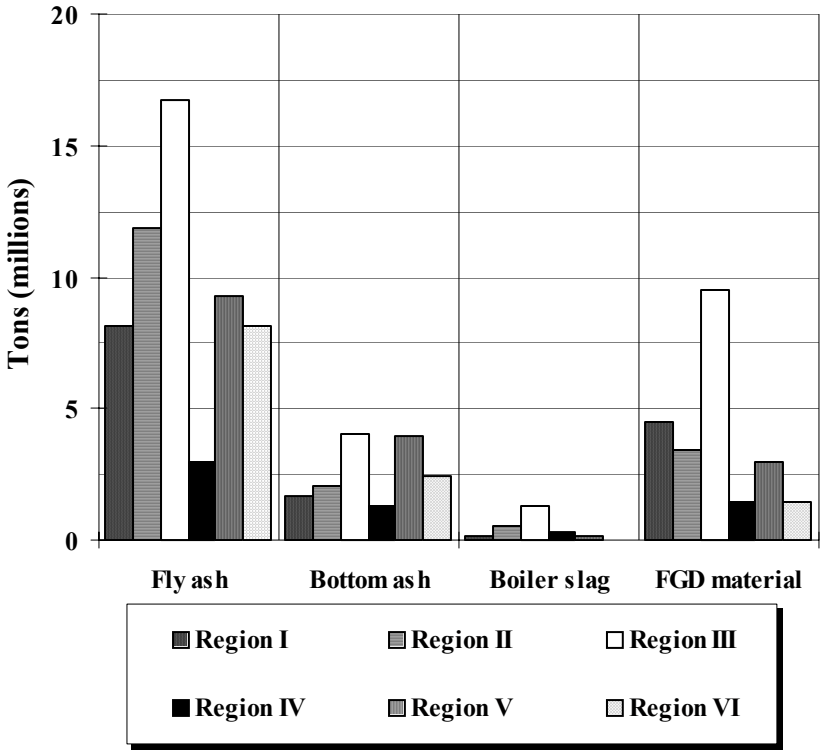

Figure 5. CCP Production by Type and Region (Source ACAA)

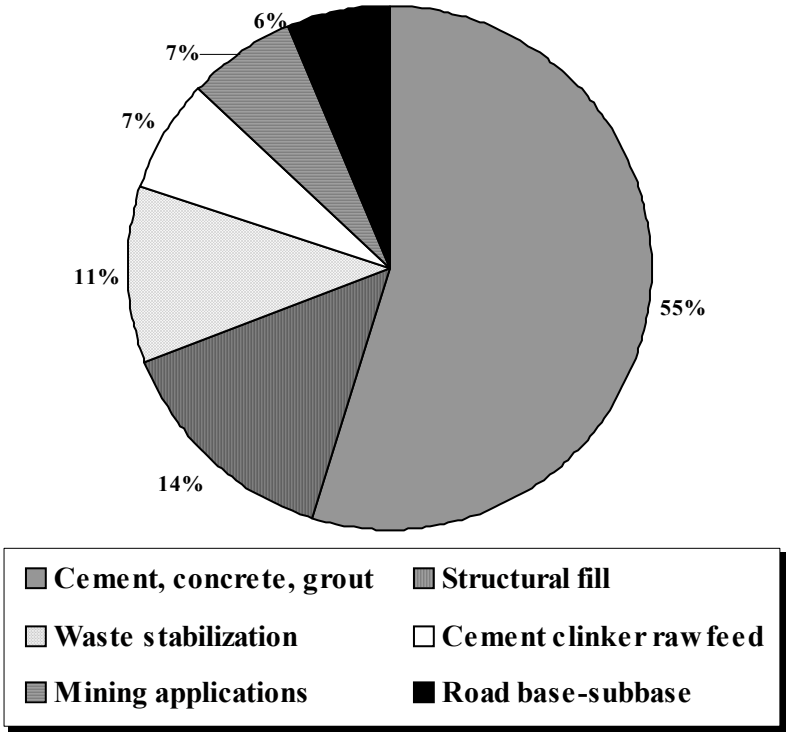

Figure 6. Leading Fly Ash Uses 2000 (Source ACAA)

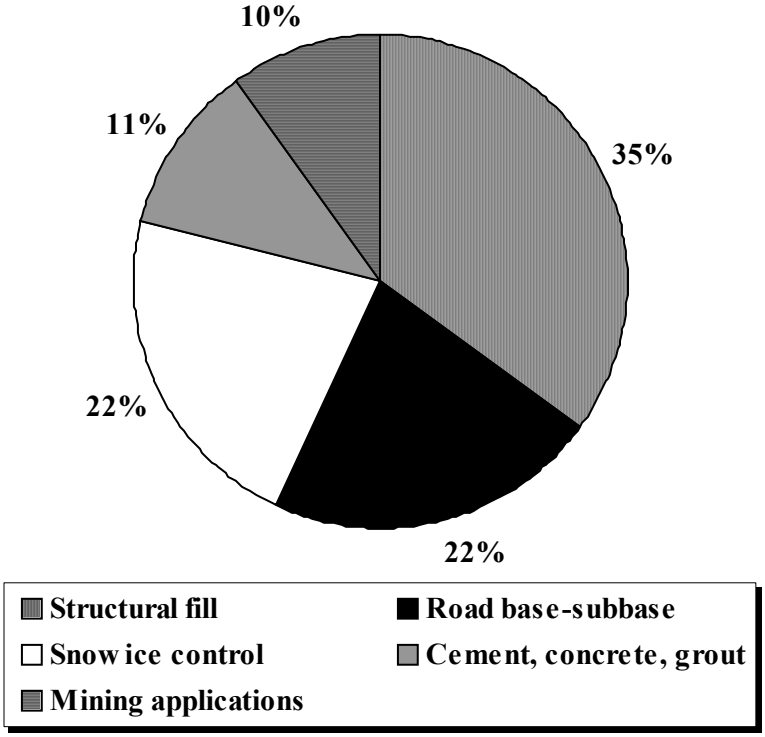

Figure 7. Leading Bottom Ash Uses 2000 (Source ACAA)

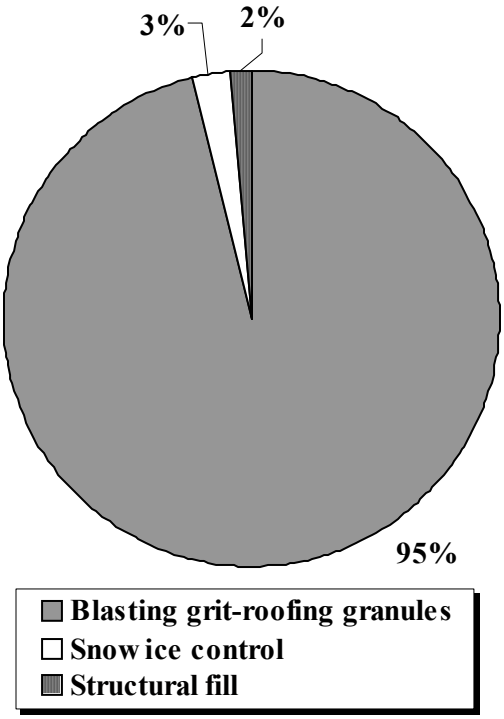

Figure 8. Leading Boiler Slag Uses 2000 (Source ACAA)

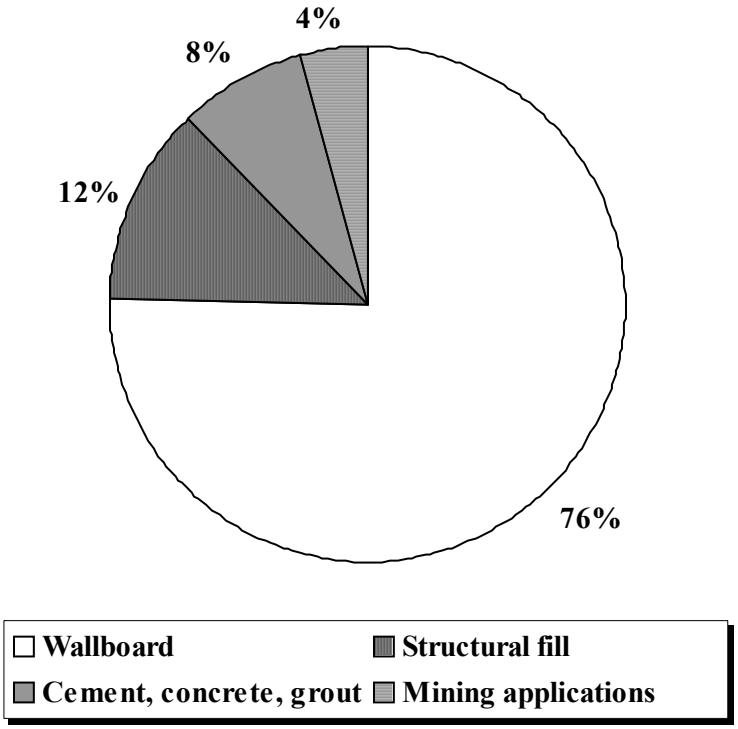

Figure 9. Leading FGD Material Uses 2000 (Source ACAA)

PHYSICAL AND CHEMICAL CHARACTERISTICS OF CCB

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Abstract

The chemical and physical characteristics of fly ash particles are determined by the mineral matter in the original coal, combustion conditions in the boiler, and post combustion cooling conditions. Syngenetic minerals were present in the coal forming swamp and are more closely associated with the coal's organic matrix. Epigenetic minerals were deposited in a coal seam's pores and fractures after coal formation was complete. During combustion, inorganic minerals become fluid or volatile and react with oxygen. In the post-combustion portion of the boiler, they form crystalline minerals, spherical amorphous particles, or condense as coatings on particles. Size and shape are the primary physical characteristics of fly ash particles. Chemical characteristics include mineral speciation, elemental concentration, and solubility. Major elements (iron, calcium, aluminum, and silicon) are those that have a concentration in fly ash greater than 2 percent as oxides. The concentration of oxides of minor elements (sodium, magnesium, manganese, and potassium) is between 2 and 0.2 percent. Other cations are considered trace elements at concentrations generally less than 200 ppm. The effect of the formation conditions is evident from the variability of the fly ash. Examples of physical and chemical characteristics are taken from information in EPRI's 1987 report, the 1997 CIBO report, analyses of CCB samples in the NETL inventory, and other sources in the literature.

Introduction

Coal Combustion By-Products (CCB) are the non-combustible mineral portion of coal that has been subjected to temperatures above 500<C. This heat-treated residue is commonly referred to as ash. In modern combustion systems, a variety of ashes is produced, and there is generally a serious effort to market the ash. Removing the onus of a waste has provided the impetus for a change in terminology from ash to coal combustion residue to coal combustion by-product and coal combustion product. Whatever it's called, the origin is related to the formation of coal.

The formation of coal has been described as "an inefficiency in the carbon cycle," (Barghoorn, 1952) when the carbon in plants remains in terrestrial sediments and is not recycled to the atmosphere (Figure 1). It can be considered one of the geologic mechanisms of carbon sequestration. Coal is, by definition, a readily combustible rock containing more than 50 percent by weight and 70 percent by volume of carbonaceous material (Schopf, 1966). Another definition describes coal as a combustible solid, usually stratified, which originated from the accumulation, burial, and compaction of partially decomposed vegetation in previous geologic ages (Hendricks, T.A. 1945). On an elemental basis, the carbonaceous structure is composed of carbon, hydrogen, oxygen, and small amounts of organically bound sulfur, nitrogen, phosphorous, chlorine, and other elements.

On a proximate basis, coal is composed of moisture, mineral matter, volatile matter, and fixed carbon (Hessley *et al*., 1986). Although one of the first effects of coalification is removal of water, some physically and chemically bound water remains in the coal. The mineral matter in coal is determined by low temperature ashing or by dissolution in HF. Volatile matter includes gases that are released by thermal decomposition (pyrolysis) of coal, such as hydrogen, carbon monoxide, hydrocarbons, tar vapors, ammonia, carbon dioxide, and water vapor other than residual moisture. The fixed carbon is the solid combustible material and the non-volatile organics in coal. It is estimated by subtracting the percentages of moisture, ash, and volatile matter from 100. The heating value and rank of the coal increase with increased fixed carbon content (Figure 2). On a practical basis, coals are usually compared on a moisture and mineral matter free basis (mmmf).

Ultimate analysis of coal is the determination of the carbon and hydrogen, sulfur, nitrogen, and oxygen (Hessley *et al*., 1986). Carbon includes organic and any mineral carbonate. Hydrogen is part of the organic portion of the coal and in the moisture. Nitrogen is assumed to be part of the organic matter. Sulfur occurs as organically bound in

pyrites and in inorganic sulfates. Oxygen, which can be in the organic and inorganic portions of the coal, is determined by difference. The ultimate coal composition on an mmmf basis is the hypothetical pure coal substance.

Minerals in Coal and Ash

Coal ash originates from the inorganic portion of the coal. Inorganic compounds are added during deposition and metamorphism, but are not necessarily an integral part of the coal structure. Combustion and post combustion cooling also have a significant effect on the mineral phases in CCBs.

Minerals in Coal

A variety of minerals have been identified in coal. Although some of the inorganic compounds originate in the plant material, most are deposited during (syngenetic) or after (epigenetic) coalification. Syngenetic minerals can be formed by precipitation in an aqueous medium during early stages of coalification or they may be detrital clastics transported into the peat swamp by wind or water. Epigenetic minerals are deposited within the coal seam, in cracks, fractures and bedding planes, by ascending or descending solutions. They also may be produced from syngenetic minerals by increased temperature and pressure. Minerals associated with the coal matrix are sometimes denoted as included minerals, while minerals that are independent of the organic portion may be called excluded minerals. Mackowsky (1968) indicated that most of the silicates, quartz, and phosphates had been transported into the peat swamp. Carbonates, sulfides, chalcedony, and quartz from the weathering of feldspar and mica were formed within the swamp. These minerals tend to be intimately intergrown with the organic matrix. Some carbonates, sulfides, and oxides were deposited in cleats and fractures. Illite, chlorite, and some pyrite were formed by the transformation of syngenetic minerals.

Inorganic matter in coal includes a variety of minor or trace elements. The concentration of these elements in coal may be greater than their average concentration in the earth's crust (Table 1). When compared to the overlying carbonaceous shale (Table 2), coal has a lower concentration of trace elements, reflecting the influx of detrital inorganic sediments in the shale. The distribution of trace elements varies too widely to be described by a general statement. Coals from different areas may show distinctive trace element characteristics and, within a single coal seam, the trace element distribution may not be consistent. This suggests that no single process has been responsible for the accumulation of trace elements in coal.

In a study of 35 coal samples from eight countries, Vassilev and Vassileva (1996a) identified approximately 100 minerals. The minerals were characterized as major (> 1% by wt), minor (.1><1% by wt), and trace (<0.1 % by wt). On a semi-quantitative basis, the mineral groups in decreasing order of importance are: silicates, carbonates, oxyhydroxides, sulfides, sulfates, phosphates, others.

In another study of 41 coals, Vassilev *et al.* (1996) relate mineral assemblages to the rank of the coal. The coals were divided according to rank based on dry ash free carbon concentration (C_{daf}). The lower rank coals are enriched in mineral matter including calcium and magnesium oxides. The highest rank coals have increased contents of silica, aluminum, iron, potassium, sodium, and titanium.

The quartz in 40 samples of a Powder River Basin (PRB) coal was primarily detrital, but trace amounts of Beta-form quartz, with apatite and zircon, was attributed to air-fall and reworked volcanic ash deposited in the peat swamp (Brownfield *et al*., 1999). In a study of Gulf Coast lignites, enrichment of some elements was attributed to proximity of igneous rocks or to deposition of volcanic ash (Warwick *et al.,* 1997). The mineral composition of the coal seam also can be modified by post-coalification circulation of geothermal fluids (Kolker, 1999; Daniels *et al.*, 1990).

The minerals phases identified in various coals are summarized in Table 3 and the modes of occurrence and maximum concentration of selected elements listed in Table 4.

Combustion System

The generation of coal combustion by-products depends on the combustion system, boiler and its operating conditions, and post-combustion parameters (Figure 3). In pulverized coal (PC) fired power stations, the furnace operating temperature is typically above 1400 degrees C (~2500 degrees F). The finely divided coal particles are injected into the furnace and ignited while suspended in air. The volatile matter and organic matrix react with air to produce heat, CO_2, H_2O, SO_2, and NO_x. At these temperatures, minerals may oxidize, decompose, fuse, disintegrate, or agglomerate (Clarke and Sloss, 1992). For instance, although some SO_2 is produced from the sulfur in the organic matrix, most is the result of the oxidation of pyrite. Another product of pyrite oxidation is iron oxide that is found in ash particles as hematite or magnetite. Discrete mineral particles may undergo fusion and partial melting in the boiler. Depending on the temperature conditions in the post combustion zone, the particles may cool slowly and develop a characteristic crystalline structure (Figure 4). If cooling is rapid, the minerals may condense to a spherical, glassy particle. If mineral grains originate within the coal matrix, they can become liquid during combustion while volatile elements enter the vapor phase. As they cool, these gaseous compounds may condense to very small particles (aerosols) or coalesce to slightly larger spherical particles. They also may condense on the surface of other particles, leading to surface enrichment of volatile species. Non-volatile compounds will agglomerate to form fly ash particles. Expansion of trapped volatile matter may cause the particle to expand, forming a hollow, low-density cenosphere. Residence time within the boiler is relatively short and some minerals, especially those with high melting points, are transported through the combustion zone almost unchanged.

Based on their boiling points and the phase change temperature of their oxides, several authors have described the partitioning of trace elements in CCBs (Germani and Zoller, 1988; Meij, 1989; Yokoyama *et al.*, 1991). The first group of elements, which are concentrated in bottom ash or equally distributed between bottom ash and fly ash, includes typically lithophile elements: Ba, Mg, and Mn. In a second group, trace elements enriched in the fine particulate fraction are usually chalcophile elements such as As, Cd, Pb, Se, and Zn. Group 3 includes volatile elements that remain in the vapor state: Hg and Br. Several elements partition between the groups (Figure 5).

According to Davison *et al.* (1974), the concentration of the elements Pb, Sb, Cd, Se, As, Ni, Cr, and Zn increased with decreasing particle size. The concentration of the elements Fe, Mn, V, Si, Mg, C, Be, and Al increased with decreased particle size only for particles with a diameter less the 11 Fm. These elements showed no size dependence for larger particles. The concentrations of Bi, Sn, Cu, Ti, Ca, and K showed no dependence on particle size.

Vaporization and condensation form an ultra fine aerosol during PC combustion (Senior *et al.*, 2000a). Factors such as residence time, temperature history, and level of turbulence control the size and morphology of the aerosol particles. Fly ash particles with aerodynamic diameters less than 0.4 Fm were attributed to condensation. Non-volatile elements, such as Fe, were found to concentrate in larger ash particles. Between 10 and 30 pct of the volatile elements As, Sb, Se, and Zn are in the condensed fly ash particles. Arsenic and Sb are soluble in silicate glass and may be retained by glassy particles that form by coalescence of minerals. Correlations between the concentrations of arsenic and calcium in fly ash are assumed to indicate the formation of calcium arsenate.

Minerals in Ash

Volatilization, melting, decomposition, and formation of new minerals, as well as oxidation, are the mechanisms that transform the minerals in coal. The transition of minerals in coal to those found in combustion by-products is related to the high temperature oxidation and to the rate of cooling of the inorganic melt. There is a significant difference between the minerals in coal and those in the ash produced from the same coals. The inclusion of heavy metals or hazardous air pollutants (HAPs) in the ash and their solubility are the primary determinants of toxicity. Concentration is not the only factor; volatility, toxicity, and solubility determine the potential for health and environmental effects. These factors are functions of speciation within the ash. A summary of the minerals identified in coal ash is given in Table 7. Because different authors use different methods of mineral identification and different concentration units, some degree of interpretation was necessary to assemble the comparative table. The mineral association of trace elements is summarized in Table 8.

Chemical Composition of Coal Ash

The Electric Power Research Institute (EPRI) conducted a study of the composition of 39 fly ash samples and 40 bottom ash samples from power plants in the United States (EPRI, 1987a). The trace element composition indicated that more volatile elements (As, B, Cl, F, S, and Se) were preferentially partitioned to the fly ash and their concentrations were higher in fly ash derived from bituminous coal. The mean and range of concentrations for major elements is shown in Table 5. Maximum trace element concentrations are given in Table 6. EPRI also conducted an extensive literature search on the inorganic and organic constituents of fossil fuel combustion residues (EPRI, 1987b; EPRI, 1987c). They concluded that the inorganic composition was highly variable. Some non-volatile elements were evenly distributed between fly ash and bottom ash, while volatile elements tend to be concentrated in fly ash.

The Council of Industrial Boiler Owners (CIBO) conducted a survey of operators of FBC units, requesting information on the physical and chemical characteristics of FBC fly ash (CIBO, 1997). Trace elements were found to be concentrated in the smaller ash particles. The composition of the FBC fly ash, as provided by respondents to the CIBO survey, is given in Table 5. Trace element data is given in Table 6.

The Pennsylvania Department of Environmental Protection (PADEP) allowed DOE personnel to copy applications and reports relative to placement of CCBs at surface mine sites (Kim and Cardone, 1997). The information included analyses of 99 fly ash samples. A summary of the major element and trace element data is given in tables 5 and 6. The mean concentration of major and trace elements in ash from Bulgarian power plants, as reported by Vassilev and Vassileva (1997), is in the same range as the data reported in tables 5 and 6.

In evaluating the chemical composition of fly ash in tables 5 and 6, it must be recognized that the data provided by several entities has limitations. First, ash is a non-homogeneous material, and it must be assumed that the sample was representative. In the data submitted, blanks are not always identified as values below detection limits or as elements not included in the analysis. Also, detection limits may vary, which makes comparing analyses difficult. It's also possible to dissolve solid samples by several methods (metaborate fusion, aqua regia, and hydrofluoric acid for example) and the method used may affect the analytical results. Therefore, compilations of fly ash analyses give good indications of the range of compositions, but are not reliable indicators of concentration of elements in an "average" fly ash.

Physical Properties

The physical characteristics of combustion residues include particle size, particle shape or morphology, hardness, and density. These properties are a function of the particle size of the feed coal, the type of combustion, and the particulate control device. PC boilers typically use fuel that is ground to a diameter of less than 0.075 mm (CIBO, 1997). The fly ash has a particle diameter less than 0.010 mm. Due to the high temperature of PC combustion, fly ash particles tend to melt and condense as spheres. Fly ash particles from FBC boilers, although having similar diameters and density, tend to have a less regular shape. Armesto and Merino (1999) also found that residues from PC systems are smaller than those generated in FBC systems.

The particle size distribution is considered an important parameter in the utilization of fly ash. Sized fractions of fly ashes were found to have similar mineral compositions (Erdogdu and Turker, 1998). However, when used as a cement replacement in concrete, higher strengths were correlated with smaller particle size. The effect was attributed to the decreased porosity due to small particles filling a higher percentage of concrete pores.

Comparing the size distribution of minerals in fly ash with that in the original coal showed that both types of particles are larger than 1Fm, but fly ash particles are larger with a median diameter of 20Fm and a maximum diameter in the range of 150 to 200 Fm (Wigley and Williamson, 1998). The larger size of fly ash particles is attributed to coalescence of mineral grains during cooling. In a random population of fly ash samples from PC combustion, the median particle diameter was 27 Fm (Kim, 2002).

In a study of 27 samples of pulverized fuel ash from Australian and Japanese coals, Nagataki *et al.*, (1995) determined that specific gravity of the samples varied from 2.01 to 2.31. The maximum bulk density was between 0.7 and 1.4 g/cm^3, while the surface area varied between 0.7 and 37 m^2/g. The average specific gravity of fly ash particles used in the NETL leaching experiments was 2.32 (Kim, 2002).

The morphology of fly ash grains is determined by the heating and cooling regimes in the PC boiler. Micro spheres, typically between 30 and 100 Fm in diameter, can be described as hollow cenospheres or noncrystalline glass beads (Shao *et al*., 1997). Unburned carbon particles, irregular partially melted minerals, particle fragments, and agglomerated particles tend to be slightly larger.

Summary

Inorganic compounds in coal may originate in plant material, but most are deposited during (syngenetic) or after (epigenetic) coalification. Syngenetic minerals are either chemical precipitates or detrital clastics. Epigenetic minerals are deposited within the coal seam after coalification is complete. Minerals identified in coal include silicates, carbonates, oxides, oxyhydroxides, sulfides, sulfates, and phosphates. In coal, the more volatile elements (As, Hg, Mo, PB, Sb, and Se) are usually associated with pyrite. The elements Cd and Cu are associated with sulfides, possibly with Pb and Zn sulfide. The carbonates are apparently limited to Ca, Mg, and Mn. Several elements are associated with the organic matrix or with silicates.

During combustion, minerals in coal become fluid, are subjected to high temperature oxidation, and then cooled. The maximum temperature and the rate of cooling influence the morphology and composition of the ash. Generally, more than 50 percent of fly ash is composed of spherical amorphous particles. Inorganic compounds also may be present in fly ash as crystals or as surface coatings on other particles. In fly ash, the major cations are Si, Al, Fe, and Ca with lesser amounts of Na, Mg, K, Sr, and Ti. Trace elements include As, B, Ba, Cd, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, V, and Zn. The primary minerals are quartz, mullite, hematite, clays, and feldspars. Volatilization and condensation are believed to be primary determinants of trace element partitioning in fly ash, but there is limited data on trace element associations.

Physical characteristics of combustion residues, including particle size, particle shape or morphology, hardness, and density, are a function of the particle size of the feed coal, type of combustion, and particulate control device. About 50 percent of fly ash particles are glassy spheres.

The chemical and physical properties of fly ash particles are a function of the mineral matter in the coal, combustion conditions, and post-combustion cooling.

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Table 1. Distribution of trace elements in coal ash compared to the average concentration in the earth's crust, ppm. (After Nicholls, 1968).

Element	Crust	Coal ash, minimum	Coal ash, maximum
Ag	0.7	1	10
As	1.8	100	900
B	10	86	5,800
Ba	425	300	3,500
Be	2.8	1	30
Co	25	30	300
Cr	100	50	400
Cu	55	20	500
Mn	950	200	1,000
Mo	1.5	10	200
Ni	75	50	800
Pb	12.5	5	700
Sr	375	80	3,500
V	135	100	1,000
Zn	70	100	1,000

Table 2. Trace elements in whole coal compared to concentration in shales, ppm (After Nicholls, 1968).

Element	Shale	Coal, Minimum	Coal, Maximum
Ag	.07		<0.05
As	13		100
B	100	12	145
Ba	580	35	170
Be	3	<1	2
Co	19	2	20
Cr	90	5	38
Cu	45	3	15
Mn	830	20	150
Mo	2.6	<0.5	7
Ni	68	6	35
Pb	20	8	80
Sr	300	26	250
Zn	95	25	100

Table 3. Minerals Identified in Coal.

Sample B	[1] PRB	[1] PRB	[2] Vari	ous[3] Lig	nite[4] UK	[5]	B[6]
Units	wt%mm	wt%mm	Ma/ Mi/ T	vol%mm	NA	NA	Frequency
# of Samples	3	1	40	34	48	?	75
Quartz 12		27	α Ma β T	33 cristo	U bolite U	U	63
Kaolinite 13		19	Ma	10		U	73
Illite 1	3	8		4		U	9
Montmorillonite <1		2		1			
Feldspar <1		2		4	U		
Silicates 27		29		2	U	15	
Pyrite 16		1	T	4	U	U	18
Sulfides <1		1					2
Siderite <1		<1					15
Calcite 3			Mi	6	U	62	
Carbonates 2		<1		6	U	56	
Rutile/Anatase <1		3	T				0
Phosphates <1		6	T	3		U	47
Other	9						
Micas			Mi	3			
Zeolites					U		
Barite			T	1			
Zircon			T				
Plagioclase			T				12
Sulfates				10	U	U	17
Oxides & Hydroxides				11			1

[1]Senior *et al*, 2000b
[2]Brownfield *et al*, 1999
[3]Vassilev *et al*, 1997
[4]Karayigit *et al*, 2001
[5]Spears *et al*, 1999
[6]Kimura, 1998

Table 4. Modes of Occurrence and Maximum Concentration (ppm) of Elements in Coal.

Reference Senio	r *et al* Sha		o *et al* Ho		wer *et al* Palm		er *et al*	
Element	Mode	Max M	ode	Max M	ode	Max M	ode	Max
As Py		250	S	25	Py	1156a	Py, Sl	45
B Cly,O		500						
Ba			O, SO_4 50	0				
Be C	ly,O	30					Sl, O	2
Cd ZnS		10					S	2.5
Co			S	25			Sl, O	12
Cr Cly,	Fe, OOH	100 O		80		401a	Sl, O	97
Cu S,O		200						
Fe			S	2,000			Py, Sl	2.6 %
Hg S,E		10					Py, O	0.50
K			O	14,000				
Mn O	, CO_3 1,	000				563a	Sl, CO_3 23	0
Mo Py	, O	50						
Na			O, SO_4 4,	500				
Ni S,O		100	S			131a	Sl, O	48
Pb Py,	S	100			Py	193a	O, S, Py	25
Sb	S, Py	40					Sl, O	2.1
Se							Py	6.1
Sn Ox,	S	20						
Sr			O, SO_4 30	0				
Zn	S, O	300	O, SO_4	50			Sl, S, Py	190

Py = Pyrite S = Sulfide Cly = Clay CO_3 = Carbonate Sl = Silicate
O = Organic OOH = Oxyhydroxide Ox = Oxide E = Elemental
SO_4 = Sulfate a = ash

Table 5. Minerals Identified in Fly Ash

Reference	Vassilev & Vassileva, 1996	Yamashita *et al*, 1998	Hower *et al*, 1999	McCarthy *et al*, 1999	
				Class F	Class C
Units	M-m-T-a	wt%	wt %	wt%	wt %
Quartz	M	5 - 40	<0.5	7.1	
Cristobalite a-M					
Kaolinite					
Illite M					
Plagioclase	m-M	1 - 20			
K-feldspar	m-M	1 - 10			
Micas m	-M				
Mullite a-M			<1	13.3	
Hematite	m-M	1 - 10		4.1	
Magnetite a				7.0	2.5
Goethite a-M					
Spinel a-m					
Gypsum		1 - 20			
Calcite				0.5	5.7
Ettringite				3.5	7.8
Alumino-Silicates		20 - 70			
Corundum a-	M				
Gibbsite a-M					
Rutile a-m					
Lime a-M					
Portlandite a-M					
Anhydrite M					
Amorphous	50 - 90 vol %		75-86	64.5	74.8

M-m-T-a = Major, minor, Trace, accessory

Table 6. Trace Element Association in Fly Ash

Reference	
Huggins *et al*, 1997	As in FA is As (V); 25% of As in BA is As(III), < 5% of Cr is toxic Cr(VI); Ni is +2 valence and Se may be selinide or selenate.
Finkelman *et al*, 1997	As = 170 ppm in FA from high S coal and 54 ppm in FA from low S, primarily condensed on ash surfaces. Cr enriched in the Fe-oxide phases, such as spinel. 70 pct of Cr in the glassy silicate. Similar results for Ni and Co. Sb and Zn present in more than one ash phase.
Senior *et al*, 2000	Elements vaporized during combustion: 40 to 80 % of As & Sb, residual may dissolve in silicates or form Ca compounds; > 80 % Se and Zn volatilized; < 40 % Cr in vapor state.
Furminsky, 2000	Most As, Pb, and Cd in FA; Se and Hg vaporized. Air/coal ratio affects partitioning of elements in vapor and solid phases, shifts condensation to lower temperature.
Hulett *et al*, 1980	Ba, Sr, Ti, As, Se concentrated in amorphous phase. V, Cr, Mn, Ni, Zn and Cu concentrated in Fe oxide/spinel

Table 7. Major element concentrations in fly ash samples, g/kg.

Element	**EPRI Data**			**CIBO Data**			**PADEP Data**		
	n	Mean	Range	n M	ean	Range	n M	ean	Range
Al 39		113	46-152	14	29.9[1]	.02 - 176	89	30	.012 - 140
Ca	39	62	7.4-223	2	56	37 - 74	19	50	.003 - 265
Fe 39		76	25-177	18	31[1]	.02 - 81	89	35	.009 - 675
K 39		14.3	3-25.3	13	1.5[1]	.001 - 15			
Mg	39	11.8	1.6-41.8	1	10		22	139	.005 - 4
Na 39		9.1	1.3-62.5	1	5				
P 24		3	1.1-10.3	1	0.5[1]				
S	39	12.6	1.3-64.4	2	15	8 - 21			
Si	39	209	90-275	2	115	90 – 115			
Sr	39	1.3	.2 - 7	1	0.3				
Ti	39	7	1.3 - 10	1	2				

[1]Median

Table 8. Trace element concentration in fly ash, mg/kg.

Element	**EPRI Data**			**CIBO Data**			**PADEP Data**		
	n	Mean	Maximum n		Median	Maximum n		Median	Maximum
Ag				19	1	39	78	0.4	22
As 39		156	385	23	12	46	92	20	21,030
Ba 39		1,880	10,850	20	320	7,700	93	212	2,960
Be				13	2	12			
B				11	90	652	80	50	3,995.4
Cd 2		12	17	23	.6	13	81	1	30
Co				16	14	179	30	28	83
Cr 29		247	651	23	29	141	92	40	360
Cu 39		185	1,452	20	43	99	91	41	474
Hg				22	.3	7	84	0.4	5.44
Mn 39		357	1,332	15	126	57,700	86	79	27,614
Mo 36		44	236	21	6	61	79	12	108
Ni 39		141	353	22	35	1,020	91	39	752
Pb 39		171	2,120	24	15	73	93	33	225
Sb 7		43	131	17	5	1,370	64	27	140
Se 30		14	49	22	5	46	77	3	201
Sn 18		44	56						
Th				12	3	25			
V 35		272	652	13	61	1,120			
Zn 39		449	2,880	22	36	105	93	41	1,196

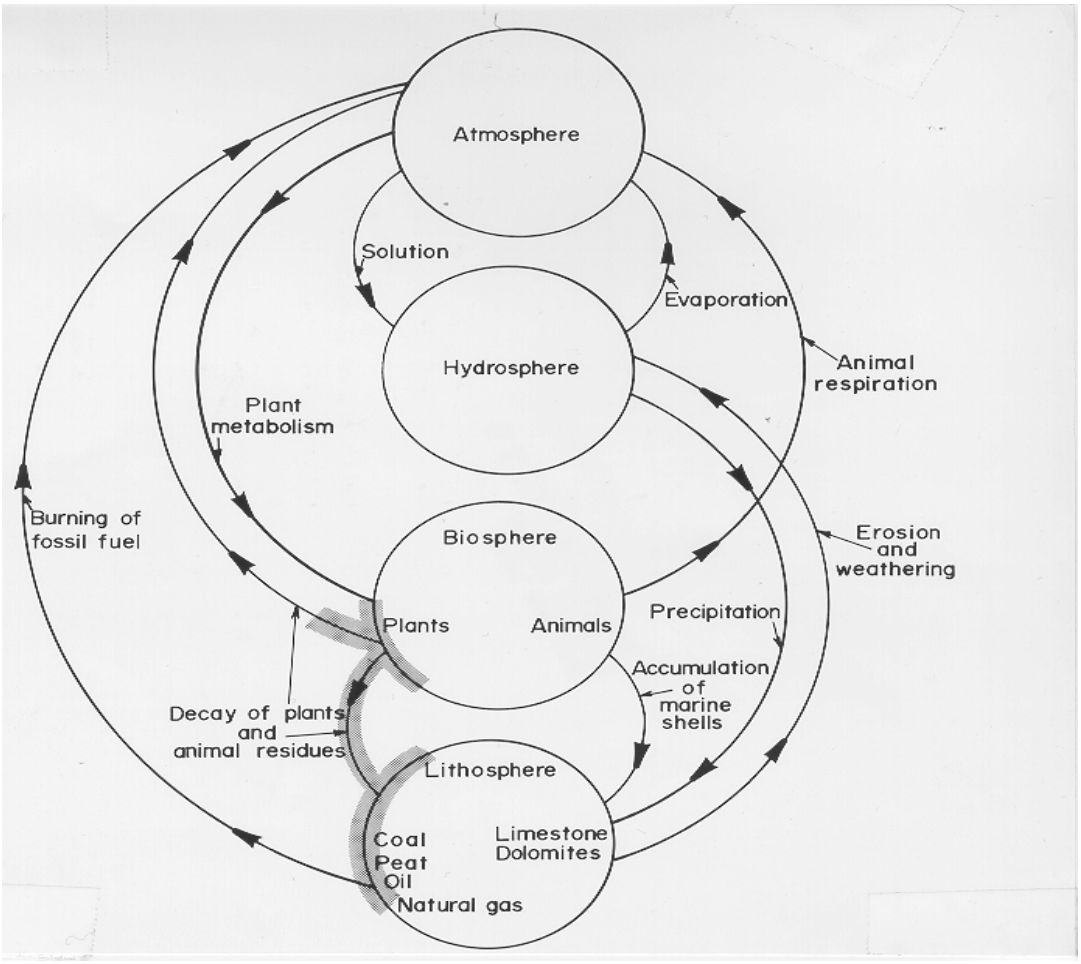

Figure 1. The generation of fossil fuel resources due to the migration of carbon from the biosphere to the lithosphere within the carbon cycle.

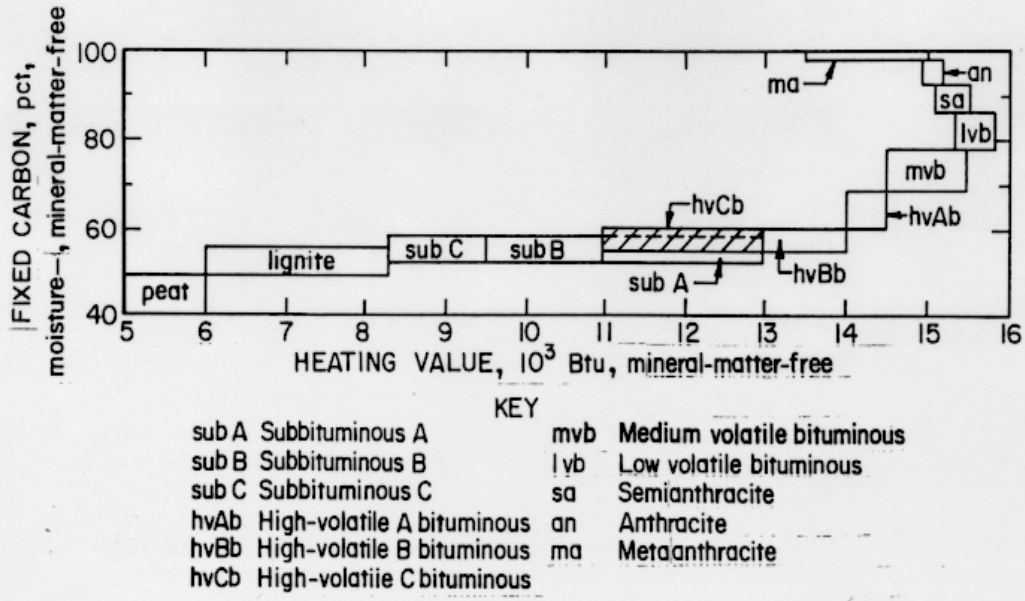

Figure 2. Variation in heating value and rank with increased concentration of fixed carbon.

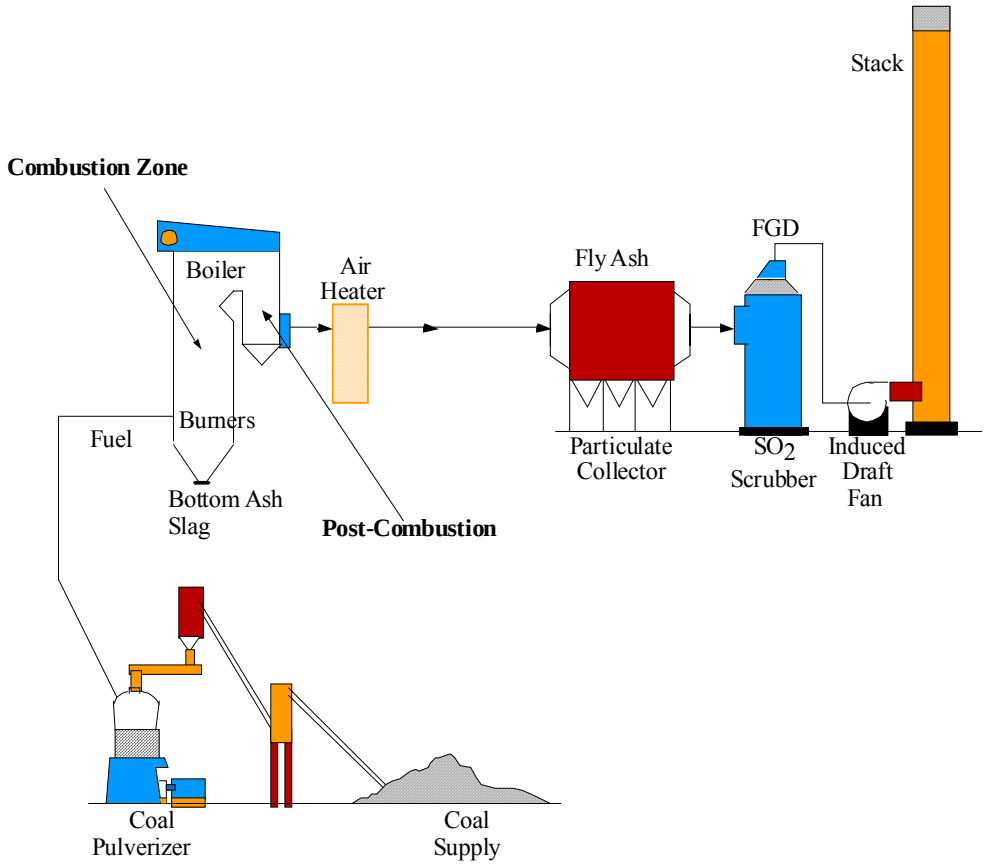

Figure 3. Generation of Coal Combustion By-Products (CCB) in a PC Utility Boiler

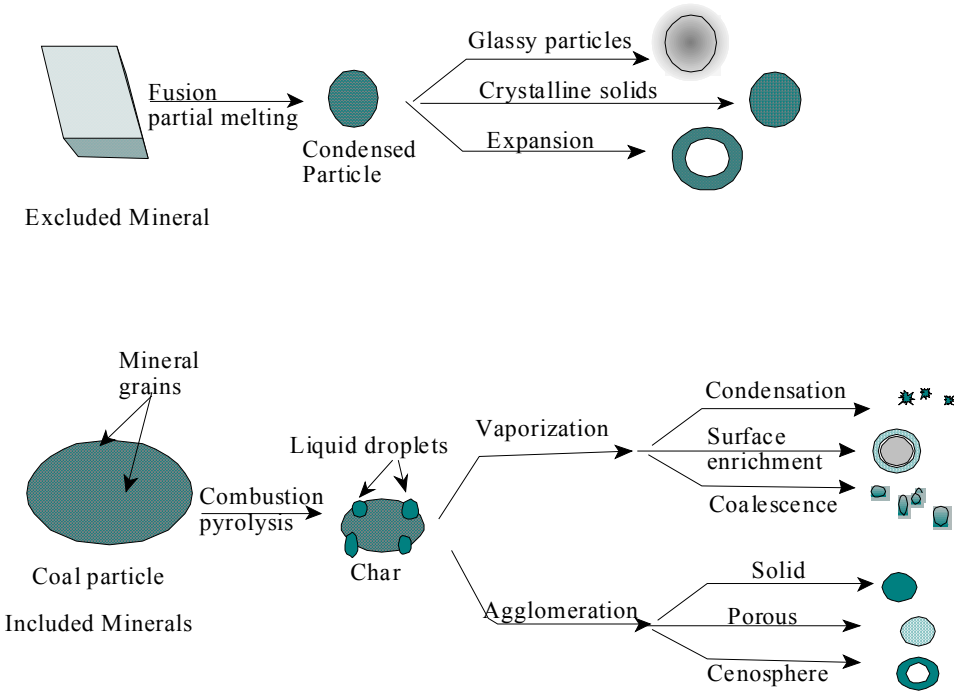

Figure 4. Transformation of mineral matter in coal to ash (After Clarke & Sloss, 1992, p.38)

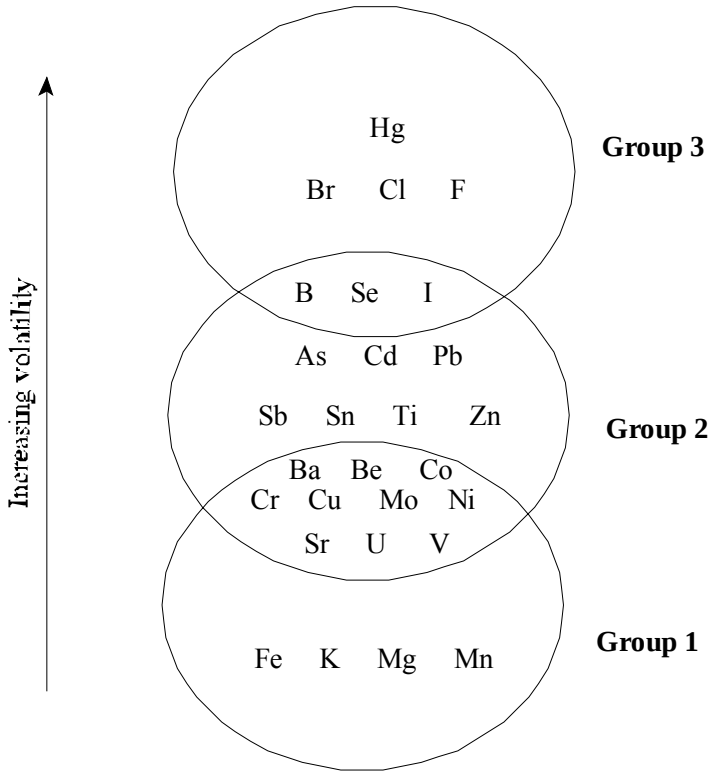

Figure 5. Classification of trace elements in coal by their relative volatility (After Clarke & Sloss, 1992, p.37).

WESTERN REGION FLY ASH SURVEY

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Abstract

A questionnaire to determine the factors influencing fly ash production and usage in the Western Region was sent to generating stations in Colorado, Wyoming, Utah, Montana, North Dakota, New Mexico, and Arizona, and to power plants using coal from any of these States. David Goss of Public Service of Colorado and Co-Chair of the Western Region Ash Group refined the questionnaire. Topics covered included: the type and source of coal, combustion system, scrubbers, average percent ash, % CaO, % LOI, class of fly ash, tons fly ash produced, disposed, used, category of usage, transport, marketers, and market area. Coal-fired plants using Western Region coal in Nebraska, Nevada, West Texas, Minnesota, and Washington are included in this report. Of the 70 coal-fired generating stations in these States, 38 responded (Figure 1) and are reported in the results of this survey.

Coal Areas in the Western Region

Several major coal basins lie within the Western coal region of the United States including: the Williston, Powder River, Green River, Uinta (Wasatch Plateau), San Juan, and Black Mesa basins (Figure 1). Coal-bearing sequences in these areas are of Late Cretaceous/Eocene age. During the Late Cretaceous, foreland basins stretched along the western margin of the Western Interior seaway and most of the Late Cretaceous coals developed in nearshore environments (Table 1). Tertiary-age coals in the Western Region are not associated with nearshore environments; rather they developed in inter-montane fluvial and lacustrine environments.

Western Region coals vary in ash content. This region's Late Cretaceous coals have higher ash content than those deposited in the Tertiary, particularly those developed in fluvial environments (Table 1). Many of these Tertiary coals were developed in raised mires that tend to have less flooding and, therefore, less influx of inorganic material. In the Tertiary, Washington's Eocene coals are an exception and were deposited in a lower-delta plain environment, similar to the Late Cretaceous coals, with concurrent volcanic activity. Most of this region's Late Cretaceous coals developed during regressive cycles brought on by increased sediment supply from tectonically active highlands. Volcanic activity also added inorganic material, mainly silica, reaching the mires as windblown or stream deposits. These differences in depositional environment are reflected in the ash percent and chemical properties of the ash by-products produced from electrical generation.

Western United States Coal Electrical Generation and Production

The American Coal Ash Association (ACAA) includes all of the Western United States, Hawaii, and Alaska in Region VI (Figure 1). In 1998, Region VI produced approximately 10.9 million MT of CCPs of which about 2.04 million MT (18 percent) was used. This is lower than the 29 percent usage of CCPs in the United States.

Within ACAA's Region VI is a major coal producing area, the Western Region. In 1998, this region (Figure 1) surpassed the eastern Appalachian coal region as the leading coal-producing area in the United States. In part, the demand for western low-sulfur coal was fueled by the low cost and the sulfur emissions reduction requirements of the 1990 Clean Air Act Amendments (CAAA) for low-sulfur coal. Demand for western coal also was enhanced in 1998 by a large drop in hydroelectric generation in regions west of the Mississippi. Conversely, coal production in the appalachian and Interior regions was hindered by mild weather and bringing back on-line significant amounts of nuclear-powered capacity (Freme and Hong, 2000).

Although western coals are considered low sulfur, 44 percent of the units at the power plants surveyed have some form of scrubber system. Both units at the Springerville plant (Arizona) have dry scrubbers and none of this fly ash is marketed. The Wyodak No.1 unit (Wyoming) has a dry scrubber and all of the ash from this unit is placed in disposal ponds. The Hayden (Colorado), Rawhide (Colorado), and Stanton (North Dakota) plants all have spray dryer scrubbers that contaminate the fly ash and effectively make this material unusable. At the Sherburne station, two units have wet scrubbers and the third unit has a spray dryer scrubber. In all three units, the alkaline fly ash is

used as a sorbent in the scrubber to replace all or a portion of the lime. All fly ash from this plant is high in SO_3 and does not meet ASTM C618 (1995) specifications (Michael R. Thomes pers. communication, 2000). Units 1 and 2 at Cholla (Arizona) have wet venturi scrubbers and the fly ash is contaminated. The remaining plants surveyed have scrubber systems that do not contaminate the fly ash. Fly ashes contaminated by FGD material are not classified as C or F fly ash and are not included in the following discussion.

Classification of Western coal fly ash

Lignite, subbituminous, and bituminous coals are burned at Western power plants and produce both Class F and Class C fly ash. The Class C fly ashes typically come from Tertiary coals that developed in fluvial environments (Table 1). The following ash and CaO percentages are plant averages. Twelve surveyed plants burn Powder River Basin (Wyoming) subbituminous coal, producing Class C fly ash (Figure 2) that typically have >15 percent CaO. Eocene Fort Union Powder River Basin coals are low in ash (4–5 percent), but the Dave Johnston plant burns Wasatch Formation coal from the Powder River Basin that has 8 percent ash. Fly ash from this plant is much lower in CaO (8 percernt) than the Fort Union Formation ashes that range from 21–30 percent CaO. The Dave Johnston material is the only low-calcium Class C fly ash in this group. The Arapahoe station burns various Powder River Basin coals and some Green River coal, probably lowering the CaO content. The remaining Class C fly ash is produced from Williston Basin lignite (North Dakota). Coal Creek station burns Fort Union Formation coal from a different bed than the Powder River Fort Union coal. The percent ash is higher than in any of the Powder River coals and the percent CaO of the fly ash is lower.

Class F fly ashes are produced from subbituminous and bituminous coals from the Green River Basin, Uinta Basin, Wasatch Plateau, San Juan Basin, Black Mesa area, and Washington (figures 1 and 3). These coals are consistently higher in ash than those producing Class C fly ash and were developed in lagoonal back barrier or interdeltaic mires (Table 1). The Uinta and San Juan Basin fly ashes have very low CaO (<5 percent). San Juan Basin coals produce the greatest quantities of ash, especially Fruitland Formation coals. Fly ash from this formation has some of the lowest CaO percentages of all reported in the survey (Figure 3). None of the Class F fly ashes in this group would be classified as high calcium, but Wasatch Plateau fly ash is consistently higher in percent CaO. A few stations that replied to the survey burn several types of coal and produce both Class F and Class C fly ash. These stations are not shown on figures 2 and 3.

Generally, plants reporting Class C fly ash have less than one percent LOI content. The Arapahoe (Colorado) and Sheldon (Nebraska) stations are exceptions with two percent LOI and 30 percent LOI, respectively. Cyclone burners at Sheldon are a major reason for the high LOI content. Sheldon fly ash is only used for soil modification.

Plants reporting Class F fly ash show more variation in LOI content. Nine of these plants have less than two percent LOI. The three Utah plants have from three percent to 12.5 percent LOI. Only the Hunter plant, with three percent LOI, has minimal use of fly ash and the rest is disposed. Cherokee (Colorado) averages 6.25 percent LOI and both Cameo (Colorado) and W.N. Clark (Colorado) have very high LOI content. The W.N. Clark fly ash is collected with the bottom ash in a silo. This material is used for deicing winter roads and occasionally as a soil stabilizer. None of the Cherokee station fly ash is used because of the high percentage of inert material, a constituent of the LOI (Dave Goss personal communication, 2000).

Fly Ash Market in the Western United States

Market Areas

Most power plants use ash marketers to sell their fly ash. Major marketers in this region are ISG Resources, Boral Materials Technologies, Mineral Solutions, Phoenix Cement, and Depauw Fly Ash. The western United States fly-ash market is limited by the distance to market, a result of relatively few large population centers (Figure1) and power plants that are often located near coal sources, rather than near large cities (Figure 1). Although true for most of the plants surveyed, several plants are located near two large populations centers, Minneapolis and Denver (Figure 1). Black Dog and High Bridge (Mineral Solutions) sell all but a minor amount of their fly ash in the Minnesota and Wisconsin markets, and Riverside sells 50 percent of their fly ash. The remaining plants (A.S. King, Sherburne County) have ash that either is contaminated by FGD or is produced from a blend of coal and petroleum coke, not meeting classification standards. Seven of the Colorado plants surveyed are near Denver. Three plants are within the Denver Metropolitan area, but only the Cherokee plant sells a large percentage (51 percent) of their fly

ash. The Pawnee plant (Boral), east of Denver has markets in Nebraska, Kansas, and Colorado and sells 65 percent of the fly ash they produce. The remaining plants in Colorado sell little or no fly ash because of scrubber system contamination, collection of fly ash with bottom ash, or LOI content. All of the fly ash from Centralia in Washington is sold. ISG markets this fly ash in nearby Portland and Seattle and has storage facilities in these cities (Tom Fox ISG personal communication, 2000).

Arizona and California have a high population density (Figure 1) and are market areas for the Mojave, Apache (Boral), Cholla, Four Corners, and San Juan (Phoenix Cement) power plants. Except for San Juan, which was just beginning to market fly ash in 1998, all of these plants sell greater than 50 percent of their fly ash in Arizona and California as well as New Mexico, Utah, and Colorado. These plants produce Class F fly ash that is desirable in this area to prevent ASR in concrete. Although Utah is a relatively populated State, very little fly ash from the Utah power plants surveyed is sold because of inconsistency or low quality. Wyoming is very sparsely populated and only the Jim Bridger plant (ISG Resources) markets a large percentage (86 percent) of the Class F fly ash produced. The Naughton plant produces Class F also, but because of unburned organic material only 17 percent of the fly ash is marketed. Scrubber contamination, quality problems, or distances to market are factors affecting the fly ash usage from other Wyoming plants. North Dakota and Montana are also sparsely populated States. Two of the three plants in this area sell 25-35 percent of the fly ash produced. The cold climate limits the construction season and the cost to transport fly ash to more populated areas with longer seasons is prohibitive. The two plants in West Texas (DePauw Fly Ash) sell 100 percent of their Class C fly ash in Texas, New Mexico, Oklahoma, and Kansas.

Fly Ash Quality

The classification and quality of fly ash can be very important in determining whether fly ash is sold. Fly ash contaminated by FGD by-products is a major factor. Seven of the 38 responding power plants list FGD material collected with some or all of the fly ash as the reason their material is not sold, amounting to 1.44 million MT of disposed fly ash.

Percent LOI, either inert material or unburned carbon, is a limiting factor as well. Fly ash with LOI greater than 6 percent does not meet ASTM C 618 (1995) specifications. Low NO_x burners burn the coal at a lower temperature, leaving more carbon in the ash. Twenty-five of the reporting power plants have one or more units with low NO_x burners. However, when the respondents were asked if low NO_x burners played a role in making their fly ash unmarketable, only three of the 25 thought it was a factor. LOI content influences the fly ash color. Color can be very important for some applications and markets. Light-colored fly ash is preferred for cement or concrete products, particularly in California. The type of unburned carbon remaining in the fly ash is important when AEA is used for frost resistance. This can be a limiting factor for some fly ash usage in the northern States of the Western region.

ASR is a problem throughout the Western United States because of the aggregate available, and many western States limit the CaO content of the fly ash that can be used when the aggregate is potentially reactive. Class F fly ash is often preferred to limit the effects of ASR.

Transportation and Storage

Although the Western United States and particularly Wyoming have a good railroad network, very few marketers transport fly ash by rail. The Wyoming Jim Bridger plant (ISG Resources) is an exception shipping 90 percent of the fly ash sold to markets in California and Utah. The San Francisco Bay area is a major consumer of this fly ash, and ISG has fly ash storage facilities here (Tom Fox personal communication, 2000). The Four Corners plant (New Mexico) ships 60 percent of their fly ash sold by truck to a railhead several kilometers away where it is then shipped to California and Arizona markets. The Arizona Cholla plant ships 40 percent by rail to California. Phoenix Cement markets both the Four Corners and Cholla fly ash and has storage facilities in each major market area (Ron Helms personal communication, 1999). More fly ash is produced in the winter months especially in the northern States, but without storage facilities, this fly ash can't be saved for the summer months when there is a construction market. The fly ash must have characteristics that give it greater marketability to justify the expense of storage facilities.

Coal Creek (North Dakota) ships 40 percent of its fly ash by rail to nearby markets of Montana, North Dakota, Minnesota, and Canada. The Gerald Gentleman plant (Nebraska) uses rail to ship 18 percent of their fly ash to the Denver market. Most of the fly ash shipped by rail is Class F and is from plants located great distances from their

markets. These producers ship large quantities making rail transport economically viable. Fly-ash producers using truck as their main mode of transportation are either closer to their markets, do not have rail load out facilities, or can not market large enough quantities of fly ash to make rail transport economically viable.

Summary and Conclusions

Both Class F and Class C fly ash are produced in the Western United States. The Class C fly ash is generally high in calcium and produced from subbituminous and lignite coals from the Powder River and Williston basins, respectively. Class F fly ash is low in calcium and produced from bituminous and subbituminous coals in the Green River, Wasatch, San Juan, Black Mesa, and Centralia regions.

Fly ash has many characteristics making it attractive as an admixture to concrete, including strength, lowering heat of hydration, workability, and resistance to ASR. Use of fly ash lowers the cost of the concrete, saves energy, and reduces CO_2 production. In the Western United States, 1.509 million MT of fly ash is sold for concrete products and 0.4 million MT is sold for use in cement. Other major uses include backfill (662 thousand MT), stabilization (182 thousand MT), and road base (109 thousand MT). Class C fly ash has more diverse in application but there is more Class F fly ash sold.

Several factors influence the marketing of fly ash in the Western United States:

- Quality, consistency, and class of fly ash are very important in determining usage and market area;
- FGD contamination restricts a significant amount of fly ash from use;
- LOI content can limit usage because of unburned carbons (AEA) or color characteristics;
- Transportation infrastructure is important, but truck transport is preferred except when large quantities can be sold to distant markets;
- Storage facilities at different locations in the market area increase sales, but are only economically viable if the quality of the product is in demand;
- Western fly ash usage can't be entirely predicted by proximity to market; the quantity sold and market area is often determined by the quality of the fly ash. Fly ash produced at a power plant some distance from a market but of superior quality has the potential to be shipped greater distances, such as the fly from the Jim Bridger plant. Fly ash of lesser or inconsistent quality from a plant near a market may have limited usage, such as the Utah fly ash. In this respect, fly ash can act as a specialty mineral instead of a commodity mineral.

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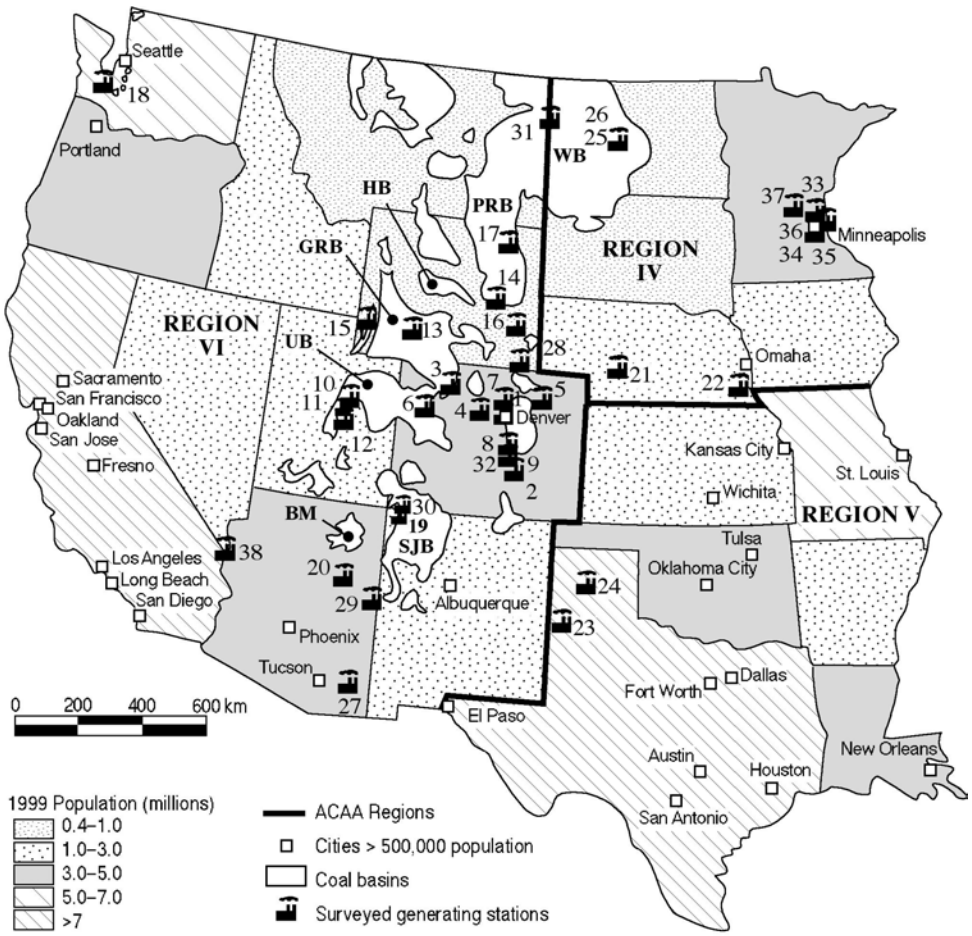
Table 1. Western US coal basin- depositional environment and ash content.
Basin abbreviation in parenthesis is shown on Fig. 1.

Area	Basin	Formation	Age	Coal Type	Depositional environment	Ash content*	Stations	Reference
Canada, North Dakota	Williston (WB)	Fort Union	Paleocene	Lignite	Fluvial-deltaic raised swamp	Medium 3		Flores & Keighin 1999
Wyoming	Powder River (PRB)	Wasatch E	ocene	Subbituminous	Fluvial	Medium	1	Flores & Bader 1999
		Fort Union	Paleocene	Subbituminous	Fluvial-raised swamp	Low 16		
S. Central Wyoming	Hanna (HB)	Hanna Paleocene		Bituminous	Low-lying fluvial	Low-medium	1	Flores *et al*. 1999
		Ferris Paleocene		Bituminous		Medium		
SE Wyoming, NE Colorado, NW Utah	Green River-Hams Fork (GRB)	Fort Union	Paleocene	Subbituminous	Low-lying, fluvial	Medium		Flores & Bader 1999
		Williams Fork	Late Cretaceous	Bituminous I	nterdeltaic	Medium	7	
		Adaville	Late Cretaceous	Subbituminous I	nterdeltaic	Low	1	
NE Utah, W. Colorado	Uinta-Wasatch Plateau (UB)	Black Hawk	Late Cretaceous	Bituminous	Lagoonal, back-barrier	Medium 3		
NW New Mexico, SW Colorado	San Juan (SJB)	Fruitland High	Late Cretaceous	Subbituminous-Bituminous	Lower delta, back-barrier	Medium-high	2	
		Menefee					2	
Arizona	Black Mesa (BM)	Wepo	Late Cretaceous	Subbituminous	Lower delta, back-barrier	Medium 1		
Washington Centr alia		Skookumchuck	Eocene	Subbituminous	Back- barrier	Medium	1	

*Low Ash- <8%, Medium Ash 8-15%, High Ash >15%



Generating station number and name:

1 Arapahoe	11 Huntington	21 Gerald Gentleman	31 Lewis & Clark
2 Comanche	12 Hunter	22 Sheldon	32 W. N. Clark
3 Hayden	13 Jim Bridger	23 Tolk	33 A. S. King
4 Cherokee	14 Dave Johnston	24 Harrington	34 Black Dog
5 Pawnee	15 Naughton	25 Coal Creek	35 High Bridge
6 Cameo	16 Laramie River	26 Stanton	36 Riverside
7 Valmont	17 Wyodak	27 Apache	37 Sherburne County
8 Martin Drake	18 Centralia	28 Rawhide	38 Mohave
9 R. D. Nixon	19 Four Corners	29 Springerville	
10 Carbon	20 Cholla	30 San Juan	

Figure. 1. Western United States with ACAA regions, Western Region coal basins, surveyed generating stations, and population data. Abbreviations for coal basins are defined in Table 1 from Hoffman, 2002. Printed with permission from the Geological Society of London.

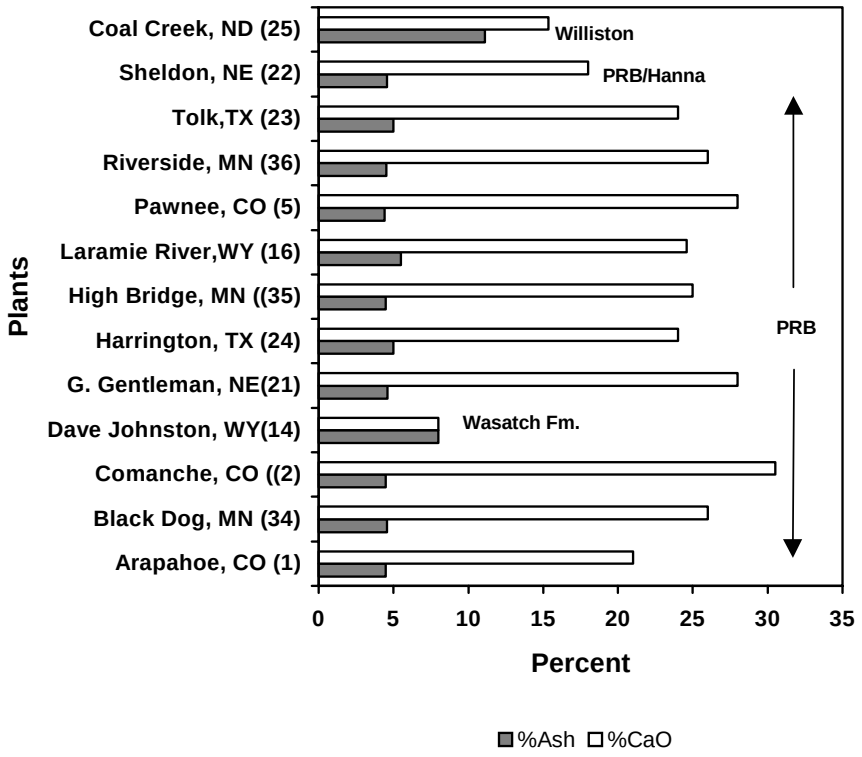


Figure 2. Average percent ash from coal and average percent CaO from fly ash for plants reporting Class C fly ash. Number in parenthesis identifies plant on Figure 1. Modified from Hoffman, 2002. Printed with permission from the Geological Society of London.

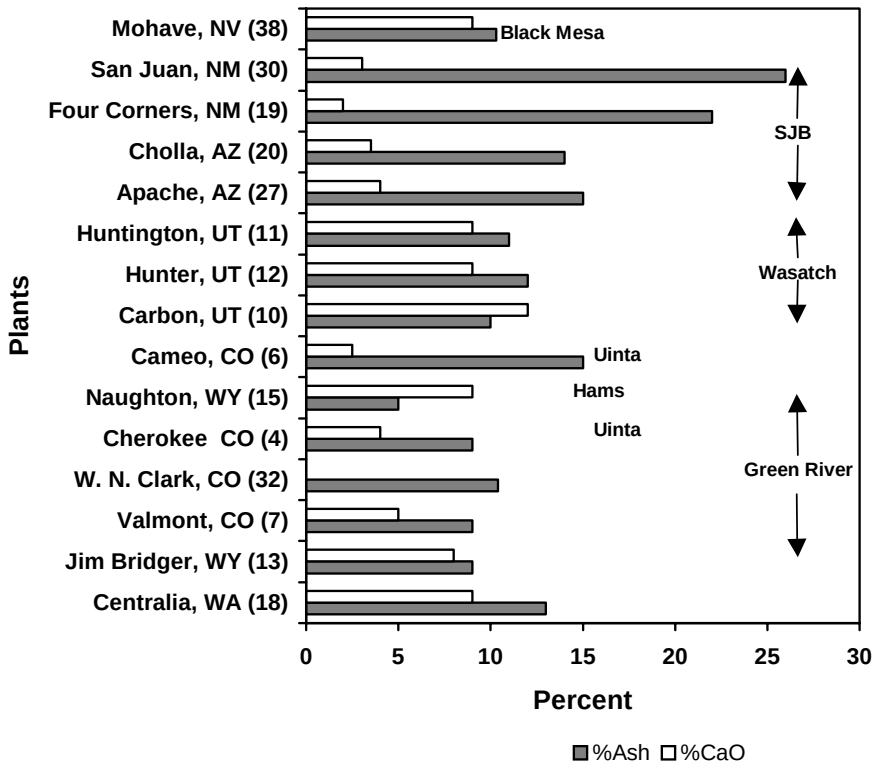


Figure. 3 Average percent ash from coal and average percent CaO from fly ash for plants reporting Class F fly ash. Number in parenthesis identifies plant on Figure 1. Modified from Hoffman, 2002. Printed with permission from the Geological Society of London.

ASTM STANDARDS TO SUPPORT MINE APPLICATIONS OF COAL COMBUSTION BY-PRODUCTS

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Abstract

The American Society for Testing and Materials (ASTM) E 50 Committee on Environmental Assessment and Subcommittee E 50.03 on Environmental Risk Management/Sustainable Development/Pollution Prevention initiated several standards related to the placement of coal combustion by-products (CCBs) in 1998. These standards, which are in various stages of the ASTM balloting process, are as follows:

- Guide for the Use of Coal Combustion By-Products for Underground Mine Backfill
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Recontouring and Highwall Reclamation
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Revegetation and Mitigation of Acid Mine Drainage

The common goal of these standards is to provide guidelines for appropriate selection, testing, and placement techniques when CCBs are placed in mine settings. Each standard has a specific scope based on the type of mine placement. The surface mining standards address different types of beneficial uses for CCBs. The standards will supplement the existing requirements by which the U.S. Department of the Interior Office of Surface Mining (OSM) ensures the environment is protected during coal mining and reclamation. The standards provide information on appropriate testing and suggest specific tests. The standards provide guidance on how this information can aid individuals/groups associated with the proper placement of CCBs in mine settings.

Introduction

The U.S. Department of the Interior Office of Surface Mining (OSM) is charged with the responsibility of ensuring that the national requirements for protecting the environment during coal mining are met and making sure the land is reclaimed after it is mined. When coal combustion by-products (CCBs) are used at surface coal mines, State or Federal coal mining regulators are involved to the extent that SMCRA (Surface Mining Control and Reclamation Act) requires the mine operator to ensure that:

- All toxic materials are treated, buried, and compacted, or otherwise disposed of, in a manner designed to prevent contamination of ground or surface water (30 CFR 816/817.41).
- The proposed land use does not present any actual or probable threat of water pollution (30 CFR 816/817.133).
- The permit application contains a detailed description of the measures to be taken during mining and reclamation to ensure the protection of the quality and quantity of surface and groundwater systems, both on- and off-site, from adverse effects of the mining and reclamation process (30 CFR 780.21).
- The rights of present users of such water are protected (30 CFR 816/817.41). Any disposal of CCBs at mine sites must be in accordance with those standards and with applicable solid waste disposal requirements (30 CFR 816/817.89).

SMCRA gives primary responsibility for regulating surface coal mine reclamation to the States, and 24 coal-producing States have chosen to exercise that responsibility. On Federal lands and Indian reservations (Navajo, Hopi, and Crow) and in the coal States that have not set up their own regulatory programs (Tennessee and Washington), OSM issues the coal mine permits, conducts the inspections, and handles the enforcement responsibilities. As a result of the activities associated with SMCRA, coal mine operators now reclaim as they mine, and mined lands are no longer abandoned without proper reclamation. OSM also collects and distributes funds from a tax on coal production to reclaim mined lands that were abandoned without being reclaimed before 1977. OSM has a Coal Combustion Residues Management Program that focuses on providing expert technical information on

the use of CCBs in mine reclamation for the mining industry, regulatory agencies, and other stakeholders.

There is considerable variation in State-mandated permitting and other regulatory requirements for CCP utilization. Some States have specific beneficial use policies, while other States have no regulations or guidance addressing beneficial use. Although the National Environmental Policy Act (NEPA) strictly applies only to Federally funded projects, many States have similar mechanisms for assessing the environmental impacts of nonfederal projects. These mechanisms may require State permits that address any or all of the following issues: wetlands/waterways, National Pollutant Discharge Elimination System (NPDES) discharge, underground injection, erosion and sediment control, air quality considerations, and storm water management.

In 1999, the U.S. Environmental Protection Agency (EPA) completed a two-phased study of CCBs for the U.S. Congress as required by the Bevill Amendment to the Resource Conservation Recovery Act (RCRA). At the conclusion of the first phase in 1993, EPA issued a formal regulatory determination that the characteristics and management of the four large-volume fossil fuel combustion waste streams (i.e., fly ash, bottom ash, boiler slag, and flue gas emission control waste) do not warrant hazardous waste regulation under RCRA and that utilization practices for CCBs appear to be safe. In addition, EPA "encourage[d] the utilization of coal combustion by-products and support[ed] State efforts to promote utilization in an environmentally beneficial manner." In the second phase of the study, EPA focused on the by-products generated from fluidized bed combustion (FBC) boiler units and the use of CCBs from FBC and conventional boiler units for mine reclamation, among other things. Following completion of the study, EPA issued a regulatory determination that again concluded that hazardous waste regulation of these combustion residues was not warranted. However, EPA also decided to develop national solid waste regulatory standards for CCBs, including standards for placement of CCBs in surface or underground mines, either under RCRA, SMCRA, or a combination of the two programs (65 CFR 32214, May 22, 2000).

In 1998, the American Society for Testing and Materials (ASTM) E 50 Committee on Environmental Assessment and Subcommittee E 50.03 on Environmental Risk Management/Sustainable Development/Pollution Prevention initiated several standards related to the placement of CCBs to involve the CCB industry in aiding appropriate use of CCBs in underground and surface mine settings. The common goal of these standards is to provide guidelines for appropriate selection, testing, and placement techniques when CCBs are placed in mine settings.

Background

Three standards related to the use of CCBs in mine settings are in preparation and/or ballotting under ASTM E50.03:

- Guide for the Use of Coal Combustion By-Products for Underground Mine Backfill
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Recontouring and Highwall Reclamation
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Revegetation and Mitigation of Acid Mine Drainage

The focus of these standards is to provide guidance on assessment, selection, and placement of CCBs in either underground or surface mine settings. The CCB industry is well represented on Subcommittee E50.03 and is developing standards to facilitate appropriate evaluation of CCBs for use in mine settings. The standards under development are "Standard Guides." ASTM defines guides as "a series of options or instructions that do not recommend a specific course of action" (ASTM, 1989). ASTM E50.03 has opted to develop a series of standard guides as the first step toward developing standard practices and performance specifications for several CCB use applications. These guides provide "options or instructions" that help a specifier or user of CCBs understand the character and appropriate use of CCBs. This is the course of action for the series of mining standards under development. With input from the users of the standard guides, other more specific standards are likely to be developed for discreet applications where performance criteria can be identified and appropriate tests and limits can be set.

Summary of Standards in Preparation

Guide For the Use of Coal Combustion By-Products for Underground Mine Backfill

This standard guide covers the use of coal combustion by-products (CCBs) for underground mine backfill applications, for the purpose of controlling mine subsidence or for the remediation of acid mine drainage. It does not apply to surface mine reclamation applications. There are many important differences in physical and chemical characteristics that exist among the various types of CCBs available for use in underground mine backfill. Because of physical and chemical characteristics, CCBs commonly used in mine backfill applications are fly ash, flue gas desulfurization (FGD) material, and FBC fly ash. CCBs proposed for each project must be investigated thoroughly to identify the appropriate mix proportions to meet the project objectives. This guide provides procedures for consideration of engineering, economic, and environmental factors in the development of such applications.

The testing, engineering, and construction practices for using CCBs in mine backfill are similar to generally accepted practices for using cement or concrete in mine backfill. CCB-based grouts and flowable fill should be designed with generally accepted engineering practices.

The underground mine standard guide incorporates information on formulating the grout for injection; on-site issues such as storage of CCBs, access to water, and site access; and grout injection.

Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Recontouring and Highwall Reclamation

This standard guide covers the use of CCBs for surface mine reclamation applications, as in beneficial use for reestablishing land contours, highwall reclamation, and other reclamation activities requiring fills or soil replacement. The purpose of this standard is to provide guidance on identification of CCBs with appropriate engineering and environmental performance appropriate for surface mine recontouring and highwall reclamation applications. It does not apply to underground mine reclamation applications. There are many important differences in physical and chemical characteristics among the various types of CCBs available for use in mine reclamation. CCBs proposed for each project must be investigated thoroughly to design CCB placement activities to meet the project objectives. This guide provides procedures for consideration of engineering, economic, and environmental factors in the development of such applications and should be used in conjunction with professional judgment. This guide is not intended to replace the standard of care by which the adequacy of a given professional service must be judged, nor should this guide be applied without consideration of a project's unique aspects.

The testing, engineering, and construction practices for using CCBs in mine reclamation are similar to generally accepted practices for using other materials, including cement and soils, in mine reclamation. Physical properties are generally key to the use of CCBs in recontouring and highwall reclamation.

Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Revegetation and Mitigation of Acid Mine Drainage

This standard guide covers the use of CCPs for surface mine reclamation applications related to area mining, contour mining, and mountaintop removal mining. The issues addressed include: beneficial use for abatement of acid mine drainage, treatment of mine spoils, and revegetation. It does not apply to underground mine reclamation applications. There are many important differences in physical and chemical characteristics that exist among the various types of CCBs available for use in mine reclamation. CCBs proposed for each project must be investigated thoroughly to design CCB placement activities to meet the project objectives. This guide provides procedures for consideration of engineering, economic, and environmental factors in the development of such applications.

As in the previous standard guide, the testing, engineering, and construction practices for using CCBs in mine reclamation are similar to generally accepted practices for using other materials. The chemical properties of CCBs are of great importance in identifying appropriate CCBs for revegetation and mitigation of acid mine drainage.

Use of CCBs for Mine Reclamation

Fly ash, bottom ash, boiler slag, FGD material, and FBC ash, or combinations thereof, can be used for mine reclamation. Each of these materials typically exhibits general physical and chemical properties that must be considered in the design of a mine reclamation project using CCBs. The specific properties of these materials vary from source to source, so environmental and engineering performance testing is recommended for the material(s) or combinations to be used in mine reclamation projects. Depending on the mine reclamation application, fly ash, bottom ash, boiler slag, FGD material, FBC fly ash, FBC bottom ash, or combinations thereof may have suitable and/or advantageous properties. Each of these materials typically exhibits general engineering properties that must be considered in engineering applications. These general engineering properties are discussed in the following subsections; however, it should be noted that the specific engineering properties of these materials can vary greatly from source to source and must be evaluated for each material or combination of materials to be utilized for a structural fill. Some of these properties are: unit weight, compaction characteristics, strength, consolidation characteristics, permeability, erosion characteristics, swelling, liquefaction and frost heave, specific gravity, grain-size distribution, moisture, and thixotropy. Many CCBs exhibit advantageous performance for use in mine settings. The standards identify which of these properties should be evaluated and, in many cases, provide ranges of expected behavior. The performance of CCBs can then be compared to other materials with which the specifier, regulator, or user is familiar.

The major elemental components of CCBs are silicon, aluminum, iron, calcium, magnesium, sodium, potassium, and sulfur. These elements are present in various amounts and combinations dependent primarily on the coal type (bituminous, subbituminous, or lignite) and type of CCB (such as coal fly ash, FBC fly ash, FGD material, etc.). Trace constituents may include trace elements such as arsenic, boron, cadmium, chromium, copper, chlorine, mercury, manganese, molybdenum, selenium, or zinc (Batelle, 1987). The primary elemental constituents of CCBs are present either as amorphous (glassy) phases or crystalline phases. Coal combustion fly ash is typically 70+percent amorphous material. FGD and FBC products are primarily crystalline, and the crystalline phases typically include calcium-based minerals.

Properties that are indicative of performance and based on the chemical composition of a CCB include alkalinity, pozzolanic activity, and hygroscopy. Environmental performance is directly linked to the chemical composition of a CCB and should be evaluated for CCBs to be used in mine settings. An understanding of the environmental performance of CCBs is needed to determine the potential for impacts on groundwater and surface water to ensure protection of human health and the environment.

Future Standards

The mine-related standards described are in various stages of preparation and balloting. It is anticipated that these three standard guides will be approved through the ASTM process before EPA finalizes standards for placement of CCBs in surface or underground mines. Discussions in ASTM E50.03 have already begun to broach the topic of development of more specific standard performance specifications or standard practices related to mine placement of CCBs.

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Debra F. Pflughoeft-Hassett is a Research Manager in Residuals Research at the Energy and Environmental Research Center (EERC) of the University of North Dakota. Her principal areas of interest and expertise include utilization and characterization of coal combustion by-products (CCBs), waste management, and environmental impacts of CCB use and disposal. She has worked on the development of databases containing characterization information on CCBs and on the development of chemical characterization protocols. She has expertise in applying

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COAL COMBUSTION RESIDUES AND MERCURY CONTROL[9]

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Abstract

The burning of coal in electric utility boilers generates residual materials including fly ash, bottom ash, boiler slag, and wet flue gas desulfurization (FGD) scrubber sludge/solids. These residual materials are collectively referred to as "coal combustion residues" (CCRs). Currently more than 70 percent of the CCRs are land-disposed, and the other 30 percent are reused or recycled for commercial uses such as production of wallboard, cement, and asphalt. Use of mercury emission control technologies on coal-fired electric utility boilers will probably increase the amount of mercury in certain types of CCRs and also could change the composition and physical properties of these materials, possibly impacting their suitability for commercial reuse and recycling applications. Many of the potential retrofit mercury control technologies for coal-fired electric utility power plants remove mercury from the flue gas and concentrate the captured mercury into CCRs (i.e., fly ash collected by particulate matter (pm) control devices or solids/sludges generated by wet FGD scrubbers). Concern has been raised as to whether the mercury in the CCRs may later be re-released back into the environment.

A life-cycle evaluation is being conducted by National Risk Management Risk Laboratory (NRMRL) to help evaluate any potential environmental trade-offs and to ensure that there is not an increased environmental risk for the management of CCRs resulting from mercury control technologies. In support of this evaluation, NRMRL is gathering data and information to assess future increases in mercury concentrations in CCRs resulting from applications of mercury emissions control requirements to coal fired electric utility boilers. I will summarize some of the CCR information gathered by NRMRL to date and identify major information gaps and priorities of EPA's research to ensure that mercury controlled at the coal fired electric utility power plant stack is not later released from the CCRs in an amount that is problematic for the environment.

Introduction

The burning of coal in electric utility boilers generates residual materials including fly ash, bottom ash, boiler slag, and wet FGD scrubber solids/sludges. These residual materials are collectively referred to as "coal combustion residues" (CCRs). Currently, about 70 percent of the CCRs are land-disposed, and the other 30 percent are reused or recycled for commercial uses such as production of wallboard, cement, and asphalt. Use of Hg emission control technologies on coal fired electric utility boilers will probably increase the amount of Hg in certain types of CCRs, and also could change the composition and physical properties of these materials, possibly impacting their suitability for commercial reuse and recycling applications. Many of the potential retrofit Hg control technologies for coal fired electric utility power plants (discussed in Chapter 7 of Reference 9) remove Hg from the flue gas and concentrate the captured Hg into CCRs (i.e., fly ash collected by PM control devices or solids/sludges generated by wet FGD scrubbers). Concern has been raised as to whether the Hg in the CCRs may later be re-released back into the environment.

A life-cycle evaluation is being conducted by NRMRL to help evaluate any potential environmental trade-offs and to ensure that there is not an increased environmental risk for the management of CCRs resulting from Hg control technologies. In support of this evaluation, the NRMRL is gathering data and information to assess future increases in Hg concentrations in CCRs resulting from application of Hg emissions control requirements to coal fired electric utility boilers. This chapter summarizes some of the CCR information gathered by NRMRL to date and identifies the major data gaps and priorities of EPA's research to ensure that Hg controlled at the coal fired electric utility power plant stack is not later released from CCRs in an amount that is problematic for the environment.

CCR Types

The coal combustion process generates many different types of residues. At a given power plant, CCRs can be grouped as those generated on a continuous basis in high-volume quantities and those generated either continuously or intermittently in low-volume quantities. These low-volume CCRs include those resulting from maintenance and coal cleaning. However, the focus of this chapter is on high-volume CCRs. High-volume CCRs include the bottom ash or slag removed directly from the boiler furnace and the fly ash collected by downstream PM control devices. For those coal fired electric utility boilers using wet FGD scrubbers for SO_2 emissions control, large quantities of scrubber solid wastes and sludges are generated. Nationwide quantities of high-volume CCRs generated in 1999 from coal combustion are available from data prepared by the American Coal Ash Association (ACAA).[1] Table 1 summarizes the characteristics and nationwide generation quantities for the major types of CCRs resulting from combustion of coal in power plants.

CCR Mercury Concentrations

An initial review by NRMRL indicated that limited laboratory data were available on Hg concentrations in CCRs. Therefore, a nationwide Hg mass balance approach was taken to estimate Hg concentrations in CCRs. This Hg mass balance approach used data from the EPA Parts II and III ICR databases on coal Hg concentrations and control device Hg capture efficiencies. The EPA ICR data were used with additional ACAA data on CCR generation rates, to estimate Hg concentrations in various CCRs. The Hg concentrations estimated with the nationwide mass balance approach are shown in Table 2. Table 2 shows calculated mean, 5th percentile, and 95th percentile values for Hg concentrations in CCRs. Mercury concentrations are projected to be highest in fly ash, with a mean value of 0.33 ppm and a 95th percentile value of 1.2 ppm. Mercury concentrations in wet FGD scrubber solids/sludges are calculated to have a mean value of 0.20 ppm and a 95th percentile value of 0.72 ppm. Mercury concentrations in bottom ash and boiler slag were calculated to be much lower, with mean values of 0.067 ppm, and 0.042 ppm, respectively.

Table 1. Coal combustion residues

Coal Combustion Residue	Description	Average Quantity Generated Per Ton of Coal Burned a	Total Nationwide Quantity Generated in 1999$_b$
Fly ash	Fine, powdery non-combustible mineral matter in the boiler flue gas and collected by electrostatic precipitator or fabric filter.	160 lb/ton	63,000,000 tons
Bottom ash	Dark gray, granular, porous non-combustible mineral matter heavier than fly ash and collected in bottom of the boiler furnace.	40 lb/ton	17,000,000 tons
Boiler slag	Coarse, black, glassy mineral matter that forms when molten bottom ash contacts quenching waters in wet-bottom furnaces.	100 lb/ton	3,000,000 tons
Wet FGD scrubber solids/sludges	Solid material or sludge generated by scrubbing processes used to remove sulfur from the flue gases.	350 lb/ton	25,000,000 tons

(a) Source: Reference 2.
(b) Source: Reference 1.

Table 2. Calculated Hg concentrations in CCRs using EPA ICR data.

Coal Combustion Residue	Hg Concentration (ppm) a		
	5th Percentile	**Mean**	**95th Percentile**
Fly ash	0.062	0.33	1.20
Bottom ash	0.019	0.067	0.16
Boiler slag	0.012	0.042	0.10
Wet FGD scrubber solids/sludges	0.038	0.20	0.72

(a) Changes in Hg control technology requirements for coal fired electric utility power plants will cause changes in the Hg concentration in fly ash and wet FGD scrubber solids/sludges.

Subsequent to performing the nationwide Hg mass balance to determine Hg concentrations in CCRs, more extensive laboratory data became available from the Electric Power Research Institute (EPRI) and the University of North Dakota Environmental and Energy Research Center (UND/EERC). A summary of available laboratory measurements of Hg in CCRs is shown in Table 3. The laboratory measurements in Table 3 generally show good correlation with the nationwide mercury mass balance predictions in Table 2. For example, the EPRI fly ash data (382 samples) have a mean mercury concentration of 0.44 ppm, with a 95th percentile value of 1.13 ppm, and the UND/EERC data (20 samples) have a mean Hg concentration of 0.22 ppm, and a 95th percentile value of 1.03 ppm. Both these sets of data correlate well with fly ash calculations obtained by the nationwide Hg mass balance, which indicates a mean concentration of 0.33 ppm and 95th percentile value of 1.2 ppm.

Table 3. Summary of available test data on Hg concentrations in major types of CCRs.

Coal Combustion Residue	Test Data Source (Reference)	Number of Samples	HG Concentration (ppm)					
			Min.	**5th Percentile**	**Median**	**Mean**	**95th Percentile**	**Max.**
Fly Ash	EPRI (Reference3)	382	0.0002	0.0002	0.09	0.44	1.13	27.7
Fly Ash	UND/EERC (Reference 4)	20	<0.002	0.002	0.076	0.22	1.03	1.24
Fly Ash	EPA (Reference 5) (fine fly ash)	n.r.	0.005	n.r.	0.10	n.r.	n.r.	2.50
Fly Ash	EPA (Reference 5) (mechanical hopper)	n.r.	0.008	n.r.	0.073	n.r.	n.r.	n.r.
Fly Ash	EPA (Reference 5) (1993 Data)	n.r.	0.013	n.r.	0.10	n.r.	n.r.	n.r.
Bottom Ash	EPA (Reference 5)	12	0.003	n.r.	0.009	n.r.	n.r.	0.040
Bottom Ash	EPA (Reference 6) (combined bottom ash & slag)	n.r.	0.005	n.r.	0.023	n.r.	n.r.	4.2
Boiler Slag	EPA (Reference 5)	12	0.005	n.r.	0.023	n.r.	n.r.	4.2
Wet FGD/Solids/Sludges	EPA (reference 5)	15	0.073	n.r.	4.8	n.r.	n.r.	39.0

(a)n.r. = not reported.

Nationwide Management Practices

A summary comparison of the quantities and management techniques for various CCRs is presented in Figure 1. The CCRs are either land-disposed (in a monofill or surface impoundment) or are being used for commercial applications. In the United States in the year 1999, approximately 110 million tons of CCRs were generated. Approximately one-third (31 percent) of these materials were reused or recycled in various commercial uses, with the remainder being land-disposed.

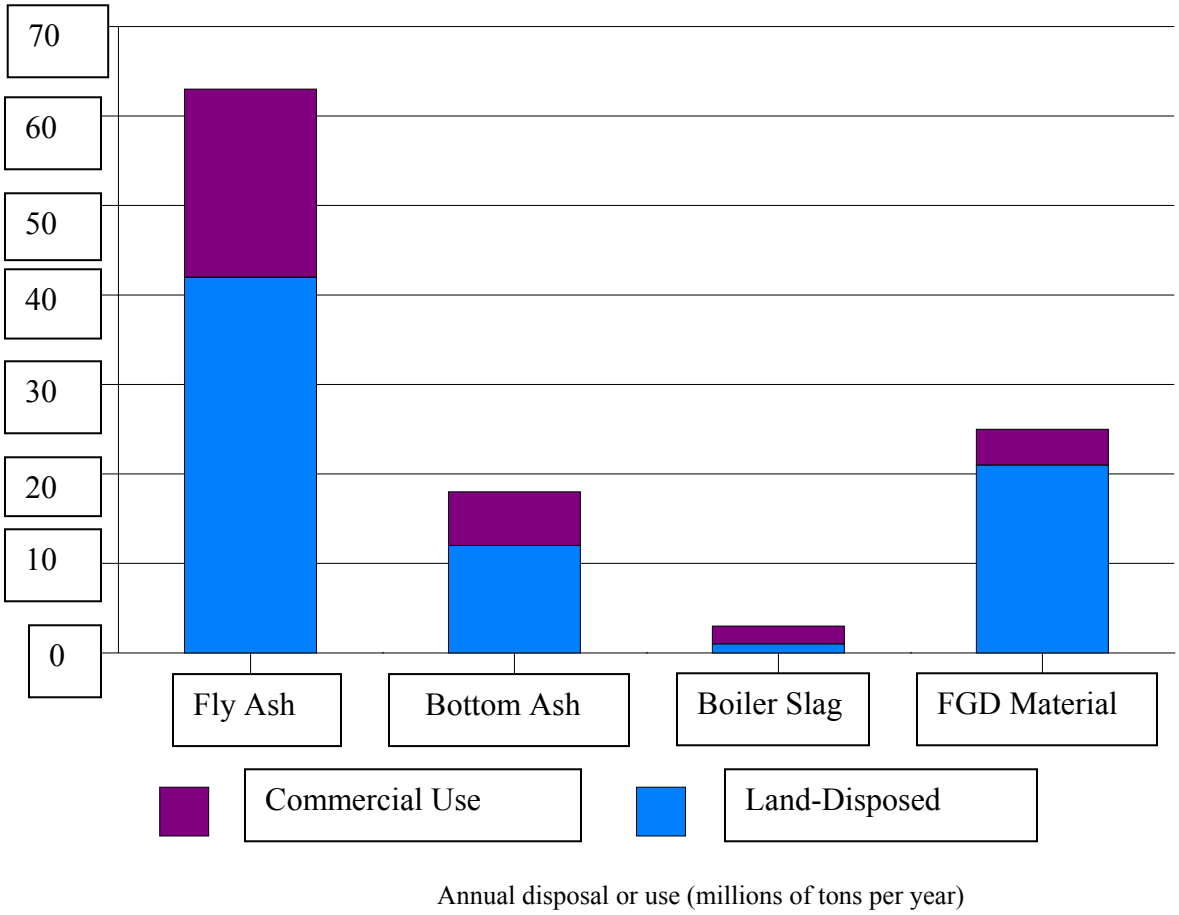

Figure 1. Nationwide CCR management practices in the year 1999 (source: Graph prepared using data from Reference 1).

Reuse and Recycling of CCRs

The primary commercial uses of CCRs are listed in Table 4. The table presents how each of four types of high-volume CCRs were used for commercial application in 1999. The use of fly ash as a replacement ingredient for concrete or grout is the most common use for any CCR. In this application, the fly ash can serve as a replacement for sand or as a partial replacement for portland cement in the concrete mix. Significant amounts of fly and bottom ash are used for structural fills (e.g., creation of highway embankments). The addition of CCR to form a road base allows for greater long-term strength development than conventional materials. Bottom ash is used as a substitute for salt for road de-icing operations. Almost all of the boiler slag generated in 1999 was used as blasting grit or roofing granules. Wet FGD scrubber solid wastes and sludges that do not contain high levels of fly ash can be used either directly or, with additional processing, in the production of gypsum wallboard. The substitution of wet FGD scrubber solids/sludges for natural gypsum in wallboard manufacturing has been growing rapidly.

Table 4. Primary Commercial Uses of CCRs.

Commercial Application or Use	**Coal Combustion Residue**								**Nationwide** Total (tons)
	Fly Ash		**Bottom Ash**		**Boiler Slag**		**Wet FGD Solid/Sludge**		
	Tons	%	Tons	%	Tons	%	Tons	%	
Concrete/ grout	10,000,000	49	700,000	13	11,000	0.5	290,000	6.6	11,000,000
Waste stabilization/ solidification	1,900,000	9.3	69,000	1.3	0	0	16,000	0.4	2,000,000
Structural Fill	3,200,000	15	1,400,000	26	52,000	2.2	580,000	13	5,200,000
Mining applications	1,500,000	7.3	150,000	2.8	10,000	0.4	230,000	5.2	1,900,000
Raw Feed for Cement Clinker	1,300,000	6.1	160,000	2.9	0	0	0	0	1,500,000
Road base/ subbase	1,200,000	5.9	1,100,000	20	5,500	0.2	17,000	0.4	2,300,000
Flowable Fill	850,000	4.1	13,000	0.2	0	0	0	0	860,000
Other	460,000	2.2	450,000	8.3	76,000	3.2	180,000	4.1	1,200,000
Mineral Filler	160,000	0.8	63,000	1.2	12,000	0.5	0	0	240,000
Soil Modification	78,000	0.4	17,000	0.3	13,000	0.5	2,100	<0.1	110,000
Agriculture	78,000	0.4	43,000	0.8	0	0	80,000	1.8	200,000
Snow and Ice Control	3,200	0.1	1,100,00	20	51,000	2.2	0	0	1,200,000
Blasting Grit/ Roofing Granules	0	0	160,000	2.9	2,100,000	90	0	0	2,300,000
Wallboard	0	0	0	0	0	0	3,100,000	69	3,100,000
Nationwide Total[a]	21,000,000	100	540,000	100	2,300,000	100	4,500,000	100	33,000,000

(a) Sum of individual values may not equal total due to rounding.

For some commercial uses of CCRs, there is concern regarding the potential re-release of Hg, particularly for those uses involving high-temperature processes. In cement manufacturing, for example, the high temperatures in the cement kiln will revolatilize the Hg contained in the coal fly ash that is used as a material substitute. Questions exist regarding the fraction of Hg in the fly ash that may be emitted when fed to a cement kiln. Other commercial processes that expose CCRs to elevated temperatures include wallboard manufacturing (during the drying process) and when CCRs are used as fillers in asphalt.

For some of the other commercial uses, it appears unlikely that significant Hg in CCRs would be re-introduced into the environment. For example, Hg is unlikely to be re-volatilized or leached from concrete, flowable fill, or structural fill. However, the various commercial uses will be evaluated to determine if there is any significant increase in environmental risk as a result of changes occurring to CCRs.

Land-Disposal of CCRs

There are currently approximately 600 waste disposal units (monofills or surface impoundments) being used for disposal of CCRs from electric utility coal-fired electric utility power plants in the United States.[5] The monofills used for these residues may be located either on-site at the power plant or off-site. Surface impoundments are almost exclusively located at the power plant site. While the distribution of units presently is about equal between monofills and surface impoundments, there is an increased trend to use monofills as the primary disposal method.

On May 22, 2000 the EPA made the regulatory determination that the disposal of CCRs does not warrant regulation under subtitle C of RCRA and retained the hazardous waste exemption for these materials provided under RCRA section 3001(b)(3)(C).[7] However, the EPA also determined that national regulations under subtitle D of RCRA are warranted for CCRs when they are disposed of in landfills or surface impoundments, and that regulations under subtitle D of RCRA [and/or possibly modifications to existing regulations established under authority of the Surface Mining Control and Reclamation Act (SMCRA)] are warranted when these materials are managed in surface or underground mines. The national regulations will apply to disposal of coal combustion wastes that are generated at electric utility and independent power producing facilities and managed in surface impoundments, landfills, and mines.

The EPA will re-evaluate the risk posed by managing coal combustion residues if levels of Hg or other hazardous constituents change due to any future Clean Air Act air pollution control requirements for coal burning utilities. When any rule making under the Clean Air Act proceeds to the point where an assessment of the likely changes to the character of CCRs is completed, EPA will evaluate the implications of these changes relative to existing or planned national RCRA regulations governing these materials and take appropriate action.

Current Status of CCR Research Activities

The EPA/NRMRL is preparing a report on characterization and management of CCRs from coal fired electric utility power plants. The report examines changes in the Hg content of CCRs that potentially could occur as the result of implementing different control technologies to reduce stack emissions of Hg from coal fired electric utility power plants. This report is scheduled to be published in the near future.

Test methods to characterize CCRs and to determine Hg volatilization and leaching from CCRs in various management practices are being reviewed by EPA/NRMRL. The goal of this review is to ensure that leaching and volatilization testing conducted by all parties, inside and outside of the EPA, is uniform and appropriate.

Multiple-site, full-scale field test programs are currently being conducted under a DOE/NETL cooperative agreement to obtain performance and cost data for using different Hg control technologies to reduce Hg emissions from existing coal fired electric utility power plants (discussed in Chapter 7 of Reference 9). As part of these test programs, field data are being collected that will help determine changes in the Hg content of CCRs as a result of implementing these Hg controls technologies. In addition, CCR commercial applications requiring elevated temperature processes, such as cement manufacturing and wallboard production, are being evaluated to determine the amount of Hg revolatilization that occurs, and the impacts of this revolatilization on the environment.

The EPA/NRMRL is planning to prepare a report, scheduled for publication in 2003, presenting data and other information relating to changes to CCRs as a result of implementing different Hg control technologies. This report also will help identify any potential concerns due to increased environmental risk from the management of CCRs resulting from Hg control measures.

Future CCR Research Activities and Needs

Coordination with industry and others will continue to identify available data and information that will help to characterize any changes to CCRs as a result of Hg control measures. Different methods are being used to characterize CCRs, which result in data of questionable value. The EPA ORD/NRMRL is working closely with EPA/OSW to identify methods for characterizing CCRs to identify potential changes to CCRs as a result of Hg control measures.

Samples of the resulting CCRs from the ongoing full-scale field test programs of different Hg control technologies will be collected to characterize the resulting CCRs and to identify any changes occurring to CCRs that would increase environmental risk from waste management and potential commercial applications.

Questions regarding the potential release of Hg from land-disposal result in the need to conduct field test measurements to ensure that Hg is not being emitted through either biological processes or leaching. Opportunities will be identified to help address questions regarding any increased environmental risk due to changes occurring to CCRs.

Questions also exist relating to CCRs being used in high-temperature processes such as cement manufacturing and wallboard production. Effort is needed to determine the amount of Hg that may be released during the manufacturing process and other life-cycle stages, including final disposal in a landfill.

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Session 2

Testing and Terminology

Session Chairperson:
Debra Pflughoeft-Hassett
Energy and Environmental Research Center
University of North Dakota
Grand Forks, North Dakota

Are You Using the Appropriate Coal Combustion By-Products (CCBs) and Coal Combustion Products (CCPs) Terminology in Your Coal Mining Reclamation Applications?
Howard Humphrey, American Coal Ash Association, Syracuse, New York

Instrumentation for Elemental Analysis of Coal Ash Products
LeRoy Jacobs, Wyoming Analytical Laboratories, Golden, Colorado

Evaluating CCBs for Environmental Performance
David Hassett, Energy and Environmental Research Center, University of North Dakota, Grand Forks, North Dakota

Evaluation of Physical Properties and Engineering Performance of CCBs in the Laboratory and the Field
Andrew Stewart, Power Products Engineering, Eden Prairie, Minnesota

Environmental Tracers of Leachate Derived from Pressurized Fluidized Bed Combustion By-Products in an Abandoned Coal Mine Setting
Ralph Haefner, U.S. Geological Survey, Columbus, Ohio

QA/QC and Variability of CCBs Relating to Mine Applications
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ARE YOU USING THE APPROPRIATE COAL COMBUSTION BY-PRODUCTS (CCBs) AND COAL COMBUSTION PRODUCTS (CCPs) TERMINOLOGY IN YOUR COAL MINING RECLAMATION APPLICATIONS?

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Abstract

This paper is directed to defining the usage of various terms for coal combustion by-products (CCBs) and coal combustion products (CCPs) that are associated with their utilization in coal mining reclamation applications throughout the United States, with an emphasis on the Western States. It addresses a need that has been recognized by the ACAA and others in the industry on listing and defining the usage of the various terms and phrases that are commonly used by those who are involved with the management and use of coal ash and coal combustion by-products/products. Also, it addresses a specific need that was mutually identified by the ACAA and the Utility Solid Waste Activities Group (USWAG) for more precise definitions of coal combustion by-products/products terms. This need has developed as a result of the use of the term flue gas desulfurization material and other coal ash terms in coal mining reclamation applications. This paper draws on the more precise definition of terms that are embodied in an ASTM E 50. The draft standard terminology of coal combustion products in ASTM E 50 focuses on the usage of terms in standards that exist, are under development, or are proposed by ASTM E50.03 where the focus is not on the use of coal combustion products/by-products in standards by other ASTM committees. Also, this paper draws on the ACAA draft document titled *Glossary of Terms Concerning the Management and Use of Coal Combustion Products,* which is a comprehensive usage of CCBs and CCPs terminology. The objective of this paper is to help users of coal combustion by-products/products in coal mining reclamation applications understand the terminology associated with these by-products/products both from the precise usage and the general usage standpoints.

Introduction

The terms Coal Combustion Products (CCPs) and Coal Combustion By-Products (CCBs) in the title of this paper and the term Coal Combustion Products and the acronym CCB in the title and program of this interactive forum provides an insight into the current usage of these two particular terms by industry and its various stakeholders, Federal and State government regulatory and other agencies, and ultimately the general public. Other insights on usage are: the reference in the Office of Surface Mining (OSM) home page (www.mcrcc.osmre.gov/ccb) for this forum that CCBs include fluidized bed combustion residues and flue gas desulfurization sludge, which may not be considered as being appropriate by the CCPs industry because of the use of the words "residues" and "sludge"; the definition also on this home page for Flue Gas Desulfurization (FGD) material shown in the CCB Information Network *Guide to the Literature Terms and Definitions* (Updated 10/14/98), which differs from the current ASTM definitions and which will be addressed later.

The collective terms CCBs and CCPs are used to define or refer to the Industry that is involved with the management and use of coal ash, CCPs, and CCBs. [1]CCPs are defined as – "fly ash, bottom ash, boiler slag, fluidized-bed combustion (FBC) ash, or flue gas desulfurization (FGD) material produced primarily from the combustion of coal or the cleaning of the stack gases." The term CCPs was first used in this country in 1998. It has become the preferred Industry term for coal ash that is used, and industry has used it to replace the term CCBs. The basis for this change was to emphasize the value that the materials from the combustion of coal or the cleaning of the stack gasses have when they are manufactured or processed to meet certain technical standards and when they are used commercially. Many government agencies (Federal and State) and other organizations continue to use the term CCBs. In addition, the terms coal combustion wastes (CCWs), coal combustion residues (CCRs), or fossil fuel combustion wastes (FFCWs) are used in Federal regulations in the same context as the term CCBs. As a result of

the interchangeable use of these terms (CCBs, CCPs, CCWs, CCRs, and FFCWs) there has been an industry movement to provide clarity based on use of these by-products. [2]The term "products" applies when the material is used and the term "wastes" applies when the material is discarded. However, this clarification is not accepted universally due in part to the many factors that may require a by-product to be disposed rather than utilized. As an example, the quote from an [3]article by Debra Pflughoeft-Hassett in the [4]*Energeia Newsletter* states: "70 percent of CCBs are being placed in permanent disposal sites in the United States annually, so the term waste is often applicable. However, the term wastes more appropriately refers to the missed opportunity from disposal of these materials rather than utilizing them."

Background

The majority of the terms associated with the CCPs/CCBs industry are defined in various publications that include standard making organizations such as ASTM and ACI, Federal and State government regulatory or other agencies, etc. However, there is an issue with consistency in the usage of collective terms and with the definition for FGD material as can be observed from usage of the collective terms mentioned and the reference to the lack of conformance of the definition for FGD material to the current definitions. A case for the need for practical working definitions was made in the previously mentioned article in *Energeia* by Debra Pflughoeft-Hassett. Ms. Pflughoeft-Hassett was a part of a movement by industry, including ACAA, the Utility Solid Waste Activities Group (USWAG), and other stakeholders, to provide for a more precise definition of coal combustion by-products/ products terms. The need was identified as a result of the use of the term flue gas desulfurization material and other coal ash terms in coal mining reclamation applications. This movement has resulted in the development of two documents that further define terms and usage. The first is a "draft standard terminology for CCPs" that has been developed by the coal ash task group of ASTM Subcommittee E 50.03 and is about to become a standard terminology for CCPs. The second is a draft document titled *Glossary of Terms Concerning the Management and Use of Coal Combustion Products* that has been published by the ACAA for its members.

ASTM Subcommittee E50.03

Currently this subcommittee deals with coal ash, sustainability, risk management, and pollution prevention. A restructuring plan has been proposed for this subcommittee to have a more defined focus that will involve "the promotion of knowledge, stimulation of research, development and maintenance of standards and related documents for pollution prevention, and beneficial use."[5] The subcommittee has developed two existing standards regarding beneficial use of CCBs, which are:

- **E1861-97** Guide for the Use of Coal Combustion By-Products in Structural Fills
- **E2060-00** Guide for the Use of Coal Combustion Products for Solidification/Stabilization of Inorganic Wastes

The subcommittee is working on new standards as follows:

- Standard Guide for Terminology of Coal Combustion Products
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Recontouring and Highwall Reclamation
- Guide for the Use of Coal Combustion By-Products for Surface Mine Reclamation: Revegetation and Mitigation of Acid Mine Drainage.

The focus of the draft of the *Standard Guide for Terminology of Coal Combustion Products* is on the usage of terms in standards that exist, are under development, or are proposed by ASTM E50.03. It does not address the use of coal CCPs in standards by other ASTM committees.

ASTM uses a procedure of consensus in developing standards. The definitions from the draft standard terminology of CCPs document reflect that a consensus has been achieved.

ACAA Glossary of Terms

The terms and phrases in this glossary are associated both with the production, handling, storage, and use of CCPs, and with coal ash disposal. Additionally, some environmental and regulatory terms associated with the use and disposal of these materials are included. This is a continuing effort and it is the best effort of the ACAA to reflect common usage in the industry. The terms and phrases have not been developed by consensus.

Is There an Appropriate Collective Term?

The current usage of the collective terms CCBs, CCPs, CCWs, CCRs, and FFCWs by different stakeholders for referring to essentially the same materials is a factor that must be understood and recognized. Industry has avoided the interchangeable use of the terms CCWs, CCRs, and FFCWs with CCBs and CCPs because the usage of CCWs, CCRs, and FFCWs is in the context that these are "solid wastes" which have to be disposed. The recognition that these materials have value and could be used in various commercial applications resulted in a normal marketing approach in order to avoid the use of the term "wastes" and the connotation or association with that use. The main challenge with the "wastes" designation is the body of government regulations that exists to protect public health and safety when a material is designated as a solid waste and the difficulty in getting the government regulators to recognize and allow for "beneficial use." The CCPs industry effort to avoid using the word wastes is not unique. It is common to other commercial or industrial processes that produce by-products in their effort to promote "beneficial use" and address solid waste regulatory requirements. The usage of the collective term CCBs recognizes that the coal ash or other materials are the by-products of a coal fired power plant combustion or flue gas cleaning process. The usage of the collective term CCPs recognizes that (1) gypsum that is manufactured as a part of the flue gas cleaning process at the coal fired power plant or (2) fly ash that is produced at the power plant to meet standards such as ASTM C 618 and that may involve the use of specific technologies are products. As a result, the usage of these two terms—CCBs or CCPs—are appropriate and one can add a caveat "depending on the context." The ACAA addresses this usage of the various collective terms in its publications and communications by describing its preferred term CCPs. This is a practice that is generally employed by University and other nongovernmental organizations in their usage of CCPs or CCBs. The usage of the other collective terms will continue and the potential exists for government departments and agencies such as the USDOE National Energy Technology Laboratory (NETL) to develop additional collective terms to incorporate by-products from other processes such as gasification.

What is this authors perspective on usage of the terms associated with the management and use of CCPs?

The use of English words take on different meanings over time. This is supported by situations that have been reported in the press where public or other officials have been severely criticized because of their use of words whose meaning have changed over time for a number of reasons and whose current use was considered inappropriate. Words and phrases are constantly being added to the English language to meet the needs of the various stakeholders in the society and can be euphemisms, jargon, bureaucratese, etc. The Federal and State Government through regulations or other initiatives, the CCPs industry, University researchers, and others are contributing to this addition of words and phrases in order to meet communication and other needs associated with the management and use of CCPs. Each stakeholder generally defines these words and phrases and the pecking order of our society will result in the Government usage dominating or being referenced by the CCPs industry regardless of the origins of the use of these words and phrases. The words and phrases associated with CCPs management and use are influenced or affected by their usage in other standards such as ASTM or ACI and by their usage in different regions of the country.

What are some of the key CCPs terminology that affects the utilization of CCPs in coal mining reclamation applications?

The terminology for CCPs that is presented in this section addresses the key or major terms and definitions from the draft standard terminology for CCPs as referenced above. Also, a commentary is provided for each of the definitions using information from the *ACAA Glossary of Terms* as referenced above or from other sources. The order of the

information is not alphabetical and is as follows:

Coal ash – a collective term referring to any solid materials or residues (such as fly ash, bottom ash, or boiler slag) produced primarily from the combustion of coal.

Commentary—Coal ash is a widely used term in the industry and it is included in the definition of CCPs and CCBs. The ACAA Glossary provides additional information to this definition as follows: "Collective term referring to any materials or residues produced directly from the combustion of coal and especially from coal-fired power plants. [6] *'It is much like volcanic ash. It consists of limestone, iron, aluminum, silica sand, and clay. In addition it contains trace quantities (in the parts per million range) of the oxidized forms of other naturally occurring elements. These same elements exist in soil, rock, and coal.' The coal can be bituminous, subbituminous, lignite, or a mixture of these coals. The residues of mixtures of small quantities of other fuels, such as petroleum coke, fuel oil, etc., with coal also are referred to as coal ash. Current usage of the coal ash collective term is synonymous with the term coal combustion ash and coal combustion residue (CCR). Also, coal ash is a component of the term coal combustion by-product (CCB) covering only the materials or residues associated with the combustion of coal and not the residues from flue gas cleaning."*

The reference to mixtures of other fuels in this commentary is a condition that is coming to the forefront as to when is coal ash not coal ash because of the percentage of ash from the mixtures of other fuels which could be biomass. This determination could have implications for use in coal mining and other applications.

Fly Ash – coal ash that exits a combustion chamber in the flue gas and is captured by air pollution control equipment such as electrostatic precipitators, baghouses, and wet scrubbers.

Commentary—Fly ash is included in the definition for CCPs or CCBs. Fly ash is historically the most commonly marketed coal combustion product. The ACAA Glossary provides additional information to this definition as follows:

"Fly ash is typically a pozzolan. Some fly ashes also exhibit self-hardening properties in the presence of moisture."

Fly ash has various uses in coal mining applications throughout the country. Fly ash that does not conform to ASTM C 618 offers a low cost advantage for uses in coal mining applications that does not involve its use as an admixture in concrete. Fly ash in the Western States is sometimes a part of dry scrubber material.

Fly ash-lime content – the total calcium content of fly ash, including reactive and non-reactive calcium species expressed as calcium oxide (CaO)**.**

Commentary—Fly ash from bituminous coals usually has a relatively low calcium oxide content (less than 2 percent) when compared to fly ash from subbituminous or lignite coals (generally more than 10 percent).

Cementitious ash – fly ash that hardens irreversibly when mixed with water. Also referred to as self-cementing ash.

Commentary—Class C fly ash is cementitious.

Cementitious mixture – A combination of more than any one of the following materials to make a cement paste: hydraulic cement, portland cement, coal fly ash, FBC ash, lime, ground granulated blast furnace slag, lime kiln dust, and cement kiln dust. It may be used by itself for grout, to bind aggregates or fine materials to make concrete or controlled low strength materials (CLSM), or for soil stabilization and solidification.

Commentary—This definition references CCPs to a greater extent than other definitions.

Class C fly ash – fly ash that meets criteria defined in ASTM C618 for use in concrete**.**

Commentary—The phrase "for use in concrete" has been added for clarification.

Class F fly ash – fly ash that meets criteria defined in ASTM C618 for use in concrete.

Commentary—The phrase "for use in concrete" has been added for clarification.

Conditioned ash – ash that has been moistened with water during the load out process at the temporary storage silo at the power plant to allow for its handling, transport, and placement without causing fugitive dusting.

Commentary—Conditioned ash is usually designated for placing in a landfill, although it can be used in beneficial applications that include coal mining reclamation projects.

Dry fly ash – fly ash that has been collected by particulate removal equipment such as electrostatic precipitators, baghouses, mechanical collectors, or fabric filters.

Commentary—Dry fly ash is transported in bulk carriers (truck or rail cars or barges).

Ponded ash – ash that is in an ash pond or that has been excavated from an ash pond.

Commentary—Ponded ash is being used in construction and coal mining reclamation applications

Bottom ash – agglomerated ash particles formed in pulverized coal boilers that are too large to be carried in the flue gases and impinge on the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Bottom ash is typically grey to black in color, is quite angular, and has a porous surface structure.

Commentary—Bottom ash is used as an aggregate in construction and coal mining applications.

Boiler slag – a molten ash collected at the base of slag tap and cyclone boilers that is quenched with water and shatters into black, angular particles having a smooth, glassy appearance.

Commentary—Boiler slag is in high demand for beneficial use (blasting grit, roofing granules, etc.), but supplies are decreasing because of the removal from service of power plants (due to their age) that produce boiler slag.

Fluidized-bed combustion (FBC) ash – the fly ash and bed ash produced by an FBC boiler.

Commentary—The ACAA Glossary expands on this definition by stating "FBC fly ash is removed from the flue of an FBC boiler using a baghouse filter or electrostatic precipitator. FBC bed ash is the residue that is removed from the bottom of the FBC boiler. Some FBC fly ashes exhibit self-hardening properties in the presence of moisture." The FBC ash from high sulfur coals has been identified to have chemical characteristics that can cause it to swell when water is added due to the formation of ettringite.

Fluidized-bed combustion (FBC) bed ash – the spent bed material that is produced by an FBC boiler. The bed ash is usually collected separately and can be considered as being equivalent to bottom ash in dry bottom or wet-bottom wall-fired furnace.

Commentary—FBC bed ash must be tested for the formation of ettringite.

Fluidized-bed combustion (FBC) products – the unburned coal, ash, spent bed material, and unreacted sorbent produced by an FBC boiler.

Commentary—FBC products possess chemical characteristics that could be of advantage in acid mine drainage and mine-land reclamation applications. FBC products must be tested for the formation of ettringite.

Flue gas desulfurization (FGD) – removal of gaseous sulfur dioxide from boiler exhaust gas. Primary types of FGD processes are wet scrubbers, dry scrubbers, and sorbent injection. Sorbents include lime, limestone, sodium-based compounds, and high-calcium coal fly ash.

Dry FGD ash **–** see dry FGD material.

Dry FGD material **–** the product that is produced from dry FGD systems and consists primarily of calcium sulfite, fly ash, portlandite ($Ca(OH)_2$), and/or calcite.

Fixated FGD material **–** a designed mixture of dewatered FGD sludge that is primarily calcium sulfite with either a high-lime fly ash or a low-lime fly ash combined with a cementitious material. FGD sludge is also known as scrubber sludge, scrubber material, FGD solids, filter cake, or centrifuge cake.

Lime spray drier ash **–** see dry FGD material.

Stabilized FGD material **–** another name for fixated FGD material.

Wet FGD products **–** the product of wet FGD processes or systems. It is composed primarily of water, calcium sulfite/sulfate solids, and small quantities of fly ash. Wet FGD products can be thixotropic**.**

FGD gypsum **–** gypsum formed from an oxidizing and calcium-based flue gas desulfurization process.

FGD material **–** a product of an FGD process typically using a high-calcium sorbent such as lime or limestone. Sodium-based sorbent and high-calcium coal fly ashes also are used in some systems. The physical nature of these materials varies from a wet thixotropic sludge to a dry powdered material depending on the process.

FGD material dry scrubbers **–** the dry powdered material from dry scrubbers that is collected in a baghouse along with fly ash and consists of a mixture of sulfites, sulfates, and fly ash.

Commentary—The format of the definitions of the materials presented above is intended to provide users with an understanding of the FGD process and the materials from the various FGD processes. These definitions are precise and should clear up the inappropriate use and definitions for FGD material.

Beneficial use of a CCP - the use of or substitution of the coal combustion product (CCP) for another product based on performance criteria. For purposes of this definition, beneficial use includes but is not restricted to raw feed for cement clinker, concrete, grout, flowable fill, and controlled low strength material; structural fill; road base/subbase; soil-modification; mineral filler; snow and ice traction control; blasting grit and abrasives; roofing granules; mining applications; wallboard; waste stabilization/solidification; soil amendment and agriculture.

Commentary—There are various regulatory definitions of beneficial use. This definition is for beneficial use of a CCP.

Product – any object possessing intrinsic value, capable of delivery either as an assembled whole or as a component part or parts, and produced for introduction into trade or commerce.

Commentary—This definition provides the basis for the collective term CCPs.

Ammoniated ash – ash that contains ammonia and/or ammonium salts as a result of the addition of ammonia or ammonium salts to the flue gas at the power plant.

Commentary—This definition is provided to make users in coal mining reclamation applications aware of the existence of this ash.

What are some of the terms, which are covered in the ACAA Glossary, that are relevant to this discussion?

The definition of the collective terms that are not presented in the section above and are covered in the ACAA Glossary are presented as follows:

Coal combustion ash – collective term referring to any materials or residues produced from the combustion of coal.

Commentary—This is the same definition that is used by the OSM on its website. The OSM identifies other collective terms under this definition that includes coal ash, coal combustion residue, and coal combustion material.

Coal combustion by-products (CCBs) – collective term referring to fly ash, bottom ash, boiler slag, fluidized bed combustion ash or flue gas desulfurization (FGD) material resulting from the combustion of coal and the cleaning of the stack gases. Also a collective term referring to any large volume material or residue produced from the combustion of coal or the cleaning of the stack gasses, regardless of ultimate commercial application or disposal.

Commentary—This is the same definition that is used by the OSM on its website except that the sentences are not in the same order.

Coal combustion residue (CCR) – collective term referring to any materials or residues produced from the combustion of coal. CCR has been a term used in scientific literature and by the United States Environmental Protection Agency (EPA) and environmental groups, but used little by the coal ash industry.

Commentary—This definition is the same as that for coal combustion ash described above except for the clarification on usage.

Coal combustion wastes (CCWs) – a collective term for materials or residues produced from the combustion of coal or the cleaning of stack gases that are disposed of as a solid waste. This term is used in Federal and State regulations and by environmental groups.

Commentary—The OSM definition states: "A collective term for materials or residues produced from the combustion of coal or cleaning of stack gasses for which there are no commercial markets and they are disposed of as a solid waste."

Ettringite – a high–calcium sulfoaluminate mineral *($Ca_6.Al_2(SO4)_3(OH)_{12}.26H_2O$)* that is expansive because of its crystal structure; a mineral composed of hydrous basic calcium and aluminum sulfate that expands when wet upon forming its crystalline structure.

Commentary—The definition in the draft terminology ends after the formula.

Ettringite formation – the phenomenon that leads to the formation of ettringite and can occur in coal ash/lime/sulfur mixtures. Ettringite is formed by the combination of aluminum from the coal ash, lime, and sulfates from the scrubber process and water. These four substances are required for ettringite to form. Swelling problems due to ettringite formation have occurred with coal ash that contains scrubber or FBC residue. Swelling problems rarely occur with coal ash that does not contain scrubber or FBC residue.

Commentary—This definition is not in the draft terminology for CCPs.

Flowable fill – a material that flows like a liquid, is self-leveling, requires no compaction or vibration to achieve maximum density, hardens to a predetermined strength, and is sometimes a controlled low strength material (CLSM). Coal combustion products (CCPs) are used in manufacturing flowable fills. The proportion of the CCPs in the flowable fill mixture can be 100% for an all ash flowable fill that consists of a combination of a Class C (high lime) fly ash and a Class F fly ash and water. It can be a major portion of a mixture that consists primarily of fly ash or fly ash and bottom ash and a small amount of cement or cement and lime. Also, it may consist of only a high lime Class C fly ash (derived from the burning of Powder River Basin subbituminous coal) and sand with no addition of cement. The term flowable fill also applies to fixated FGD material that is enhanced with added lime or cement and that is used in underground mine filling applications.

Commentary—The draft terminology for CCPs has a definition for flowable fill but it is not as complete as this.

Fossil fuel combustion wastes (FFCWs) – a collective term utilized by the EPA for materials or residues produced from the combustion of coal or the cleaning of stack gasses.

Commentary—This is the same definition that is used by the OSM on its website.

Conclusion

The draft terminology for CCPs should become a standard guide in the near future. At that time it will be available from ASTM. Users of CCPs in coal mining applications are encouraged to acquire a copy of this *Standard Guide for Terminology of Coal Combustion Products*.

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INSTRUMENTATION FOR ELEMENTAL ANALYSIS OF COAL ASH PRODUCTS

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Abstract

Good instrumentation is becoming more available for the chemical analyst to determine the elemental and trace element content of coal ash by-products. The trick needed, to instill engineering confidence and receive good or even great analysis, is to be able to apply the appropriate instrument to the matrix at hand. In this presentation, I will present a brief overview of analytical instrumentation commonly in use in many analytical laboratories and a little on how to apply the instrument to a coal ash or fly ash matrix. Unfortunately, some of the following explanations of the analytical techniques have to be abbreviated and necessarily simplified because of shortness of time and writing ability. However, be assured that many books, articles, and more books explaining theoretical and practical applications have been written and will be written on each of the analytical techniques given in this short presentation.

Atomic Absorption Spectrophotometer (AA)

"Atomic absorption spectrometry is based upon the absorption of resonance radiation by an atomic vapor of the analyte. The resonance radiation corresponds to the wavelengths associated with the excitation of ground state gaseous analyte atoms."[1]

For coal combustion products, this statement has some sinister meanings. It means to the analyst in the chemistry lab that the sample must be in a form to use the AA instrument to obtain the desired analysis. It calls for total solubilization or a 100 percent extraction with acid or bases to obtain the desired analyte, either in a water-soluble form or a vapor. Sometimes this is not the easiest thing to do for coal combustion products, especially when dealing with very insoluble material like calcium sulfate or many barium compounds. When the material is presented to an AA in the appropriate form, the solution is then aspirated through a flame, which desolvates the material and causes, in most cases, a sufficient amount of analyte to not only ionize but also a portion of the species to be in a ground state of zero. That's the portion of the sample that we deal with. By the use of a lamp which contains a small amount of the element that is being analyzed, emitting light specific to that element is shown through the now desolvated elemental species, which is in the ground state zero causing the element to absorb the light and jump to an excited state. This absorption, or really lack of light shining through the flame, can be qualitatively sorted with grating or prism and the response, or really the decrease in response, can be quantified with photo multipliers and equated to standards in the appropriate matrix. Methods exist for the use of AA when analytically applied to fly ash or coal ash and have been used to determine majors and minors in fly ash or coal ash. Drawbacks include the difficulty in dissolution of the ash especially for silicon, titanium, and barium compounds.

Graphite Furnace Atomic Absorption (GFAA)

Graphite Furnace Atomic Absorption Spectrophotometer (GFAA) is another way to vaporize an analyte from a solution into an optical path for determining the absorption signal. "Electrically heated graphite tubes, which are more efficient than flames in atomizing the sample, are commonly used for producing atomic vapors. Only micro liter quantities of the sample solution are required for the determination of analyte at concentrations two to three orders of magnitude below those measurable by conventional flame atomization."[1] The graphite furnace or graphite rod is normally a pyrolyzed, trace element free, graphite that is heated very rapidly by resistive heating to very hot temperatures, on the order of 1000 to 3000 ^{o}C. Drying and ashing steps can be included in the ramped heating stages, which can help when analyzing trace elements in organics. As in the case of flame AA, generally only one

element at a time is determined.

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES or more commonly ICP)

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES or more commonly ICP), again uses a solution, usually aqueous, that is to be analyzed by aspirating a portion of the sample in the form of a fog, into an argon plasma torch where the fogged solution is sent through an extremely hot argon plasma at about 10,000^{o}K (10,273 ^{o}C) where most contained elements are excited and emit light that is characteristic of the contained elements. When the elements return to a lower or normal electronic state, which is characteristic of the elements ionized, the emitted light can be quantified by using a prism or grating to sort, according to wavelength, and quantified by impinging the identified wavelength on a photo multiplier. The ICP is calibrated versus standards containing known amounts of the analyte elements. Standard solutions should match as closely as possible the analyte sample matrix. Disadvantages to this instrument are that the ICP combines to a large extent the disadvantages of AA along with those of emission spectrography, all in one instrument. In AA, the sample must be a form that can be vaporized, which normally means aqueous solubilization or, at the very least, 100 percent extraction of the analyte, which can be difficult to achieve. Emission spectrograph (or spectrometry) has many spectral and molecular interferences because gratings that achieve ultra high resolution to minimize spectral overlap haven't been invented. The only thing that saves the ICP from abject trashing of the technique is the ultra hot argon plasma torch. Most elements when subjected to 10,000^{o}K tend to excite and consequently emit light that can be quantified very well. Detection limits with ICP are very good for most elements. Many samples and many elements per sample can be analyzed quickly making ICP a workhorse in most laboratories. Drawbacks, in a similar fashion to AA methods include (1) difficulty in dissolution of the ash especially for silicon, titanium, and barium compounds, and (2) matching the matrix of coal combustion products.

Inductive Coupled Plasma/Mass Spectrometry[2] (ICP/MS)

Inductive Coupled Plasma/Mass Spectrometry[2] (ICP/MS) analysis is a different way of looking at elemental analysis. The sample, normally in a aqueous solution, is ionized in the argon plasma, as in the case with ICP-OES. Then, a portion of the argon/sample plume is taken through a "skimmer cone" that goes from essentially atmospheric pressure to a vacuum and in a very short distance into a low resolution mass spectrometer source that operates at a vacuum. Instead of looking at emitted light from the ionized element, the ions resulting from the ICP plume are mass analyzed. Interferences in the low-resolution quadrupole ICP/MS are many and varied. The mass analyzer normally used is a quadupole mass spectrometer, which means that, at best, resolution in the mass analyzer is unit resolution. Resolution in a mass spectrometer is defined as the ability of the mass analyzer to separate elemental species from isotopic and positively charged molecular interferences that are common in ICP/MS. These instruments are good production instruments with very low detection limits, but again, the sample must be in aqueous solution. The disadvantage is that the instrument cannot handle high "salt" concentrations. Therefore, for coal combustion products, after dissolution, the aqueous sample must be diluted up to 500 to 1000 times, causing dilution errors as well as possible misidentification of mass spectra or contamination from reagents. A way around this, for ICP/MS, is to use a high resolution MS, which has a better chance of sorting out the elemental ions from interferences. For production instruments, resolutions on the order of 5,000 to 10,000 are necessary which means a magnetic sector instrument. But (isn't there always a but), the use of the magnetic sector instrument means that the throughput of the sample/time period falls and that the electronic and mechanical maintenance of a magnetic sector instrument is considerably higher.

X-ray Fluorescence Spectrometry (XRF)

In the analysis of coal combustion products, an analytical instrument that would analyze solids without being matrix dependent and have high precision would be very helpful, especially in the analysis of major concentrations of the elements determined. X-ray Fluorescence Spectrometry (XRF) comes close. There are two major different types of XRF instruments: wavelength dispersive (WDXRF) and energy dispersive (EDXRF). EDXRF is very fast in acquiring spectra and is a very good choice of instrumentation when qualitative and a minimum of quantitative analysis is needed. The second general type of instrument is wavelength dispersive X-ray fluorescence

spectrometer. The WDXRF is better suited to fly ash and coal combustion product analysis than almost any other analytical instrument. The WDXRF analyzes primarily solids, but can be used for liquids in special cases. Most instruments can be used to analyze elements in the periodic table from atomic number 11 (sodium) and up. Sample preparation is everything for this instrument and particle size, crystal effects, and matrix corrections must be carefully controlled. If the sample matrix is close to a standard matrix, then standardization is fairly simple. If not, then an "analytical trick" can be used to level the matrix so that every sample looks very similar in elemental composition to the instrument. That "analytical trick" is lithium borate fusion, in which fly ash, cements, iron ores, concrete, and many other sample types are diluted and fused with a mixture of lithium tetra borate and lithium carbonate to a fairly high dilution, say 10:1, before presenting to the WDXRF. Sensitivity for most elements in this dilution is sufficient to achieve good peak intensity and counting rates. The WDXRF shines when it comes to precision in determining relative intensity of the appropriate element peaks.

X-ray diffraction (XRD)

X-ray diffraction (XRD) is used to identify crystalographic[3] changes, stability of phases, unit cell dimensions, degree of crystalinity, molecular weights, atomic structure, and allotropic modifications. In normal analysis, XRD has but limited use in the analysis of fly ash and coal combustion products, except when the analysis just listed could become important. Generally, the limits of detection when applied to identification of a crystal species doesn't go much below 2.5 percent of the amount of analyte species, so XRD is best used when high concentrations are to be identified.

Glow discharge mass spectrometry[4] (GDMS)

Glow discharge mass spectrometry[4] (GDMS) is a mass spectrometric analytical technique applicable to the analysis of inorganic composition of solids, especially for determining trace element composition. Since the instrument is a mass spectrometer, it is also capable of determining isotopic composition simultaneously with elemental content.

Spark Source Mass Spectrography (SSMS)

The development of spark source mass spectrography (SSMS) in the late 1960s parallels current GDMS development in that solids are analyzed with little or no sample preparation and a mass spectrometer is used to differentiate the output signal. SSMS will very quickly scan most liquids (through evaporation on a conductive substrate) and most solids after mixing with a conductive substrate for major, minor, and trace element identification. After qualitative identification of elements with the SSMS, the next question is always "how much" of the analyte is present. Semiquantitation for trace elements (0.1 to 100 ppm) is possible; however, precision is a major stumbling block for the SSMS technique. The basic problem with the SSMS is the source: the rf driven spark is erratic in nature and it is difficult to reproduce sparking conditions from sample to sample. In fact, the spark source, since it is so erratic, requires a total integrating ion detector, such as a photoplate, to average the variations over time.

The glow discharge source, in contrast to the spark source, provides a stable source of ions for mass spectrometric analyses. In a direct current source mode, which is the normal source mode, the GDMS is used to run conducting samples, such as metals and semiconductors. A newer source called a radio frequency (rf)-source will allow the analysis of nonconductors, such as fly ash, by using radio frequency to generate elemental ions from the sample.

A stable source of ions allows sequential scanning of the ion beam for the mass to charge ratios of interest using a Faraday detector or Daly detector. It allows for faster, more precise quantitation of elemental content. The quanitation of trace, minor, and major elements is possible over nine orders of magnitude. Since the instrument is a mass spectrometer, it also has the capability to do isotopic analysis and isotopic dilution in a wide variety of solids and liquids.

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EVALUATING COAL COMBUSTION BY-PRODUCTS (CCBs) FOR ENVIRONMENTAL PERFORMANCE

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Abstract

Determining the environmental performance of CCBs is no small task and has long been investigated, scrutinized, and debated by groups interested in the environmentally safe management of CCBs. A regulatory perspective of this issue frequently requires some predetermined testing of CCBs based upon the designation of solid waste under RCRA (Resource Conservation and Recovery Act) Subtitle D. A variety of laboratory leaching methods have been developed and/or applied to CCBs. These include batch tests, column tests, and serial and sequential leaching tests, but few of these procedures are designed specifically for CCBs. Because the tests are not designed for use with CCBs, they do not account for several typical reactions in CCBs under hydration. It has long been known that laboratory leaching procedures cannot precisely simulate field conditions nor predict field leachate concentrations. However, with careful application of scientifically valid laboratory procedures, it is possible to improve laboratory-field correlations and modeling efforts focused on predicting field leachate concentrations.

The CCB industry needs to develop a selection of laboratory leaching procedures that more closely simulate field management scenarios. These procedures need to follow guidelines raised by the U.S. Environmental Protection Agency (EPA) in its recent reevaluation of waste characterization. It is anticipated that a limited number of procedures can be identified and selected to accomplish goals for various management options. Some of the technical/scientific variables that need to be addressed for different scenarios are:

- Long-term hydration reactions that can impact leachate concentrations of several constituents of interest.
- The means by which water contacts the CCB in order to simulate the reduced permeability frequently exhibited in CCB utilization applications.
- Impact of pH and other CCB properties on the leachate and resultant leaching.
- Prediction of, and changes in, leaching over time.

A discussion of these issues is intended to initiate an industrywide evaluation of the use of laboratory evaluations to predict environmental performance of CCBs in mine settings and in other management scenarios.

EPA Leachate Methods

According to the U.S. Environmental Protection Agency (EPA), the following information relates to SW-846:

1. Any reliable analytical method may be used to generate the vast majority of environmental data for the Superfund and Resource Conservation and Recovery Act (RCRA) programs.
2. EPA regulations do not routinely restrict the choice of analytical methods to those published in SW-846.
3. The choice of methods other than SW-846 methods, or modifications of SW-846 methods, is encouraged to improve site-specific analytical performance.

This is good news to those who recognize the limitations of toxicity characteristic leaching procedure (TCLP) leaching when used to evaluate CCBs for potential for environmental impact.

The TCLP is often used in a generic manner for the prediction of leaching trends of wastes, although the intent of this test was for the prediction of leaching under co-disposal conditions in sanitary landfills. The application of acidic conditions to predict field leaching that can occur under a wide range of conditions may lead to false prediction of leaching trends. Additionally, conditions imposed on leaching systems by inappropriate leaching solutions may alter the distribution of redox species that would be found in the field and, in some cases with reactive wastes, 18 hours, as specified in the TCLP and other short-term leaching tests, may be an insufficient equilibration time. In order for a batch leaching test to be useful in determining potential for environmental impact, several

qualities must be embodied by the protocol:

1. The test must be relevant with respect to providing both scientifically and legally defensible data.
2. The test must be relatively easy to conduct.
3. When being used with CCBs, the test must take into account the unique properties of the material, especially the hydration reactions of alkaline CCBs.

Synthetic Groundwater Leaching Procedure (SGLP)

A generic test of leachability, the synthetic groundwater leaching procedure (SGLP), with a long-term leaching (LTL) procedure, developed at the Energy and Environmental Research Center (EERC) at the University of North Dakota, has been used for nearly 20 years to predict leaching of coal combustion residues and other similar solid waste materials under field conditions (Hassett, D.J., 1987; 1997). Specific uses have included characterization of coal ash disposed of in monofills and prediction of mobility of selenium in mined areas. In many applications, this test has demonstrated trends significantly different from TCLP and other commonly used leaching protocols. In the case of coal ash, the trends indicated for leaching by the SGLP show very different trends than the TCLP. These differences can be explained by the fact that many commonly used leaching tests impose conditions different from those in a field environment on samples and, thus, bias data in a manner leading to inappropriate interpretation for environmental impact. Elements most often affected include arsenic, boron, chromium, vanadium, and selenium.

Long-Term Leaching

Long-term leaching using the LTL procedure, which is an extended-time SGLP, is used for waste materials after disposal that may undergo hydration reactions upon contact with water. The implication for the usefulness of these tests is magnified by the increase in reactive wastes that will be produced using advanced combustion systems to comply with the Clean Air Act. These materials, which are almost always reactive, behave much differently under field conditions than would be predicted using the TCLP or other short-term leaching procedures. At the present time, the SGLP test, along with long-term leaching, has been used in a number of States, including Minnesota, North Dakota, and Indiana, for determination of environmental impacts of coal conversion solids. The test has been written up in draft form for consideration by the American Society for Testing and Materials (ASTM) as a standard for leaching of coal ash.

Since many CCBs are reactive materials that become chemically altered upon contact with water, leaching tests must be based on an experimental protocol that takes this into account. Appropriate leaching must include long-term contact between water and ash to allow chemical and mineralogical changes to take place. The inappropriate or premature removal of leachate constituents must be absolutely avoided. Sequential batch and column leaching often remove potentially reactive constituents from ash-water systems and, although appropriate for other uses, will provide misleading information when applied to CCBs. Static, long-term batch leaching most appropriately mimics natural conditions of ash disposal with water infiltration since fly ash typically becomes relatively impermeable upon contact with water. The use of a batch leaching test where ash-water equilibrate for up to 30 or 60 days allows for the formation of important secondary hydrated phases such as ettringite and promotes equilibrium conditions with respect to environmentally important major, minor, and trace elements. Because of the importance of hydration reactions, interpretation of the potential for environmental impact should be based upon the longest-term leaching test results.

Liquid-to-Solid Ratio

The SGLP is appropriate for the screening of ash for potential environmental impact. The liquid-to-solid ratio, at 20:1, is the same as specified in the EPA TCLP and has a scientific basis for determining hazardousness. As with the TCLP, end-over-end agitation is used; however, the leaching solution in the SGLP is dependent on local conditions at the disposal location and also determined by the solution most likely to contact the waste material. Solutions that have been used include: synthetic acid precipitation, distilled deionized water, and groundwater either from the site or prepared in the laboratory based on groundwater analyses from the disposal site. Although not perfect, this type of batch leaching test is, for the present time, what is being used and is considered by many to be adequate, perhaps even conservative. Arguments have been made for alternative tests. Although arguments can be made for the use of these alternative tests, they are usually made in the absence of an understanding of the

fundamental nature and chemistry of CCBs. For this reason, arguments that may appear reasonable may, in the broader context of ash hydration mechanisms and ash chemistry, be fundamentally flawed and provide misleading information if used to predict the environmental impacts of CCBs.

The proposed test is intended to provide a true indication of leachability of ash constituents based on a current state-of-the-art understanding of ash chemistry, mineralogy, and hydration reactions. Certain chemical reactions can occur when ash and water are mixed, which are referred to as hydration reactions. Although the common understanding of hydration is usually limited to incorporation of water, the term is used in this document in a broader sense to refer to all reactions, including incorporation of water, that ash undergoes when contacted by water, either as groundwater or rain infiltration. Although the simple introduction of water does not ensure that leachate will be generated, it can be assumed that in the case of reactive ash, there will be chemical reactions (ash-ash interactions) forming, what are generally referred to as, secondary hydrated phases.

Ettringite Formation

The most notable of these hydrated phases is ettringite. Ettringite is a mineral with the nominal composition $Ca_6Al_2(SO_4)_3(OH)_{12} \bullet 26H_2O$. Ettringite is also the family name for a series of related compounds. Ettringite formation can result in the chemical incorporation of trace elements that exist as oxyanions in aqueous solution. These include, but are not limited to arsenic, boron, chromium, molybdenum, selenium, and vanadium. In the incorporation of these trace elements into ettringite, the trace element is substituted for the sulfate in the nominal structure. Thus, true chemical fixation is the most important removal mechanism, although sorption of arsenic species has been reported in the literature.

The general conditions that allow for ettringite formation are the presence of soluble aluminum, calcium, and sulfate and a source of alkalinity. A pH environment of between about 11 and 12.5 is most favorable, although ettringite has been known to form in pH environments below these limits. Since calcium, aluminum, and sulfate are involved in ettringite formation, it is not uncommon to see reductions in the solution concentrations of these constituents as ettringite forms. Further, ettringite consists of more than 38 percent water. Thus, ettringite formation is often accompanied by an apparent drying of the material in which it is forming. Ettringite formation can occur over several hours or can take months, depending on the availability of the essential constituents required for synthesis. The solubility of calcium, aluminum, and sulfate is highly variable between ash types. The rates of solubility can vary between the three constituents. This means that the rate of formation of ettringite is difficult to predict from a simple chemical analysis of the ash and will generally be related to the rate of availability of one limiting constituent. In areas with high-sulfate groundwater, cases have been documented where infiltration of natural waters through CCBs has resulted in an improvement of water quality.

Estimation of Leachate Mobility

The SGLP provides data that can be used for the estimation of mass of analyte that can be mobilized in short-term and long-term field leaching scenarios. Additionally, this test can predict analyte concentration evolution, meaning in higher concentrations approaching an equilibrium concentration or decreasing concentrations leading to equilibrium concentrations that will be lower than predicted by a short-term batch leaching test. Column leaching tests are generally not applicable to the leaching of potentially reactive wastes described above. In column tests, flow through the waste can deplete readily mobilized constituents, several of which, including aluminum, calcium, and sulfate, are necessary for ettringite formation. In addition to potentially minimizing the formation of secondary hydrated phases, column tests are often run at artificially high flow rates. A measurable flow is necessary for a laboratory test in order to generate sufficient leachate for analysis. In many ash monofills, the compacted ash can have a lower hydraulic conductivity than surrounding sediments.

Summary

The information presented above has described a leaching method suitable for use with alkaline CCBs or other reactive alkaline finely divided materials. The method described will generate legally and scientifically defensible data for the evaluation of CCBs for potential environmental impacts. While there are few researchers who rely on TCLP leaching to determine potential environmental impacts of CCBs, some regulatory agencies still routinely mandate this test. Because of the importance of the potential implications related to the disposal of up to

100 million tons of material each year, the significance of generating scientifically and legally defensible data cannot be overemphasized.

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EVALUATION OF PHYSICAL PROPERTIES AND ENGINEERING PERFORMANCE OF CCBs IN THE LABORATORY AND THE FIELD

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Abstract

Physical evaluation of CCBs in the laboratory and their subsequent performance in a field setting can at times be vastly different. It is an important aspect of CCB utilization that is often overlooked by engineers and end users. The focus of this paper is on two applications of fly ash used as a means for stabilizing native soils. Extensive laboratory testing was performed on several different soils and fly ash mixtures as well as on the soils and fly ash alone. Predictions of field performance were then determined from these laboratory tests. Field-testing methods were then determined in order to verify the performance of the actual field applications.

The laboratory methods for mixing and moisture control were very exact and therefore difficult to replicate in the field setting. Recognition of this in determining optimum field design mixes is extremely important. Field application, therefore, leads to the use of volumetric measurements that were easy to control. Predetermined physical areas of soil and known truck volumes of fly ash were utilized in order to obtain the desired level of stabilization. Testing of the field mixes determined that the method, though somewhat subjective, achieved the desired levels of replacement.

Introduction

The Coal Creek Station (CCS) facility is a two-unit 1100-megawatt lignite-fueled power plant located 50 miles northwest of Bismarck, North Dakota that has been in operation since 1980. CCS has consistently produced a high quality fly ash that has been demonstrated over the years to effectively enhance the performance of concrete. The use of the ash as a soil enhancement method had not been demonstrated. The Falkirk Mine (FALKIRK) supplies fuel for CCS and utilizes 160-ton haul trucks to move the lignite fuel to the plant. Poor soil conditions and road construction in regraded areas has been an area of concern and high costs for the mine.

The primary goal of this effort was to demonstrate the improved engineering performance and cost benefit of CCS fly ash in the construction of haulroad subgrade and subcut. CCS fly ash was used in conjunction with spoils and/or subsoil in haulroad subgrade and subcut construction at the site. A section of haulroad subgrade and subcut was constructed in May of 2000 using CCS fly ash blended with spoils and with subsoil while the remaining haulroad subgrade and subcut was constructed using conventional spoils and subsoil (unmodified soils). Construction techniques were the same for the entire haulroad subgrade and subcut placed and the haulroad was surfaced with gravel prior to use. This construction provided an excellent opportunity to monitor the performance of a fly ash enhanced haulroad subgrade and subcut and compare it to the performance of a conventional haulroad subgrade and subcut constructed at the same site with native soils.

Approach

Power Products Engineering (PPE) of Minneapolis, Minnesota and Midwest Testing (MT) of Bismarck, North Dakota were retained to assist in the development of CCS fly ash and soil blends for use in the construction and to monitor field demonstration. The project team worked closely with the North Dakota Department of Transportation (NDDOT), the Public Service Commission (PSC) and the North Dakota Department of Health (NDDOH) in all phases of the project.

Phase I of the project was initiated on August 18, 1999 and was completed with laboratory testing results exceeding the project expectations. This phase was initiated immediately after the project was approved for funding by both

the Lignite Energy Council (LEC) and the North Dakota Industrial Commission (NDIC).

Laboratory Testing

As of April 1, 2000, all of the laboratory strength testing had been completed on mixes containing 10%, 15%, 20%, and 25% CCS fly ash by dry weight and 10% portland cement. The laboratory testing was performed during October and November of 1999 at MT's Bismarck facility.

A summary of the laboratory results for 3-day and 28-day strengths can be found in tables 1 and 2 below. The original goal of the project was to achieve a minimum strength gain of 25% above the native soils, or a minimum of 150 psi. Overall, the strength gains achieved for the laboratory mixes far exceeded the expectations of the project team, thus verifying that CCS fly ash can be beneficial for soil enhancement.

Table 1. Sandy Lean Clay

Test Duration	% Fly Ash	Soil Strength (psi)	Optimum Moisture (%)	% Gain
3 Days	0	197	9.0	-
	15	219	10.1	11
	20	235	9.5	19
	25	232	8.6	18
28 Days	0	197	9.0	-
15		480	10.3	144
	20	537	11.8	173
25		447	10.7	127

Table 2. Fat Clay

Test Duration	% Fly Ash	Soil Strength (psi)	Optimum Moisture (%)	% Gain
3 Days	0	186	7.8	-
	15	209	10.9	12
	20	214	10.8	15
	25	219	10.8	18
28 Days	0	186	7.8	-
15		636	11.3	242
20		668	11.0	259
	25	605	10.7	225

Laboratory testing was completed on the 15% and 20% mixes to determine the California Bearing Ratio (CBR) values at points above and below optimum moisture. This CBR testing is a standard that is utilized by the NDDOT for determining adequate bearing capacity of road bases. The CBRs were run on samples that were 100% compacted per the modified proctor test at 7 days of curing and a 96-hour soak.

The NDDOT requested an additional set of tests be performed at a 10% fly ash replacement level. This set of tests was conducted and is for NDDOT information only. Tests were done on both the Sandy Lean Clay and the Fat Clay at -4% and -2% and optimum moistures for 3, 7, and 28-day cures.

Testing of a portland cement mix at a 15% replacement level also was performed as requested by the NDDOT. This testing was done in order to compare the fly ash performance to an equal replacement of portland cement on both the engineering level and the economic level. The resulting strengths are extremely high and demonstrate the overkill represented by using portland cement.

Field Demonstration

FALKIRK obtained bids from several contractors for field construction and ultimately chose Donn Brown Construction of Des Lacs, North Dakota as the general contractor. Jost Cement of Burlington, North Dakota was hired to load, haul, and place the fly ash for the project.

A project pre-construction participant meeting was held May 9, 2000 at the offices of The Falkirk Mining Company. Attending the meeting were representatives of Donn Brown Construction, Jost Cement, Great River Energy, Industrial Services Group, The Falkirk Mining Company, The Coteau Properties, and PPE, Inc. Discussions centered on the results of the laboratory testing completed to date, future testing needs, and the field-testing and placement program. These discussions encompassed both performance testing and environmental testing.

Field placement of the fly ash modified soils began on May 22, 2000 and was completed on May 31, 2000. The demonstration was performed on 1900 feet of haulroad, centerline stations 216+00 to 235+00, located in the Riverdale Mine area south and west of the FALKIRK office complex. A level of 15% fly ash addition was placed in each of the test sections. This level was determined to be the best for this application based on the requirements of the haulroad and the laboratory test results.

The amount of fly ash to be placed in each section was determined based upon a direct volume of soil to be placed in a given segment and the required number of cubic yards of fly ash to equal 15% of that soil volume. The compacted lift thickness was determined to be 6 inches and the weight of the dry fly ash was used to determine the number of loads to be placed in a lift based on a 25 ton load per truck. An example calculation is outlined below:

- Soil Volume in a Subgrade Segment = 500' x 70' x 4'/27 cubic feet per yard = 5186 yds^3
- Ash Volume = 15% of 5186 yds^3 = 778 yds^3
- Loads per Lift = (778 yds^3 x 27 ft^3/ yds^3 x 75lb/ ft^3)/2000lb/ton = 788 tons/segment. For an average load of 25 tons per truck and 8 lifts per segment, the loads per lift = 4.

Station 216+00 to 220+00 had sandy lean clay (mine subsoil) placed in a subgrade application; this application was shortened by 100 feet due to wet conditions caused by heavy rains over the weekend prior to placement. Station 220+00 to 225+00 had fat clay (mine spoils) placed in a subgrade application. Station 225+00 to 230+00 had fat clay (mine spoils) placed in a subcut application. Station 230+00 to 235+00 had sandy lean clay (mine subsoil) placed in a subcut application.

PPE and MT provided technical support during the time of the haulroad subgrade and subcut construction. Both firms were present on the construction site at the time of fly ash haulroad subgrade and subcut construction to offer technical advice and input to the FALKIRK construction crew.

Construction of the road was generally performed in the following steps:

- FALKIRK retained the services of Jost Cement to provide pneumatic tankers to haul fly ash from the CCS silo to the jobsite. FALKIRK, PPE, and Jost Cement worked with GRE and ISG to provide the appropriate amount of CCS fly ash to the site on a schedule determined by GRE, ISG, and FALKIRK.
- FALKIRK utilized two 657 tractor scrapers to place the soil on the roadbed. The soil was placed in loose lifts approximately 8 inches in depth. The material was obtained from stockpiles located south of the haulroad.
- Fly ash was transported from the CCS to the construction site in the pneumatic trucks and spread evenly over the loose material in four truck widths for the length of the test segment.
- The fly ash and soil was then mixed using a set of disks pulled by a tractor; due to the wetness of the existing subsoil and spoils, no water was added. It was found that the soils had approximately 22% moisture and after mixing with the fly ash the moisture was found to be reduced to between 10% to 12%.
- After the fly ash was thoroughly mixed with the soil, it was respread with a blade and compacted with a sheep's

foot roller. In some cases, the FALKIRK scrapers also were utilized for compaction. Final compaction at the end of each shift consisted of several passes with a rubber-tired roller to seal the surface.

- After each lift was placed, MT performed moisture and density tests and collected samples for laboratory testing.
- After compaction and testing, the process was repeated until the specified grades and slopes were obtained.

Testing of the fly ash haulroad subgrade and subcut was accomplished through field sampling and nuclear density testing of each lift performed by MT. Sampling consisted of performing field proctor tests on a daily basis and retaining these samples for laboratory testing at 7 and 28 days. Nuclear density and moisture tests were performed on each lift to determine the amount of compactive effort obtained. The field requirements were for 95% of modified proctor to be obtained.

A total of 95 field density and moisture tests were performed on the fly ash modified soil sections as well as the control sections. Of the 54 tests performed on the modified soils, 11 were below 95% compaction; however, all of the failed tests were determined to be at 90% of modified proctor and were accepted by FALKIRK as passing. Of the 31 tests performed on the unmodified soils, 4 failed to meet 95%, but were well above 90% and were accepted by FALKIRK as passing.

The NDDOT was on-site on June 13, 2000 to perform the falling weight deflectometer testing. The results of those tests could not be processed due to an equipment problem; a letter discussing the problem is included in Appendix I. The one-year tests, conducted in July 2001, were completed and are discussed later in this Final Report. Additionally, NDDOT personnel were on-site on May 31, 2000 to observe the placement of fly ash and to collect samples for testing in their laboratory.

One-Year Testing

A one-year evaluation was performed on the sections constructed in May 2001 to determine the long-term ability of the soils to stand up to haulroad traffic as well as the water monitoring reports. The Standard Penetration Tests results indicate no substantial change in the N values for the material. Tests were performed on May 23, 2001 at the same locations as the original tests of June 12, 2000. Table 3 outlines the results of the two sets of tests. In all but four of the test locations, the N values increased over the course of a year and numerous freeze-thaw cycles. This indicates the typical fly ash benefit of increased strength over time.

The NDDOT performed falling weight deflectometer testing on the haulroad in July of 2001. The general conclusions of the testing were that the fly ash in Application 1 enhanced the fly ash and soil mix, and Application 2 indicated that the fly ash soil mixture didn't perform as well as the control. The caveat here is that the equipment utilized by the NDDOT does not perform well on soils that are not underneath pavement sections. As the report states "Limited FWD test results appear to indicate that the use of fly ash as a stabilizing agent provides an increase in soil strength when incorporated in Application 1. Similar increases were not measured when fly ash was incorporated into Application 2; however, insufficient data prevents the formulation of final conclusions or recommendations."

Conclusions

The field test performed at FALKIRK was an overwhelming success. The results (1) of the construction and subsequent year of haul truck traffic and (2) the freeze-thaw cycles and testing all point to the fact that the road has not only performed well, but the test indicates an overall increase in the strength. Correlation to the laboratory test increases were difficult to measure in the field due to the type of testing required. However, the standard penetration test indicates a general improvement in the soils, which demonstrated the fact that the calculations for field placement of fly ash were accurate.

Table 3. Standard Penetration Test Results

Boring	Station	N- Values Test Interval: 0 to 1&1/2 Feet		N- Values Test Interval: 2 to 3&1/2 Feet	
		June 2000	May 2001	June 2000	May 2001
1	217+00	51	50	45	57
2	218+00	38	53	41	47
3	219+00	37	60	44	61
4	221+00	28	57	-	-
5	222+00	31	51	-	-
6	223+00	33	52	-	-
7	226+00	42	24	24	50
8	227+00	29	37	-	-
9	228+00	31	35	-	-
10	231+00	32	38	-	-
11	232+00	38	53	-	-
12	233+00	29	50	-	-
13	238+00	26	39	31	49
14	239+00	29	35	41	39
15	240+00	32	34	36	35

The benefits of using fly ash to stabilize the soils are seen in the reduced amount of rebuilding required and the improved performance. These are benefits that will add to the mine's ability to haul more coal with less damage to equipment. A side benefit to the direct economics is that the fly ash actually can be counted on to take a very wet soil and dry it enough to make it very usable. Finally, with regards to specific applications at FALKIRK and other mine mouth facilities where fly ash is available, the true costs for using fly ash are far lower. Typically, the power plants will have excess fly ash that is not being sold for beneficial use and, therefore, they will give this to their mining partners at little or no cost.

The recommendation of the project team is that there is a need to work with the NDDOH and the PSC to get rules and or guidelines in place for the use of fly ash at the mines. These rules and guidelines are vital to the continued use of fly ash to enhance the mining operations. With rules and guidelines, the mining facilities will be able to use fly ash in their day-to-day operations as a matter of standard practice.

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ENVIRONMENTAL TRACERS OF LEACHATE DERIVED FROM PRESSURIZED FLUIDIZED BED COMBUSTION BY-PRODUCTS IN AN ABANDONED COAL MINE SETTING

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Abstract

In 1994, an abandoned coal mine in east-central Ohio was reclaimed with 125 tons per acre of pressurized fluidized bed combustion (PFBC) by-product generated at an experimental coal-burning power plant in eastern Ohio. The dry PFBC by-product and 50 tons per acre of yard-waste compost were applied to the surface of a 7-acre area and disked into the spoil. Assessing and documenting the environmental effects of this and other coal combustion by-products (CCBs) is essential for regulatory agencies to approve CCB use in this setting. This is especially important with regards to trace elements including arsenic, selenium, and boron, which are found in elevated concentrations in many CCBs.

Properties and constituents of water derived from the PFBC by-product that may serve as environmental tracers include boron concentrations, magnesium-to-calcium (Mg:Ca) mole ratios, and sulfur-isotope ratios ($\delta^{34}S$). In this context, an environmental tracer is defined as any conservative constituent or characteristic of a sample that can be used to indicate that leachate has mixed with or influenced the chemistry of that sample. For example, boron was used as a tracer of PFBC by-product because it is present as an uncharged, and thus conservative, species (boric acid as H_3BO_3 or $B(OH)_{3(aq)}$). Boron was found in elevated concentrations (median of 690 µg/L) in interstitial-water samples from the PFBC by-product application area, but was found in significantly lower concentrations outside the application area (median of 70 µg/L). Similarly, Mg:Ca mole ratios and $\delta^{34}S$ of interstitial water from within the PFBC by-product application area were elevated as compared to those in interstitial-water samples from outside the application area. Because dolostone was used as the sorbent in the PFBC process, water samples that contain PFBC by-product leachate had Mg:Ca ratios greater than 1, whereas all other water samples had Mg:Ca ratios less than 1. Mixing diagrams that include sulfur-isotope ratios and other conservative tracers provide estimates of the relative contribution of sulfate derived from the PFBC by-product. Sulfur-isotope ratios of sulfate from the PFBC by-product (maximum of +4.8 per mil) and solid-phase sulfide in pyrite from the mine site (minimum of -26.3 per mil) were used as end members. The resulting mixing equation indicated that as much as 75 percent of the sulfate in interstitial waters was derived from the PFBC by-product. Similar mixing evaluations done for ground and surface waters indicated that only very small amounts, if any, of the dissolved sulfate was derived from the PFBC by-product. No deleterious concentrations of toxic trace elements from the PFBC by-product, including arsenic and selenium, were observed in any water samples obtained at the site.

Waters influenced by leachate from the PFBC by-product could be distinguished from other waters at the site because the feed coal and sorbent originated from a different mine (and different geologic environment) than the reclamation site. Thus, the isotope signatures and geochemistry of the PFBC by-product as compared to spoil and rocks found at the site were distinctly different. Monitoring at the study site concluded in September 2001, and no further monitoring is planned.

Introduction

Many abandoned coal mines in Ohio and throughout the Appalachian coal region are characterized by acid mine drainage (AMD). These mines typically are reclaimed with alkaline amendments such as crushed limestone or agricultural lime to raise the pH of soil so that vegetation can be reestablished (Barton, 1978). Abandoned mine sites also commonly have limited, if any, topsoil so amendments may be necessary to improve water-holding properties of the soil. Flue-gas desulfurization (FGD) by-products are desirable in this application because they are alkaline, they typically have high calcium-carbonate equivalents, and they may improve soil texture. However, before beneficial

uses of FGD by-products can be supported by regulatory agencies and the electric-power industry, environmental data must be collected to show potential influences on water quality in the environmental settings of interest. Specifically, questions remain regarding the transport and fate of major elements such as sulfur and trace elements such as arsenic, selenium, and boron that may be derived from the FGD by-product.

In late 1994, an abandoned surface coal mine in eastern Ohio (from hereon referred to as the Fleming site) was reclaimed with pressurized fluidized bed combustion (PFBC) by-product generated at American Electric Power's Tidd Plant in Brilliant, Ohio. Workers at The Ohio State University tested the mine spoil from the Fleming site and analyzed the PFBC by-product to determine that the mine spoil required approximately 125 tons per acre of PFBC by-product to attain a pH of 7 (Stehouwer and others, 1996). The PFBC by-product was applied to the surface and was disked into the spoil. Site instrumentation and monitoring of vadose-zone water (interstitial water), ground-water, and surface water from springs began soon after reclamation to determine the mobility and fate of elements derived from the PFBC by-product. This paper presents some of the constituents and properties of water that were used as environmental tracers to identify leachate derived from the PFBC by-product in an abandoned mine setting.

The Fleming site is located within the Pottsville and Allegheny system of Pennsylvanian-age sedimentary rocks of eastern Ohio. The Lower Kittanning (No. 5) coal was mined from the site by surface operations over a 20-year period approximately corresponding to 1950 through 1970. The mine site was abandoned after depletion of the coal and clay reserves in the early 1970s. Soon thereafter, local residents lodged complaints regarding flooding and sedimentation along a nearby road. Springs were discharging AMD with pH less than 4 and high concentrations of dissolved solids, including iron and sulfate. Reclamation of the site was completed in the late summer and fall of 1994 by regrading the spoil to the approximate pre-mining topographic contour and applying composted yard waste and PFBC by-product.

The site was instrumented after reclamation so that changes in water quality could be assessed through time. Soil-suction lysimeters were installed in the PFBC by-product application area and in a control area reclaimed by traditional methods (graded spoil covered with approximately one foot of topsoil). Attempts were made to extract interstitial water from all lysimeters during each sampling round; however, small sample yields resulted in insufficient sample volumes for some analyses. Water samples were collected from the lysimeters, monitoring wells, and springs in June 1995 (sampling round 1), January 1996 (round 2), June 1996 (round 3), June 1997 (round 4), June 1998 (round 5), June 2000 (round 6), and June 2001 (round 7).

Water samples were analyzed in the laboratory by methods described in Stehouwer and others (1996), Haefner (1998), and Dick and others (1999). The USGS National Water Quality Laboratory in Denver, Colorado and the Ohio Agricultural Research and Development Center laboratory in the Department of Natural Resources in Wooster, Ohio analyzed water samples for major and trace constituents. Water-quality constituents selected for analysis were based on known composition of PFBC by-product and acid mine drainage, and on anticipated water-rock interactions. The USGS Isotope Laboratory in Reston, Virginia analyzed water samples for sulfur-isotope ratios.

Results

The by-product was produced as the result of a PFBC process and is not strictly an FGD by-product. Chemical reactions in the FGD process are similar to the PFBC process; thus, the PFBC by-product is chemically and physically comparable to other FGD by-products. The solid-phase chemistry of the PFBC by-product is dominated by calcium, magnesium, sulfate, and aluminum (Table 1). The PFBC by-product also contains elevated levels of the trace elements arsenic, boron, barium, chromium, nickel, lead, and selenium. For comparison, Table 1 also includes maximum concentrations of trace elements in spoil and aquifer materials. These results indicate that, for many constituents, concentrations of elements can be higher in the mine spoil and aquifer materials than they are in the PFBC by-product. Only boron is found at greater concentrations in the PFBC by-product than in the spoil and aquifer materials. Additional descriptions of chemical and physical properties of PFBC by-products are reported in Stehouwer and others (1996), Haefner (1998), and Dick and others (1999).

Table 1. Solid-phase composition of PFBC by-product and mine spoil and aquifer materials from the Fleming abandoned mine site, Tuscarawas County, Ohio.

	PFBC By-product	Maximum concentration from mine spoil and aquifer materials
Major-oxide abundance (percent of total by weight)		
CaO	34	--
MgO	17	--
SO_4	16	--
Al_2O_3	14	--
H_2O[a]	10	--
FeO	6	--
K_2O	2	--
Trace-element concentration (parts per million)		
As	75	91
B	190	120[b]
BE	3	9
BA	150	730
Cd	<2	<2
Cr	37	210
Ni	23	100
Pb	15	110
Se	1.3	21.5
Sr	160	720

a. Water was added after the PFBC process to reduce fugitive dust.
b. Botomon and Stith (1978).

Haefner (1998) and Dick and others (1999) describe the properties and constituents that can be used to differentiate between water types found at the Fleming site. These include specific conductance, pH, selected major ions and trace elements (calcium, magnesium, sulfate, and boron), magnesium-to-calcium (Mg:Ca) mole ratios, and sulfur-isotope ratios. To illustrate these differences, bar graphs of median values of selected constituents in interstitial water are shown in Figure 1. The median pHs for all sampling rounds were at least one order of magnitude greater in application-area interstitial-water samples as compared to interstitial water from the control area. Median concentrations of elements such as boron and sulfate are greater in application-area interstitial waters than in control-area interstitial waters by more than a factor of two.

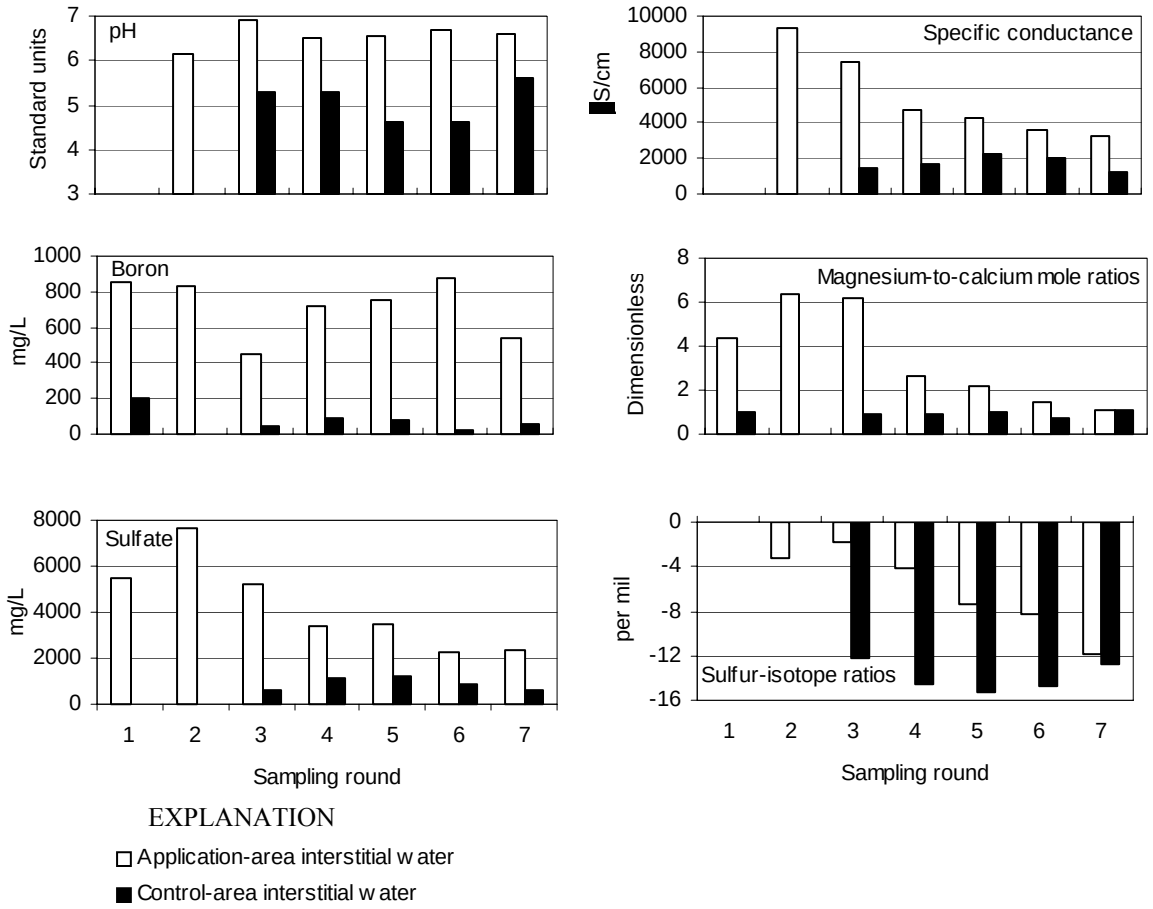

Figure 1. Bar graphs of median values for selected constituents from each sampling round from water samples collected at the Fleming abandoned mine site, Tuscarawas County, Ohio.

Boron (as H_3BO_3 or $B(OH)_{3(aq)}$) was used as an "environmental tracer" of PFBC by-product because it is present as an uncharged and conservative species. In this context, an environmental tracer is defined as any conservative constituent or characteristic of a water sample that indicates that leachate has mixed with or influenced the chemistry of that sample. Boron was present in elevated concentrations (median of 690 micrograms per liter) in interstitial-water samples from the PFBC by-product application area, but was found in much lower concentrations outside the application area (median of 70 micrograms per liter). Elevated concentrations of boron may be a concern because at higher concentrations, boron is known to be phytotoxic to some plants (Pierzinski and others, 1994); however, maximum concentrations of boron (1.7 milligrams per liter in a sample of application-area interstitial waters) did not approach phytotoxic levels at the rate applied in this study. Although not shown here, the median concentrations of chloride, fluoride, potassium, and strontium also were greater in the application area than in the control area. Elements that have lower median concentrations in the PFBC by-product application area included iron, nickel, and zinc, presumably because of pH dependence on the solubility of these elements and their related solid phases. Concentrations of arsenic and selenium were at or near the detection limit in all water samples (2 micrograms per liter).

A plot of sulfate concentrations as a function of magnesium-to-calcium (Mg:Ca) mole ratios shows distinction between waters influenced by PFBC by-product leachate and all other water samples (Figure 2). Elemental ratios are ideal for detecting the leachate because they are less influenced by precipitation or dilution. Samples of interstitial water from the application area have Mg:Ca ratios greater than 1, whereas all other water samples have ratios equal to or less than 1. Upgradient and downgradient groundwaters plot in different regions on Figure 2 mostly due to higher sulfate concentrations in downgradient groundwater; however, down-gradient groundwaters also have

slightly higher Mg:Ca mole ratios which may indicate that a small amount of leachate derived from the PFBC by-product has reached groundwater.

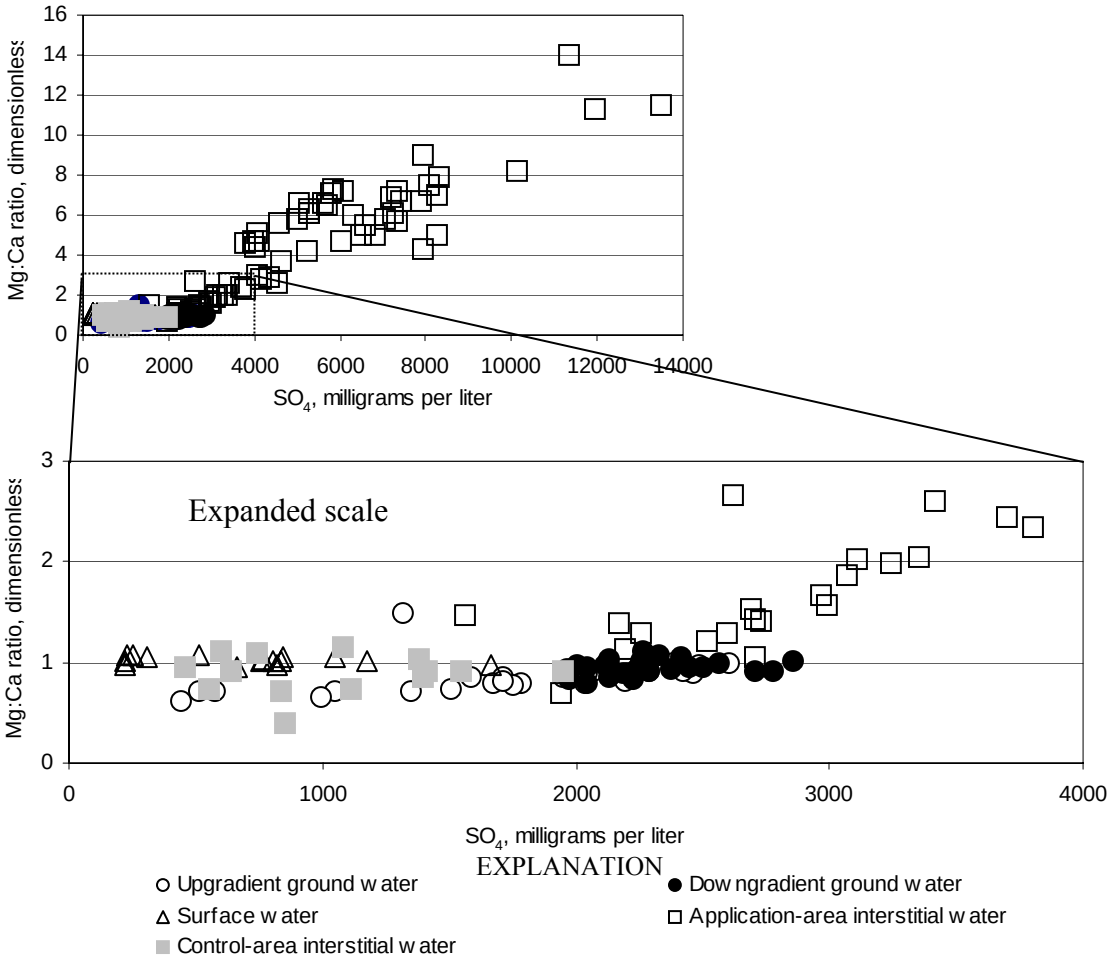

Figure 2. Magnesium-to-calcium mole ratios as a function of sulfate concentrations for water samples from the Fleming abandoned mine site, Tuscarawas County, Ohio.

Sulfur-isotope ratios ($\delta^{34}S$) were measured to determine whether they could be used as a tool to trace leachate derived from the PFBC by-product in an environment where water quality is already influenced by high sulfate concentrations. The sulfur-isotope composition of spoil and aquifer materials from the Fleming site is reported in Haefner (1998) and ranges from −26.3 to +13.6 per mil. The most negative values are associated with materials that have the highest sulfur content, thus the dominant source of sulfate at the mine site has relatively depleted sulfur-isotope ratios (Haefner, 2001). For coal sequences, bacterial reduction of sulfate in seawater during deposition results in coal seams with sulfide that have isotope ratios ranging from −30 to +20 per mil (Thode and others, 1949). This wide range of sulfur-isotope ratios is most likely due to infiltration of sulfate from seawater or non-marine water. Sulfur-isotope ratios also were measured in the PFBC by-product and ranged from +4.6 to +4.8 per mil.

The median sulfur-isotope ratio in dissolved sulfate for all water samples from the application-area interstitial waters was −4.1 per mil; whereas the median for control-area interstitial waters was −14.5 per mil. The relatively higher sulfur-isotope ratios in application-area interstitial waters reflect the influence of the positive ratio of the PFBC by-product. Sulfur-isotope ratios of sulfate in surface water are essentially the same as down-gradient groundwater and reflect the relatively negative isotopic composition of aquifer materials and spoils. The median values in interstitial waters for each sampling round shows that the sulfur-isotope ratios increase between sampling rounds 2 and 3, but decrease between all subsequent sampling rounds (Figure 1). Sulfur-isotope ratios in groundwater (not shown here) show a continuing decreasing trend over all seven sampling rounds, indicating that the source of the sulfate in

groundwater is likely from the disturbance of the mine spoil during reclamation, not the PFBC by-product. If the source of increased sulfate were the addition of PFBC by-product, the sulfur-isotope ratio should increase (become less negative).

A plot of the inverse of sulfate with respect to sulfur-isotope ratios also shows a clear distinction between water samples influenced by PFBC by-product leachate and those that were not (Figure 3). These relations were used in an isotope-mixing model reported in Haefner (2001). Using the positive value of the PFBC by-product (+4.8 per mil) as one end member of mixing and the most negative value from pyrite obtained from the mine spoil and aquifer materials (-26.3 per mil) as the other end-member of mixing, the mixing model provided estimates that up to 75 percent of the sulfate in application-area interstitial waters was derived from the PFBC by-product leachate during round 3 (June 1996). The contribution of sulfate from the PFBC by-product has decreased since round 3 to a median value of slightly greater than 20 percent in round 7 (June 2001). Similar mixing evaluations done for ground and surface waters indicated that only very small amounts of the dissolved sulfate was derived from the PFBC by-product.

These results indicate that little, if any, leachate from the PFBC by-product has reached groundwater or down-gradient springs. The primary reason that these graphical techniques allow clear distinction between the water types at the Fleming site is that the coal burned (Pittsburgh No. 8) and the sorbent used (dolomite from northwest Ohio) in the PFBC process were from different formations than those at the Fleming site. These methods may not prove as successful in haulback situations, where coal and (or) the sorbent was retrieved from the same mine where the by-product is placed.

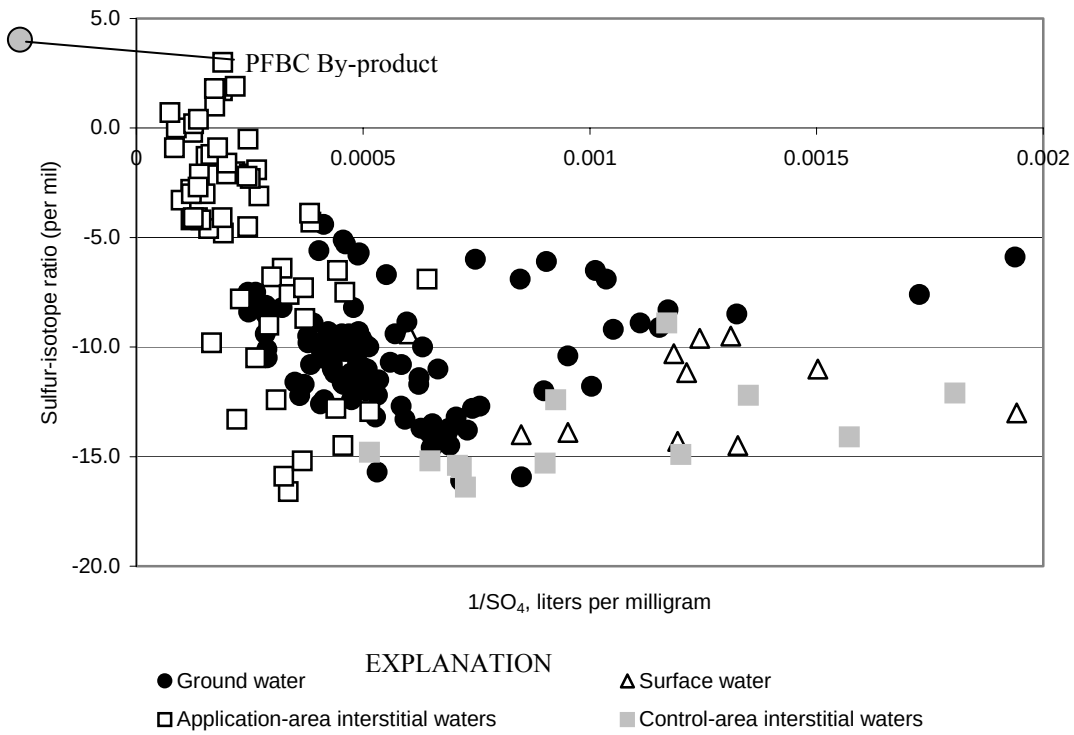

Figure 3. Sulfur-isotope ratios from water samples from the Fleming abandoned mine site, Tuscarawas County, Ohio.

Summary and Conclusions

A seven-acre abandoned mine site (the Fleming site) in eastern Ohio was reclaimed with 125 tons per acre of pressurized fluidized bed combustion (PFBC) by-product and 50 tons per acre of yard-waste compost. The hydrology and water quality at the site was studied over a 7-year period to determine the environmental effects of reclamation with this material. The two main processes of interest in this study were (1) dissolution and leaching of PFBC by-products applied to the surface of the study area, and (2) the generation of acid mine drainage (AMD) in spoil left at the surface of the site after mining ceased. Addition of alkaline PFBC by-product was intended to increase pH, thereby reducing the solubility of major and trace elements.

Water quality in application-area interstitial waters clearly showed the influence of leachate derived from the PFBC by-product. Application-area interstitial waters had elevated pH and specific conductance along with higher concentrations of boron, calcium, chloride, fluoride, magnesium, potassium, strontium, and sulfate as compared to water samples taken in a control area where traditional reclamation strategies were employed. Of these elements, only boron presents potential difficulties because boron is known to be phytotoxic at higher concentrations and one of the goals of abandoned mine reclamation is reestablishment of vegetation. Analysis of magnesium-to-calcium mole ratios of water samples provided evidence that interstitial waters from the PFBC by-product application area had higher Mg:Ca ratios than all other waters at the mine site. Sulfur-isotope ratios also showed the influence of PFBC by-product leachate because sulfate derived from the PFBC by-product had relatively positive isotope ratios as compared to spoil and aquifer materials. Increases in pH appear to have reduced the solubility of some elements, thus the median concentrations from application-area interstitial waters were lower for iron, nickel, and zinc than in the control area. These graphical techniques were successful with Fleming site waters because the coal and sorbent used in the PFBC process were from different formations than those at the Fleming site and thus had different geochemical signatures.

Reclamation of the site was successful in that vegetation was reestablished and erosion was reduced. It also was successful in the sense that water quality in the PFBC by-product application area shows higher pH and reduced concentrations of dissolved iron, nickel, and zinc. Except for potentially phytotoxic concentrations of boron, concentrations of elements of concern were only detected at or near the detection limits.

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QA/QC AND VARIABILITY OF CCBS RELATING TO MINE APPLICATONS

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Abstract

Coal combustion products (CCPs), namely, fly ash, bottom ash, and flue gas desulfurization materials, continue to be used in increasing amounts in construction and mining applications such as cementing, grouting and concrete applications, road base construction, soil amendments, backfills, soil cements, solidification and stabilization processes, and controlled low strength material fills. Depending on the specific application, the role of CCPs in a material mix design can vary from that of an economical extender to an active, and essential, key component. The performance of a CCP in many applications will be a direct function of the chemical and physical properties of the CCP itself. For instance, the chemical properties of fly ash are a determining factor when judging its suitability for use in cementing and concrete applications, while physical properties such as granulometry, bulk density, and compacted density can be critical for grouts, fills, and base products. The physico-chemical properties of coal combustion products are a derivative of fuel chemistry and the processing and combustion regimes used during firing. This presentation will briefly describe various CCPs and identify common characteristics that can be used as general indicators of product consistency. Typical relationships between chemical and physical parameters will be highlighted, as well as trend lines and measures of variability in chemical and physical properties. Potential ramifications due to shifts in utility operating programs will be noted. A number of examples will be provided demonstrating measures developed to establish the appropriateness of a particular CCP for specialized applications, with emphasis placed on measuring the correct parameter for a given use. Quality control and quality assurance schemes and protocols common to the industry also will be briefly outlined.

Introduction

Coal combustion products, namely, fly ash, bottom ash, and flue gas desulfurization materials, continue to be used in increasing amounts in construction and mining applications such as cementing, grouting and concrete applications, road base construction, soil amendments, backfills, soil cements, solidification and stabilization processes, and controlled low strength material fills. Depending on the specific application, the role of coal combustion products (CCPs) in a material design can vary from that of an economical extender to an active, and essential, key component. The performance of a coal combustion product in many applications will be a direct function of the chemical and physical properties of the CCP itself. For instance, the chemical properties of fly ash are a determining factor when judging its suitability for use in cementing and concrete applications, while physical properties such as granulometry, bulk density, and compacted density can be critical for grouts, fills, and base products. The physico-chemical properties of coal combustion products are a derivative of fuel chemistry and the processing and combustion regimes used during firing.

Fly Ash

Fly ash is produced as a by-product of burning coals that have been crushed and ground to a fineness of 70 to 80 percent passing a 75-mm (No. 200) sieve. After combustion, much of the noncombustible, inorganic components residing in coal condense in the exhaust gas stream as tiny, glassy spheres. These mostly alumino-silicate spheres will range from several hundred microns in diameter to sub-micron size.

Fly ash is the most widely utilized coal combustion product. The American Coal Ash Association (ACAA-2000) estimates that more than 20,000,000 of the 63,000,000 tons (31%) of fly ash produced annually are effectively utilized. The primary application for fly ash (more than 60 percent of the material used) is as a replacement or addition to cement in concrete and related applications. The National Ready Mix Association (Oct. 2000) estimated

that just over 50 percent of all ready mix concrete contained fly ash. Concretes made with fly ash used on average a cement replacement rate of 18-19 percent. The success of fly ash in areas of cement and concrete can not be explained by assuming that fly ash is used simply as a nonfunctional filler material. Rather the successful penetration of fly ash in these markets is attributable to the many benefits offered by its use. Improved workability, increased ultimate strengths, and enhanced durability are properties offered by fly ash that can not always be achieved by using cement alone.

These attributes are a direct consequence of the physico-chemical properties of fly ash. The alumino-silicate glass in fly ash will undergo dissolution and limited solubilization in a high pH environment, such as exist in a portland cement-based concrete pore solution. Silica and to a lesser extent alumina anions released from the ash will interact with calcium made available from cement to precipitate and polymerize forming calcium silicate gel (CSH). (Note that in the absence of high pH activators such as calcium and alkali hydroxides provided by cement, fly ash will not provide any strength development). This gel will be very similar in composition and structure to the CSH formed by the hydration of portland cement itself. Calcium silicate gel is essentially the "glue" that binds the aggregate together in concrete and is responsible for concrete setting and strength gain. The fly ash reaction, termed pozzolanic reaction after a location in Italy known for providing natural volcanic pozzolans, consumes calcium hydroxide (a cement reaction by-product) to produce additional binding CSH gel. When the calcium hydroxide, which is susceptible to attack by some aggressive agents, is removed and more CSH gel is created, a less permeable and potentially stronger concrete is made. This concrete will be better able to withstand attack by aggressive agents such as sulfates, alkalis, chloride ingress, and penetration of water.

In recognition of the widespread use of fly ash in cementitious applications, the American Standards Testing Materials Association (ASTM) developed standards specifically addressing coal fly ash for use as a concrete admixture. The specification was first introduced in the 1950s and has since undergone a number of modifications to reflect changes in both testing methods and the types of available fly ash. The current designation for the specification is *ASTM C 618-00 – Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete*. This specification provides chemical, physical, and performance criteria for coal fly ash use in concrete. This specification references *ASTM C 311-00 -Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete* for guidance on sampling and testing methods.

ASTM C 618 recognizes two distinct coal fly ashes: Class F and Class C. These fly ashes are distinguished by differences in chemical requirements as seen in Table 1. The distinction provided by ASTM is related only to the sum of the oxides: SiO_2, Al_2O_3, and Fe_2O_3. In practice, the reduced sum of the oxides presented by Class C fly ash are directly proportional to an increase in calcium content reported as CaO, and sometimes an associated increase in magnesium reported as MgO. This can easily be discerned from a comparison of the chemistry of typical fly ashes provided in Table 2.

Fly ash chemistry is a direct consequence of the residual constituents of the combusted coal. Subbituminous coals will typically produce high-CaO, Class C fly ash while bituminous coals produce low-CaO, Class F fly ash. Lower rank coals such as lignite tend to produce fly ash with chemistry intermediate to the two classes and may be classified as either Class C or F depending on performance. These differences in elemental composition obviously influence both the mineralogy and the glass composition of the fly ash. Class F fly ash tends to contain a small proportion of non-reactive crystalline materials such as quartz and mullite. This ash will contain a relatively well ordered glass component that will vary in concentration based on coal chemistry and combustion conditions. A high proportion of glass is associated with increased reactivity.

The presence of higher concentrations of calcium leads to the formation of additional crystalline compounds in Class C fly ash. A number of these compounds such as tricalcium aluminate, dicalcium silicate, and anhydrite are cementitious in their own right and are, in fact, found in cement. The glass phase of Class C fly ash is also more highly substituted and thus reactive. These differences result in Class C fly ash possessing both pozzolanic and cementitious properties. This ash will react with water without an activator to undergo setting and limited strength development. Class C fly ash will typically generate more heat and more strength in concrete at a given dosage level than Class F fly ash; however, the concrete's resistance to attack by aggressive agents such as sulfates or alkalis may be compromised. In the case of sulfate attack, the reduced durability is due to the susceptibility of the Class C fly ash itself to sulfate attack.

The topo-chemical nature of the fly ash hydration process suggests that reactivity is determined not only by chemical composition, but also by available surface area as well. As such, maximum particle size and, more specifically, particle size distribution (which controls surface area) are critical to performance. Particle size distribution not only influences reactivity but impacts rheological performance of materials like grouts. Fly ash fineness and particle size distribution are influenced by both fuel source and processing (i.e., coal grinding). In addition to a limit on maximum allowed particle size (fineness), ASTM C 618 specifies other physical testing such as loss on ignition (a measure of residual carbon) and specific gravity.

Performance testing such as the strength activity index, which compares the compressive strength of control mortar cubes to mixes made by partially replacing cement with fly ash, is used (in addition to other performance tests) to benchmark both performance and consistency.

ASTM C 618 is designed to identify important differences in fly ash that have been determined critical for concrete applications by relying on a combination of chemical and performance testing. The specification further offers simple, rapid testing (LOI, SG, Fineness) to provide a measure of product uniformity and for identification of changes in fuel, combustion, or processing that can impact quality. Physical testing of grab samples must be conducted daily on each 400 tons of fly ash produced, while chemical and performance testing is conducted on composite samples monthly or every 3,200 ton production basis.

The typical fly ash quality program will incorporate the testing philosophy proposed by ASTM C 618. Quality control at an established facility will consist of rapid uniformity testing (fineness, LOI, etc.) of production site samples allowing for go/no-go decisions on material acceptance or beneficiation (air classification, selective collection, blending) prior to acceptance for storage. Tests such as LOI and fineness are quite sensitive to changes in fuel feed or plant processing and are used to trigger more detailed investigations. Dispatched loads will be sampled and tested on a frequency consistent with ASTM as a minimum requirement. Chemical and performance testing generally will be conducted on a less frequent basis, again in accordance with ASTM C 618 stipulations. The chemical testing is used to detect any major changes in composition that could result in modifications in fly ash performance. Generally chemistry will be quite consistent unless a dramatic change is made in fuel chemistry or some alternative material is added into the combustion system, e.g., sodium carbonate for precipitator enhancement. Performance testing will identify changes related both to compositional and physical changes in the fly ash, e.g., coarsening of fly ash will result in lower strength activity index values. More aggressive sampling and testing intervals are often mandated depending on product consistency and performance demands.

Additional testing outside the scope of ASTM may be employed at specific sites or for certain applications that have unique requirements. Examples of such testing are foam index testing for air entrainment issues; particles size distribution or Blaine fineness as a measure of reactivity or rheological performance; free lime content for heat development and reactivity, pH and buffering capacity, and total or leachable metal concentrations. These types of tests are initiated due to the specific requirements of a particular application.

The simplicity of the quality program based on ASTM C 618 specifications and the testing procedures of ASTM C 311 warrants some discussion. It should be emphasized that this system has been determined adequate for monitoring <u>coal</u> fly ash for use in concrete and was developed over an extensive time period. Ash sources other than coal fly ash may be suitable for concrete application, but the existing testing scheme is not necessarily sufficient to make that determination. In the case of alternative materials or applications such as grouts, fills, mineral filler, stabilization, etc., the typical fly ash quality system will provide notification of any disruption in ash production that could signify a change in material characteristics. However, depending on the performance demands of a product for its intended final use, standard quality programs may not be monitoring all pertinent parameters. In these cases, consideration should be given to the material demands for a specific job and suitable quality measures should be instituted on agreement between the supplier and customer. An example would be the routine measure of fly ash pH and periodic TCLP testing for fly ash used in stabilization projects or general geotechnical performance data.

Guidance and recommended testing methods for specific fly ash properties can be found in other ASTM specifications such as *ASTM D 5759-95 - Characterization of Coal Fly Ash and Clean Coal Combustion Fly Ash for Potential Use; ASTM E 1861-97 - Use of Coal Combustion By-Products in Structural Fills;* and *ASTM E 2060 – Use*

of Coal Combustion Products for Solidification/Stabilization of Inorganic Wastes. More specialized testing techniques also may be developed for the particular needs of individual projects.

Bottom Ash and Flue Gas Desulfurization Materials

Bottom ash represents the agglomerated ash particles formed in pulverized coal boilers that are too large to be carried in the flue gases and impinge on the boiler walls or fall through open grates to ash hoppers at the bottom of the boiler. These materials may be accompanied by boiler slag that is a glassy slag material sometimes distinguished from bottom ash. The chemical composition of these materials will be similar to fly ash. If one combines bottom ash and boiler slag into one category, the ACCA reports that approximately 7,000,000 tons of the 20,000,000 tons of bottom ash and boiler slag produced per annum are utilized.

Bottom ash can range in appearance from an almost glassy to a more textured visceral product. Particle sizes can range from quite coarse (3/8 plus) to that of fine sand. The material typically has a lower bulk density than similarly graded coarse-grained soils and will place and compact in a manner similar to non-cohesive coarse soils or fine aggregate. This material has found use as an aggregate in masonry applications and road base and stabilization work. Grinding and grading can produce specific gradations.

There are no specific ASTM specifications that apply to the production of bottom ash. In practice, specifications are typically formulated around the performance demands of a specific project. Common quality measures include: gradation, chemical composition, pyrite content, bulk density, specific gravity and hardness or friability. It should be stressed that the performance of these products can be generalized, but materials may vary from source to source. Full characterization of products should be established during a complete material evaluation process. When CCBs are to be used in a designed system such as a structural fill, sufficient design and testing should be conducted to ensure performance and appropriate quality. The program should be arranged to reflect the material properties required for the specific project. Broad guidance can be found in the previously referenced ASTM specifications: E 1861 and E2060.

Flue gas desulfurization (FGD) materials consist primarily of calcium sulfate dihydrate or calcium sulfite hemihydrate, although fly ash may be commingled depending on plant processing schemes. The sulfate form has found use in applications that commonly employ gypsum such as wallboard and cement manufacture. In these applications important criteria include: purity, crystalline particle size, speciation, specific impurities, and moisture levels. FGD materials also have been used as soil amendments and in stabilization and fill operations. In these cases, consideration must be given to the localized environment where the products will be used. Once sufficient testing is conducted to ensure that these materials are suitable for a given application, an appropriate quality program can be instituted.

Conclusion

The quality programs based on ASTM C 618 and C 311 effectively allow for determining the suitability of coal fly ash for concrete and cementing applications. Programs based on these criteria are also responsive to changes in fuel and combustion or processing schemes that might influence chemical or physical characteristics of fly ash not specifically monitored under current specification guidelines. The quality of coal fly ash for use in alternative applications, or the utilization of other combustion products, is best monitored by a combination of sampling and testing procedures based on ASTM C 618 and other referenced specifications and by developing relevant testing protocols based on the particular performance demands of the application.

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numerous conferences. He holds a B. S. in Chemistry from the University of East Texas and a PhD in Analytical Chemistry from the University of North Texas. His university research focused on the hydration of fly ash and the impact that various inorganic materials had on these reactions.

Table 1. ASTM C 618 Requirements.

CHEMICAL REQUIREMENTS	F	C
Silicon Dioxide (SiO_2) plus Aluminum Oxide ($A1_2O_2$), min %	70.0	50.0
Sulfur Trioxide (SO_3) max %	5.0	5.0
Moisture Content, max %	3.0	3.0
Loss on Ignition, max %	6.0	6.0
SUPPLEMENTARY OPTIONAL CHEMICAL REQUIREMENTS	**F**	**C**
Available alkalis, as equivalent as Na2O, max %	1.5	1.5
PHYSICAL REQUIREMENTS	**F**	**C**
Fineness		
Amount retained when wet-sieved on 45um (No. 325), sieve, max %	34	34
Strength Activity Index		
With portland cement, @ 7 days, min percent of control	75	75
With portland cement, @ 28 days, min percent of control	75	75
Water requirement, max percent of control:	105	105
Soundness:		
Autoclave expansion or contraction max %	0.8	0.8
Uniformity requirements:		
The density and fineness of individual samples shall not vary from the average established by the 10 preceding tests if the number is less than 10, by more than:		
Density, max variation from average %	5	5
Percent retained on 45 um (No. 325) max variation, percentage points from average	5	5

Table 2. Chemistry of Various Fly Ash Types.

	Bit. Class F	**Lignite Class F**	**Sub. Class F**	**Portland Cement**
Silicon Dioxide (SiO_2) 55.2		55	35	22
Aluminum Oxide (Al_2O_3)	28.6	23	20	4
Iron Oxide (Fe_2O_3)	6.9	4	6	3
Sum of Oxides	**90.7**	**82**	**61**	**29**
Calcium Oxide (CaO)	1.7	10	28	66
Magnesium Oxide (MgO)	0.8	2	5	1
Sulfur Trioxide	0.1	0.3	1.5	2.7
Loss on Ignition (LOI)	4.2	0.2	0.2	0.9

Session 3

Western Mining: Applications/Case Studies

Session Chairperson:
Joe Galetovic
Office of Surface Mining
Denver, Colorado

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ASHES TO ASHES:
RETURNING CCBs TO THE GROUND AT NAVAJO MINE

Andy Young
BHP Billiton, Navajo Mine
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Abstract

Navajo and San Juan mines in northwest New Mexico use ash (CCBs) from two mine-mouth generating stations as a backfill material (mine fill) to achieve an approximate original contour. Approximately 4 million tons annually of ash is placed in mined out pits and ramps at the two mines. Placement of ash is governed by a detailed ash disposal plan developed and approved by OSM (Navajo) and the State of New Mexico (San Juan) that describes performance standards for the use of ash as mine backfill.

The performance standards require physically characterizing the ash, covering the ash with spoil, avoidance of burying of ash beneath large drainages, and reclaiming the area. The precautionary measures will prevent the ash from being exposed on the ground and will prevent plant roots and surface water from directly coming into contact with the buried ash. Due to the arid environment of Northwest New Mexico and the absence of any significant bedrock groundwater, future ash placement will be in dry pits and ramps.

Environmental studies of mine areas containing historically buried ash substantiate that no harmful effects are occurring. The studies include:

- vegetation monitoring above buried ash,
- rooting depth measurements,
- analyses of blood samples drawn from cattle grazing above buried ash,
- laboratory characterization,
- leachate simulation, and
- surface and groundwater monitoring.

In particular, Navajo Mine monitors a suite of wells in a historic saturated ash disposal area that has become saturated due to adjacent agricultural activities.

Ash placed as mine backfill at Navajo and San Juan mines is not only environmentally safe, due to the substantial natural protection offered by the mine pits, but in lieu of other beneficial uses is a sound long-term solution for ash disposal.

Introduction

Navajo Mine is a large surface coal mine located in northwest New Mexico. The mine supplies 8.5 million tons of coal to the Four Corners Generating Station, a 2,040-megawatt power plant. Navajo Mine hauls back and disposes of approximately 1.6 million tons per year of ash from the power station into old pits and ramps.

To fulfill regulatory requirements, Navajo Mine submitted to OSM an ash disposal plan and permit revision, requesting approval for the beneficial use of ash as backfill on Permanent Program Lands. The revision was approved in the spring of 2000.

The detailed plan includes:

- descriptions of the physical and chemical properties of the ash,
- the proposed disposal locations,
- volumes and rates of disposal,
- an estimate of the final surface configuration,
- schedule,

- type and depth of cover,
- fugitive dust control plan, and
- the probable hydrologic consequences (PHC) resulting from the use of ash as backfill on permanent lands.

The description within the PHC details the hydrogeological reasons why ash buried beneath Permanent Program Lands will likely remain permanently dry and is summarized below. Primarily, this is due to natural barriers, low precipitation, a lack of saturated bedrock units, and engineered controls that will minimize contact of groundwater with ash that is used as backfill at Navajo Mine. Consequently, ash disposed of as mine backfill at Navajo Mine is not only environmentally safe due to the substantial natural protection offered by the pits, but is the best long-term solution for ash in the absence of other beneficial uses for ash.

General Comments on Natural Barriers and Engineering Controls

All areas slated for future ash disposal share the following engineering or regulatory controls:

- Ash is generally placed only in inactive pits that have been completely mined out. A 'typical' ash disposal area (figures 1 and 2) is trapezoidal in cross-section, with the top width averaging 400 feet, the bottom width 150 feet, and a depth of up to 120 feet. The length of the disposal area is a function of the pit length and disposal volumes. This arrangement results in the ash being restricted to relatively small areas within the mine. This facilitates long-term solutions to reclamation design and planning issues associated with minimizing potential exposures to the ash.
- Ash must be covered by a minimum of 10 feet of spoil material (Figure 3), plus any required spoil mitigation material, plus the required topsoil thickness. Average ash cover depth is on the order of 12 feet.
- The AOC (approximate original contours, the reclaimed lands configuration) surrounding all ash disposal areas is designed to have positive drainage away from the ash and avoid any puddling or other collection of water above or adjacent to disposal areas.
- All post-mining drainages that intersect an ash disposal area must flow across the ash disposal area at approximately right angles to the long axis of the disposal site to minimize potential infiltration of surface waters into the ash.
- Pit-run spoil has a low permeability of 10^{-6} cm/sec (four samples that range from 1.66×10^{-6} to 5.4×10^{-6} cm/sec), which will minimize vertical infiltration of surface water. Flow data collected for the Chinde Wash Gain/Loss Study (Navajo Mine Permit Application Package NM0003E, OSM) record that there are no losses of surface water where the temporary diversion flows across regraded spoil for approximately 4,770 feet.
- Active ash disposal areas must regularly be plated (with spoil material) to cover the surface and minimize fugitive dust.
- Ash disposal areas will be revegetated to support the post-mine land use of grazing and have been very successful as demonstrated with the lands previously used for ash disposal. Recently, these areas have met revegetation success criteria to qualify for an OSM Termination of Jurisdiction. The studies included determination of an appropriate thickness of cover (spoil) (Palmer, 1986; Stutz and Buchanan, 1987) over the ash to prevent plant roots from contacting the CCBs and sampling of plant tissue (Palmer, 1986) that determined metals were not concentrating in vegetation.
- Disturbed areas are bonded for 10 years after final seeding.

Another favorable condition for ash disposal in pits is the geology of Navajo Mine pits that are slated for ash disposal. After mining is completed, the pit floor will be on the top of a low-permeable (10^{-7} cm/sec, comparable to many commercial grade liners) shale/mudstone parting. The surrounding spoils will be a mixture of sandstones, mudstones, and shales. The permeability of these materials is in the 10^{-6} cm/sec range.

North and South Barber Pits

North and South Barber pits will terminate against a highwall of intact low permeability rock with the pit floor lying on shales and mudstones. The upper portion of the highwall is comprised of the Kirtland Shale. The USGS (1971) describes the lower shale member of the Kirtland Shale as "greenish-gray silty and sandy mudstone. Sparse thin sandstone beds occur locally. Mudstone contains some swelling clays. Forms badlands..." The Fruitland–Kirtland contact is gradual, thus much of the upper portion of the Fruitland Formation is also comprised of silty and sandy

mudstones.

The overburden and coal dip at 2 to 3 percent slope to the southeast. The spoil banks (mined material) are in effect upslope from the advancing pit floors and highwalls. Thus the final pit floor will be at a much lower elevation than ramps or previously mined areas. The geologic setting and permeability characteristics of the strata and spoil will effectively seal the ash from exposure to surface or groundwater.

There are currently no significant sources of surface or groundwater inflow to the Barber, Pinto, or Hosteen pits, and the pits are predicted to remain dry following mining. Although monitoring wells completed in the coal seams contain water east of the highwall, no seeps have developed along the highwalls within the coal or overburden units. Pre-mine water level data from the coal seams record that the seams were dry (unsaturated) in the majority of the lease, particularly Barber (well KF83-7), Pinto, and Doby (KF83-3) pits, except for a few localized areas in Area III (Lowe/Dixon pits).

Groundwater movement within these seams, determined from aquifer tests, even under worst-case conditions, is no greater than 2.68×10^{-5} cm/sec (Navajo Mine Permit Application Package NM0003E (OSM)). Future movement of water toward the pit will be limited because the yield is very low and the storage of water within the coal seams is also low.

There are several drainage channels planned in the AOC that will flow across the disposal area. These are in the Barber ramp 2, ramp 3, and ramp 5 areas and drain watersheds larger than 640 acres in size. As described above, these channels are designed to flow at right angles to the long axis (pit) of the ash disposal area.

During 1999 and the first quarter of 2000, Navajo Mine completed a gain/loss study along Chinde Wash to determine if water losses were occurring along the temporary diversion. Four quarters of synoptic flow measurements were taken from the Chinde Wash temporary diversion above and below where it flows along regraded spoil. The flow measurements record no loss of flow across regraded spoil and demonstrate the low permeability of the unconsolidated spoil material at Navajo Mine. The study confirms that drainages that cross buried ash will not lose appreciable amounts of water due to the low permeability (10^{-6} cm/s) and short distance in which flowing water would be above buried ash (Navajo Mine Permit Application Package NM0003E (OSM)).

Spoil/Ash Total Metal Concentrations

Parameter concentrations (mg/kg) of a solid matrix of CCB and of spoil disposed of at Navajo Mine are presented in Table 1. The only notable parameter differences with the spoil are that fly ash has elevated concentrations of barium, and slightly higher concentrations of selenium and chromium. Although not listed, concentrations of boron also are slightly higher. For the remainder of the trace metals, the concentrations of spoil, fly ash, and bottom ash are similar or less. Both bottom ash and fly ash have lower concentrations of sulfate, sodium, and calcium when compared to spoil.

Groundwater and Leachate Studies

The probable hydrologic consequences resulting from pit disposal of CCB at Navajo Mine is no degradation in the quality or quantity of post-mine groundwater. This probable consequence of CCB disposal is the result of review and analysis of data collected from Navajo Mine. The data reviewed includes results of laboratory analysis on parameter concentrations of the ash, leachate tests, water quality and quantity data from Navajo Mine ash and coal wells, and aquifer transmissivity tests.

Bitsui Area

Intensely irrigated agricultural fields immediately to the east of Bitsui have caused portions of backfilled and reclaimed pits in Bitsui to become saturated. Shallow groundwater has accumulated in Aeolian (wind blown) sand units south and east of the Bitsui area and is perched on top of the low permeability shale and mudstone units of the Fruitland Formation. The non-natural saturation measured in the reclaimed area results from excess irrigation water

migrating down gradient from the agricultural fields and toward the backfilled pit. Regional shallow groundwater gradients (Keller-Bliesner, 1997) in the sand unit indicate that the groundwater contained in the Aeolian sand will discharge to Bitsui Wash.

The Bitsui area was mined between 1964-1965 and was backfilled in the mid-1970s. Some of the backfill in this area consisted of ash from the Four Corners Generating Station. Navajo Agricultural Products Industry (NAPI) activity began in the early 1980s. Navajo Mine has been monitoring groundwater levels and quality in the Bitsui area since 1995. A total of seven wells monitor spoil, ash, and the No. 8 coal seam within the immediate Bitsui area (Figure 4). Additionally, water levels and chemistry data are collected from No. 8 coal seam well KF84-16 that is 1,400 feet to the east of the Bitsui area.

Monitoring of static water level (SWL) (Figure 4) in the No. 8 seam coal in the Bitsui area began in 1985 in wells KF83-1 and KF84-16. Over an 11-year period from 1985 to 1996, SWLs in the No. 8 coal seam rose 11 feet in well KF83-1 to the southeast and 6 feet in well KF84-16, further to the east. SWL in both wells appear to have reached an equilibrium stage with relatively little change in SWL since 1996.

No. 8 coal seam wells Bitsui-2 and Bitsui-3 are located in the former highwall adjacent to the mined out area and have been monitored since 1995. SWLs from these two wells record a pattern of initial recharge followed by a period of steady state that is similar to wells KF-84-16 and KF83-1.

The cumulative effect of the return flows from irrigation has produced perennial surface water flows in Bitsui Wash and a large perennial pond upslope of the mined out area. These perennial sources of water at a higher elevation than the former Bitsui pit would have sufficient volume of flow, given enough time, to migrate down slope and saturate the Bitsui mined out area. The likely sequence is that soon after NAPI began irrigating, return flows began accumulating in the mined out areas until a steady state condition developed.

Leachate Study

Concentrations in the surface water leachate for boron and selenium slightly increased when leached through fly ash (Leachate Study, PAP NM003E). However, the levels of boron declined when leached through a mixture of ash and spoil, and the increased selenium concentrations are similar to the selenium concentrations in leachate produced by spoil alone. The iron concentration in both surface and groundwater decreased following leaching through spoil, CCB, or a mixture of the two. Leachate produced from mixtures of ash and spoil has lower TDS and lower trace metal concentrations than natural groundwater from coal seams #4-6.

In general, the leachates produced do not widely differ from that of coal seam groundwater. TDS concentrations in the leachate have increased (except for bottom ash, which had a lower TDS than the groundwater) due to increases in sulfate, calcium, and chloride concentrations. However, the increased TDS concentration is small in comparison to the original concentration of the coal groundwater.

Trace metal concentrations are similar for all the leachates produced, with the exception of fly ash alone, which increased boron concentrations. However, boron concentrations in groundwater leached through a mixture of ash and spoil are similar to the original concentration of the groundwater

The leach study predicts that in the event CCB should contact groundwater, regardless if the water originates from coal seam groundwater or infiltrating surface water, no degradation to post-mine groundwater should occur. The leach study concludes that the spoils are capable of retarding the movement of metals in water. Specifically, levels of metals such as barium, iron, selenium, and lead decreased in some cases. Geochemical processes postulated as responsible are adsorption, the high cation-exchange-capacity (CEC) measured in the spoil, and precipitation.

Groundwater Chemistry in Bitsui

Data collected during the Supplemental Groundwater Study (SGS) (APPENDIX 11-MM, PAP NM0003E) provide a field confirmation of laboratory predictions made in the leach study. The purpose of the SGS was to investigate possible impacts to groundwater from previous CCB disposal at Navajo Mine. The investigation was accomplished by installing six groundwater-monitoring wells in and around ash and spoil disposal areas in Bitsui pit (Figure 4). The wells were monitored quarterly for static water levels and water quality.

Results from the SGS and more recent monitoring indicate that parameter concentrations are similar for water derived from an ash well when compared to water derived from a spoil well. Monitoring data has recorded elevated levels, as compared to other wells in the area, of boron and variable concentrations of arsenic in well Bitsui-1 (figures 5 and 6). Bitsui-1 is screened in ash and has approximately a fifty-foot column of water in the well. No other parameters in Bitsui-1 are elevated relative to the down gradient spoil wells (Bitsui-4, Bitsui-5, and Bitsui-6). TDS concentrations in Bitsui-4, Bitsui-1, and Bitsui-6 are similar.

Elevated levels of boron from Bitsui-1 compare favorably with lab results and predictions made in the leach study for surface and groundwater leached through fly ash. The lack of elevated constituents in surrounding Bitsui spoil monitoring wells, particularly boron, confirms predictions that geochemical processes within the spoil are attenuating metals migration and thus limiting the extent of effects from saturated CCBs.

The determination of no significant impact to post-mine groundwater from CCB disposal is based on laboratory and field studies conducted at Navajo Mine. The primary basis for this conclusion relies upon the basic chemical characteristics of the CCBs. CCBs are similar in chemical composition to spoil with the exception that fly ash has greater concentrations of boron, selenium, chromium, and barium. Leachate studies and well monitoring verified changes in water chemistry due to contact with spoil and CCBs and that boron levels can increase within the ash alone. However, the studies also verified that attenuation processes active in the spoil could reduce metal concentrations, particularly boron.

In the unlikely event that groundwater does saturate CCBs on Permanent Program Land, the probable result is that concentrations of boron may increase and that the overall chemistry of the major ions will likely change. However, as this water migrates into spoil following contact with the CCBs, boron concentrations are predicted to decrease due to attenuation. Other trace metal concentrations in groundwater are not predicted to increase.

Conclusion

The natural barriers and engineering controls at Navajo Mine will effectively minimize ash used as backfill on Permanent Program Lands from contacting surface water or groundwater. Permanent program ash disposal areas are purposely far from NAPI (irrigation) activities and consequently will remain dry. Placing ash beneath 10 feet of cover and forcing post-mine drainages to cross ash at right angles greatly reduces the potential for ash to contact water. The naturally low permeability of spoil and overburden in combination with an arid environment provide substantial long-term protection against the possibility of the ash becoming saturated.

Navajo Mine has collected detailed site-specific data quarterly during the past five years from groundwater wells completed in or adjacent to ash, spoil, and coal. The data from the ash wells record that metals are not leaching from ash, except for low level increases in arsenic and boron (below drinking water standards). Furthermore, arsenic and boron concentrations have decreased to background levels due to attenuation and precipitation within the spoils 75 feet down gradient of the disposal area. These monitoring well data demonstrate that, in the unlikely event that groundwater does contact ash, metals will not leach or will not migrate through spoil.

Results of revegetation studies above ash disposal areas record no effect to vegetation and that these lands will support the post-mine land use of grazing.

Navajo Mine has submitted a detailed plan to OSM for the beneficial use of ash as mine backfill and the disposal process is monitored and regulated by OSM. The conclusion from the extensive studies detailed in the ash disposal

plan and in this report is that there are no predicted effects to air, vegetation, or surface water and groundwater. Ash disposed of as mine backfill at Navajo Mine is not only environmentally safe due to the substantial natural protection offered by the pits, but is the best long-term solution for ash, when disposal is the only beneficial use currently available.

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Andy Young works as a hydrologist in the Environmental Department at BHP Billiton's Navajo Mine. He is responsible for surface and groundwater monitoring, including data collection, monitoring reports, and permitting. He recently permitted the disposal of ash on Permanent Program Lands through the Office of Surface Mining. Prior to working at Navajo Mine, Andy worked for the State of Montana in both the Coal Regulatory and Hazardous Waste Clean-up Programs. Andy holds an MS degree in Geology from the University of Montana.

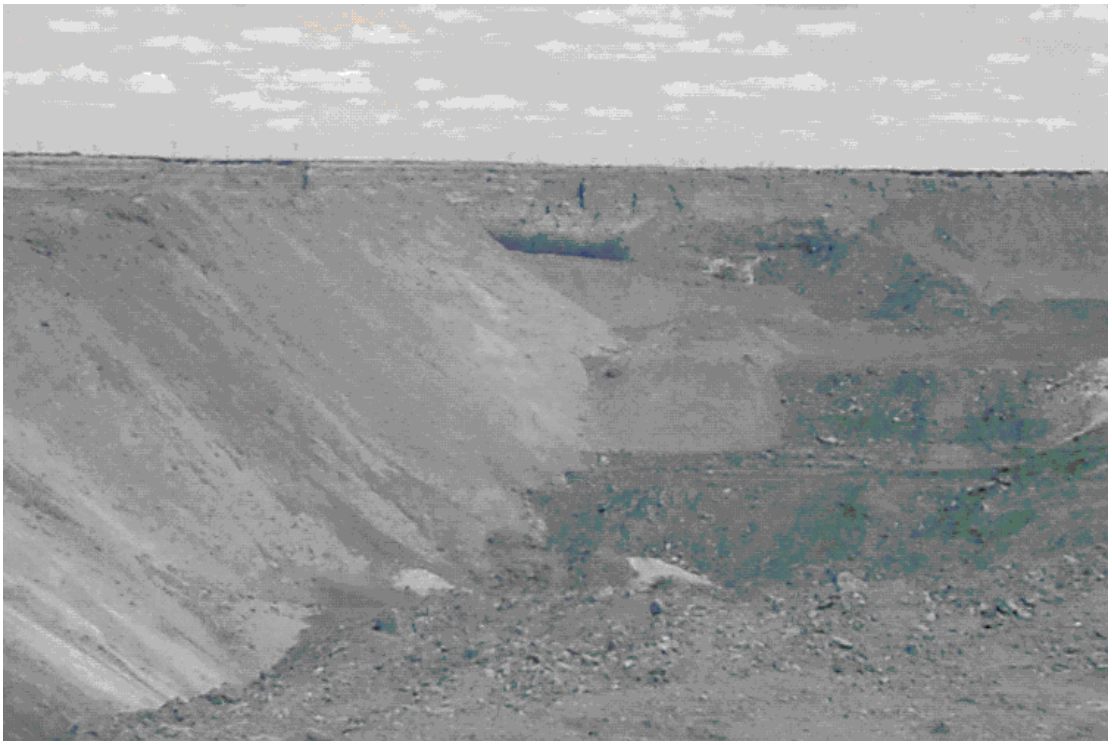

Figure 1. Typical Ash Disposal Area

Figure 2. Transportation of Ash to the Disposal Area

Figure 3. Building Ash Cover with Dozers

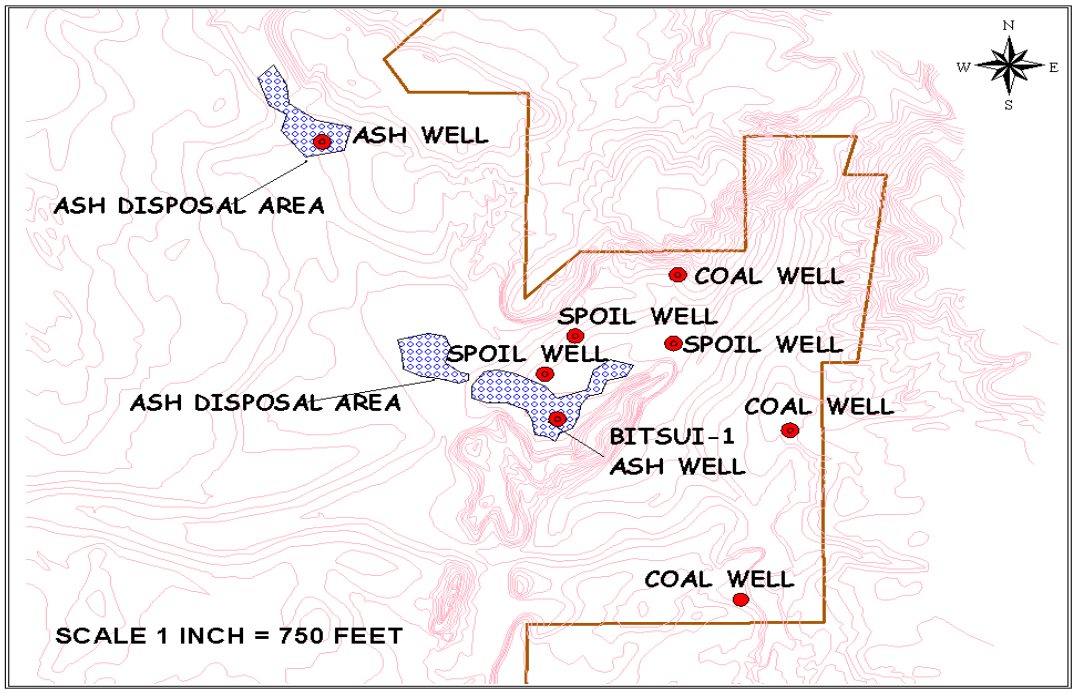

Figure 4. Bitsui Area, Navajo Mine showing approximate locations of ash disposal and monitoring wells.

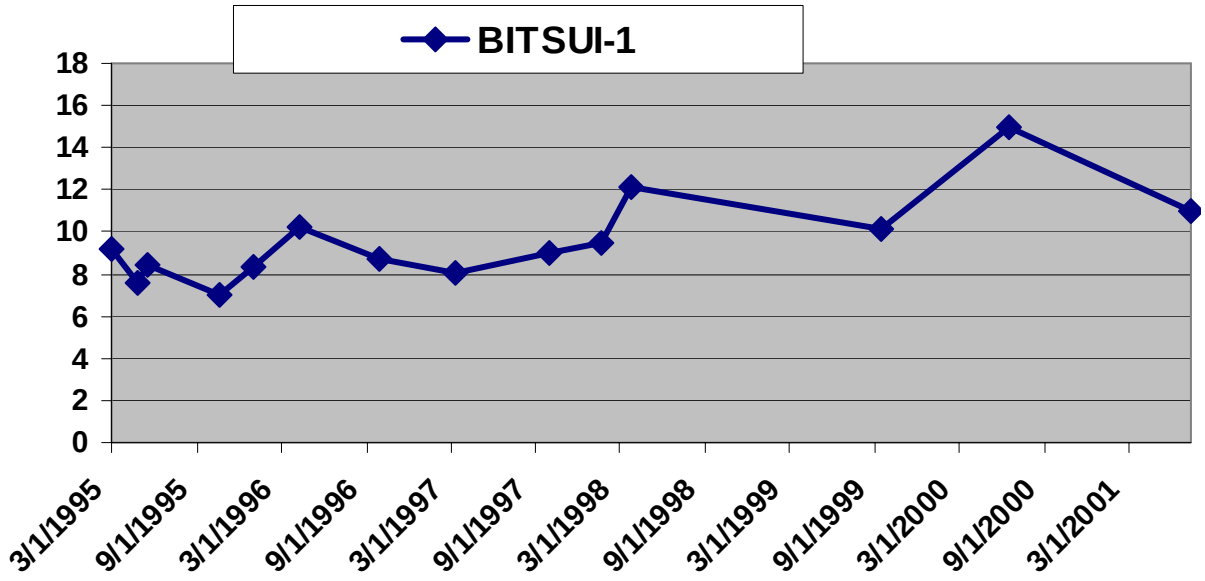

Figure 5. Bitsui ash well. Boron concentrations in mg/l.

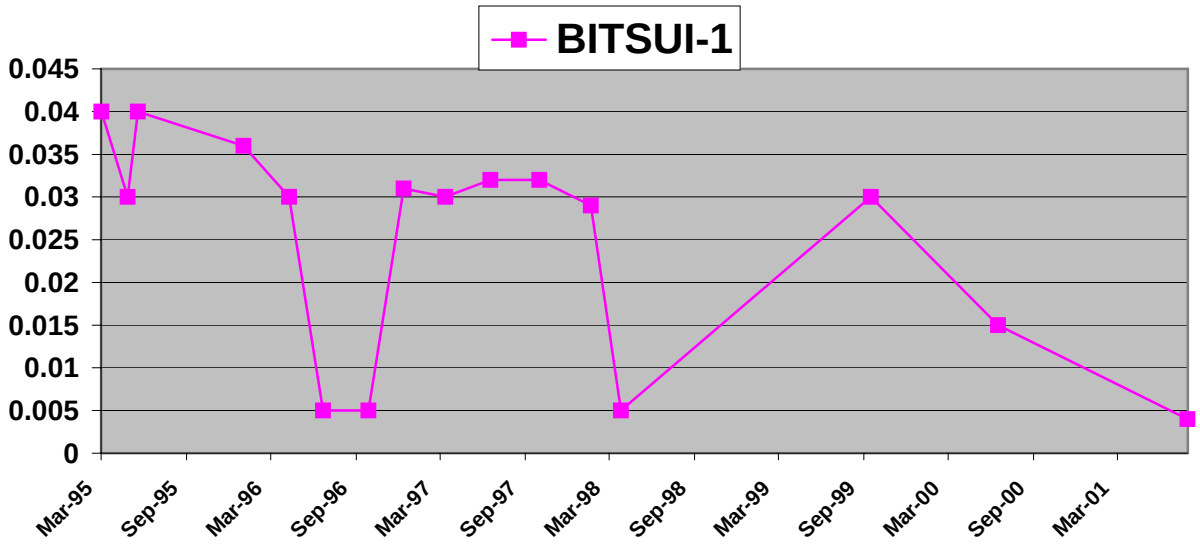

Figure 6. Bitsui ash well. Arsenic concentrations in mg/l.

Table 1. Ash and spoil concentrations from Navajo Mine, in mg/l.

PARAMETER	ASH	SPOIL
Antimony	8.5	<10
Arsenic	8.65 13.9	
Barium	746	204
Beryllium	0.6 1.32	
Cadmium	0.3 1.14	
Chromium	6	2.8
Cobalt	1.7 7.6	
Copper	9 9.4	
Lead	3 38.2	
Manganese	60.1 284	
Mercury	0.11 0.26	
Nickel	2.5 11	
Selenium	4.35	0.6
Silver	0 <3	
Thallium	0 <100	
Zinc	14.5 65.4	

COLSTRIP STEAM ELECTRIC STATION
COAL COMBUSTION BY-PRODUCT DISPOSAL

James M Parker, P.E.
Gordon D Criswell, P.E
PPL Montana
Coalstrip, Montana

Abstract

The Colstrip Steam Electric Station consists of four coal-fired power plants capable of generating almost 2100 megawatts. These plants burn Powder River Basin (PRB) subbituminous coal from the local mine in Southeastern Montana. Wet scrubbers are utilized for SO_2 and particulate control. Approximately 1 million tons of by-products are produced annually (flyash, SO_2 scrubbing by-product, and bottom ash). This material is pumped as slurry to the final disposal pond where the water is decanted and returned to the plants for reuse because the site is a Zero-Discharge facility. Bottom ash is slurried from the bottom of the boiler to local ponds at the plant, then dewatered and trucked to the final disposal pond. All ponds are designed to minimize seepage. Once the ponds are filled with solids, they are fully dewatered and reclaimed with a native grass mix. Bottom ash is offered for sale and the sale of other by-products is being reviewed. An extensive groundwater-monitoring network exists around the disposal ponds to monitor seepage impacts of the saline material on the local groundwater. Expensive mitigation measures have been necessary to minimize impacts to the groundwater. Plans are underway to utilize Paste Technology and reduce the water inventory This will reduce resultant pond seepage at the disposal pond to a minimum, eliminate the need for new disposal ponds, and reduce reclamation costs.

Introduction and Site Description

PPL Montana, LLC (PPLM) operates a four-unit, mine mouth, coal fired electricity generating facility in Colstrip, Montana, the Colstrip Steam Electric Station (CSES). The CSES is located in Rosebud County in southeastern Montana and consists of four subbituminous coal-fired units. Colstrip units 1 and 2, which are two 333-megawatt, coal-fired steam electric generating units, have been in use since 1975. Colstrip units 3 and 4 are two 800-megawatt generating units adjacent to units 1 and 2. Unit 3 has been on line since October, 1983. Unit 4 came on line near the end of 1985 and began producing commercial power in April of 1986.

Pollution Control

Wet venturi scrubbers are utilized for particulate and sulfur dioxide removal. These scrubbers utilize lime, either high calcium or dolomitic. Scrubbing efficiency for SO_2 is 95 percent and for particulate is 99.5 percent. The main by-products from the scrubbers are calcium sulfate and fly ash in a liquid slurry. Approximately 675,000 tons of mixed fly ash and calcium sulphate are produced annually. The annual production of bottom ash is approximately 280,000 tons. In generating these totals, CSES is base loaded and operates at a capacity factor between 80 and 90 percent.

By-Products Handling System

To avoid impacts to water resources in the area, PPLM operates closed-loop process water/scrubber systems. All slurried wastes from the scrubbers and generating plants are transported in pipelines and impounded in ponds designed and constructed to minimize seepage losses. The pond system presently servicing Colstrip units 1 and 2 has been in use since 1975. The pond system servicing units 3 and 4 has been in use since 1983. Bottom ash and scrubber by-products are combined at one of the final disposal sites, the units 3 and 4 effluent holding pond (EHP). This pond is located approximately four miles southeast of the main CSES. Prior to being conveyed to the final disposal site, the bottom ash is handled separately in a smaller pond system at the CSES. Another final disposal site, the units 1 and 2 stage I and II evaporation pond, is located approximately two miles northwest of the CSES.

Capacities, total pond surface areas, and surface areas generally utilized in the process pond system, servicing units 1 through 4, are summarized in Table 1. Process ponds located in the units 1 through 4 plant area, the units 1 and 2 stage I and II evaporation ponds, and the units 3 and 4 EHP are shown in Figure 1.

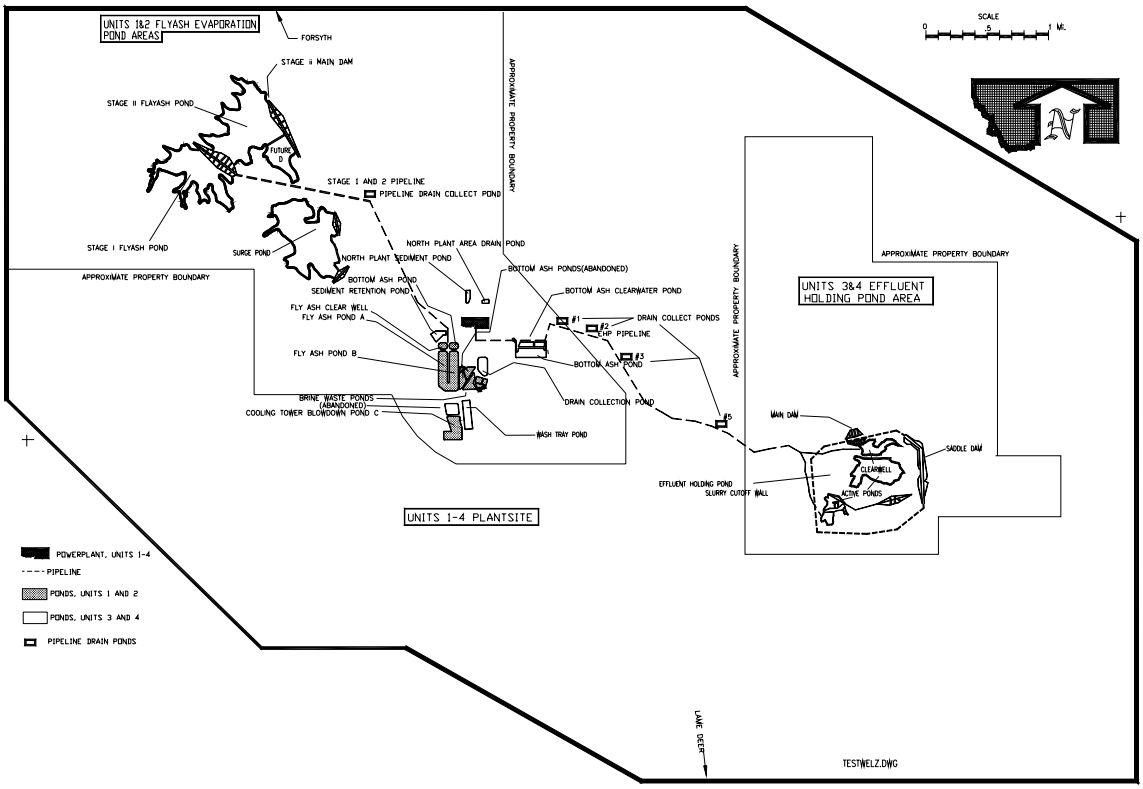

Figure 1. Units 3 and 4 Effluent Holding Pond.

By-products produced by the units 1 and 2 scrubber systems are in slurry form and are transported via pipeline to the units 1 and 2 Stage II evaporation pond, where the suspended solids are settled. The Stage II evaporation pond, located immediately down-gradient from the Stage I pond, had been used to store decant from the Stage I pond, while Stage I was in the final stages of filling. In 1994, the Stage I pond was completely full and the Stage II pond started collecting effluent. The Stage I pond has been reclaimed. Decant is collected in the Stage II clearwell and returned to the plants for reuse in the scrubber system.

Handling of effluent produced by units 3 and 4 is similar to that of units 1 and 2. Scrubber slurry is piped to the units 3 and 4 EHP. The slurry is deposited directly into an active cell of the EHP for settling of suspended solids. Decant from the cell then flows to the EHP clearwell, where it is recirculated to the plant scrubber system. Utilization of several cells in the EHP allows for sediment in all areas of the pond to be periodically dewatered. This allows the dewatered slurry to consolidate and provide a barrier to help prevent seepage.

The units 1 and 2 Stage II pond is synthetically lined with 80 mil high density polyethylene (HDPE). Construction of an impervious slurry containment wall on the perimeter of the units 3 and 4 EHP was completed to the depth necessary to prevent effluent seepage through the more permeable strata (up to 80 feet in depth).

A summary of the average chemical/physical characteristics for each of the ponds in the units 1 through 4 process pond system is located in Table 2. Scrubber slurry contains significant concentrations of dissolved constituents, particularly magnesium, calcium, sodium, and sulfate. The chemical composition of pond water generally varies, as water balance needs change in the Colstrip generating units process system.

Environmental Considerations

Due in part to environmental constraints, offsite use of by-products is limited. Market influences have played a part in the amount of by-products recycled as well. Since 1996, about 51,000 tons of by-products have been marketed offsite. This amount is comprised exclusively of bottom ash from units 1 and 2. Units 3 and 4 are prohibited from placing any by-products outside of the pond system. Environmentally, there is a clear distinction between units 1 and 2 and units 3 and 4. This distinction is due mainly to differences in ownership and vintage of the unit pairs. PPLM is currently preparing a request to the Montana Department of Environmental Quality (DEQ) to allow the offsite use and marketing of bottom ash from units 3 and 4.

Scrubber slurry does not appear at this time to have any significant market value. One reason is the mixed nature of two potentially marketable by-products: fly ash and calcium sulfate. Mixing greatly reduces the value of each compared to that value if the products were collected separately. The levels of highly mobile constituents further reduce slurry's marketability. If placed in an environment where leaching has a high probability of occurring, significant groundwater or surface water degradation could take place.

A comprehensive surface water and groundwater monitoring system has been installed and operated to monitor the quantity and quality of water in the vicinity of the process water systems. It is the policy of PPLM that its Colstrip operations will meet all applicable environmental laws and regulations and that impacts to the environment will be minimized. The Montana DEQ is the primary regulating agency. There are two governing sets of rules pertaining to the by-products disposal system at Colstrip: (1) Montana's non-degradation rules and the Certificate of Environmental Compatiblity; and (2) Public Need granted when the plant was first built. Both prohibit substantial negative impacts to the surrounding surface and groundwater.

Hydrologic monitoring of the pond system at Colstrip is conducted on an ongoing basis as part of the environmental monitoring program coordinated by PPLM's Environmental Engineering Department (EED). Water quality samples are generally collected in the spring and fall of each year from groundwater monitoring wells and surface water locations. All PPLM process ponds are sampled a minimum of once every three years. Flow data and water quality samples also were collected from designated surface water monitoring sites on East Fork Armells Creek. Private wells, mostly near the units 1 and 2 evaporation pond are also monitored. Monthly static water level (SWL) measurements of all monitoring wells also is conducted. Currently, water quality is routinely measured at about 408 locations. Not all locations are monitored routinely; the total number of sites potentially monitored by this program approaches 600.

Based upon data from this monitoring program, as well as known problems with the pond liners and process piping, 23 systems collecting impacted groundwater are operating adjacent to the ponds. These systems have been installed over a period of years starting in about 1988. The cost of these systems and other environmental mitigation measures will total $10.3 million by the end of 2002. This total included a $4.9 million expenditure to completely rework a plant site pond whose clay liner had been breached by years of dredging and associated activities.

Paste Technology and Benefits

In 2000, groundwater mitigation measures were required at the units 3 and 4 EHP to address significant seepage through the Saddle Dam. This seepage was related to settlement of the dam because of unconsolidated baked shale in the area. Investigation into this event led to a recommended solution of rebuilding the dam just downstream of its current location with extensive measures to avoid the problems caused by the baked shale material. The estimated cost of this project was $16 million. PPLM then investigated other possible solutions with the idea of using Paste Technology coming to the forefront. In addition to the EHP Saddle Dam seepage, the groundwater monitoring system indicated other areas around the EHP where groundwater mitigation measures were needed to prevent negative impacts to the groundwater. Even with the impervious slurry containment wall, it was becoming apparent that the seepage from the pond was going to be an ongoing problem. Even more extreme mitigation measures would be necessary in the future if the current disposal method was continued. The use of Paste Technology would allow PPLM to address both the Saddle Dam and general seepage concerns from the EHP.

PPLM has contracted with Golder Paste Technology, Ltd., in order to evaluate the feasibility of utilizing Paste Technology to address the seepage issues. Laboratory bench work was completed in early 2001 that indicated that a paste product could be produced from the CSES scrubber slurry. This paste would be at a 68 percent solids level with a 10.5 inch slump. Additional laboratory testing and flow loop testing was completed in the summer of 2001 in order to better define process parameters. From this work, it was projected that the paste would reduce the free water available for seepage by 95 percent from the current process. A pilot plant was set up at the CSES in late 2001 in order to verify this process with a real-time scrubber process slurry. The pilot plant was operated for about two weeks. After some modifications, the ability to produce a paste product at 68 percent solids was confirmed. PPLM and Golder are currently in the preliminary engineering design stage for the paste facility with a target operational date of April, 2003. Conceptually, the paste plant will consist of a deep tank dewatering system located at the units 3 and 4 EHP. Positive displacement pumps will move the paste material to the desired location in the EHP. Clearwater effluent from the process will flow to a clearwell where it will be returned to the scrubbers for reuse.

The cost of this paste concept is expected to be less than half of the recommended repair to the Saddle Dam. By depositing paste in the cell adjacent to the Saddle Dam and eliminating the water storage, no additional work is expected to be needed for the Saddle Dam. The structural integrity of the dam is intact. By reducing the free available water for seepage by using paste, no seepage problems are expected. In addition, the paste is expected to eliminate the seepage concerns in the other areas of the EHP and help eliminate potentially significant future mitigation costs. Another benefit of utilizing paste as the final disposal product will be the ability to stack the paste material and increase the capacity of the disposal pond, thereby eliminating the need for an additional disposal pond at very high costs and environmental concerns. In conjunction with the paste facility, water management measures (forced evaporation and increased use of pond return water at the CSES) will be implemented to eliminate the excess water that is currently stored in the EHP because of the inherent design of the current disposal method.

Summary

PPL Montana, LLC operates a four-unit, mine mouth, coal fired electricity generating facility in Colstrip, Montana with wet venturi scrubbers for particulate and sulfur dioxide removal. Scrubbing efficiency for SO_2 is 95 percent and 99.5 percent for particulate. Approximately 675,000 tons of a fly ash/calcium sulphate mixture and 280,000 tons of bottom ash are produced annually. All slurried wastes from the scrubbers and generating plants are transported in pipelines and impounded in ponds designed and constructed to minimize seepage losses. Environmental and market constraints limit offsite sale of by-products to roughly 10 percent of the bottom ash produced.

A comprehensive surface water and groundwater monitoring system has been installed and operated to monitor the quantity and quality of water in the vicinity of the process water systems. Based upon data from this monitoring program, extensive mitigation measures have been necessary. In total, about $10.3 million has been spent since 1988.

The original design measures, implemented to control seepage from final disposal ponds containing coal combustion by-products, have not been as effective as anticipated. Paste Technology appears to provide an option that can be most effective in reducing seepage (95 percent reduction in free available water) and is the most cost-effective approach.

Gorden Criswell is the Manager of Process Support for Colstrip Steam Electric Station where he has been employed since 1983. He is a Registered Professional Engineer in the State of Montana. He holds a BS in Chemical Engineering from Montana State University.

Jim Parker is the Director of the Environmental Engineering Department at the Colstrip Steam Electric Station where he has been employed since 1982. He became involved with coal combustion by-products in 1992. Currently, he is leading the effort to amend Colstrip permits to allow offsite use of units 3 and 4 bottom ash. He is a Registered Professional Engineer, State of Montana, 1985. He holds a BS in Environmental Engineering, 1980, from Montana College of Mineral Science and Technology.

Table 1. Units 1 through 4 Process Pond Descriptions

Pond Name	Total Capacity (acre/feet)	Total Surface Area (acres)	Surface Area Generally Utilized (acres)	Lining
(1)Unit 1&2 Fly Ash Pond A/B With Clearwell	490	27.1	25.2	Clay
(2)Unit 1&2 Bottom Ash Pond with Clearwell	24	1.8	Variable	Clay
(3)Unit 1&2 Stage 1 Fly Ash Evaporation Pond	2350	114	114	Partial Clay
(4) Unit 1&2 Stage 2 Fly Ash Evaporation Pond	4370	176 (total for 5 cells)		High Density Polyethylene
(5)Unit 3&4 Auxiliary Scrubber Drain Pond	0.51	0.23		Hypalon
(6)Unit 3&4 Wash Tray Ponds	85	8	7.1	Clay
(7)Unit 3&4 Drain Collection Pond	72	6	5.85	Clay
(8)Unit 3&4 Bottom Ash Pond	20.6	5.5 (total for 2 pond)	Variable	Clay
(9)Unit 3&4 Bottom Ash Clearwater Pond	17.8	2.1	1.65	Clay
(10)Unit 3&4 Effluent Holding Pond	Variable	337 (total of areas C,F,G, & H)	50	Clay over shale & sandstone outcrops. Slurry wall on perimeter of pond system
(11)Unit 3&4 Effluent Holding Pond Clearwell	1887	30	10.6	Clay over shale & sandstone outcrops. Slurry wall on perimeter of pond system

(1) Unit 1&2 Fly Ash Pond A/B With Clearwell – Receives Fly Ash from Scrubber; Decant Water returned to Scrubber; Fly Ash Slurried to Evaporation Pond
(2)Unit 1 & 2 Bottom Ash Pond with Clearwell – Disposal of Bottom Ash and drain collection Pit Effluent; Decant recycled to Plant; Overflows to Fly Ash Pond
(3)Unit 1&2 Stage 1 Fly Ash Evaporation Pond – Final Disposal for Fly Ash Slurry; Decant recycled to Plant; No longer in Use.
(4) Unit 1&2 Stage 2 Fly Ash Evaporation Pond – Receives Fly Ash Slurry from Unit 1&2; Final Disposal for Fly Ash Slurry; Decanted into Clearwell and recirculated to Plant.
(5)Unit 3&4 Auxiliary Scrubber Drain Pond – Miscellaneous Scrubber building drains.
(6)Unit 3&4 Wash Tray Ponds – Occasionally receives Fly Ash Water from Unit 1-4 Scrubbers; Recirculated to Scrubbers. No longer routinely used.
(7)Unit 3&4 Drain Collection Pond – Received miscellaneous Plant wash down water; Contains some process water; Abandoned in 1999 no longer in routine use.
(8)Unit 3&4 Bottom Ash Pond – Receives Bottom Ash and Bottom Ash Water; Decanted into Bottom Ash clearwell; Alternate Use between 2 ponds.
(9)Unit 3&4 Bottom Ash Clearwater Pond – Receives decant from Bottom Ash Pond; Recirculated to Plant.
(10)Unit 3&4 Effluent Holding Pond – Receives Unit 3&4 Scrubber Fly Ash Slurry; Decanted into Fly Ash Clearwell.
(11)Unit 3&4 Effluent Holding Pond Clearwell

NOTE: Units 3 and 4 Effluent Holding Ponds partitioned into “cells,” or areas C,G, and F. Total Capacities and Surface Areas are maximum water surface elevation values.

Table 2a. Physical Parameters

Process Pond	Specific Conductance (umhos/cm)	Lab pH	Total Dissolved Solids @ 180 Degrees C	Sodium Adsorption Ratio
Unit 1&2 Fly Ash A	11,122	5.3	15,795	1.5
Unit 1&2 Fly Ash B	15,060	5.8	21,800	
Unit 1&2 Fly Ash Evaporation Stage I	10,080	7.5	14,633	1.4
Unit 1&2 Fly Ash Evaporation Stage II	12,925	7.6	17,225	2.8
Unit 1&2 Fly Ash Evaporation Stage II Clearwell	14,450 7.6		20,750	
Unit 1&2 Bottom Ash Clearwell	5,330	9.5	6,134	2.3
Unit 3&4 EHP Area F	17,800	7.0	21,500	4.0
Unit 3&4 EHP Area C-G	16,400	7.0	25,450	3.0
Unit 3&4 EHP Area H	19,200	6.1	28,100	4.6
Unit 3&4 EHP Area E	16,600	6.0	23,200	
Unit 3&4 EHP Area Clearwell	16,619	6.9	25,471	3.3
Unit 3&4 Bottom Ash Pond	4,229	9.8	3,200	8.5
Unit 3&4 Drain Collection Pond	11,094	7.9	15,179	3.3
Unit 3&4 Wash Tray Pond	12,284	5.9	18,385	3.3

Table 2b. Common Ions

Process Pond	Total Hardness CaCO3	Alkalinity CaCO3 Lab	Bicarbonate HCO3 Lab	Carbonate	Sulfate SO4
Unit 1&2 Fly Ash A	10,420	15	18		10,778
Unit 1&2 Fly Ash B					14,860
Unit 1&2 Fly Ash Evaporation Stage I	10,346	72	92		10,070
Unit 1&2 Fly Ash Evaporation Stage II	10,600	37	40	<1	11,950
Unit 1&2 Fly Ash Evaporation Stage II Clearwell					13,150
Unit 1&2 Bottom Ash Clearwell	3,770	125	49		3,927
Unit 3&4 EHP Area F	17,560	90	100		19,100
Unit 3&4 EHP Area C-G	16,900	160	190		18,100
Unit 3&4 EHP Area H	18,100	39	48		19,500
Unit 3&4 EHP Area E					14,600
Unit 3&4 EHP Area Clearwell	16,600	98	117		18,007
Unit 3&4 Bottom Ash Pond	985	270	63		1,978
Unit 3&4 Drain Collection Pond	9,120	184	144		9,945
Unit 3&4 Wash Tray Pond	10,080	29	4.8		12,626

Table 2c. Common Ions

Process Pond	Calcium	Magnesium	Sodium	Potassium	Chloride	Fluoride
Unit 1&2 Fly Ash A	523	2,224	389	20	93	3.2
Unit 1&2 Fly Ash B	477	2,955	854		263	
Unit 1&2 Fly Ash Evaporation Stage I	480	2,117	300	33	71	2.4
Unit 1&2 Fly Ash Evaporation Stage II	447	2,485	775	36.5	226	2.4
Unit 1&2 Fly Ash Evaporation Stage II Clearwell	427	2,910	903		271	
Unit 1&2 Bottom Ash Clearwell	564	541	286	17	61	1.1
Unit 3&4 EHP Area F	500	3,960	1,170	60	220	5
Unit 3&4 EHP Area C-G	580	3,800	960	60	220	6
Unit 3&4 EHP Area H	530	4,030	1,445	88	400	18
Unit 3&4 EHP Area E	612	3,280	1,210		365	
Unit 3&4 EHP Area Clearwell	524	3,688	1,044	58	259	6
Unit 3&4 Bottom Ash Pond	352	44	590	18	46	0.5
Unit 3&4 Drain Collection Pond	524	2,010	758	65	155	6
Unit 3&4 Wash Tray Pond	496	2,407	918	53	218	4.7

Table 2d. Nutrients

Process Pond	Nitrate + Nitrite as N	Ortho-Phosphate PO4-P
Unit 1&2 Fly Ash A	19.4	0.1
Unit 1&2 Fly Ash B		
Unit 1&2 Fly Ash Evaporation Stage I	18	0.1
Unit 1&2 Fly Ash Evaporation Stage II	8.1	0.05
Unit 1&2 Fly Ash Evaporation Stage II Clearwell		
Unit 1&2 Bottom Ash Clearwell	7.2	0.05
Unit 3&4 EHP Area F	8	0.1
Unit 3&4 EHP Area C-G	6	0.1
Unit 3&4 EHP Area H	11.7	0.1
Unit 3&4 EHP Area E		
Unit 3&4 EHP Area Clearwell	7.4	0.1
Unit 3&4 Bottom Ash Pond	0.3	0.05
Unit 3&4 Drain Collection Pond	4.1	0.04
Unit 3&4 Wash Tray Pond	7.5	0.1

Table 2e. Trace Elements

Process Pond	Al	B	Cd	Cu	Fe	Pb
Unit 1&2 Fly Ash A		80				
Unit 1&2 Fly Ash B		72.2				
Unit 1&2 Fly Ash Evaporation Stage I		76				
Unit 1&2 Fly Ash Evaporation Stage II	0.3	63.2	0.003	<0.01	<0.03	0.04
Unit 1&2 Fly Ash Evaporation Stage II Clearwell		70.9				
Unit 1&2 Bottom Ash Clearwell		22.8				
Unit 3&4 EHP Area F		106				
Unit 3&4 EHP Area C-G		85				
Unit 3&4 EHP Area H		130				
Unit 3&4 EHP Area E		125				
Unit 3&4 EHP Area Clearwell		98.8				
Unit 3&4 Bottom Ash Pond		2.6				
Unit 3&4 Drain Collection Pond		54.4				
Unit 3&4 Wash Tray Pond		54.9				

Table 2f. Trace Elements

Process Pond	Mn	Hg	Ni	Se	V	Zn
Unit 1&2 Fly Ash A				0.055		
Unit 1&2 Fly Ash B				0.063		
Unit 1&2 Fly Ash Evaporation Stage I			0.022			
Unit 1&2 Fly Ash Evaporation Stage II	14.7	<0.001	0.15	0.092	<0.1	<0.01
Unit 1&2 Fly Ash Evaporation Stage II Clearwell			0.098			
Unit 1&2 Bottom Ash Clearwell			0.014			
Unit 3&4 EHP Area F						
Unit 3&4 EHP Area C-G						
Unit 3&4 EHP Area H						
Unit 3&4 EHP Area E			0.443			
Unit 3&4 EHP Area Clearwell			0.241			
Unit 3&4 Bottom Ash Pond			0.011			
Unit 3&4 Drain Collection Pond			0.095			
Unit 3&4 Wash Tray Pond			0.060			

HYDROLOGY MONITORING AND CCB PLACEMENT AT TRAPPER MINE

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Abstract

The use of coal combustion by-products (CCBs) as backfill in selected mined areas at Trapper Mine commenced in 1984. CCBs are utilized as backfill in the reclaimed landscape at Trapper to reestablish approximate original contour in the last open cut of a mined area. CCB placement is carefully controlled to ensure contact with groundwater and surface water is minimized. Placement occurs only in areas of the pit at a minimum of ten feet above the predicted post-mining groundwater table. Permit requirements specifying minimum acceptable distances from reclaimed surface water drainages and minimum cover depths also are observed. Surface water diversions and interim cover measures are utilized to the extent possible during backfilling operations to minimize environmental exposures of CCB materials. An extensive hydrology monitoring network consisting of a series of wells strategically placed at locations downgradient of CCB deposits is operated to ensure the placement techniques are effective in isolating these materials. Groundwater monitoring results indicate groundwater quality in CCB monitoring wells is comparable to quality found in other backfill monitoring wells at the site not associated with CCB placement.

Trapper Mine Description

Trapper Mine is a surface coal mine located in northwestern Colorado approximately 6½ miles south of the city of Craig. The permit area encompasses slightly more that 10,300 acres. Mining operations are conducted along the northern flank of the Williams Fork Mountains to recover multiple seams of high-quality low-sulfur subbituminous coal for delivery to the adjacent Craig Station power generating facility. Elevations at Trapper range from approximately 6,300 to 7,400 feet above mean sea level. The predominant vegetation type at the site is mountain shrub transitioning to big sagebrush in the lower elevations and aspen in the higher portions of the permit area. The average annual precipitation is 16.7 inches, with roughly one-third of this occurring as snowfall. Soils are well developed, generally deep and formed in alluvium and colluvium derived from sandstone and shale parent materials. Topographically, cultivated lowlands (typically winter wheat or alfalfa/native grass hay) give way to rolling upland hills and long steep slopes historically utilized as rangeland and wildlife habitat with relatively steeper slopes occurring in the higher elevations.

Mine Operation

Mining operations commenced at Trapper in 1977. Three Page 752 LR draglines equipped with 32-cubic-yard buckets are utilized as the primary earthmovers on the job and operate concurrently in different areas of the mine. Historically, mining operations have been oriented along the dip slope axis on slopes averaging approximately 14 percent. With coal seams dipping more steeply than the overlying topography, overburden depths range from a few tens of feet near the outcrops to approximately 160 feet at the economic limits of recovery. Multiple seams ranging from 3 to 15 feet in thickness are recovered with production averaging 2MM tons annually.

CCB Placement at Trapper Mine

The use of coal combustion by-products (CCBs) as backfill in selected mined areas at Trapper Mine commenced in 1984. CCBs from the adjacent Craig Station are utilized as backfill in the reclaimed landscape at Trapper to reestablish approximate original contour in the last open cut of mined area. The Craig Station typically consumes between 4MM and 5MM tons of coal annually. A roughly 10:1 coal burn to by-product ratio results in between 0.4MM to 0.5MM tons of CCB delivery annually to Trapper for placement. CCB materials accepted include fly ash, bottom ash, and scrubber sludge.

CCB Characterization

Before CCB materials were accepted for placement at Trapper, a comprehensive study was conducted to define the significant characteristics of the CCBs produced at Craig Station and to determine the potential environmental impacts and protective measures required to minimize those impacts. The preliminary study was conducted by Radian Corporation for Utah International during 1980 and 1981 and was entitled "Evaluation of Hydrologic Impacts of Disposing of the Craig Station Power Plant wastes in the Trapper Mine, Moffat County Colorado." This study was referenced and utilized as an integral part of the permitting process required to manage CCBs on the Trapper Mine site. Details regarding the permitting process are presented elsewhere in these proceedings.

The Radian study addressed numerous objectives and integrated the findings derived from each phase of inquiry into recommendations for a complete long-term plan ensuring the safe, efficient, and environmentally protective management of CCBs from the Craig Station. Specific areas of investigation included a thorough assessment of the hydrogeologic setting of the Trapper Mine and adjacent areas with particular emphasis placed on groundwater hydrology, and water quality including the definition of an overall water balance for the site; comprehensive evaluations defining the relevant physical and chemical characteristics of coal, fly ash, bottom ash, scrubber sludge, and various Trapper Mine overburdens; and leaching studies designed to characterize the anticipated CCB leachate chemical constituent composition and to identify attenuating patterns in constituent level behaviors resulting from the subsequent exposure of CCB leachates to Trapper Mine overburdens and undisturbed strata. In addition, the influences and effects of various CCB placement disposal options within the mined area disturbance profile (pit bottom, intermediate bench or spoils trough) on leachate development were examined.

Significant findings from the Radian study include the following:

- CCBs derived from the Craig Station are non-toxic/non-hazardous materials and are not subject to regulation under RCRA.
- Infiltration and percolation rates at Trapper are typically quite low and there is an associated low potential for CCB leachate development to occur.
- Trapper Mine spoil permeabilities tend to far exceed the permeabilities exhibited by CCBs. Therefore, percolating waters moving through the soil/spoil profile will tend to preferentially move around rather than through CCB placements.
- Unattenuated CCB leachates were shown to contain aluminum, barium, chromium, boron, and molybdenum concentrations exceeding recommended drinking water and/or agricultural water quality standards. Trapper Mine spoils consistently attenuate concentrations of these constituents to acceptable levels.
- No direct hydrologic connection between the Upper Williams Fork coal bearing stratigraphic member and the Yampa River was identified. The strata to be disturbed by coal mining and CCB placement are hydrologically isolated from the Yampa River system.
- The selective mine placement of fly ash, bottom ash, and scrubber sludge is unlikely to produce groundwater contamination at Trapper. The primary reasons cited in support of this conclusion were the minimal infiltration characteristics prevalent at the site, the moisture storage capacities of the overburdens at Trapper and the related water balance influence, the relative impermeability of the CCBs as compared to spoil materials, and the attenuating influence of the Trapper Mine overburdens on CCB leachates.
- And finally, all placement options evaluated within the mine are suited for CCB placement providing proper disposal practices are observed.

CCB Placement Design

The disposal practices recommended for implementation at Trapper were designed to maximize the hydrologic isolation of the CCB materials while taking advantage of the site-specific conditions predominating at the site. Trapper Mine is somewhat unique in that the surface mining operations are situated on the side slope of the Williams Fork Mountains. This setting allows for the maximum post-mining groundwater elevation in the low wall of each pit or mined area to be predicted with relative ease. Spoils in the down slope areas of pits can be expected to resaturate to an elevation controlled by the intersection of the mined area with the lowest point of the unmined end wall in a pit (the critical pit crest elevation). Typically these points of intersection occur where drainages intersect the mined areas. These points act to limit the extent of vertical resaturation of spoil materials. If ground-waters accumulate in the unconsolidated spoils of backfilled areas quicker than they can be conveyed down gradient through undisturbed strata adjacent to the pits, spoil springs, or surface expressions of this accumulated water, will form to limit the maximum elevation of the groundwater table in the vicinity of the end wall. The spoil springs in effect act as drains

to prevent the unconsolidated mined materials placed above them from becoming saturated with groundwater. Trapper takes advantage of this circumstance by placing CCBs a minimum of 10 feet above the critical pit crest elevation defined in each area. In this fashion, CCBs are isolated from groundwater and protected from saturated conditions.

The CCB placement methodology employed consists of a typical end dump configuration where the CCB materials are placed on a prepared and leveled bench or terrace within the last open cut of a mined area. To begin, the lowermost benches are established at points above the minimum critical pit crest elevation required. Sequential leveling of the materials is achieved with bulldozers as subsequent lifts are prepared and compaction of the materials is achieved by progressively wheel-rolling with the haul trucks used to transport the CCBs from Craig Station to the mine. This process is repeated until approximate original contour elevations are achieved in the backfill area.

Protective measures designed to isolate the CCB materials from exposure to surface water also are utilized. During construction of a CCB monofill, surface water runoff is diverted around the site to the extent possible. Permit requirements dictate that reconstructed drainages be located a minimum of 50 feet horizontally from the edge of a CCB backfill placement. The establishment of these stable permanent drainages situated away from CCB backfill areas provides long-term protection from CCB exposure to surface waters.

The Trapper Mine reclamation plan calls for CCB materials to be buried with a minimum of 6 feet of cover prior to proceeding with routine reclamation activities. A minimum of 5 feet of overburden is overlain with a minimum one foot of topsoil to eliminate surface exposure of CCB materials during final reclamation. These cover materials act to limit surface water infiltration and subsequent water contact with the CCB materials by virtue of their water holding capacity combined with the related prevailing annual moisture deficit characteristic of the water balance in Trapper area. Cover materials also act to limit surface water contact with CCBs because of their ability to convey water more readily than the CCB materials themselves. This results in the tendency for water to move around rather than through the CCB deposits.

Hydrologic Monitoring

An extensive groundwater hydrology monitoring network consisting of a series of wells strategically placed at locations down gradient of CCB deposits is operated to ensure the placement techniques are effective in isolating these materials. In addition to routine groundwater monitoring conducted at numerous wells on the Trapper site, expanded parameter lists are utilized at selected wells specifically located down gradient of CCB placements to detect increases in constituent levels associated with CCBs. The expanded parameter list focuses on the constituents of concern originally identified in the Radian study known to be present in CCB leachates at elevated levels. Monitoring is conducted on a semi-annual basis at wells completed both in saturated backfill materials and in undisturbed down gradient strata. Eight of the 37 groundwater wells at Trapper are monitored more intensively for water quality impacts potentially associated with CCB placement. Expanded monitoring efforts at selected groundwater sites commenced in 1985.

Conclusion

To date, no indication of elevated constituent levels of aluminum, barium, chromium, boron, or molybdenum has been detected at any location. Groundwater monitoring results indicate groundwater quality in CCB monitoring wells is comparable to groundwater quality found in other backfill monitoring wells at sites not associated with CCB placement.

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MITIGATION OF UNDERGROUND COAL MINES

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Abstract

Communities of Rock Springs, Glenrock, and Hanna, Wyoming were built over abandoned coal mines. Over time, the rock comprising the roof of the mine begins to fracture and collapse into the open mine. This process continues until the space is either occupied by rubble or the caving reaches the surface, threatening public health and safety. To successfully mitigate the potential of subsidence reaching the surface, a thorough understanding of the subsidence mechanism at work in any given mine is required and the proper mitigation method selected. The paper describes typical subsidence mechanisms and mitigation methods involving the use of coal combustion by-products.

The depth to mining is important when determining whether or not subsidence will reach the surface. The paper presents brief descriptions of analytical methods to determine critical mine depth. Once the critical depth to the mine is determined, a pilot drilling and grouting program is undertaken to determine the optimal hole spacing for mitigation. During construction, holes are drilled on a grid spacing as determined in the pilot program and low strength grout, using a combination of portland cement and fly ash, is pressure injected through the drill holes into the mine voids and rubble zones to fill voids. The properties of the grout plays an important role in the mitigation work, specifically the flowability, set time, strength, and aggregate type.

CTL/Thompson, Inc. has successfully used this technique in Rock Springs and Glenrock, Wyoming for more than 13 years with construction costs exceeding $60 million. Verification drilling and the lack of insurance claims or surficial subsidence features indicate that void fill grouting is an effective method to mitigate the effects of subsidence due to abandoned underground mines.

Introduction

The communities of Rock Springs, Glenrock, and Hanna, Wyoming were built over abandoned coal mines. Over time, the rock comprising the roof of the abandoned mines begins to fracture and collapse into the open mine. This process continues until the space is either occupied by rubble or the caving reaches the surface, threatening public health and safety. To successfully mitigate the potential of subsidence reaching the surface, a thorough understanding of the mining method and subsidence mechanism at work in any given mine is required and the proper mitigation method selected.

CTL/Thompson, Inc. has successfully used a “void fill” grouting technique in Rock Springs and Glenrock, Wyoming for more than 13 years during reclamation projects funded by the State of Wyoming, Department of Environmental Quality, AML Division, with construction costs exceeding $60 million. The void fill technique involves the drilling of small diameter holes on a grid spacing and injecting low strength grout. The grout is a combination of portland cement, fly ash, aggregate, and water and is pressure injected through the drill holes into the mine voids and rubble zones to fill voids. The properties of this grout play an important role in the mitigation work, specifically, the flowability, set time, strength, and aggregate type.

Mining Techniques

Mining in Wyoming underground coalfields typically utilized a “room and pillar” technique (Figure 1). The mines were accessed by vertical or sloped shafts called entries, with airshafts excavated parallel to the entry. Once the

entry shaft penetrated the mineable coal layer, motor roads or haulways were cut parallel and perpendicular to the strike of the seam. Rooms typically 20 feet wide and 100 to 300 feet long were then cut with pillars approximately 15 to 40 feet wide between rooms for support. During operation of the mine, between 30 to 60 percent of the coal was extracted by room and pillar mining.

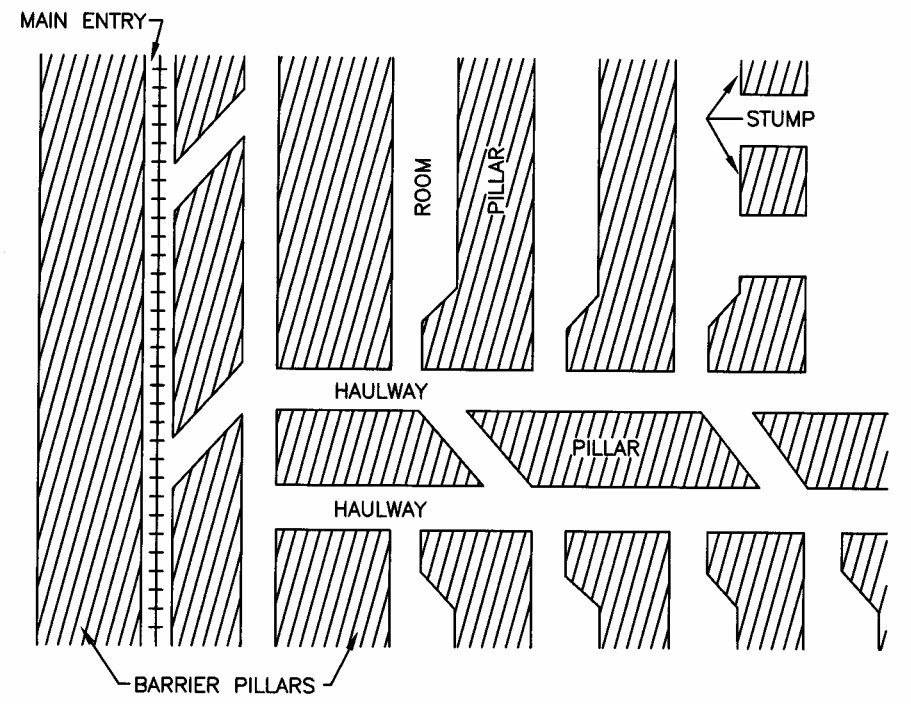

Figure 1. Room and Pillar Mining

Typically, 15 to 35-foot wide sections of the support pillars were removed leaving "stump" pillars. Following the retreat mining, the remaining pillars and roof coal were shaved. By the time the mines were closed, the overall coal extraction could reach 75 to 85 percent.

Closure and abandonment of the mines following the retreat mining was typically not well documented. As a result, mines were often larger and more extensively developed than shown on the mine map. Investigation has shown that many mines were closed by dumping debris, timbers, trash, and coal slack back into the entry. Airshafts and hoist shafts were often closed with a relatively shallow "plug" with soils and debris placed above the plug.

Subsidence Mechanism

When the mine is abandoned, the rock overlying the extraction is stressed and will subside into the extraction. The occurrence of subsidence and the mechanisms by which the overburden rock is distressed and displaced depend upon physical properties of the overburden, coal and floor materials, the size of individual extractions and extraction ratios achieved. Subsidence may be caused by failure of the mine roof, coal pillars, or mine floor materials. Subsidence may take the form of sinkholes or a chimney-type caving, a gentle sagging or trough-type subsidence, or settlement of backfill materials in entry or airshafts. The following paragraphs discuss subsidence mechanisms.

Caving Subsidence

Subsidence can produce sinkholes or depressions at the ground surface by caving of materials overlying comparatively shallow mine working. Caving occurs as the roof over an opening fractures and collapses into the space where the extraction has occurred. This process continues until the space is either occupied by debris or the caving reaches the surface (Figure 2).

Caving is common over room and pillar operations. The depth to mining and thickness of the bedrock are critical in determining whether or not the subsidence feature will reach the surface. Also important are the thickness of the extraction and bulking and strength characteristics of the overburden rock.

The size of sinkholes caused by caving is controlled by the geometry of the mine and properties of the overburden. The depth of the sinkholes depends on the depth to mining, thickness of the extraction, and bulking properties of the overburden. The real extent of surface depressions is largely controlled by the size of the mine opening. Research has found that sinkholes typically are circular or elliptical in shape and not larger than the size of the extraction causing them. The experience in the Rock Springs and Glenrock areas indicate caving is the most likely subsidence mechanism.

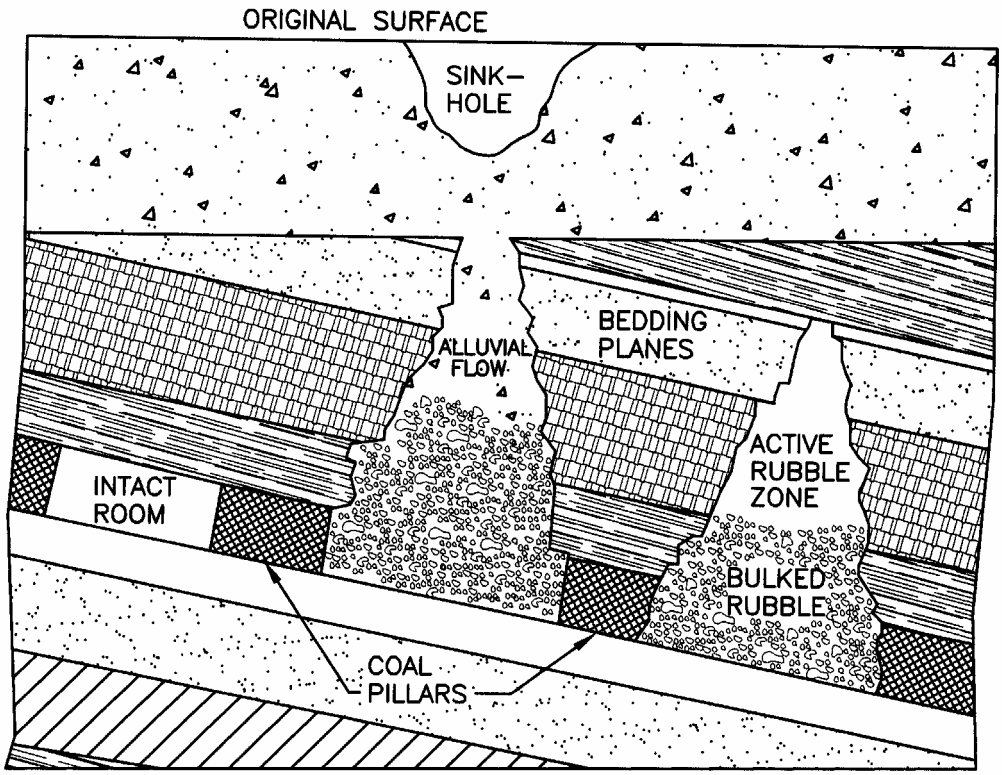

Figure 2. Caving Subsidence Mechanism

Trough Subsidence

Trough-type subsidence is a sagging of the overburden triggered where large extraction ratios and panel sizes are achieved, both in areas of room and pillar mining and longwall mining. This generally occurs as a caving of the immediate roof followed by sagging of overlying strata. Trough-type subsidence is the common mechanism over longwall mines in the United States and Europe. The presence of internal barriers and the low width to depth ratios helps reduce the magnitude of displacement. Experience in the Wyoming area indicates trough subsidence is very rare and occurs only in very shallow mines (at depths of approximately 50 feet).

Trough-type subsidence over room and pillar mining will be localized as compared to the area-wide troughs developed by longwall mining. As with sinkholes, the depth and extent of troughs will depend on the depth to mining, physical properties of the overburden, and extraction ratios achieved. The shape of depressions will be irregular due to the presence of remnant pillars. Like longwall mining, subsidence over retreat mining will develop rapidly due to the high extraction ratios achieved. Additional movement could occur from recompression of rubble or reorientation of beds that have sagged.

Shaft Collapse

The subsidence potential associated with entry or airshafts is high, because of the sudden and catastrophic nature of movement that can occur. Although small in area, shafts can be dangerous because of the haphazard way in which they were backfilled.

Evaluation of Subsidence Potential

The depth to mining is the critical factor used in evaluating the subsidence potential at a given site. The alluvial soils found in Rock Springs and Glenrock tend to flow into open holes and provide little strength in resisting subsidence. Therefore, the thickness of the bedrock over the mine becomes the critical factor in determining the subsidence potential in these areas.

There are several methods used to determine a minimum bedrock thickness above the coal seam beyond which caving subsidence will not be expected to reach the surface. The methods vary with respect to the treatment of subsidence mechanisms, mine geometry, geology, and mining method.

Mine Geometry

With this method, the critical dimensions affecting subsidence are the thickness of cover or overburden height (H) and the extraction thickness (h). Piggot and Eynon (1977) suggest subsidence will not propagate to the ground surface over room and pillar workings where the overburden to extraction thickness ratio (H/h) exceeds 10.

Bulking Factor

Caving of the roof above a mine can continue until the extraction and collapse area is filled with broken and bulked rock or the caving reaches the surface. With this method, the height to which caving can occur is based on the coal seam thickness and the bulking of the collapsed rock. The increase in the volume of the collapsed rock is referred to in terms of its "Bulking Factor" (Piggot and Eynon, 1977). The Bulking Factor is calculated in terms of thickness and defined as the original extraction height minus any remaining void divided by the height of the rubble zone above the mine roof.

National Coal Board's Method

The National Coal Board of the United Kingdom published a handbook (1975) that presents descriptive models that accurately predict ground movements over longwall mines in Europe. While useful in predicting subsidence in longwall mines, the applicability of this method in Wyoming is limited due to room and pillar mine geometries.

Complementary Influence Function

Complementary influence functions were developed (Sutherland and Munson, 1983) based on two elements: the mined element and an unmined element, assigning a surface response to each. The response of the unmined element is based on the elastic response of the strata overlying the structure while the response of the mined element is related to the breaking of the immediate roof and non-uniform distribution of voids in the rubble. This method is useful in both room and pillar and longwall applications and was used extensively in the Rock Springs area.

RUBBLE Model

The RUBBLE computer model uses a finite element method to predict rubble heights. The RUBBLE model (Benzley and Krieg 1982) is based on the principles of continuum mechanics and analyzes the geomechanical processes of roof failure and collapse caused by underground mining. Subsidence predictions using the RUBBLE model have correlated well with field measurements in the United States and Wyoming. The RUBBLE model was extensively used in the Glenrock area.

Subsidence Risk

Based on the analyses performed, subsidence risk is typically categorized as either 'low' or 'significant.' Areas around shafts or adits are classified as 'significant' due to the unreliable method of abandonment and catastrophic nature of subsidence in these areas. The remainder of the mine is classified based on the critical depth to the coal seam. Areas designated as 'low' subsidence risk are the deeper areas and generally have no development restrictions. Areas designated as 'significant' are the shallower areas and must either be mitigated or avoided.

Mitigation

Large portions of the mines in Rock Springs and Glenrock were classified as 'significant' subsidence risk based on critical bedrock thicknesses of 100 and 90 feet of bedrock cover, respectively. In both communities, areas of significant subsidence risk have been previously developed. Over the years, subsidence has reached the surface in numerous areas in the form of sinkholes. The ongoing appearance of new subsidence events prompted mitigation.

The mitigation technique selected for use by CTL/Thompson, Inc. in these communities was 'void fill' grout injection. The intent of void filling was to reduce the amount of existing void within the mine workings, thereby reducing the potential height of caving and decreasing the risk of subsidence.

The construction process involved drilling small diameter borings into existing mine voids and rubble zones followed by grout injection. A pilot program is performed prior to actual mitigation to determine the optimal hole spacing to ensure proper grout flow. The pilot programs conducted in Rock Springs and Glenrock indicated optimal hole spacing of 30-foot and 40-foot centers, respectively.

Grout

A single, low-strength grout mix comprised of water, cement, fly ash, and aggregate was used. The properties of the injected grout play perhaps the biggest role in the successful mitigation of the mines in these communities. These properties include the flowability, aggregate type, set time and strength.

Flowability

The conditions of the mine vary from drill hole to drill hole. Some areas had large amounts of open void where other areas had tight rubble with very little void. This variation makes injection of a single grout mix difficult resulting in poor grout flowability. The keys to flowability are water content, fly ash, and rounded aggregate particles. The mix design for the projects was the responsibility of the contractor. Initially, contractors had a very difficult time developing a mix design that provided strength and flowability. Specifications called for a minimum of 500-psi strength over a range of slumps from 2 to 8 inches to provide for adequate flow. The adjustable slump allowed rapid modification of the grout in the field that enabled the adaptation of the grout to varying conditions found within the mine workings. In order to promote flowability, the higher slump grout was used in areas of tight rubble, helping the grout travel through the smaller voids between the bulked rocks. The use of fly ash in the mix further enhanced Flowability. Fly ash was selected because the rounded particles significantly aided the mixes ability to flow. Fly ash also improved the strength of the mix.

Aggregate Type

The type of aggregate used in the grout also affects flowability. The specified aggregate consists of natural, clean, hard, tough, durable, rounded particles with a maximum size of ½-inch. Manufactured sands were strictly prohibited from use. The difference between rounded sand and manufactured sand not only affects flowability, but also constructability. Manufactured sands have sharp faces which tend to not only reduce the flowability of the grout in the rubble zones, but also showed a tendency to clog or lock-up in the grout pipe. The use of natural sands not only made pumping easier, but also acts as a natural lubricant within the grout to help flowability through tight rubble zones.

Set Time

The set time of the grout mix was critical in that the time it took to empty a mixing truck was longer than pouring concrete directly down the chute. The mixer truck sends the grout into the hopper of the grout pump. The pump then injects the grout through a series of pipes placed in the drill hole. The rate of pumping is generally between 5 and 30 cubic yards per hour.

Some fly ash has a tendency to hot flash, and set quickly. The use of this type of fly ash in the grout mix can not only restrict flowability through the mine, but may also set in the pipe. Fly ash conforming to ASTM C 618-93 was specified to help prevent flash setting.

Strength

The grout mix specified was to have a minimum compressive strength at 28 days of 500psi over the full range of slumps. This strength value was selected to provide enough support for the overlying bedrock, yet also remain removable if grout traveled shallow enough to be excavated during utility work or future construction. In addition, the low strength allowed a significant amount of fly ash to be utilized in the mix. The fly ash was used as bulk filler material and a workability agent. This resulted in the ability to lower the amount of cement used in the grout mix, which ultimately made the grout a more cost effective approach to mitigation.

Mitigation Effectiveness

Mitigation of abandoned coal mines is only practical if the effectiveness can be verified. During and shortly after mitigation, verification drilling, coring, geophysical logging, and visual identification of drill cuttings were used to confirm the presence of grout. Likewise, over the past 13 years, the lack of insurance claims or surficial subsidence features in mitigated areas also lend to the effectiveness of the void filling technique.

Verification Drilling

Verification drilling and coring was used to confirm the effectiveness of void filling in both Rock Springs and Glenrock. During the course of the mitigation, areas were identified where additional evaluation of the grout flow was required. Typically, these areas were between the holes of the grid spacing and in areas of low or questionable grout injection volumes. During verification drilling, the additional holes are drilled throughout the mitigated areas. Verification holes were geophysically logged where possible. If conditions made geophysical logging not possible or if roof contact was not demonstrated, grouting was attempted.

Coring

Coring was done in mitigated areas to also confirm the presence of grout. When coring was conducted, holes were rotary drilled to a point above the projected mine interval then cored through the grouted interval with a 2.5 to 3.34 inch diameter barrel. Core samples retrieved were boxed and kept as visual documentation of the effectiveness of the mitigation.

Summary

CTL/Thompson, Inc. in conjunction with the State of Wyoming, Department of Environmental Quality, Abandoned Mine Lands Division has used the void fill grouting technique to successfully mitigate more than 96 surface acres of land. This land was already developed and not only had low property values, but posed public health and safety issues. Since mitigation, property values have improved, funding from the Federal Housing Administration has been reinstated and public confidence restored. We feel void fill mitigation is a viable, proven mitigation alternative to reduce the risk of subsidence due to the presence of abandoned underground mines. In addition to the work already performed in Rock Springs and Glenrock, Wyoming, some municipalities in the Denver, Colorado area are considering the use of void fill grouting in undeveloped areas. Such mitigation would be unprecedented in the Denver region and would allow previously ‘unusable’ land to be developed.

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MONITORING AND ENVIRONMENTAL PERFORMANCE OF CCB DISPOSAL ACTIVITIES AT GREAT RIVER ENERGY'S COAL CREEK STATION

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Abstract

Great River Energy's (GRE) Coal Creek Station (CCS) generation facility is a two-unit 1100-megawatt lignite-fueled power plant located 50 miles northwest of Bismarck, North Dakota that has been in operation since 1980. Presently, CCS has two ash disposal ponds, four evaporation ponds, a recycle pond, an extended basin for cooling water storage, a river water basin for storage of raw water, and five special waste landfills for the containment of coal combustion by-products (CCBs), along with several ancillary facilities. As with any large industrial site, CCS's numerous facilities require monitoring of environmental performance, both in terms of regulatory compliance and proactive site management. With more than 20 years of power generation compliance, the sheer volume of data produced by environmental monitoring at CCS has become unwieldy to manage. This paper describes the quantity of performance monitoring data, regulatory monitoring reporting requirements, volumes of technical reports, and GRE's efforts to manage these data efficiently.

The results of GRE's efforts have led to the development of a "web-based" information system to track and monitor the performance of their facilities. By providing environmental management employees with access to "real-time" data with presentation of results, GRE has been able to address both internal and external needs regarding the historic and present status of CCB environmental issues. This paper will present an overview of the web-based information management approach, with an emphasis on the beneficial outcome for the utility and a summary of potential future enhancements.

Introduction

The Coal Creek facility is a two-unit 1100-megawatt lignite-fueled power plant located 50 miles northwest of Bismarck, North Dakota that has been in operation since 1980. Presently, CCS has two ash disposal ponds, four evaporation ponds, a recycle pond, an extended basin for cooling water storage, a river water basin for storage of raw water, and five special waste landfills for the containment of coal combustion by-products (CCBs), along with several ancillary facilities. CCS ponds and special waste landfills are currently regulated by the state of North Dakota through multiple special waste permits. As a condition of the special waste permits, a groundwater-monitoring program was initiated in 1979. At one point, the monitoring program consisted of 158 groundwater-monitoring wells, 9 observation wells/piezometers, 33 surface water samples, and 9 snowmelt samples. Individual sampling sites were monitored for as many as 47 analytical parameters. The number of records in GRE's CCB environmental monitoring Access™ database exceeded 4,400 entries.

In addition to groundwater analytical data, other supporting documentation for the program includes permit applications, well construction data, site construction and closure quality assurance documentation, Annual Water Quality monitoring reports, and miscellaneous correspondence, all of which is stored in plant project files, environmental files, and the plant library. The sheer volume of information made any analysis of the data a major undertaking and location of any specific information time consuming. Great River Energy, in order to capitalize on full use of the data collected, save time, and better manage the facility, decided to explore technological solutions to this environmental data management nightmare. This paper focuses on the technical solution to the management of the environmental performance of CCBs as related to GREs large database containing water quality monitoring results.

Approach

GRE's approach to a technological solution began with identifying requirements for a data management platform. Important considerations for selection of a technological solution included:

- Cost, both initial capital and maintenance
- Training and technical support requirements (if any)
- Security
- Corporate access and involvement (if any)
- 3rd party access (i.e., extranet)
- Portability (via dialup, Internet)
- Applications development (who and how)
- Staging of functionality (how much when)
- Legacy data (all or some, if some, how much)
- Access to legacy systems (Microsoft Access™, AutoCAD™)

Current GRE capabilities for environmental monitoring utilizing a Microsoft Access™ database included:

- Water quality data, water levels, well construction
- Access™ meets current and future needs (expandability)
- Standard for archiving
- Commonplace
- Facilitates data processing/reporting and relational needs

GRE's objectives for the enhancement of the environmental reporting and retrieval of information included:

- Tailor access to see what you need
- Easier and more efficient data access, processing, visualization, and conceptualization
- Timesavings by users (CCS, GRE, consultants)
- Improve response time
- Improve data QA
- Improve integrity and defensibility
- Increase analytical capacity
- Expansion to other activities at site (e.g., operations, Falkirk)

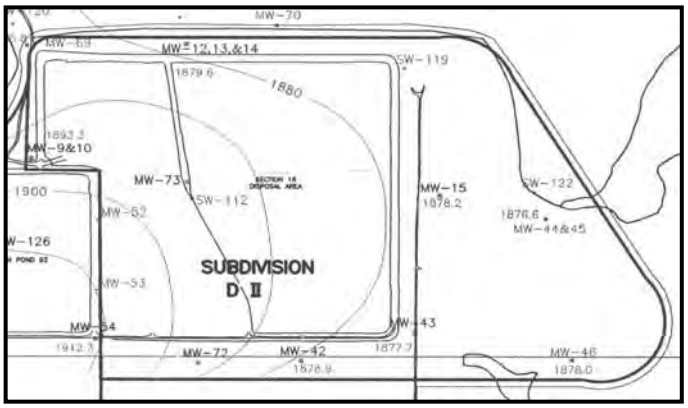
Software Requirements

Whenever possible, it is GRE's preference to purchase off-the-shelf platforms. While off-the-shelf software may not always meet all user requirements, the extra costs of customized software, which can easily get out of control, may not be worth the extra expenditure. Since the groundwater data is so substantial, the best fit would be software compatible with GRE's existing information management infrastructure and capabilities.

GRE desired minimal reliance on outside parties for maintenance of the software. The software needed to be intuitive and require minimal training as casual users might use the software only on an infrequent basis. A final requirement was that conversion to the new software application should be minimally disruptive of the current operation.

Analytical Data Requirements

One of the primary reasons for embarking on a better method of dealing with the volumes of analytical data was to have easier and more efficient data access and visualization processes. For more than 20 years, the plant had been monitoring hundreds of wells for numerous analytical parameters. Any software solution needed to have the ability to allow visualization of the physical location of monitoring wells, see Figure 1, with the ability to correlate well location data to the location and permit.



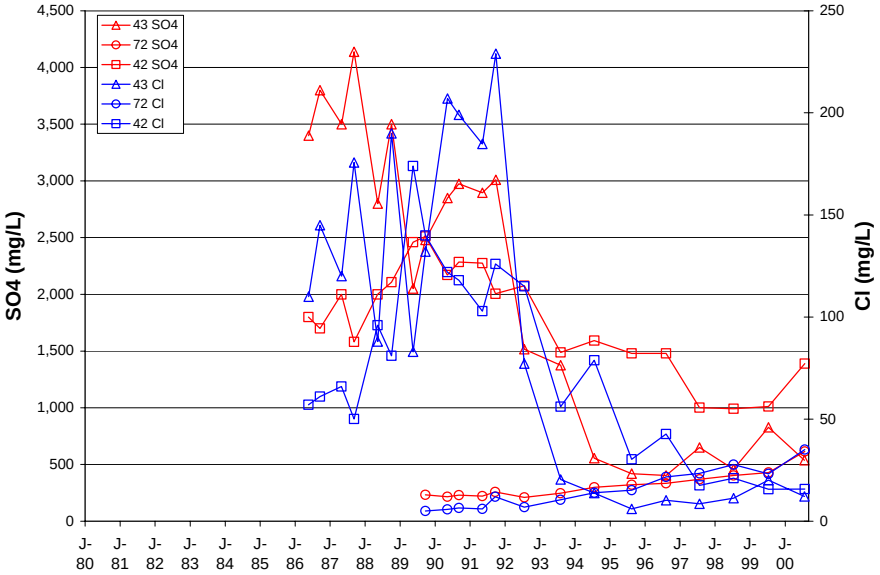


Figure 1. Sample of well location drawing with environmental time series data graph.

GRE's laboratory had improved data handling several times throughout the history of the water quality-monitoring program. Laboratory data were currently stored in a large Microsoft Access™ database (approximately 100 megabytes). Missing was the ability to easily view data trends graphically, viewed as a requirement by both routine and casual users.

All groundwater monitoring analysis includes quality control/quality assurance; however, lab anomalies and data transfer errors happen when handling large volumes of data. Improving data management had the potential to improve integrity and defensibility of the groundwater-monitoring program. The laboratory was so busy generating data and doing laboratory quality assurance/control that little time was left to take a more global review of the data. There were no easy methods to allow laboratory personnel to ask the question "Does this data differ significantly from past year's analysis and how are data entry errors identified?" The ability to assess data in such a manner would allow laboratory personnel to repeat analyses that appeared to be outliers before samples had exceeded the holding times, or to resample wells that were outliers.

Future Enhancements

GRE did not have the resources or budget to accomplish the entire scope of the data management project in a short time period. GRE's preference was to develop an approach that would allow expandability for incorporation of a "digital library" that might include such things as an archive for project reports, drawings, presentations, photographs, procedures and protocols, forms, policies, and communications. Consideration was given to platforms that could integrate legacy systems with disparate islands of information into core business practices.

Other future requirements include an easy generation and visualization process for review of the regulatory statistical requirements and enhancements for legacy and future data. Some data enhancements that were identified as potential future enhancements are addition of non-detects, method detection limits (MDLs), practical qualification limits (PQLs), qualifiers, sample/analysis dates, comments, and laboratory quality assurance such as duplicate and blank results.

The solution for the groundwater-monitoring data management had to have the potential to expand into other plant documentation activities such as the engineering library, project files, O&M manuals, and numerous other areas.

Evaluation

Once CCS established requirements for the data management system, Golder Associates was hired to evaluate available options. The criteria GRE asked Golder to use included:

Software Requirements

- Cost: relatively low cost and an "off-the-shelf" platform
- Training: user-friendly, requiring minimal training
- Maintenance: Software can be maintained with minimal outside help

Analytical Laboratory Requirements

- Input: Easy to input data
- Queries: Ability to query data
- Views: Ability to review data spatially

As part of the option evaluation the advantages and disadvantages and estimated costs also were projected. Arcview™, MapInfo™, and a web-based platform were evaluated.

Arcview™ – Is excellent software with full GIS/mapping capability, (see Figure 2, below). It is the standard for spatial analysis. Arcview™ has the ability to integrate images, CAD maps, data tables, and SQL databases into the software. It is completely customizable. The software has more capability than GRE requires and expected initial costs to develop the program are more expensive than the other options reviewed.

MapInfo™ – MapInfo™ has comprehensive desktop mapping (see Figure 3, below). It has an easy to use GUI with analysis and visualization. Map object editing, presentation layout, geographic queries, and integration of SQL database are possible in MapInfo™. Queries can be imported and data can be exported. Customization of the software is possible. The software is designed more for decision-making but can be made into what GRE desires. Costs and efforts for initial development are higher than other approaches. The software has more capability than GRE requires.

Web-based Information Management (IM) – Access to the program is through an Internet connection or modem and the application can be secured via different levels of access or types of user privileges (see Figure 4, below). Maps linked to data can be as simple or complex as desired and the data can be static or dynamic. The software would rely on existing web browsers with low-cost product development add-ins. CCS can maintain and develop the site and the system does not require extensive training or GIS expertise to operate. Fewer software licenses and other resources are required. If expectations are clearly defined, overall costs will be lower. The platform allows for file upload/download, messaging, user or member forums, and other collaboration tools.

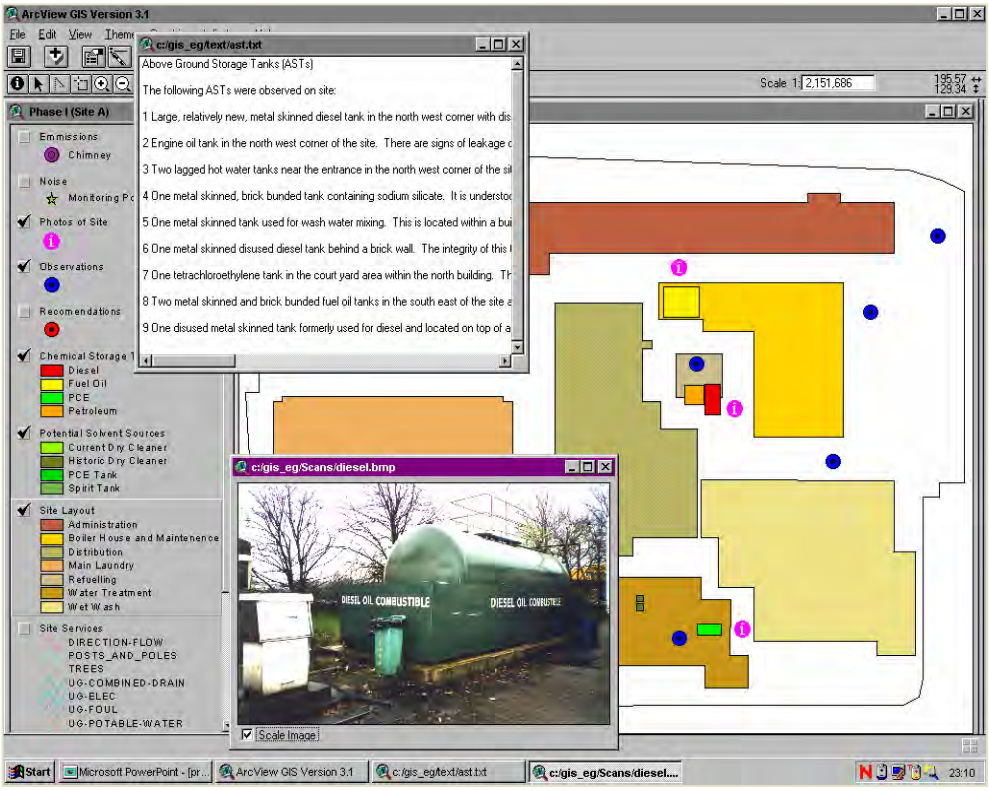


Figure 2

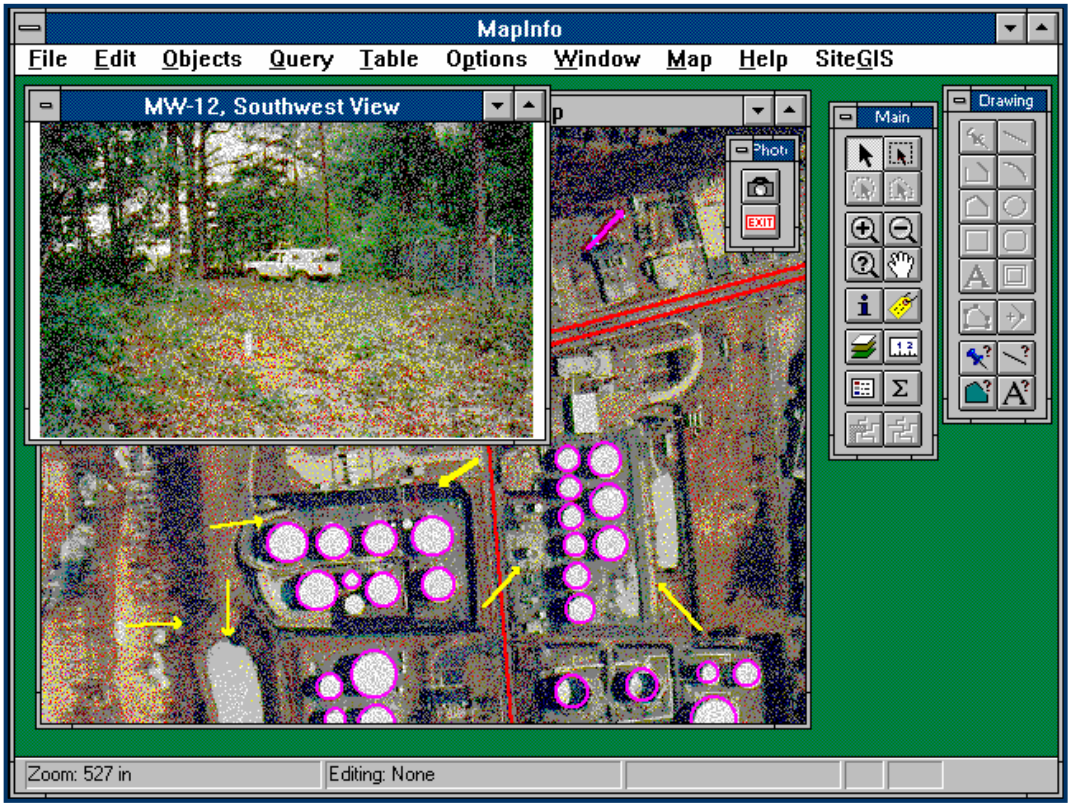


Figure 3

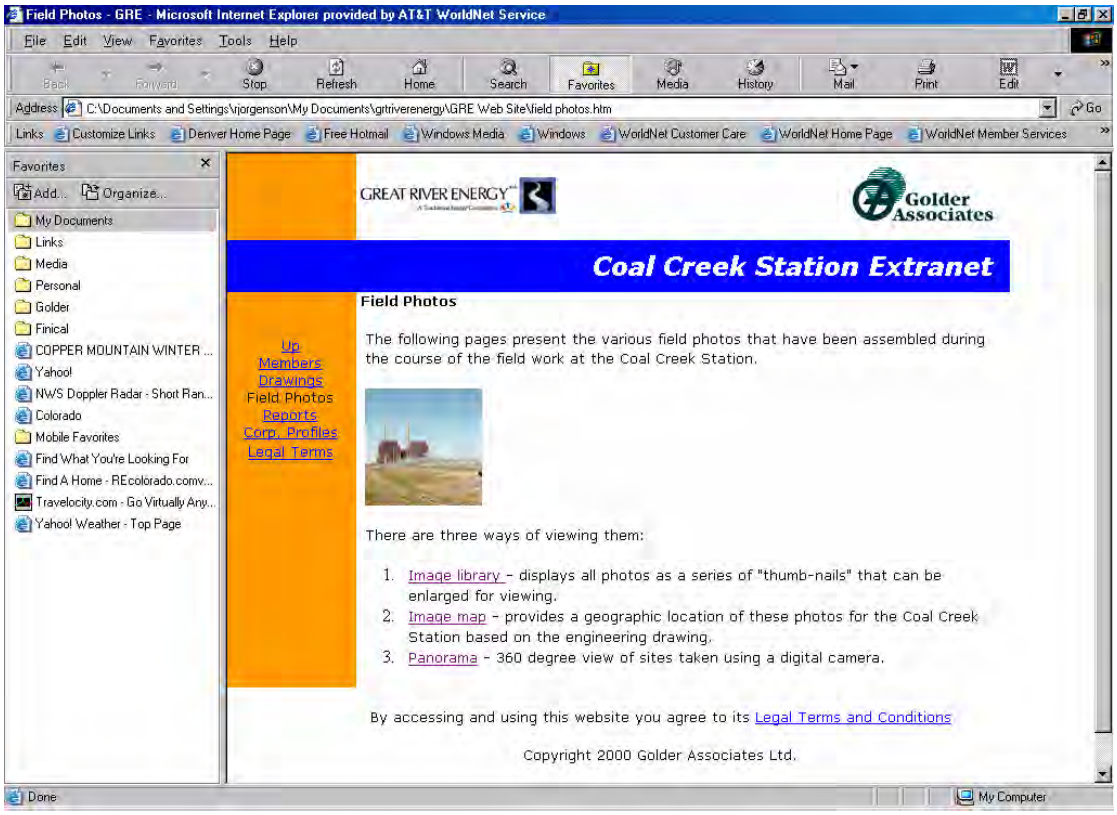


Figure 4

Web-Based Solution

GRE elected to use a web-based solution, similar to Figure 5 below, for the management and visualization of environmental performance monitoring data management. This solution was chosen based on a number of GRE criteria, including the following:

- Deploying over the web:
  - intranet (one site or multiple sites, internal only)
  - extranet (internal plus contractors and other parties)
  - virtual private network (VPN) with different levels of access or types of user privileges.
- Less training and GIS expertise needed
- Fewer software licenses and other resources required
- Overall cost will likely be less
- Relies on existing web browsers with low-cost product development add-ons

This web-based information management solution has enabled GRE staff to have real-time access to site water quality data, displayed in a meaningful format, even though employees may not be familiar with specific areas or facilities at CCS. The web-based platform, with its timely information, has enabled GRE environmental managers with the ability to rapidly and efficiently respond to requests for specific CCB monitoring information from both internal and external sources.

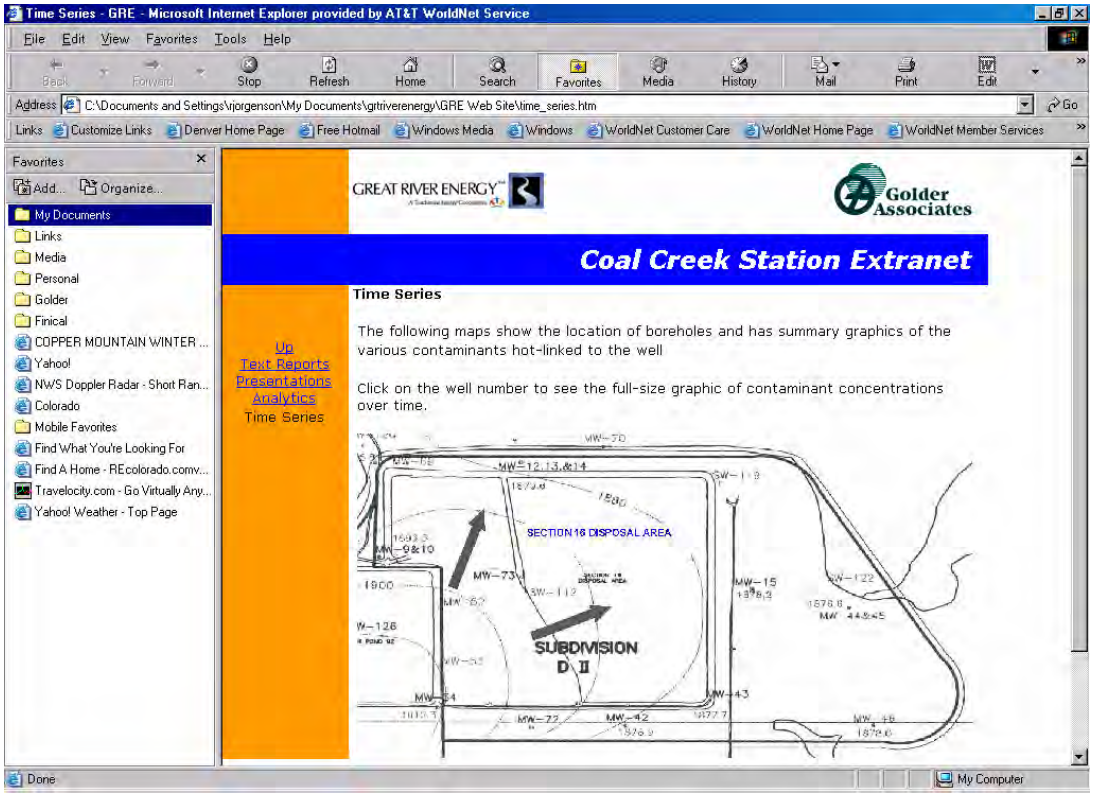


Figure 5

Future Enhancements

The future environmental management information solution for GRE will likely involve a web-based, off-the-shelf, data management platform that will serve as a portal through which data files, emails, text, drawings, forms, records, and other GRE information will flow. Users will be able to build custom formats that incorporate web-type applications to integrate services and information such as the evaluation and monitoring of environmental water quality data. GRE's existing web-based solution to management of CCS site water quality data is an example of how a web-based platform enables its users to access real-time data in a meaningful format.

In the competitive power conversion business, efficient information management isn't optional, and the management of this information can be a competitive advantage. However, effectively managing CCS's wealth of information, both present and legacy data, is no simple task. The utilization of web browsers to access information has led to off-the-shelf platforms, via enterprise information portals, that enable users to have access to a wealth of varying information in an integrated format functionally over the Internet. These off-the-shelf platforms serve as a document management service, brokering communications between Windows™ and web applications. The solution to harnessing GRE's environmental information lies in effective document management that builds on GRE's present web-based solution.

Dianne Stockdill is the Environmental Coordinator at Great River Energy's Coal Creek Station. As the Environmental Coordinator, she has experience in the many coal combustion by-product projects pursued by Great River Energy in order to support and further the use of these by-products. She is a graduate of North Dakota State University and has more than 20 years of experience in the power industry.

THE OFFICE OF SURFACE MINING'S PERSPECTIVE ON COAL COMBUSTION BY-PRODUCT DISPOSAL ON NATIVE AMERICAN LANDS

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Abstract

The Office of Surface Mining Western Regional Coordinating Center (WRCC) regulates CCB disposal operations at one surface coal mine on the Navajo Reservation. Because the Surface Mining Control and Reclamation Act of 1977 (SMCRA) and the implementing regulations do not contain specific requirements for CCB disposal at coal mines, WRCC developed a guidance document to ensure that CCB disposal at surface coal mines will comply with the requirements of SMCRA and the applicable regulatory program. Most States also have developed policies for coordinating the regulation of CCB disposal at coal mines between State agencies. There are broad differences between States, as well as on Indian lands, in the requirements and methods for regulating CCB disposal operations at coal mines. The WRCC guidance is but one approach to such regulation.

Background

Four years ago at the first CCB forum, Office of Surface Mining (OSM) Acting Director Kay Henry addressed the increased interest in coal mines as disposal sites for coal combustion by-products (CCBs). She noted that neither the Surface Mining Control and Reclamation Act (SMCRA) nor OSM's regulations specifically address the use or disposal of CCBs at surface coal mines; however, she recognized that CCB use and disposal at active mine sites is not precluded so long as such disposal is conducted in accordance with the environmental protection standards of SMCRA and with applicable solid waste disposal requirements. Director Henry also recognized the challenge to State regulatory authorities to develop appropriate strategies for integrating the concerns of State solid waste programs with SMCRA programs regarding CCB disposal on permitted coal mine sites. That challenge also is shared by OSM to the extent that we are the regulatory authority on Indian lands and in States with Federal programs.

The BHP Navajo Mine

Coincident with the first CCB forum in 1996, BHP Navajo Coal Company informed OSM's Western Regional Coordinating Center (WRCC) of its intent to expand ongoing CCB disposal operations at the Navajo Mine onto lands regulated under the Indian lands permanent program. Facing a forthcoming permitting action for CCB disposal, we embarked on developing guidance for permitting and regulating disposal operations at active mines under the Indian lands program. The resulting WRCC guidance document is the subject of this presentation.

WRCC is currently completing the technical review of BHP's permit revision application to dispose of CCBs on permanent program lands at the Navajo Mine. The public comment period ends on May 30. BHP has been disposing CCBs at the Navajo Mine since 1971 under 1968 authorizations by the Navajo Nation and Secretary of the Interior Udall, and subsequently by OSM in the mid-1980s under the initial regulatory program. BHP disposes about 1.9 million cubic yards annually and anticipates that disposal will increase to 2.6 million cubic yards per year after 2004.

A Federal Program Guidance Document for Permitting Coal Combustion By-Products

Director Henry, at the 1996 forum, also noted the differing chemical and physical characteristics of CCBs, regional differences of mine sites, and differences in regulatory requirements among the States. Our research in developing WRCC's guidance document certainly confirmed the broad differences between States (and on Indian lands) in the requirements and methods for regulating CCB disposal operations at coal mines. Accordingly, WRCC's approach to regulating CCB disposal should be regarded as but one of many approaches and one which we may modify as we work through the process.

Objectives and Strategies

In developing WRCC's guidance document we identified five objectives for regulating CCB disposal under SMCRA and applicable solid waste disposal requirements, and then formulated strategies to achieve those objectives.

Objective 1

CCB disposal operations will not cause a violation of, or create a variance from, the reclamation and environmental protection performance standards of SMCRA and the applicable SMCRA regulatory program.

Strategy 1.1 ***CCB disposal operations should comply with the backfilling and grading performance standards at 30 CFR 816.102.*** CCB disposal is usually conducted with the backfilling activities and is handled in the same manner as spoil. Therefore, the backfilling and grading performance standards should be applicable to the CCB disposal operations, except as noted below in Strategies 1.2 and 1.3.

Strategy 1.2 ***The final surface configuration of the mined-out area where CCBs are disposed should achieve the approximate original contour (AOC) in accordance with 30 CFR 816.102(a), and the AOC variances allowed at 30 CFR 816.102(k)(3)(ii), 785.16 and 816.133(d) and the thick overburden AOC exemption allowed at 30 CFR 816.102(k)(2) and 816.105 should not be applicable.*** CCB disposal operations should not be allowed in areas where AOC could not be achieved. The additional volume of CCBs, imported into the coal mine from an outside source, should not cause any variance or exemption from the AOC requirements.

Strategy 1.3 ***CCBs should not be disposed in mined-out areas if spoil would be displaced and disposed as excess spoil.*** CCB disposal should be allowed only where disposal capacity would be available after all spoil is returned to the mined-out area. CCBs should not displace spoil that otherwise would be returned to the mined-out area. In accordance with 30 CFR 816.102(b), all spoil, except excess spoil, must be returned to the mined-out area. Excess spoil includes only that spoil that is not needed to restore AOC [48 FR 23358, May 24, 1983]. Excess spoil disposal areas should not be created, or enlarged, to provide capacity for disposal of CCBs. In a decision concerning the creation of excess spoil, the IBLA noted, "There is nothing 'automatic' about the privilege to treat spoil as 'excess'." [Pacific Coast Coal v. OSM, 118 IBLA 83, Case No. IBLA 91-121, 1991]

Strategy 1.4 ***CCBs should be disposed in a controlled manner in designated disposal sites in the permit area in accordance with 30 CFR 816.89.*** CCBs are solid wastes that should be subject to the appropriate performance standards for disposal of noncoal mine wastes at 30 CFR 816.89, which follow the solid waste disposal criteria of 40 CFR Part 257.

Strategy 1.5 ***CCB disposal operations should be conducted to minimize disturbance to the hydrologic balance within the permit and adjacent areas, to prevent material damage to the hydrologic balance outside the permit area, to assure the protection and replacement of water rights, and to support the approved post-mining land uses.*** The potential for groundwater pollution is singularly the greatest environmental concern of CCB disposal at mine sites. CCB disposal should be subject to the hydrologic balance protection standards at 30 CFR 816.41.

Strategy 1.6 ***The timing of CCB disposal operations should be based on completion of all mining and reclamation operations in accordance with contemporaneous reclamation performance standards.*** CCB disposal as monofills in final pits and ramps could delay final reclamation for a considerable time (possibly many years) depending on the

disposal rate. The timing of disposal, backfilling, and final grading of CCB disposal areas should be clearly identified in the permit application and considered in the permitting decision**.**

Objective 2

CCB disposal operations must conform to applicable State, Tribal, or local solid waste disposal laws and regulations, in addition to SMCRA and the SMCRA regulatory program.

Strategy 2.1 ***The permit application should describe the steps that have been taken to comply with applicable Federal, State, and Tribal solid waste disposal laws and regulations.*** Under 30 CFR 780.18(b)(9), the permit application must contain a description of the steps to be taken to comply with the requirements of applicable air and water quality laws and regulations and health and safety standards.

Strategy 2.2 ***OSM should consult with State, Tribal, and local solid waste regulatory authorities to ensure that CCB disposal operations conform to State, Tribal, or local laws and regulations governing solid waste disposal and to coordinate the review and issuance of permits.*** Section 504(h) of SMCRA requires coordination of the review and issuance of permits with other Federal, State, or Tribal permit process applicable to the proposed operation. Section 702 of SMCRA precludes it from superseding, amending, modifying, or repealing the Solid Waste Disposal Act and other environmental statutes and rules or regulations promulgated thereunder. Therefore, consultation with the solid waste regulatory authority is appropriate.

Objective 3

CCB disposal operations must be approved in a SMCRA permit application in conformance with the permitting requirements of the applicable SMCRA regulatory program before the disposal operations may begin.

Strategy 3.1 ***Any permit revision application proposing CCB disposal is a significant permit revision subject to the notice, public participation, and notice of decision requirements of 30 CFR 773.13, 773.19(b)(1) and (3), and 778.21.*** Federal, State, Tribal, and local agencies and the public should be notified of any revision that proposes CCB disposal operations. Public interest in the location and methods of solid waste disposal is almost always high, and the agency notifications required at 30 CFR 773.13(a)(3) also support Objective 2, above.

Strategy 3.2 ***The permit application or permit revision application should contain applicable information required for an alternative land use at 30 CFR 780.23(b).*** Although CCB disposal operations conducted concurrently with surface coal mining and reclamation operations would not require a post-mining land use change pursuant to 30 CFR 816.133(c), the disposal operations would be an additional, joint land use with the coal mining and reclamation operations. Similar to the post-mining land use discussion required by 30 CFR 780.23(b), the permit application should include a specific discussion of (1) the utility and capability of the land where CCBs are disposed to support a variety of alternative uses, (2) the relationship of the proposed CCB disposal operations to existing land use policies and plans, and (3) the consideration which has been given to making all of the proposed CCB disposal activities consistent with surface owner plans and applicable State and local land use plans and programs. The description should be accompanied by a copy of the comments concerning the proposed CCB disposal operations by the legal or equitable owners of record of the surface of the land where CCB disposal would occur, and the State, Tribal, and local government agencies which would have to approve or authorize the solid waste disposal operations.

Strategy 3.3 ***The permit application should contain, for each area where CCBs would be disposed, a copy of the written consent of the surface owner for CCB disposal; a copy of the conveyance that expressly grants or reserves the right to dispose of CCBs; or if the conveyance does not expressly grant the right to dispose of CCBs, documentation that under applicable State or Tribal law, the applicant has the legal authority to dispose of CCBs.*** In conformance with the purpose of SMCRA at Section 102(b) to assure that the rights of surface landowners are fully protected, the applicant must demonstrate "right-of-entry" for CCB disposal operations.

Strategy 3.4 ***CCB disposal sites should be specifically designated, described, and identified on a map.*** Under 30

CFR 816.89(a), noncoal mine wastes (i.e., solid wastes) must be placed in a designated portion of the permit area (see the discussion for Strategy 1.4). The requirements for maps and plans at 30 CFR 780.14(b)(8) and (11) require that waste disposal facilities be shown on a map.

Strategy 3.5 ***A CCB disposal plan should be included in the Reclamation and Operation Plan required under 30 CFR Part 780.*** CCB disposal operations would be an integral part of the surface coal mining and reclamation operations approved in the permit application, and a CCB disposal plan should be included in the permit application. The backfilling and grading performance standards should be used for evaluating the proposed CCB disposal plan. The plan should:

- Identify the source and components (e.g., fly ash, bottom ash, scrubber sludge) of the CCBs.
- Describe the physical and chemical properties of the CCBs.
- Include data and analysis used to determine the physical and chemical properties of CCBs, cover requirements and, if needed, treatment or encapsulation requirements for the disposal of the CCBs.
- Identify and describe the location of designated CCB disposal areas, the volume and disposal rate of CCBs in each area, and the anticipated or actual starting and ending dates of disposal activities in each designated disposal area.
- Describe the plans and procedures to transport, handle, place, treat, if necessary, and bury CCBs. The plans and procedures should include the routes, methods and equipment to be used to transport the CCBs on the mine site; the method of placement; any special handling procedures to be employed (e.g., mixing with spoil, cell construction practices); the depth of cover to be placed over the buried CCBs; the type, amount, and source of the nontoxic and noncombustible materials that would be used to cover and, if applicable, encapsulate, or isolate, the materials; and the methods and specifications for treating the materials, if applicable.
- Describe how the disposal measures to be employed would effectively avoid acid or toxic drainage, control the impact on surface water and groundwater, and minimize adverse effects on plant growth and the post-mining land use.
- Describe the effect of CCB disposal on achieving the approximate original contour.
- Describe the timing and schedule of CCB disposal, backfilling, and final grading of CCB disposal areas.
- Include the names of persons or organizations that collected and analyzed the data and information contained in the disposal plan, the dates of the collection and analysis, and description of the methodology used to collect and analyze the information.

Strategy 3.6 ***The fugitive dust control practices in the air pollution control plan should specifically address the CCB disposal operations, including fugitive dust control during transport and placement of the CCBs within the permit area.*** Fly ash, usually the major component of CCBs, is very powdery and very susceptible to wind erosion.

Strategy 3.7 ***The probable hydrologic consequences analysis and hydrologic reclamation plan in the permit application, and the Cumulative Hydrologic Impact Assessment prepared by OSM, should specifically address the CCB disposal operations, including the probability of adverse impacts on the hydrologic balance, contamination of surface or groundwater supplies, and the time for manifestation of impacts to surface or groundwater supplies.*** The probable hydrologic consequences analysis contained in the permit application should specifically address the CCB disposal operations. Groundwater monitoring plans should specifically analyze and assess monitoring needs around CCB disposal areas and consider the length of time for the manifestation of any effects of disposed CCBs on groundwater resources. CCBs should be regularly sampled and tested throughout the disposal period to assure consistency with the materials tested for permit issuance and plan approval.

Objective 4

CCB disposal operations will be conducted only as described in the approved permit application and in accordance with the applicable performance standards.

Strategy 4.1 ***CCB disposal operations should be inspected and enforced by OSM in accordance with the inspection and enforcement provisions of the applicable regulatory program and 30 CFR Parts 842 through 846***. OSM inspectors should inspect the CCB disposal operations as an integral part of the surface coal mining and reclamation operations to ensure they are conducted only as described in the approved permit application and in accordance with applicable performance standards of SMCRA and the applicable SMCRA regulatory program.

Inspectors should understand and be aware of the disposal and reclamation requirements for CCB disposal areas, requirements for periodic sampling and testing of the CCBs, materials handling and compaction requirements, and disposal locations and elevations (depths) that may be critical. OSM inspectors should be trained specifically in the potential environmental, health and safety hazards, and special environmental considerations of CCBs and CCB disposal operations. Some CCBs can contain high levels of toxic substances. Some CCBs can be so highly alkaline that they cause caustic burns.

Objective 5

CCB disposal areas will be fully reclaimed in accordance with the applicable performance standards and the approved permit application.

Strategy 5.1 ***The evaluation of any phase I, II, or III bond release application involving a CCB disposal area, including the determination of the amount of bond to be released, should consider whether pollution of surface and subsurface water is occurring, the probability of future occurrence of such pollution, and the estimated cost of abating such pollution.*** The bond release requirements at 30 CFR 800.40(b)(1) require evaluation of "whether pollution of surface and subsurface water is occurring, the probability of future occurrence of such pollution, and the estimated cost of abating such pollution." The period of liability provisions at 30 CFR 800.13 are based primarily on achievement of successful revegetation, although 30 CFR 800.13(a) also adds "or until achievement of the reclamation requirements of the Act, regulatory programs, and permit, whichever is later." Similarly, the Phase II bond release criteria at 30 CFR 800.40(c)(2) are concerned principally with the establishment of vegetation capable of controlling erosion. Groundwater pollution, which potentially could result from CCB disposal, could take more than twenty years to manifest itself in some groundwater systems.

Richard Holbrook is the manager of the Southwest Program Operations Branch of the U.S. Office of Surface Mining's Western Regional Coordinating Center. Holbrook received a B.A. degree in Environmental Biology from the University of California at Santa Barbara in 1972. During his 15 years with OSM, he has been involved in Federal lands program activities in the western States and permitting activities under the Indian Lands Program and Washington and California Federal programs. He has authored numerous permitting guidance documents used in OSM's Western Region, including the guidance for the disposal of coal combustion by-products at coal mines on Indian lands and in States with Federal programs. Before joining OSM, Holbrook was the Environmental Quality Control Supervisor for Consolidation Coal Company's Western Region, and, was the Director of the Environmental Sciences Division of VTN Colorado, an environmental consulting firm.

Session 4

Environmental Impacts to Groundwater

Session Chairperson:
Lynn Brickett
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Pittsburgh, Pennsylvania

Field Scale Study Results for the Beneficial Use of Coal Ash as Fill Material in Saturated Conditions, Varra Coal Ash Burial Project, Weld County, Colorado
Joby Adams, Colorado Groundwater Resource Service, Fort Collins, Colorado

CCB Leaching Summary: Survey of Methods and Results
Ann Kim, U.S. DOE National Environmental Technology Laboratory, Pittsburgh, Pennsylvania

Water Quality at a Coal Ash Filled Surface Coal Mine Pit in Indiana
Ishwar Murarka, Ish Inc., Sunnyvale, California

Mine Placement of CCPs Data Collection and Risk Assessment: MRAM—An International and Interagency Cooperative Project
Andrew Wittner, U.S. Environmental Protection Agency, Annapolis, Maryland

Microbial Release of Mercury from Coal Combustion By-Products
David Hassett, Energy and Environmental Research Center, University of North Dakota, Grand Forks, North Dakota

Environmental Performance of CCPs
Ishwar Murarka, Ish Inc., Sunnyvale, California

FIELD SCALE STUDY RESULTS FOR THE BENEFICIAL USE OF COAL ASH AS FILL MATERIAL IN SATURATED CONDITIONS, VARRA COAL ASH BURIAL PROJECT, WELD COUNTY, COLORADO

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Abstract

The Varra Coal Ash Project (Varra Project) is an ongoing study to determine the feasibility of using coal ash to reclaim flooded gravel mine quarries in Weld County, Colorado. The use of coal ash as fill in saturated environments is discouraged by most regulatory agencies, and there are few studies documenting the effects of coal ash in wet systems. Nearly four years were required to obtain the required permits for conducting this field scale study to assess potential impacts of large-scale coal ash reclamation on groundwater resources.

The field scale study consisted of placing 400 tons of two types of Class F coal ash in a trench excavated to seven feet below the water table at the Varra gravel quarry near Longmont, Colorado. The trench was immediately adjacent to the quarry pond proposed for reclamation. The State of Colorado and Weld County approved the permits required to conduct the field study, based on column leaching studies and local surface and groundwater investigation results and safeguards implemented for the project.

The trench was divided into two ash cells measuring 10 feet in width, 45 feet in length, and 11 feet in depth. A 15-foot native soil divider was left between the ash cells. Twelve groundwater monitoring wells were installed up, cross, and down gradient of the ash deposit. Two monitoring wells were installed within the trench to monitor water quality of the pore waters within the ash. Groundwater monitoring wells were placed down gradient of the coal ash trench at a spacing of 10, 25, 45, 50 (point of compliance (POC) distance), and 120 feet. Groundwater monitoring was conducted weekly for the first month, monthly to the end of the first quarter, and quarterly till project termination. Surface and groundwater samples were analyzed for 29 elements and ions such as alkalinity, chloride, fluoride, nitrate, nitrite, and sulfate.

Analytical data generated from the field study indicate that the leaching characteristics of coal ash used in this study are relatively benign. The most mobile and prevalent constituent of concern appears to be boron. Molybdenum, sulfate, selenium chloride, and fluoride had elevated concentrations in water samples obtained from the ash; however, the levels associated with these elements or ions dropped to below regulatory or background levels within a month of ash placement.

Drinking water standards were not exceeded at point of compliance wells 50 feet down gradient of the trench. With the exception of boron and nitrite, water quality samples obtained from the ash for the last sampling event met drinking water standards. These data indicate that large-scale ash reclamation may be feasible at this location.

Experiment

Surface water samples were collected from the pond proposed for reclamation (immediately adjacent to the coal ash trench) between May 1999 and August 2002. The samples were obtained to establish background water quality and assess any impacts of coal ash burial in groundwater. All samples were filtered to 0.45 microns and analyzed for eight major ions and 29 elements.

Between September 2001 and February 2002, twelve soil borings were drilled with a truck mounted, hollow stem power auger. The soil borings were advanced to between 8 and 17 feet below ground surface (bgs). Soil sampling was conducted in accordance with ASTM:D 1586-87.[1] Using this method representative soil samples were obtained by advancing a two-inch outside diameter split barrel sampler ahead of the auger bit. Local soil lithology descriptions were recorded during drilling activities. As the samples were obtained in the field, they were examined and described in accordance with ASTM:D 2488-842.[2] In general, soil conditions consist of two to five feet of fine-grained alluvial deposits of brown clay, silt, and fine-grained sands, which are underlain by six feet of gravel with sand. Bedrock, which consists of a dense, dark gray shale (Pierre Shale) underlies the sand and gravel deposits.

Figure 2 depicts soil conditions based on boring log data.

All of the twelve soil borings drilled at the site were completed as two-inch diameter groundwater monitoring wells. All monitoring wells were constructed with 0.01-inch factory slotted PVC well screen with a blank PVC riser. All monitoring wells were completed within 4"x 4" above grade monuments. The depth of the wells varied between 8 and 15 feet below ground surface (bgs).

The material that the water table is located in can be described as sand with gravel with the depth to water varying between 1.5 and 13 feet below grade. The Pierre Shale underlies the unconsolidated alluvial deposits and extends to beyond the depths explored during this project. The depth to the Pierre Shale within the study area ranges between 8 feet and 15 feet below ground surface. Over the entire site, the saturated thickness of the aquifer averages 5.61 feet. The groundwater flow direction within the study area is from north to south and is reflective of local topography. The hydraulic gradient varied between 0.0095 and 0.025 ft/ft during the report period. Figure 3 depicts groundwater contours for February 2002, and Figure 3a depicts groundwater contours for May 2002.

Two slug tests were utilized to determine the hydraulic conductivity of the upper portion of the aquifer and one slug test was performed in the coal ash trench. Water level measurements and times were recorded using an in situ Troll SP4000 pressure transducer. The test results will be input into standardized software, utilizing the Bouwer Rice Method, to determine hydraulic conductivity of the aquifer. Hydraulic conductivity values (K) for the aquifer varied over an order of magnitude, ranging from 20 to 203 feet/day. The hydraulic conductivity of the coal ash was calculated to be 1.22 feet per day. Using Darcy's Law the average groundwater flow rate for the aquifer was calculated to be 2.5 feet per day. The seepage velocity within the coal ash was 0.027 feet per day (using an effective porosity of 0.27 and 0.40 for the aquifer and ash, respectively).

On February 14 and 15, 2002 a 100-foot by 10-foot trench was excavated to 11 feet bgs using a Hitachi track driven loader. The ash was placed in two cells measuring 10 feet in width, 45 feet in length, and 11 feet in depth. A 15-foot native soil divider was left between the ash cells. Concurrent with the excavation, 200 tons of Class F coal ash with gypsum and 200 tons of coal ash with sodium were transported to the site, mixed, and placed in the excavation. Mixing was performed by use of a front-end loader, and a track driven excavator was used to compact the ash after placement. The trenches were filled to ground surface with ash, and a two-foot native soil cover was placed over the ash to preclude wind or water erosion.

Water quality samples were collected from site monitoring wells on a periodic basis in order to evaluate possible changes in water quality. The sampling frequency was weekly for the first month, biweekly for the second month, monthly to the end of the first quarter, and then quarterly until project termination.

All samples were filtered to 0.45 microns prior to analysis. Samples were analyzed for alkalinity as bicarbonate and carbonate, chloride, fluoride, nitrate, nitrite, and sulfate, along with other metals aluminum, antimony, arsenic, barium, beryllium, boron, calcium, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, phosphorous, potassium, selenium, silver, sodium, thallium, titanium, uranium, vanadium, and zinc. Elements were analyzed with a Perkin-Elmer Optima 2000 ICP/AES. Ions were analyzed with a Dionex LC90 ion chromatograph. Field parameters such as pH, conductivity, and temperature were measured with a HyDAC digital conductivity, pH, and temperature meter. Analytical procedures for water and soil sample collection and analysis were performed in accordance with USEPA guidelines described in SW 846 (Test Methods for Evaluating Solid Waste/Physical/Chemical Methods, 3rd ed.).[3]

Results and Discussion

Surface water samples were obtained to document surface water quality of the gravel pond adjacent to the coal ash trench. Six samples were obtained between February 22 and May 13, 2002. A total of 12 samples were obtained for analyses between May 1999 and August 2002. All samples were obtained at the location depicted on Figure 1. The samples were analyzed for all constituents of concern identified for this project. Elemental analytical results are presented in Table 1. Major ions results are presented in Table 2.

A review of tables 1 and 2 shows that all surface water samples (identified as pond) exceeded the standard for sulfate. Pond samples exceeded the standard for iron, lead, manganese, and nitrate for one sampling event prior to coal ash placement. The primary standard for selenium was exceeded on three sampling events. However, the elevated selenium levels are considered to be naturally occurring as sampling was conducted prior to and concurrent with coal ash placement. The anticipated travel time from the coal ash trench to the pond sample point is on the order

of 56 days, assuming no retardation or dilution effects. All of the pond samples that exceeded the selenium standard were obtained prior to the 56-day trench to pond travel time. At the time of this writing, no surface water quality issues can be associated with coal ash placement.

Groundwater quality samples were collected from all monitoring wells at the same sample frequency identified for surface water samples. The samples were submitted to a contract laboratory and analyzed to determine constituents identified previously. The laboratory results are summarized in Table 1 and Table 2**.**

A review of Table 1 and Table 2 shows that all wells not completed within the coal ash trench exceeded the standard for sulfate during every sampling event, with the levels varying between 600 and 1,961 mg/L. Nitrate levels varied between 4.8 and 36 mg/L, and every well located outside the ash trench exceeded the 10 mg/L standard.

The nitrite standard was exceeded in monitoring wells MW-5 and MW-6 on sampling events one and four, respectively. With the exception of one well, all wells exceeded the standard at least once for manganese and selenium during the project. Manganese levels varied between not detected and 1.73 mg/L. Selenium varied between 0.005 and 0.151 mg/L. The average pH of groundwater in non-ash wells was 7.4.

Monitoring wells MW-11 and MW-12 were located within the coal ash trench (ash wells). The ash wells had sulfate concentrations that closely approximated wells installed outside the trench. The ash wells also had elevated nitrate concentrations; however, with time nitrate concentrations declined and nitrite concentrations increased, with a mean concentration of 3.46 mg/L. The mean boron concentration in the ash wells was 20 mg/L with all other wells having a mean concentration of 0.69 mg/L. Significant increases in molybdenum and selenium were observed in the ash wells; however, concentrations of both elements decreased to background levels within two months of the ash placement. Chloride and fluoride concentrations were elevated in samples obtained from the ash wells with levels exceeding both standards on occasion. The mean pH of groundwater in the trench was 9.8 with a range minimum and maximum of 7.4 and 11.9, respectively. Table 3 presents selected water quality comparison of ash and nonash wells.

Conclusion

As expected, the coal ash trench acted as an impermeable barrier and diverted groundwater between and around the coal ash cells. The change in hydraulic head in the vicinity of the trench was on the order of 0.43 to 0.52 feet. The hydraulic conductivity of the ash was calculated to be 1.22 feet per day, which is between one and two orders of magnitude less than the permeability of the surrounding aquifer. Other than the change in hydraulic head at the trench, no other hydrogeologic effects were noted.

As previously documented in the column leaching studies, the most mobile elements in the coal ashes used in this study were boron, molybdenum, and selenium. Sulfate is also mobile; however, background sulfate levels are very high and any contribution from the coal ash cannot be determined. In the column study, molybdenum and selenium levels dropped off sharply with passing pore volumes and reduction in pH, while boron levels appeared to be less affected by pH changes. To date, these trends are occurring in samples obtained from the coal ash trench as well. Analytical data document concentration spikes and reductions for the mentioned constituents that appear to be the result of geochemical processes.

An unexpected occurrence, which was not observed in the column study, is the reduction of nitrate to nitrite within the ash. Nitrite was detected at elevated levels within the trench and above background levels in down gradient wells MW-5 and MW-6. A water quality graph for MW-5 (attachment) depicts boron, nitrite, and selenium. There appears to be a direct correlation between nitrite and boron concentrations.

Water quality monitoring documented high (above regulatory standards) natural levels of manganese, selenium, sulfate, and nitrate. Weld County established the downstream point of compliance at 50 feet down gradient from the trench. Wells were installed downstream of the trench at 10 (MW-6), 25 (MW-5), 40 (MW-2), and 50 feet (MW-4 and MW-7). Monitoring wells MW-7 and MW-4 are points of compliance and have not been affected by the presence of coal ash within the water table. Wells MW-6 and MW-5 had apparent impacts as a result of the ash placement. Nitrite levels in samples obtained from MW-5 were in excess of the 1.0 mg/L standard in four of six sampling events. The standard for boron was exceeded on one occasion. At the time of this writing, both boron and nitrite have declining levels. The nitrite standard was exceeded in samples obtained from MW-6 on one occasion (the first sampling event). Boron levels in samples obtained from MW-6 exceeded the 5 mg/L standard during the

last sample event.

The potential of using coal ash for a large-scale reclamation appears promising as field and analytical data indicate limited impacts from the coal ash placement. Concentrations for all of the elements or compounds of concern have dramatically decreased within and outside the ash deposit within a relatively short period of time. Boron, pH, and selenium levels have reduced to below regulatory limits in samples obtained from MW-12 and both ash cells have exhibited sharp reductions in elemental concentrations to date. The seepage velocity within the ash is on the order of ten feet per year, and the concentration reductions within the ash cannot be attributed to flushing or simple dilution. If this trend occurs in much larger scale deposits, then using coal ash to reclaim saturated quarries appears viable.

References

1. ASTM D1586, Standard Test Method for Penetration Test and Split Barrel Sampling of Soils, Vol. 04.08.

2. ASTM D2488, Description and Identification of Soils (Visual-Manual Procedure), Vol. 04.08.

3. U.S. EPA, 1990, Test Methods for Evaluation Solid Waste: Physical/Chemical Methods.

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Tables

TABLE 1
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Sample Date	pH	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Se	Ag	Na	Ti	Tl	V	Zn	Hg	U
MW-1	10/5/2001	7.4	<0.02	<0.006	<0.005	0.022	<0.003	0.33	<0.001	139	<0.004	0.002	<0.003	<0.007	<0.003	0.050	179	0.045	0.045	<0.005	0.198	5.35	**0.029**	<0.002	174	<0.01	<0.005	<0.003	<0.002	<0.0002	<0.015
	2/22/2002	7.7	<0.02	<0.006	<0.005	0.043	<0.003	0.34	<0.001	149	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	175	0.035	0.30	<0.005	0.184	4.83	**0.082**	<0.002	192	<0.01	<0.005	<0.003	0.012	<0.0002	0.032
	3/4/2002	7.5	<0.02	<0.006	<0.005	0.014	<0.003	0.40	<0.001	166	<0.004	<0.002	<0.003	<0.007	<0.003	0.044	206	0.016	0.059	<0.005	0.194	5.18	**0.145**	<0.002	213	<0.01	<0.005	<0.003	<0.002	<0.0002	0.019
	3/11/2002	7.3	<0.02	<0.006	<0.005	0.016	<0.003	0.52	<0.001	160	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	195	0.013	0.053	<0.005	0.193	5.32	**0.098**	<0.002	205	<0.01	<0.005	<0.003	<0.002	<0.0002	0.028
	3/18/2002	7.6	<0.02	<0.006	<0.005	0.014	<0.003	0.71	<0.001	170	<0.004	<0.002	<0.003	<0.007	<0.003	0.062	196	0.009	0.044	<0.005	0.174	7.05	**0.098**	<0.002	225	<0.01	<0.005	<0.003	<0.002	<0.0002	0.024
	4/15/2002	7.4	<0.02	<0.006	<0.005	0.023	<0.003	1.14	<0.001	170	<0.004	<0.002	<0.003	<0.007	<0.003	0.046	205	<0.001	0.049	<0.005	0.214	5.43	<0.005	<0.002	229	<0.01	<0.005	<0.003	0.01	<0.0002	0.037
	5/13/2002	7.4	<0.02	<0.006	<0.005	0.024	<0.003	1.31	0.002	174	<0.004	<0.002	<0.003	<0.007	0.006	0.085	199	0.002	0.068	<0.005	0.205	9.46	**0.039**	<0.002	245	<0.01	<0.005	<0.003	0.011	<0.0002	0.02
	8/13/2002	7.1	<0.02	<0.006	<0.005	0.027	<0.003	1.14	<0.001	207	<0.004	<0.002	<0.003	<0.007	<0.003	0.082	243	<0.001	0.099	<0.005	0.171	6.68	**0.098**	<0.002	270	<0.01	<0.005	<0.003	<0.002	<0.002	0.028
MW-2	11/9/2001	7.3	<0.02	<0.006	<0.005	0.041	<0.003	0.35	<0.001	157	<0.004	<0.002	<0.003	<0.007	<0.003	0.045	184	**0.218**	0.040	<0.005	0.236	6	**0.094**	<0.002	181	<0.01	<0.005	<0.003	0.11	<0.0002	0.029
	2/22/2002	7.5	<0.02	<0.006	<0.005	0.057	<0.003	0.41	<0.001	155	<0.004	<0.002	<0.003	<0.007	<0.003	0.008	172	<0.001	0.033	<0.005	0.179	4.78	**0.083**	<0.002	182	<0.01	<0.005	<0.003	0.01	<0.0002	0.038
	3/4/2002	7.4	<0.02	<0.006	<0.005	0.029	<0.003	0.50	<0.001	176	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	201	<0.001	0.056	<0.005	0.189	5.28	**0.144**	<0.002	204	<0.01	<0.005	<0.003	<0.002	<0.0002	0.019
	3/11/2002	7.5	<0.02	<0.006	<0.005	0.031	<0.003	0.57	<0.001	170	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	195	<0.001	0.054	<0.005	0.185	5.23	**0.104**	<0.002	201	<0.01	<0.005	<0.003	<0.002	<0.0002	0.029
	3/18/2002	7.5	<0.02	<0.006	<0.005	0.030	<0.003	0.77	<0.001	174	<0.004	<0.002	<0.003	0.11	<0.003	0.068	196	<0.001	0.064	<0.005	0.176	6.56	**0.105**	<0.002	217	<0.01	<0.005	<0.003	<0.002	<0.0002	0.027
	4/15/2002	7.3	<0.02	<0.006	<0.005	0.034	<0.003	0.76	<0.001	174	<0.004	<0.002	<0.003	<0.007	0.004	0.043	204	<0.001	0.055	<0.005	0.211	5.10	**0.015**	<0.002	221	<0.01	<0.005	<0.003	<0.002	<0.0002	0.042
	5/13/2002	7.4	<0.02	<0.006	<0.005	0.032	<0.003	0.64	<0.001	177	<0.004	<0.002	<0.003	<0.007	0.007	0.047	199	<0.001	0.047	<0.005	0.205	6.60	**0.034**	<0.002	214	<0.01	<0.005	<0.003	0.01	<0.0002	0.024
	8/13/2002	7.2	<0.02	<0.006	<0.005	0.034	<0.003	0.95	<0.001	210	<0.004	<0.002	<0.003	<0.007	<0.003	0.058	242	<0.001	0.074	<0.005	0.163	5.83	**0.107**	<0.002	243	<0.01	<0.005	<0.003	<0.002	<0.002	0.033
MW-3	10/5/2001	7.5	<0.02	<0.006	<0.005	0.037	<0.003	0.35	<0.001	152	<0.004	<0.002	<0.003	<0.007	<0.003	0.053	176	**1.73**	0.096	<0.005	0.17	8.8	**0.027**	<0.002	190	<0.01	<0.005	<0.003	<0.002	<0.0002	0.0190
	2/22/2002	7.5	<0.02	<0.006	<0.005	0.045	<0.003	0.43	<0.001	164	<0.004	<0.002	<0.003	<0.007	<0.003	0.430	183	**0.105**	0.033	<0.005	0.155	5.11	**0.079**	<0.002	214	<0.01	<0.005	<0.003	0.015	<0.0002	0.040
	3/4/2002	7.4	<0.02	<0.006	<0.005	0.017	<0.003	0.32	<0.001	160	<0.004	<0.002	<0.003	<0.007	0.004	0.042	193	**0.11**	0.056	<0.005	0.187	4.97	**0.145**	<0.002	208	<0.01	<0.005	<0.003	<0.002	<0.0002	0.018
	3/11/2002	7.2	<0.02	<0.006	<0.005	0.019	<0.003	0.33	<0.001	170	<0.004	<0.002	<0.003	<0.007	<0.003	0.040	197	**0.104**	0.056	<0.005	0.186	5.24	**0.101**	<0.002	211	<0.01	<0.005	<0.003	<0.002	<0.0002	0.027
	3/18/2002	7.6	<0.02	<0.006	<0.005	0.019	<0.003	0.35	<0.001	178	<0.004	<0.002	<0.003	0.127	<0.003	0.043	208	**0.097**	0.051	<0.005	0.171	6.0	**0.107**	<0.002	224	<0.01	<0.005	<0.003	<0.002	<0.0002	0.031
	4/15/2002	7.4	0.027	<0.006	<0.005	0.029	<0.003	0.40	<0.001	216	<0.004	<0.002	<0.003	<0.007	<0.003	0.045	265	**0.088**	0.059	<0.005	0.213	5.8	**0.022**	<0.002	256	<0.01	<0.005	<0.003	<0.002	<0.0002	0.043
	5/13/2002	7.3	0.027	<0.006	<0.005	0.030	<0.003	0.32	<0.001	222	<0.004	<0.002	<0.003	<0.007	0.006	0.048	269	**0.054**	0.057	<0.005	0.208	7.2	**0.031**	<0.002	262	<0.01	<0.005	<0.003	<0.002	<0.0002	0.024
	8/13/2002	7.1	<0.02	<0.006	<0.005	0.025	<0.003	0.44	<0.001	225	<0.004	<0.002	<0.003	<0.007	<0.003	0.054	266	**0.03**	0.071	<0.005	0.147	6.0	**0.105**	<0.002	261	<0.01	<0.005	<0.003	<0.002	<0.002	0.035
MW-4	2/22/2002	7.5	<0.02	<0.006	<0.005	0.061	<0.003	0.42	<0.001	152	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	175	**0.281**	0.041	<0.005	0.138	6.3	**0.073**	<0.002	198	<0.01	<0.005	<0.003	0.02	<0.0002	0.042
	3/4/2002	7.5	<0.02	<0.006	<0.005	0.017	<0.003	0.32	<0.001	168	<0.004	<0.002	<0.003	<0.007	<0.003	0.044	204	**0.393**	0.052	<0.005	0.165	5.94	**0.144**	<0.002	218	<0.01	<0.005	<0.003	<0.002	<0.0002	0.021
	3/11/2002	7.2	<0.02	<0.006	<0.005	0.016	<0.003	0.32	<0.001	172	<0.004	<0.002	<0.003	<0.007	<0.003	0.045	206	**0.307**	0.058	<0.005	0.164	5.84	**0.099**	<0.002	217	<0.01	<0.005	<0.003	<0.002	<0.0002	0.028
	3/18/2002	7.6	<0.02	<0.006	<0.005	0.015	<0.003	0.32	<0.001	167	<0.004	<0.002	<0.003	0.062	<0.003	0.045	199	**0.235**	0.050	<0.005	0.154	5.77	**0.097**	<0.002	216	<0.01	<0.005	<0.003	<0.002	<0.0002	0.028
	4/15/2002	7.4	<0.02	<0.006	<0.005	0.018	<0.003	0.41	<0.001	197	<0.004	<0.002	<0.003	<0.007	0.005	0.046	248	**0.14**	0.054	<0.005	0.197	5.64	**0.011**	<0.002	253	<0.01	<0.005	<0.003	<0.002	<0.0002	0.044
	5/13/2002	7.4	<0.02	<0.006	<0.005	0.02	<0.003	0.32	<0.001	209	<0.004	<0.002	<0.003	<0.007	<0.003	0.050	254	**0.126**	0.058	<0.005	0.2	6.37	**0.026**	<0.002	251	<0.01	<0.005	<0.003	<0.002	<0.0002	0.025
	8/13/2002	7.1	<0.02	<0.006	<0.005	0.016	<0.003	0.44	<0.001	214	<0.004	<0.002	<0.003	<0.007	<0.003	0.055	257	**0.076**	0.070	<0.005	0.14	6.12	**0.099**	<0.002	251	<0.01	<0.005	<0.003	<0.002	<0.002	0.036
MW-5	2/22/2002	7.5	<0.02	<0.006	<0.005	0.063	<0.003	0.46	<0.001	150	<0.004	0.003	<0.003	<0.007	<0.003	0.045	178	**0.464**	0.047	<0.005	0.141	5.60	**0.073**	<0.002	191	<0.01	<0.005	0.005	0.015	<0.0002	0.043
	3/4/2002	7.8	<0.02	<0.006	<0.005	0.021	<0.003	0.87	<0.001	168	<0.004	<0.002	<0.003	<0.007	<0.003	0.049	214	**0.242**	0.049	<0.005	0.164	5.97	**0.135**	<0.002	217	<0.01	<0.005	<0.003	<0.002	<0.0002	0.021
	3/11/2002	7.2	<0.02	<0.006	<0.005	0.021	<0.003	2.57	<0.001	152	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	188	**0.198**	0.059	<0.005	0.167	5.00	**0.085**	<0.002	195	<0.01	<0.005	<0.003	<0.002	<0.0002	0.026
	3/18/2002	7.6	<0.02	<0.006	<0.005	0.022	<0.003	4.38	<0.001	174	<0.004	<0.002	<0.003	0.063	<0.003	0.052	212	**0.214**	0.053	<0.005	0.157	6.28	**0.087**	<0.002	238	<0.01	<0.005	<0.003	<0.002	<0.0002	0.021
	4/15/2002	7.5	<0.02	<0.006	<0.005	0.024	<0.003	5.67	<0.001	168	<0.004	0.003	<0.003	<0.007	0.004	0.096	205	**0.913**	0.479	<0.005	0.154	5.63	**0.071**	<0.002	307	<0.01	<0.005	<0.003	<0.002	<0.0002	0.043
	5/13/2002	7.5	<0.02	<0.006	<0.005	0.029	<0.003	**2.37**	<0.001	179	<0.004	0.003	<0.003	<0.007	<0.003	0.123	223	**0.807**	0.349	<0.005	0.175	5.84	**0.026**	<0.002	289	<0.01	<0.005	<0.003	<0.002	<0.0002	0.031
	8/13/2002	7.2	<0.02	<0.006	<0.005	0.022	<0.003	0.51	<0.001	208	<0.004	<0.002	<0.003	<0.007	<0.003	0.059	251	**0.171**	0.083	<0.005	0.147	6.27	**0.10**	<0.002	253	<0.01	<0.005	<0.003	<0.002	<0.002	0.038

TABLE 1
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Sample Date	pH	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Se	Ag	Na	Ti	Tl	V	Zn	Hg	U
MW-6	2/22/2002	7.1	<0.02	<0.006	<0.005	0.077	<0.003	0.46	<0.001	175	<0.004	<0.002	<0.003	<0.007	<0.003	0.044	182	**0.404**	0.051	<0.005	0.146	6.77	**0.081**	<0.002	204	<0.01	<0.005	<0.003	0.015	<0.0002	0.041
	3/5/2002	7.2	<0.02	<0.006	<0.005	0.033	<0.003	0.91	<0.001	198	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	197	**0.195**	0.054	<0.005	0.179	6.45	**0.135**	<0.002	206	<0.01	<0.005	<0.003	<0.002	<0.0002	0.02
	3/11/2002	7.7	<0.02	<0.006	<0.005	0.035	<0.003	1.04	<0.001	179	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	197	**0.101**	0.06	<0.005	0.17	5.87	**0.093**	<0.002	209	<0.01	<0.005	<0.003	<0.002	<0.0002	0.032
	3/18/2002	7.7	<0.02	<0.006	<0.005	0.035	<0.003	1.08	<0.001	177	<0.004	<0.002	<0.003	<0.007	<0.003	0.046	191	0.035	0.052	<0.005	0.174	5.57	**0.095**	<0.002	213	<0.01	<0.005	<0.003	<0.002	<0.0002	0.026
	4/15/2002	7.5	<0.02	<0.006	<0.005	0.037	<0.003	0.86	<0.001	179	<0.004	<0.002	<0.003	<0.007	0.005	0.051	202	<0.001	0.072	<0.005	0.21	5.04	**0.013**	<0.002	229	<0.01	<0.005	<0.003	<0.002	<0.0002	0.043
	5/13/2002	7.4	<0.02	<0.006	<0.005	0.036	<0.003	0.53	<0.001	176	<0.004	<0.002	<0.003	<0.007	0.005	0.049	201	0.014	0.059	0.045	0.221	5.33	**0.023**	<0.002	220	<0.01	<0.005	<0.003	<0.002	<0.0002	0.025
	8/13/2002	8.2	0.02	<0.006	<0.005	0.029	<0.003	12.60	<0.001	133	<0.004	<0.002	<0.003	<0.007	<0.003	0.680	137	1.14	1.5	<0.005	0.16	10.9	**0.093**	<0.002	509	<0.01	<0.005	<0.003	<0.002	<0.002	0.029
MW-7	2/22/2002	7.1	<0.02	<0.006	<0.005	0.077	<0.003	0.42	<0.001	163	<0.004	<0.002	<0.003	0.037	<0.003	0.044	173	**0.14**	0.047	<0.005	0.158	7.3	**0.071**	<0.002	190	<0.01	<0.005	0.004	0.017	<0.0002	0.042
	3/4/2002	7.5	<0.02	<0.006	<0.005	0.032	<0.003	0.34	<0.001	178	<0.004	<0.002	<0.003	<0.007	<0.003	0.043	204	**0.533**	0.056	<0.005	0.165	6.53	**0.142**	<0.002	201	<0.01	<0.005	<0.003	<0.002	<0.0002	0.021
	3/11/2002	7.4	<0.02	<0.006	<0.005	0.028	<0.003	0.42	<0.001	170	<0.004	<0.002	<0.003	<0.007	<0.003	0.040	191	**0.209**	0.057	<0.005	0.177	5.73	**0.094**	<0.002	193	<0.01	<0.005	<0.003	<0.002	<0.0002	0.031
	3/18/2002	7.5	<0.02	<0.006	<0.005	0.027	<0.003	0.44	<0.001	173	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	194	**0.213**	0.045	<0.005	0.159	5.9	**0.099**	<0.002	201	<0.01	<0.005	<0.003	<0.002	<0.0002	0.027
	4/15/2002	7.3	<0.02	<0.006	<0.005	0.029	<0.003	0.67	<0.001	174	<0.004	<0.002	<0.003	<0.007	0.006	0.039	204	**0.102**	0.055	<0.005	0.194	5.38	0.013	<0.002	210	<0.01	<0.005	<0.003	<0.002	<0.0002	0.044
	5/13/2002	7.3	<0.02	<0.006	<0.005	0.028	<0.003	0.58	<0.001	173	<0.004	<0.002	<0.003	<0.007	0.006	0.044	199	**0.044**	0.054	<0.005	0.197	5.8	**0.027**	<0.002	210	<0.01	<0.005	<0.003	<0.002	<0.0002	0.026
	8/13/2002	7.1	<0.02	<0.006	<0.005	0.032	<0.003	0.74	<0.001	219	<0.004	<0.002	<0.003	<0.007	<0.003	0.058	247	0.078	0.083	<0.005	0.147	6.38	**0.10**	<0.002	243	<0.01	<0.005	<0.003	<0.002	<0.002	0.037
MW-8	2/22/2002	7.4	<0.02	<0.006	<0.005	0.059	<0.003	0.33	<0.001	162	<0.004	<0.002	<0.003	0.039	<0.003	0.033	148	**0.328**	0.033	<0.005	0.148	6.4	**0.054**	<0.002	139	<0.01	<0.005	0.004	0.017	0.00022	0.038
	3/4/2002	7.4	<0.02	<0.006	<0.005	0.024	<0.003	0.26	<0.001	174	<0.004	<0.002	<0.003	<0.007	<0.003	0.038	178	**0.187**	0.042	<0.005	0.166	5.94	**0.149**	<0.002	159	<0.01	<0.005	<0.003	<0.002	<0.0002	0.018
	3/11/2002	7.1	<0.02	<0.006	<0.005	0.025	<0.003	0.28	<0.001	173	<0.004	<0.002	<0.003	<0.007	<0.003	0.037	168	**0.138**	0.049	<0.005	0.153	5.87	**0.101**	<0.002	154	<0.01	<0.005	<0.003	<0.002	<0.0002	0.029
	3/18/2002	7.6	<0.02	<0.006	<0.005	0.026	<0.003	0.30	<0.001	181	<0.004	<0.002	<0.003	<0.007	<0.003	0.037	177	**0.096**	0.049	<0.005	0.158	6.35	**0.099**	<0.002	169	<0.01	<0.005	<0.003	<0.002	<0.0002	0.03
	4/15/2002	7.2	<0.02	<0.006	<0.005	0.029	<0.003	0.37	<0.001	182	<0.004	<0.002	<0.003	<0.007	<0.003	0.036	186	**0.047**	0.053	<0.005	0.183	6.03	**0.01**	<0.002	182	<0.01	<0.005	<0.003	<0.002	<0.0002	0.038
	5/13/2002	7.3	<0.02	<0.006	<0.005	0.028	<0.003	0.31	<0.001	181	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	187	0.027	0.047	<0.005	0.189	5.92	**0.033**	<0.002	184	<0.01	<0.005	<0.003	<0.002	<0.0002	0.024
	8/13/2002	7.0	<0.02	<0.006	<0.005	0.024	<0.003	0.48	<0.001	189	<0.004	<0.002	<0.003	<0.007	<0.003	0.047	206	0.06	0.067	<0.005	0.129	6.38	**0.06**	<0.002	194	<0.01	<0.005	<0.003	<0.002	<0.002	0.037
MW-9	2/22/2002	7.0	<0.02	<0.006	<0.005	0.074	<0.003	0.40	<0.001	166	<0.004	<0.002	<0.003	0.052	<0.003	0.038	160	**0.063**	0.037	<0.005	0.154	8.29	**0.055**	<0.002	170	<0.01	<0.005	0.004	0.014	0.00022	0.039
	3/4/2002	7.5	<0.02	<0.006	<0.005	0.036	<0.003	0.28	<0.001	179	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	189	0.027	0.043	<0.005	0.174	5.95	**0.151**	<0.002	182	<0.01	<0.005	<0.003	<0.002	<0.0002	0.018
	3/11/2002	7.2	<0.02	<0.006	<0.005	0.037	<0.003	0.33	<0.001	168	<0.004	<0.002	<0.003	<0.007	<0.003	0.039	175	0.026	0.05	<0.005	0.158	5.7	**0.102**	<0.002	169	<0.01	<0.005	<0.003	<0.002	<0.0002	0.037
	3/18/2002	7.4	<0.02	<0.006	<0.005	0.037	<0.003	0.31	<0.001	179	<0.004	<0.002	<0.003	<0.007	<0.003	0.040	179	0.012	0.049	<0.005	0.166	6.08	**0.102**	<0.002	181	<0.01	<0.005	<0.003	<0.002	<0.0002	0.024
	4/15/2002	7.1	<0.02	<0.006	<0.005	0.039	<0.003	0.38	<0.001	179	<0.004	<0.002	<0.003	<0.007	<0.003	0.037	190	0.009	0.05	<0.005	0.205	5.94	**0.024**	<0.002	197	<0.01	<0.005	<0.003	<0.002	<0.0002	0.04
	5/13/2002	7.4	<0.02	<0.006	<0.005	0.037	<0.003	0.32	<0.001	178	<0.004	<0.002	<0.003	<0.007	<0.003	0.042	197	0.002	0.05	<0.005	0.206	5.72	**0.028**	<0.002	194	<0.01	<0.005	<0.003	<0.002	<0.0002	0.027
	8/13/2002	7.0	<0.02	<0.006	<0.005	0.029	<0.003	0.49	<0.001	186	<0.004	<0.002	<0.003	<0.007	<0.003	0.049	211	0.087	0.065	<0.005	0.138	6.18	**0.122**	<0.002	207	<0.01	<0.005	<0.003	<0.002	<0.002	0.032
MW-10	2/22/2002	7.0	<0.02	<0.006	<0.005	0.09	<0.003	0.43	<0.001	159	<0.004	0.004	<0.003	<0.007	<0.003	0.040	170	**1.03**	0.045	<0.005	0.148	9.2	**0.062**	<0.002	197	<0.01	<0.005	<0.003	0.014	0.00022	0.049
	3/4/2002	7.2	<0.02	<0.006	<0.005	0.031	<0.003	0.32	<0.001	168	<0.004	<0.002	<0.003	<0.007	<0.003	0.041	200	**0.076**	0.045	<0.005	0.176	5.06	**0.146**	<0.002	213	<0.01	<0.005	<0.003	<0.002	<0.0002	0.025
	3/11/2002	7.7	<0.02	<0.006	<0.005	0.031	<0.003	0.34	<0.001	166	<0.004	<0.002	<0.003	<0.007	0.003	0.040	190	0.047	0.052	<0.005	0.184	4.95	**0.102**	<0.002	205	<0.01	<0.005	<0.003	<0.002	<0.0002	0.033
	3/18/2002	7.7	<0.02	<0.006	<0.005	0.033	<0.003	0.34	<0.001	173	<0.004	<0.002	<0.003	<0.007	<0.003	0.040	193	**0.064**	0.052	<0.005	0.171	5.54	**0.098**	<0.002	215	<0.01	<0.005	<0.003	<0.002	<0.0002	0.029
	4/15/2002	7.5	<0.02	<0.006	<0.005	0.034	<0.003	0.35	<0.001	179	<0.004	<0.002	<0.003	<0.007	<0.003	0.040	217	**0.012**	0.052	<0.005	0.217	5.16	**0.013**	<0.002	288	<0.01	<0.005	<0.003	<0.002	<0.0002	0.037
	5/13/2002	7.6	<0.02	<0.006	<0.005	0.031	<0.003	0.31	<0.001	175	<0.004	<0.002	<0.003	<0.007	0.008	0.041	209	0.004	0.056	<0.005	0.218	4.97	**0.03**	<0.002	221	<0.01	<0.005	<0.003	<0.002	<0.0002	0.027
	8/13/2002	7.1	<0.02	<0.006	<0.005	0.033	<0.003	0.48	<0.001	223	<0.004	<0.002	<0.003	<0.007	<0.003	0.051	260	<0.001	0.079	<0.005	0.157	5.37	**0.107**	<0.002	252	<0.01	<0.005	<0.003	<0.002	<0.002	0.041
MW-11	2/22/2002	9.2	0.059	<0.006	<0.005	0.16	<0.003	**30.00**	<0.001	243	<0.004	<0.002	<0.003	<0.007	<0.003	0.479	110	0.005	0.735	<0.005	0.136	17.9	**0.590**	<0.002	391	<0.01	<0.005	0.016	<0.002	0.00022	0.03
	3/4/2002	11.9	0.097	<0.006	<0.005	0.137	<0.003	**31.20**	<0.001	86.5	<0.004	<0.002	<0.003	<0.007	<0.003	2.2	46.5	<0.001	2.72	<0.005	0.186	55.8	**0.351**	<0.002	986	<0.01	<0.005	0.19	<0.002	<0.0002	0.005
	3/11/2002	11.5	0.143	<0.006	<0.005	0.242	<0.003	**34.50**	<0.001	96.8	<0.004	<0.002	<0.003	<0.007	<0.003	2.5	29.3	<0.001	3.19	<0.005	0.185	60.4	**0.328**	<0.002	1050	<0.01	<0.005	0.258	<0.002	<0.0002	0.005
	3/18/2002	11.0	0.090	<0.006	<0.005	0.259	<0.003	**31.30**	<0.001	56.3	<0.004	<0.002	<0.003	<0.007	<0.003	2.71	12.4	<0.001	3.17	<0.005	<0.05	63.1	**0.233**	<0.002	982	<0.01	<0.005	0.304	<0.002	<0.0002	<0.015
	4/15/2002	11.1	0.232	<0.006	<0.005	0.191	<0.003	**21.40**	<0.001	51.5	<0.004	<0.002	<0.003	<0.007	<0.003	1.83	0.522	<0.001	2.06	<0.005	<0.05	42.6	**0.114**	<0.002	499	<0.01	<0.005	0.3	<0.002	<0.0002	<0.015
	5/13/2002	10.8	2.280	<0.006	<0.005	0.159	<0.003	**17.80**	0.004	40.0	<0.004	<0.002	<0.003	<0.007	<0.003	1.51	1.56	<0.001	1.51	<0.005	<0.05	32	**0.088**	<0.002	439	<0.01	<0.005	0.29	<0.002	<0.0002	<0.015
	8/13/2002	9.4	2.500	<0.006	<0.005	0.317	<0.003	**16.90**	<0.001	128.0	<0.004	<0.002	<0.003	<0.007	<0.003	0.815	5.99	<0.001	0.537	<0.005	<0.05	25.0	**0.042**	<0.002	314	<0.01	<0.005	0.149	<0.002	<0.002	0.0040

TABLE 1
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Sample Date	pH	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Se	Ag	Na	Ti	Tl	V	Zn	Hg	U
MW-12	2/22/2002	7.6	<0.02	<0.006	<0.005	0.126	<0.003	2.09	<0.001	193	<0.004	<0.002	<0.003	<0.007	<0.003	0.065	180	**0.107**	0.069	<0.005	0.385	6.52	**0.142**	<0.002	224	<0.01	<0.005	0.006	0.016	0.00022	0.033
	3/4/2002	8.9	0.108	<0.006	<0.005	0.166	<0.003	**21.40**	<0.001	177	<0.004	<0.002	<0.003	<0.007	<0.003	0.845	106	0.048	1.32	<0.005	0.22	24.9	**0.114**	<0.002	536	<0.01	<0.005	0.095	<0.002	<0.0002	0.009
	3/11/2002	9.8	0.158	<0.006	<0.005	0.15	<0.003	**14.30**	<0.001	154	<0.004	<0.002	<0.003	<0.007	<0.003	0.688	127	0.045	1.15	<0.005	0.323	20.9	**0.110**	<0.002	467	<0.01	<0.005	0.098	<0.002	<0.0002	0.016
	3/18/2002	9.7	0.774	<0.006	<0.005	0.11	<0.003	**25.30**	<0.001	105	<0.004	<0.002	<0.003	<0.007	<0.003	1.29	65	0.041	2.04	<0.005	<0.05	32.5	**0.130**	<0.002	637	<0.01	<0.005	0.221	<0.002	<0.0002	<0.015
	4/15/2002	8.6	0.164	<0.006	<0.005	0.12	<0.003	**7.42**	<0.001	152	<0.004	<0.002	<0.003	<0.007	<0.003	0.506	147	0.092	0.70	<0.005	0.248	17.6	**0.022**	<0.002	384	<0.01	<0.005	0.073	<0.002	<0.0002	0.0220
	5/13/2002	7.6	<0.02	<0.006	<0.005	0.00	<0.003	2.11	<0.001	180	<0.004	<0.002	<0.003	<0.007	<0.003	0.129	187	**0.080**	0.17	<0.005	0.292	8.3	**0.023**	<0.002	250	<0.01	<0.005	0.015	<0.002	<0.0002	0.0180
	8/13/2002	7.4	0.02	<0.006	<0.005	0.038	<0.003	2.40	<0.001	220	<0.004	<0.002	<0.003	<0.007	<0.003	0.074	206	**0.174**	0.10	<0.005	0.206	7.1	**0.067**	<0.002	245	<0.01	<0.005	<0.003	<0.002	<0.002	0.0270
Pond Water	5/26/1999	7.6	2.60	<0.006	<0.1	0.09	<0.004	0.21	<0.005	110	<0.01	<0.01	<0.01	**1.80**	**0.052**	0.200	53	**0.58**	<0.01	<0.004	NA	<5	<.1	<0.01	120	0.078	<0.002	<0.01	<0.02	0.00022	NA
	12/20/1999	8.3	<0.05	<0.006	<0.003	0.032	<0.004	0.44	<0.005	210	<0.01	<0.01	<0.01	<0.006	<0.002	0.057	290	<0.005	NA	<0.004	0.19	6.4	<.01	<0.01	300	NA	<0.002	<0.01	<0.02	<0.0002	NA
	2/28/2000	8.2	<0.05	<0.003	<0.003	<0.02	<0.004	0.66	<0.005	170	<0.01	<0.01	<0.01	<0.01	<0.002	0.059	450	<0.005	<0.01	<0.004	<0.05	9.3	<0.005	<0.01	410	<0.01	<0.002	<0.01	<0.02	<0.0002	0.041
	4/4/2000	8.2	0.056	<0.003	<0.003	0.980	<0.003	0.38	<0.004	179	<0.01	<0.01	<0.01	<0.01	<0.002	0.060	440	<0.005	<0.01	<0.04	0.09	10.0	<0.005	<0.01	460	<0.01	<0.002	<0.01	<0.02	<0.0002	0.047
	11/9/2001	8.4	<0.02	<0.006	<0.005	0.025	<0.003	0.88	<0.001	125	<0.004	<0.002	<0.003	<0.007	<0.003	0.070	444	0.017	0.075	<0.005	0.061	11.9	**0.045**	<0.002	495	<0.01	<0.005	<0.003	0.02	<0.0002	0.043
	2/22/2002	8.2	<0.02	<0.006	<0.005	0.050	<0.003	1.02	<0.001	128	<0.004	<0.002	<0.003	<0.007	<0.003	0.062	375	<0.001	0.076	<0.005	0.14	9.9	**0.049**	<0.002	425	<0.01	<0.005	0.01	<0.002	<0.0002	0.052
	3/4/2002	8.3	<0.02	<0.006	<0.005	0.012	<0.003	0.82	<0.001	142	<0.004	<0.002	<0.003	<0.007	<0.003	0.057	368	0.015	0.077	<0.005	0.16	9.1	**0.099**	<0.002	388	<0.01	<0.005	<0.003	<0.002	<0.0002	0.029
	3/11/2002	7.8	<0.02	<0.006	<0.005	0.010	<0.003	0.91	<0.001	148	<0.004	<0.002	<0.003	<0.007	<0.003	0.071	460	0.003	0.115	<0.005	0.16	11.9	**0.054**	<0.002	498	<0.01	<0.005	<0.003	<0.002	<0.0002	0.041
	3/18/2002	8.6	<0.02	<0.006	<0.005	0.011	<0.003	0.99	<0.001	154	<0.004	<0.002	<0.003	<0.007	<0.003	0.069	449	0.012	0.089	<0.005	0.149	12.8	**0.068**	<0.002	500	<0.01	<0.005	<0.003	<0.002	<0.0002	0.037
	4/15/2002	8.6	<0.02	<0.006	<0.005	0.012	<0.003	0.79	<0.001	152	<0.004	<0.002	<0.003	<0.007	0.009	0.065	443	<0.001	0.098	<0.005	0.183	10.9	**0.006**	<0.002	491	<0.01	<0.005	<0.003	<0.002	<0.0002	0.047
	5/13/2002	8.4	<0.02	<0.006	<0.005	0.002	<0.003	0.87	<0.001	138	<0.004	<0.002	<0.003	0.05	<0.003	0.071	479	0.006	0.12	<0.005	0.194	17.7	0.007	<0.002	519	<0.01	<0.005	<0.003	<0.002	<0.0002	0.043
	8/13/2002	8.42	<0.02	<0.006	<0.005	0.011	<0.003	1.40	<0.001	129	<0.004	<0.002	<0.003	<0.007	<0.003	0.100	692	<0.001	0.18	<0.005	0.142	17.5	**0.037**	<0.002	749	<0.01	<0.005	<0.003	<0.002	<0.002	0.057
Standards			5.0	0.006	0.050	2.0	0.004	0.75/5.0	0.005	no std.	0.100	0.050	.20/1.0	0.30/5.0	0.050	2.50	no std.	0.050	no std.	0.200	no std.	no std.	0.05/0.02	0.050	no std.	no std.	0.002	0.10	2.0	0.002	no std.
			A	P	P	P	P	A	P		P	A	A/S	S/A	P	A	n/a	S		P			P/A	P			P	A	A	P	

Notes: NA = Not Analyzed A - Agricultural Standard P - Primary Drinking Water Standard S - Secondary Drinking Water Standard All values reported in milligrams per liter (mg/L)

NA = Not Analyzed
A - Agricultural Standard
P - Primary Drinking Water Standard
S - Secondary Drinking Water Standard
All values reported in milligrams per liter (mg/L)

TABLE 2
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Date	pH	Total Alkalanity	Alkalinity as Bicarbonate	Alkalinity as Carbonate	Alkalinity as Hydroxide	Chloride	Fluoride	Sulfate	Nitrate	Nitrite
MW-1	10/5/2001	7.4	408	408	<1	<1	47.3	1.4	**1020**	8	0.01
	2/22/2002	7.7	549	549	<1	<1	47	1.4	**600**	**34**	0.008
	3/4/2002	7.5	536	536	<1	<1	58	1.3	**1160**	**24**	0.007
	3/11/2002	7.3	536	536	<1	<1	58.5	1.4	**1240**	**15**	<0.005
	3/18/2002	7.6	536	536	<1	<1	59.3	1.03	**1484**	**22**	<0.07
	4/15/2002	7.4	500	500	<1	<1	77.4	1.01	**1207**	**24**	<0.07
	5/13/2002	7.4	500	500	<1	<1	89.2	1.2	**1300**	**24**	<0.1
	8/13/2002	7.05	549	549	<1	<1	74	0.81	**1390**	**19.4**	<0.05
MW-2	11/9/2001	7.3	463	463	<1	<1	41.8	1.5	**900**	5	<0.005
	2/22/2002	7.5	512	512	<1	<1	43	1.3	**800**	**31**	<0.005
	3/4/2002	7.4	512	512	<1	<1	57	0.1	**1180**	**22**	0.008
	3/11/2002	7.5	524	524	<1	<1	59.4	1.7	**1180**	**22**	<0.005
	3/18/2002	7.5	512	512	<1	<1	51.1	0.93	**1337**	**22**	<0.07
	4/15/2002	7.3	512	512	<1	<1	60.8	0.98	**1197**	**26**	<0.07
	5/13/2002	7.4	500	500	<1	<1	57.9	0.85	**1240**	**24**	<0.1
	8/13/2002	7.2	500	500	<1	<1	59.7	0.89	**1493**	**19.6**	<0.05
MW-3	10/5/2001	7.5	451	451	<1	<1	45.5	1.5	**1160**	6	0.058
	2/22/2002	7.5	512	512	<1	<1	43	1.3	**850**	**35**	0.332
	3/4/2002	7.4	524	524	<1	<1	53	1.4	**1180**	**33**	0.025
	3/11/2002	7.2	524	524	<1	<1	55.8	1.3	**1220**	**18**	0.027
	3/18/2002	7.6	524	524	<1	<1	50.6	0.92	**1358**	**16**	<0.07
	4/15/2002	7.4	500	500	<1	<1	69.5	0.93	**1556**	**12**	<0.07
	5/13/2002	7.3	463	463	<1	<1	62.7	0.75	**1840**	**10**	<0.1
	8/13/2002	7.1	536	536	<1	<1	55.2	0.82	**1961**	**18.9**	<0.05
MW-4	2/22/2002	7.5	549	549	<1	<1	43	1.5	**800**	**27**	0.065
	3/4/2002	7.5	524	524	<1	<1	51	1.3	**1160**	**22**	0.129
	3/11/2002	7.2	536	536	<1	<1	46.6	1.7	**1200**	**13**	0.073
	3/18/2002	7.6	524	524	<1	<1	56.1	0.98	**1511**	**17**	<0.07
	4/15/2002	7.4	488	488	<1	<1	65.1	0.96	**1415**	**14**	<0.07
	5/13/2002	7.4	488	488	<1	<1	64.1	0.78	**1640**	**11**	<0.1
	8/13/2002	7.1	634	634	<1	<1	53.5	0.81	**1513**	**19**	<0.05

TABLE 2
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Date	pH	Total Alkalanity	Alkalinity as Bicarbonate	Alkalinity as Carbonate	Alkalinity as Hydroxide	Chloride	Fluoride	Sulfate	Nitrate	Nitrite
MW-5	2/22/2002	7.5	537	537	<1	<1	43	1.4	**800**	**27**	0.218
	3/4/2002	7.8	512	512	<1	<1	57	1.3	**1180**	**20**	0.133
	3/11/2002	7.2	488	488	<1	<1	80.5	1.7	**1240**	**23**	**1.74**
	3/18/2002	7.6	463	463	<1	<1	122.3	0.99	**1292**	**11**	**1.99**
	4/15/2002	7.5	475	475	<1	<1	184.7	1.11	**1283**	**13**	**3**
	5/13/2002	7.5	500	500	<1	<1	105	1.01	**1440**	**9**	**1.0**
	8/13/2002	7.2	549	549	<1	<1	52.3	0.9	**1375**	**19**	<0.05
MW-6	2/22/2002	7.1	537	537	<1	<1	56	1.4	**800**	**36**	**3.52**
	3/4/2002	7.2	512	512	<1	<1	48	1.6	**1120**	**22**	0.102
	3/11/2002	7.7	536	536	<1	<1	53	1.4	**1160**	**16**	0.03
	3/18/2002	7.7	512	512	<1	<1	52.5	0.95	**1260**	**22**	<0.07
	4/15/2002	7.5	524	524	<1	<1	65.5	1	**1181**	**26**	<0.07
	5/13/2002	7.4	512	512	<1	<1	58.7	0.77	**1180**	**25**	<0.1
	8/13/2002	8.2	378	378	<1	<1	196	3	**1316**	**5**	<0.05
MW-7	2/22/2002	7.1	537	537	<1	<1	42	1.4	**800**	**27**	0.006
	3/4/2002	7.5	536	536	<1	<1	50	1.1	**1060**	**31**	0.175
	3/11/2002	7.4	536	536	<1	<1	54.9	1.5	**1140**	**20**	0.021
	3/18/2002	7.5	524	524	<1	<1	48.5	0.92	**1222**	**19**	<0.07
	4/15/2002	7.3	561	561	<1	<1	63	0.97	**1186**	**25**	<0.07
	5/13/2002	7.3	512	512	<1	<1	57.2	0.71	**1160**	**23**	<0.1
	8/13/2002	7.1	536	536	<1	<1	52	0.71	**1348**	**18.3**	<0.05
MW-8	2/22/2002	7.4	524	524	<1	<1	32	1.2	**600**	**22**	0.026
	3/4/2002	7.4	549	549	<1	<1	45	1.3	**940**	**16**	0.018
	3/11/2002	7.1	524	524	<1	<1	38.4	1.5	**980**	**17**	<0.005
	3/18/2002	7.6	524	524	<1	<1	42.7	0.89	**1102**	**15**	<0.07
	4/15/2002	7.2	536	536	<1	<1	58.6	0.9	**1119**	**23**	<0.07
	5/13/2002	7.3	524	524	<1	<1	50.1	0.61	**1080**	**19**	<0.1
	8/13/2002	7.0	610	610	<1	<1	38.3	0.62	**1098**	**9.7**	<0.05

TABLE 2
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Date	pH	Total Alkalanity	Alkalinity as Bicarbonate	Alkalinity as Carbonate	Alkalinity as Hydroxide	Chloride	Fluoride	Sulfate	Nitrate	Nitrite
MW-9	2/22/2002	7.0	537	537	<1	<1	42	1.3	**800**	**35**	0.198
	3/4/2002	7.5	536	536	<1	<1	49	1	**1040**	**18**	0.076
	3/11/2002	7.2	524	524	<1	<1	51.2	1.5	**1040**	**16**	0.009
	3/18/2002	7.4	524	524	<1	<1	47.3	0.88	**1180**	**21**	<0.07
	4/15/2002	7.1	549	549	<1	<1	58.2	0.88	**1159**	**24**	<0.07
	5/13/2002	7.4	536	536	<1	<1	51.4	0.67	**980**	**19**	<0.1
	8/13/2002	7.0	610	610	<1	<1	42.5	0.56	**1097**	**12**	<0.05
MW-10	2/22/2002	7.0	549	549	<1	<1	47	1.4	**750**	**36**	0.34
	3/4/2002	7.2	536	536	<1	<1	53	1.1	**1140**	**32**	0.01
	3/11/2002	7.7	524	524	<1	<1	51.2	1.7	**1040**	**24**	<0.005
	3/18/2002	7.7	524	524	<1	<1	50.6	0.9	**1260**	**23**	<0.07
	4/15/2002	7.5	549	549	<1	<1	64.9	0.93	**1248**	**24**	<0.07
	5/13/2002	7.6	512	512	<1	<1	58.8	0.82	**1220**	**23**	<0.1
	8/13/2002	1.1	512	512	<1	<1	56	0.92	**1504**	**22.4**	<0.05
MW-11	2/22/2002	9.2	121	61	60	<1	151	**5.0**	**1200**	**22**	**2.0**
	3/4/2002	11.9	234	36	198	<1	**427**	2	**1500**	4	**2.1**
	3/11/2002	11.5	362	158	204	<1	**543**	**7**	**1440**	4	**4.1**
	3/18/2002	11.0	228	24	204	<1	**444**	1.98	**1435**	8	**5.0**
	4/15/2002	11.1	252	48	204	<1	147	1.67	**767**	**14**	**4.1**
	5/13/2002	10.8	217	73	144	<1	119	1.86	**360**	**14**	**2.2**
	8/13/2002	9.4	132	24	108	<1	68.6	1.4	**681**	**14.2**	**1.4**
MW-12	2/22/2002	7.6	488	488	<1	<1	53	1.7	**900**	**15**	**3.4**
	3/4/2002	8.9	243	171	72	<1	234	**2.2**	**1420**	**14**	**4.2**
	3/11/2002	9.8	389	341	48	<1	194	**7**	**1340**	**10**	**3.2**
	3/18/2002	9.7	291	171	120	<1	**370**	**3.16**	**1862**	7	**7.2**
	4/15/2002	8.6	376	316	60	<1	155	**1.49**	**1349**	2	**3.1**
	5/13/2002	7.6	475	475	<1	<1	74	0.88	**1380**	1	0.8
	8/13/2002	7.4	475	475	<1	<1	56.2	0.86	**1298**	0.89	<0.05

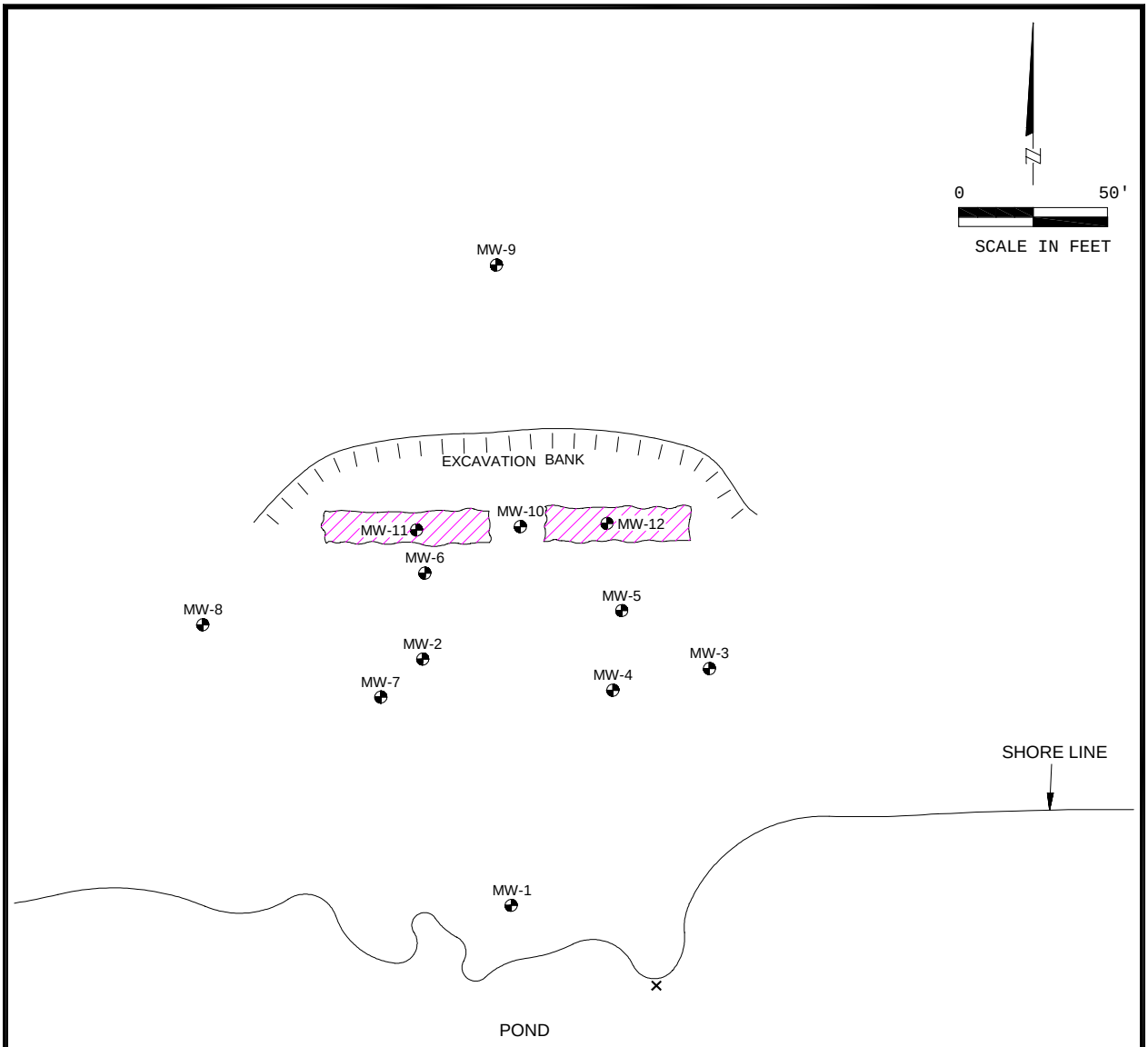
TABLE 2
Analytical Results
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

Sample ID	Date	pH	Total Alkalanity	Alkalinity as Bicarbonate	Alkalinity as Carbonate	Alkalinity as Hydroxide	Chloride	Fluoride	Sulfate	Nitrate	Nitrite
Pond Water	5/26/1999	7.6	NA	NA	<5	NA	59	0.76	**320**	9.8	<0.10
	12/20/1999	8.3	470	470	<5	<5	66	0.89	**1500**	**17**	<0.20
	2/28/2000	8.2	280	280	<5	<5	78	0.93	**2800**	0.91	0.79
	4/5/2000	8.2	290	290	<5	<5	77	0.98	**2700**	N/A	N/A
	11/9/2001	8.4	274	238	36	<1	80.9	1.70	**2400**	1.3	0.019
	2/22/2002	8.2	378	378	<1	<1	78	1.80	**2100**	13	0.039
	3/4/2002	8.3	414	414	<1	<1	75	1.40	**2320**	7	0.045
	3/11/2002	7.8	341	305	36	<1	82.3	**2.00**	**2200**	17	0.33
	3/18/2002	8.6	292	244	48	<1	86.8	1.15	**2941**	1.59	<0.07
	4/15/2002	8.6	292	244	48	<1	100.5	1.16	**2298**	2.04	<0.07
	5/13/2002	8.4	304	256	48	<1	106	0.90	**2700**	0.24	<0.1
	8/13/2002	8.4	279	219	60	<1	147	1.2	**3735**	0.16	<0.05
Standards			no std.	no std.	no std.	no std.	250	2.0	250	10	1
							S	A	P	P	P

Notes:
NA = Not Analyzed
A - Agricultural Standard
P - Primary Drinking Water Standard
S - Secondary Drinking Water Standard
All values reported in milligrams per liter (mg/L)

TABLE 3
Analytical Comparisons
Ash - Non-Ash Wells
Varra Coal Ash Project
Weld County, Colorado
CGRS No. 1-135-2755

	Non-Ash Wells			Ash Wells		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
pH	7.37	6.95	8.16	9.60	7.4	11.9
Selinium	0.07	0.005	0.151	0.16	0.022	0.59
Boron	0.84	0.257	12.6	18.43	2.09	34.5
Molybdenum	0.08	0.033	1.5	1.39	0.069	3.19
Sulfate	1178.20	600	1961	1209.42	360	1861.9
Calcium	176.43	133	225	134.50	40	243
Nitrate	20.56	4.8	36	9.21	0.66	22



LEGEND

MW-1 MONITORING WELL LOCATION

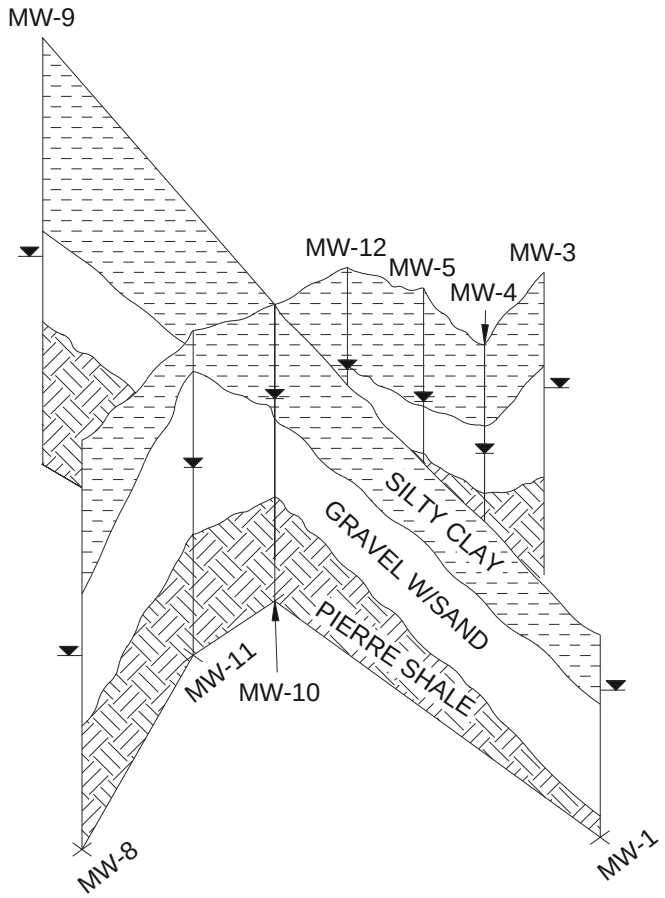
× SURFACE WATER SAMPLE LOCATION

COAL ASH TRENCH

FIGURE 1

SITE CONDITION MAP
VARRA COAL ASH PROJECT
LONGMONT, COLORADO

PROJECT NO.	PREPARED BY	CGRS
1-135-	RACAD	
DATE	REVIEWED BY	COLORADO GROUNDWATER RESOURCE SERVICES
06/20/02		



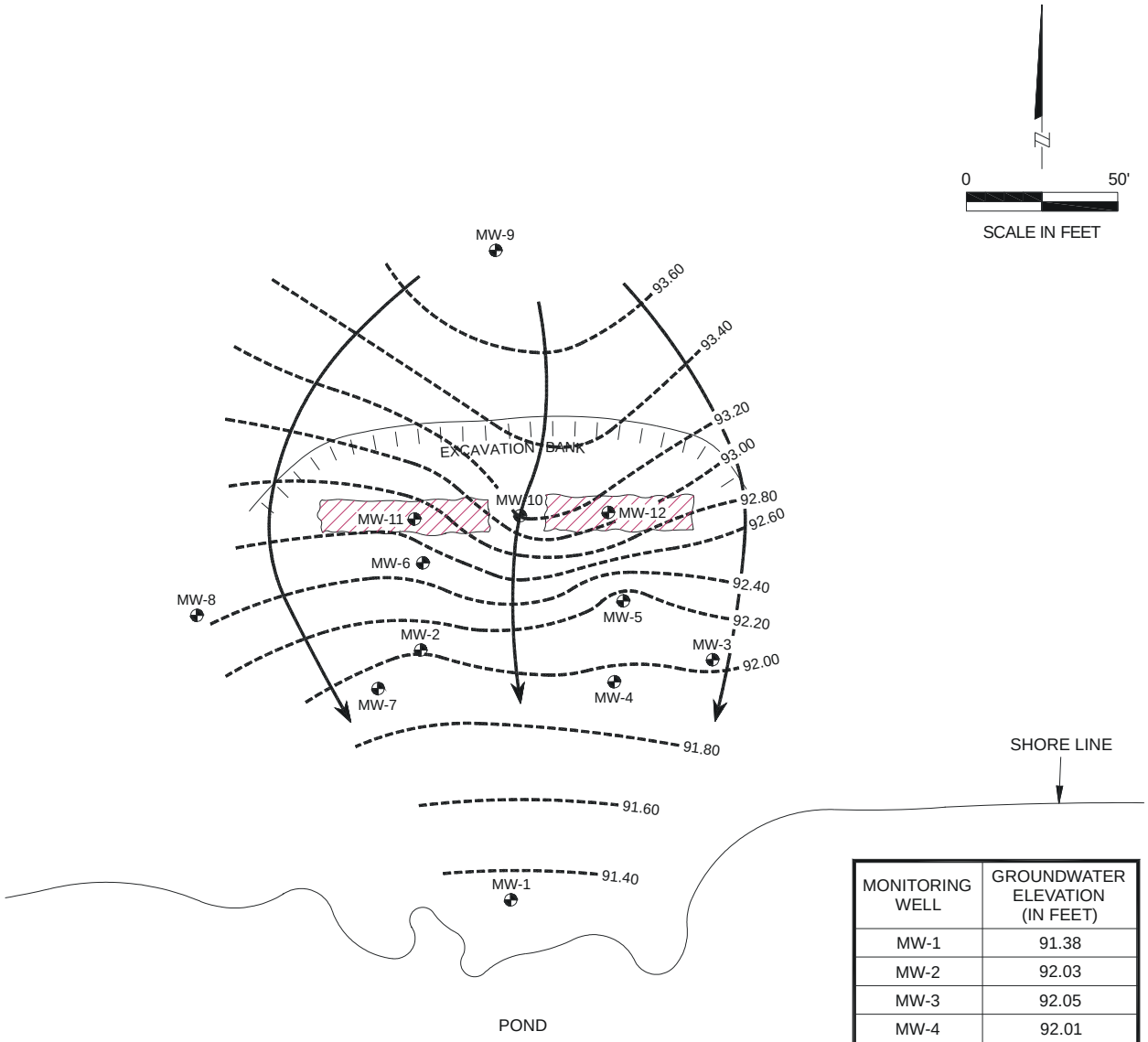
LEGEND

WATER TABLE SURFACE

FIGURE 2

FENCE DIAGRAM
VARRA COAL ASH PROJECT
LONGMONT, COLORADO

PROJECT NO.	PREPARED BY	CGRS
1-135-2755aa	RACAD	
DATE	REVIEWED BY	COLORADO GROUNDWATER RESOURCE SERVICES
06/20/02		



MONITORING WELL	GROUNDWATER ELEVATION (IN FEET)
MW-1	91.38
MW-2	92.03
MW-3	92.05
MW-4	92.01
MW-5	92.10
MW-6	92.51
MW-7	91.94
MW-8	92.44
MW-9	93.79
MW-10	93.24
MW-11	92.72
MW-12	93.12

LEGEND

MW-1 — MONITORING WELL LOCATION

INFERRED GROUNDWATER CONTOURS (CONTOUR INTERVAL = .20 FT.)

INFERRED FLOW DIRECTION

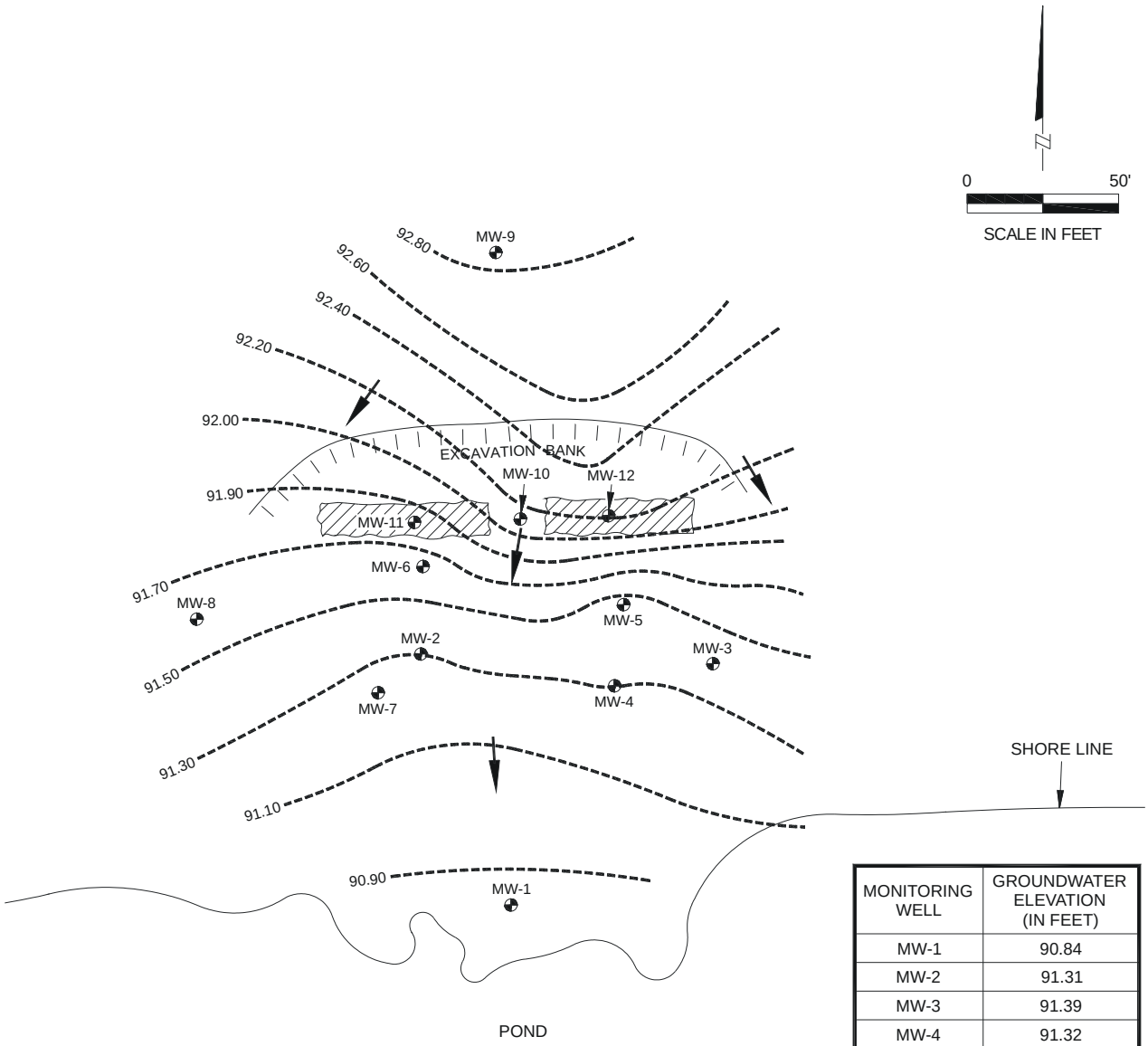
STREAM LINES

COAL ASH TRENCH

FIGURE 3

WATER TABLE CONTOUR MAP
FEBRUARY 22, 2002
VARRA COAL ASH PROJECT
LONGMONT, COLORADO

PROJECT NO.	PREPARED BY	CGRS
1-135-2755aa	RACAD	
DATE	REVIEWED BY	COLORADO GROUNDWATER RESOURCE SERVICES
06/20/02		



MONITORING WELL	GROUNDWATER ELEVATION (IN FEET)
MW-1	90.84
MW-2	91.31
MW-3	91.39
MW-4	91.32
MW-5	91.41
MW-6	91.65
MW-7	91.24
MW-8	91.63
MW-9	92.85
MW-10	92.28
MW-11	91.85
MW-12	92.40

LEGEND

MW-1 — MONITORING WELL LOCATION

INFERRED GROUNDWATER CONTOURS (CONTOUR INTERVAL = .20 FT.)

INFERRED FLOW DIRECTION

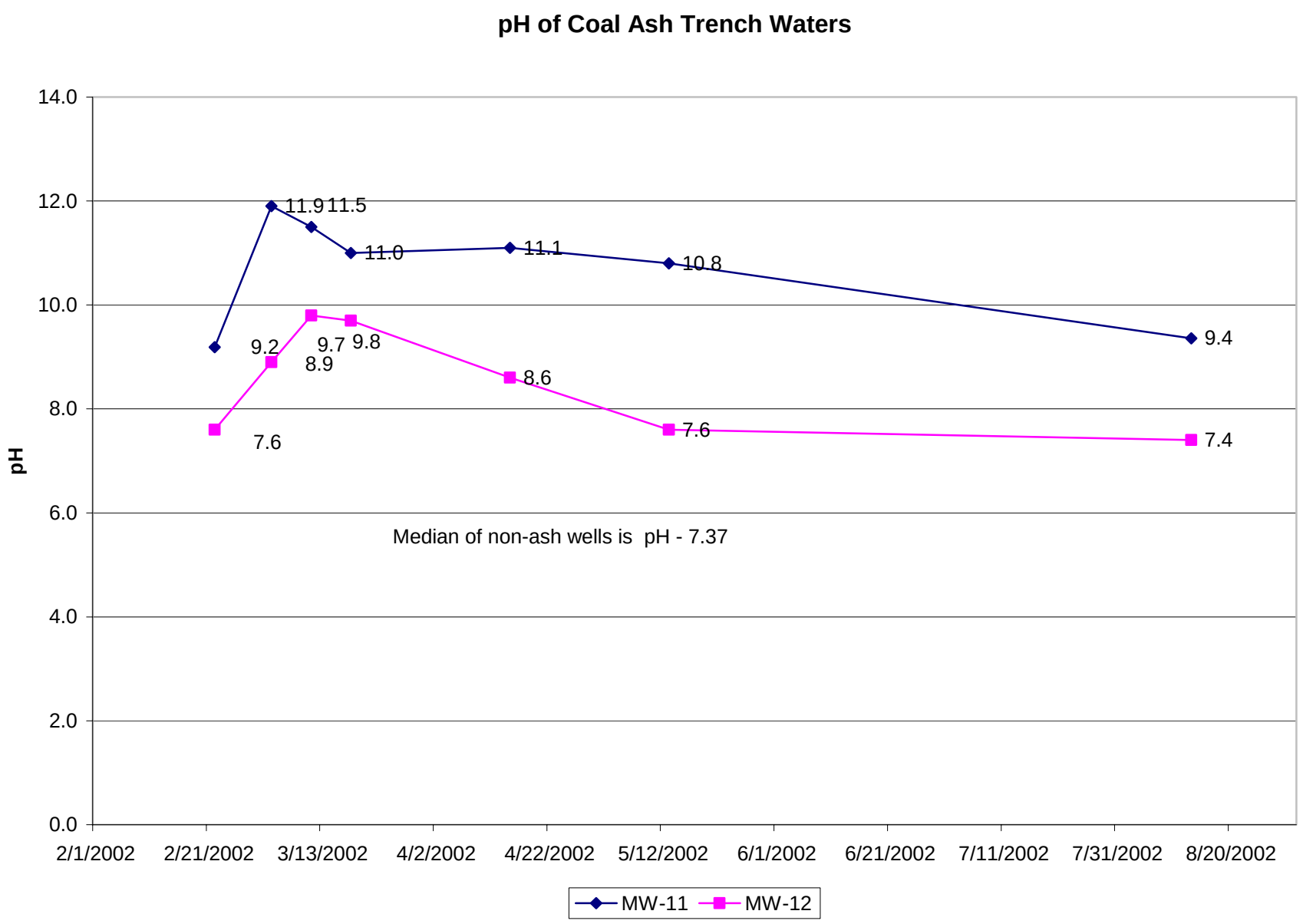
COAL ASH TRENCH

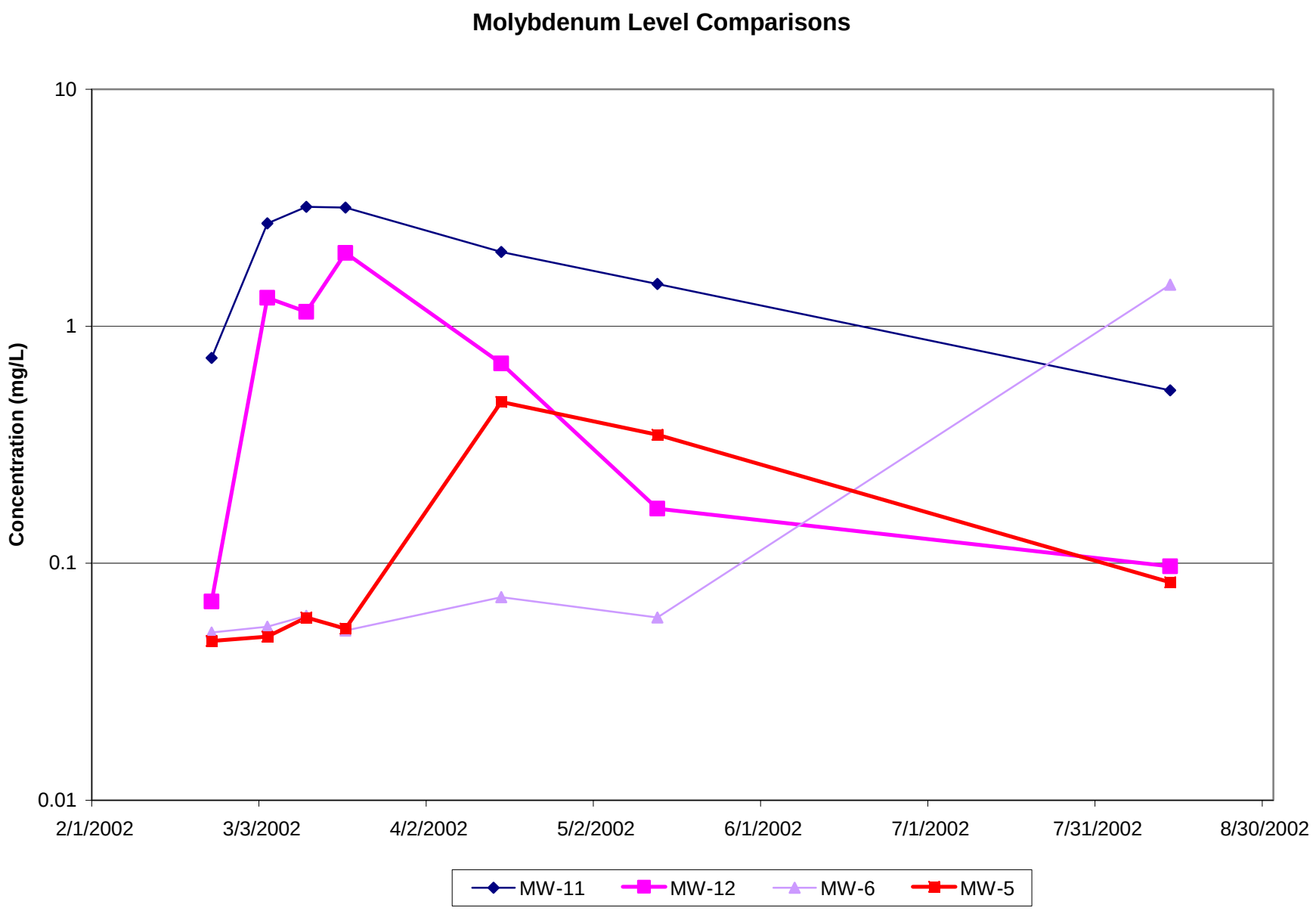
FIGURE 3A

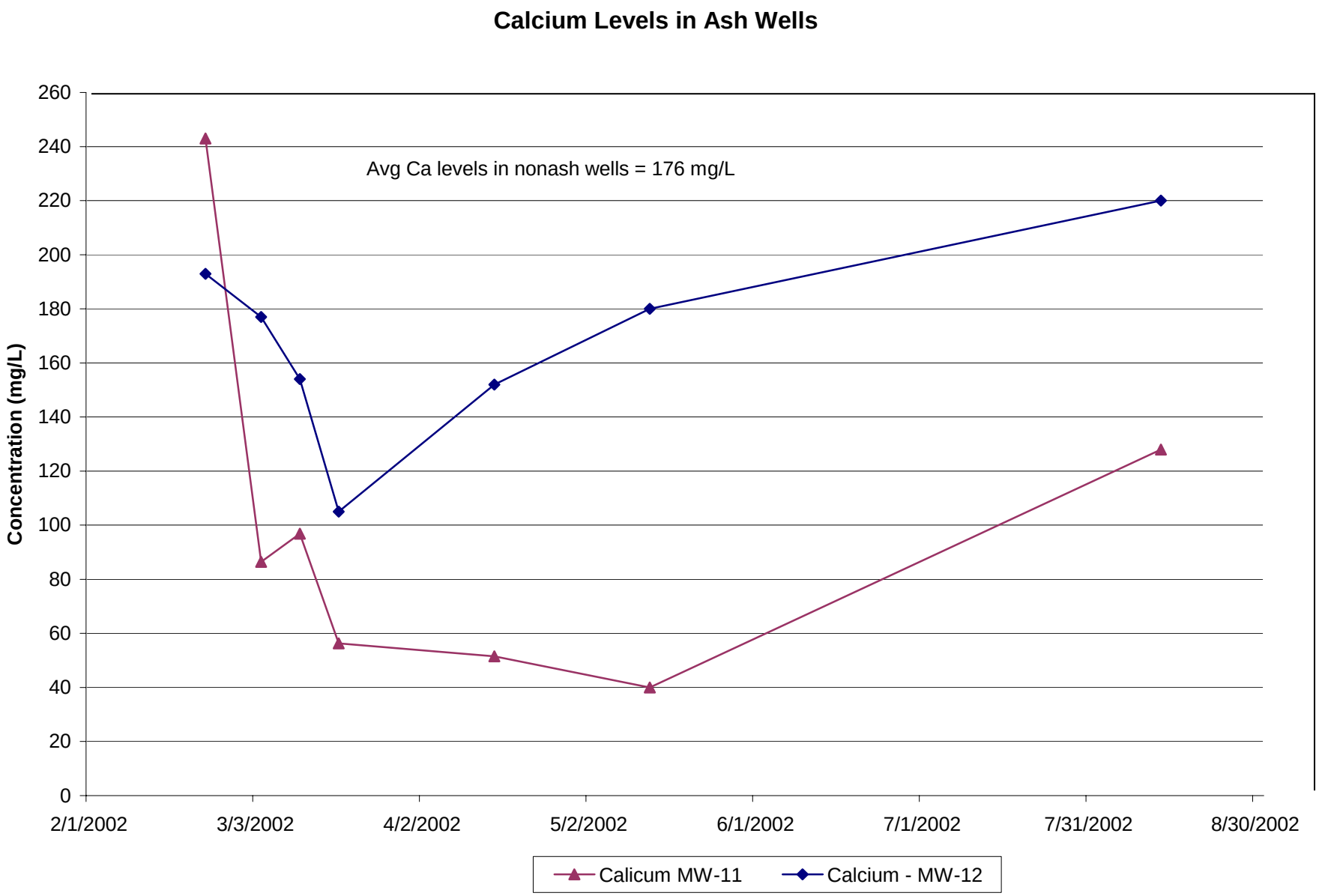
WATER TABLE CONTOUR MAP
MAY 13, 2002
VARRA COAL ASH PROJECT
LONGMONT, COLORADO

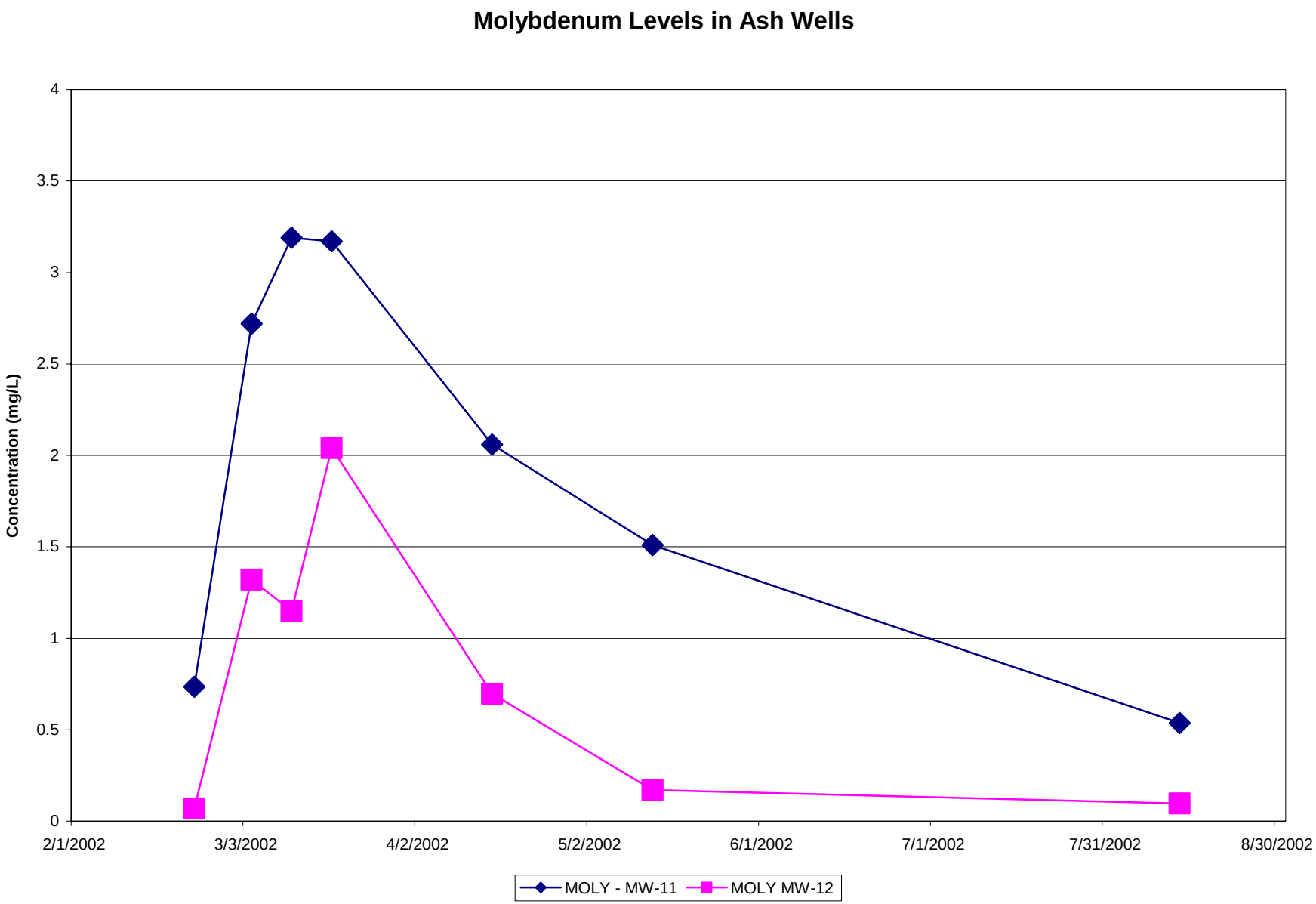
PROJECT NO.	PREPARED BY	CGRS
1-135-2755aa	RACAD	
DATE	REVIEWED BY	COLORADO GROUNDWATER RESOURCE SERVICES
06/20/02		

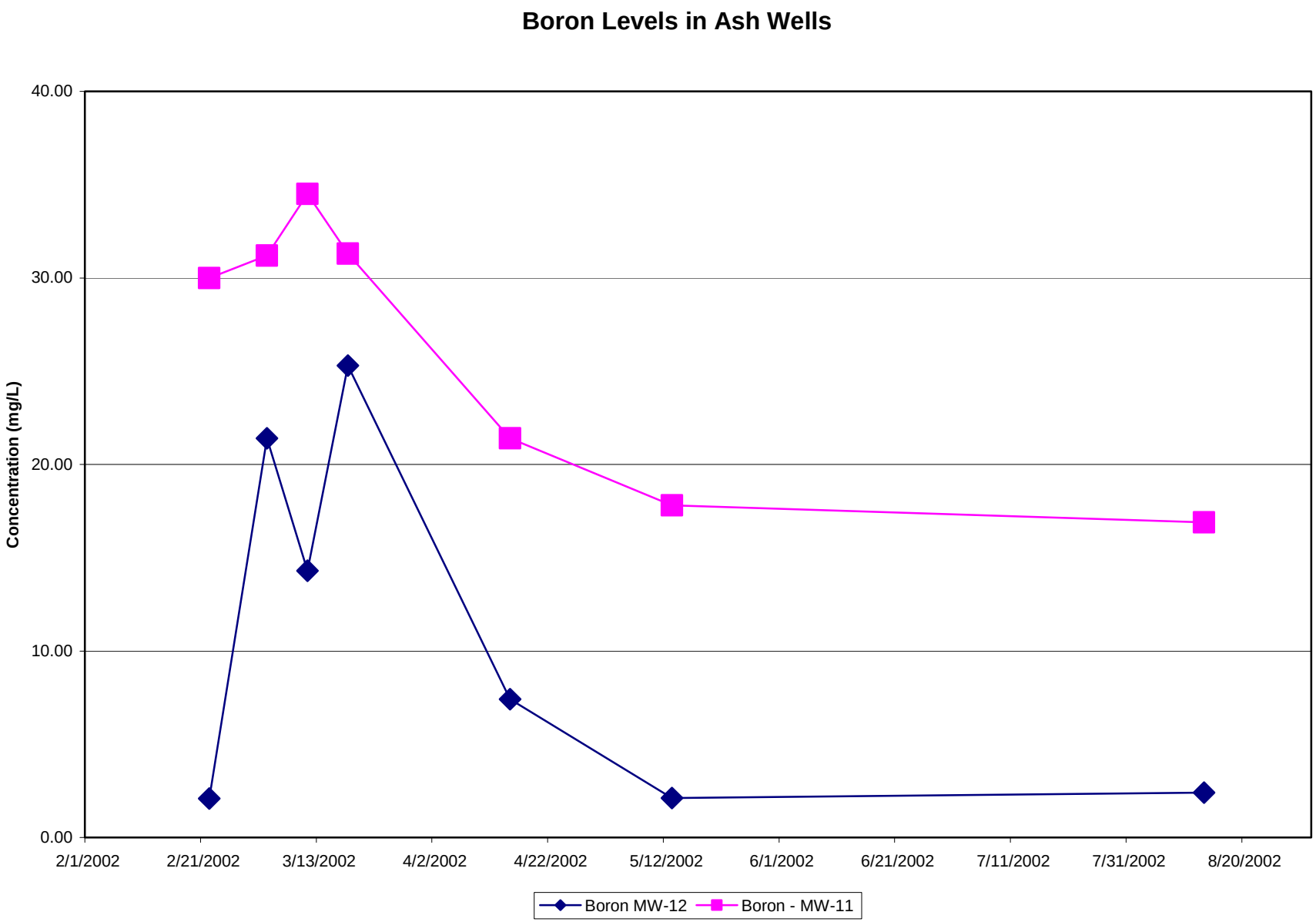
Graphs


pH of Coal Ash Trench Waters
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
pH
11.9
11.5
11.0
11.1
10.8
9.4
9.2
9.7
9.8
8.9
8.6
7.6
7.6
7.4
Median of non-ash wells is pH - 7.37
2/1/2002
2/21/2002
3/13/2002
4/2/2002
4/22/2002
5/12/2002
6/1/2002
6/21/2002
7/11/2002
7/31/2002
8/20/2002
MW-11
MW-12


Molybdenum Level Comparisons
Concentration (mg/L)
10
1
0.1
0.01
2/1/2002
3/3/2002
4/2/2002
5/2/2002
6/1/2002
7/1/2002
7/31/2002
8/30/2002
MW-11
MW-12
MW-6
MW-5


Calcium Levels in Ash Wells
Avg Ca levels in nonash wells = 176 mg/L
Concentration (mg/L)
260
240
220
200
180
160
140
120
100
80
60
40
20
0
2/1/2002
3/3/2002
4/2/2002
5/2/2002
6/1/2002
7/1/2002
7/31/2002
8/30/2002
Calicum MW-11
Calcium - MW-12


Molybdenum Levels in Ash Wells
Concentration (mg/L)
4
3.5
3
2.5
2
1.5
1
0.5
0
2/1/2002
3/3/2002
4/2/2002
5/2/2002
6/1/2002
7/1/2002
7/31/2002
8/30/2002
MOLY - MW-11
MOLY MW-12


Boron Levels in Ash Wells
Concentration (mg/L)
40.00
30.00
20.00
10.00
0.00
2/1/2002
2/21/2002
3/13/2002
4/2/2002
4/22/2002
5/12/2002
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6/21/2002
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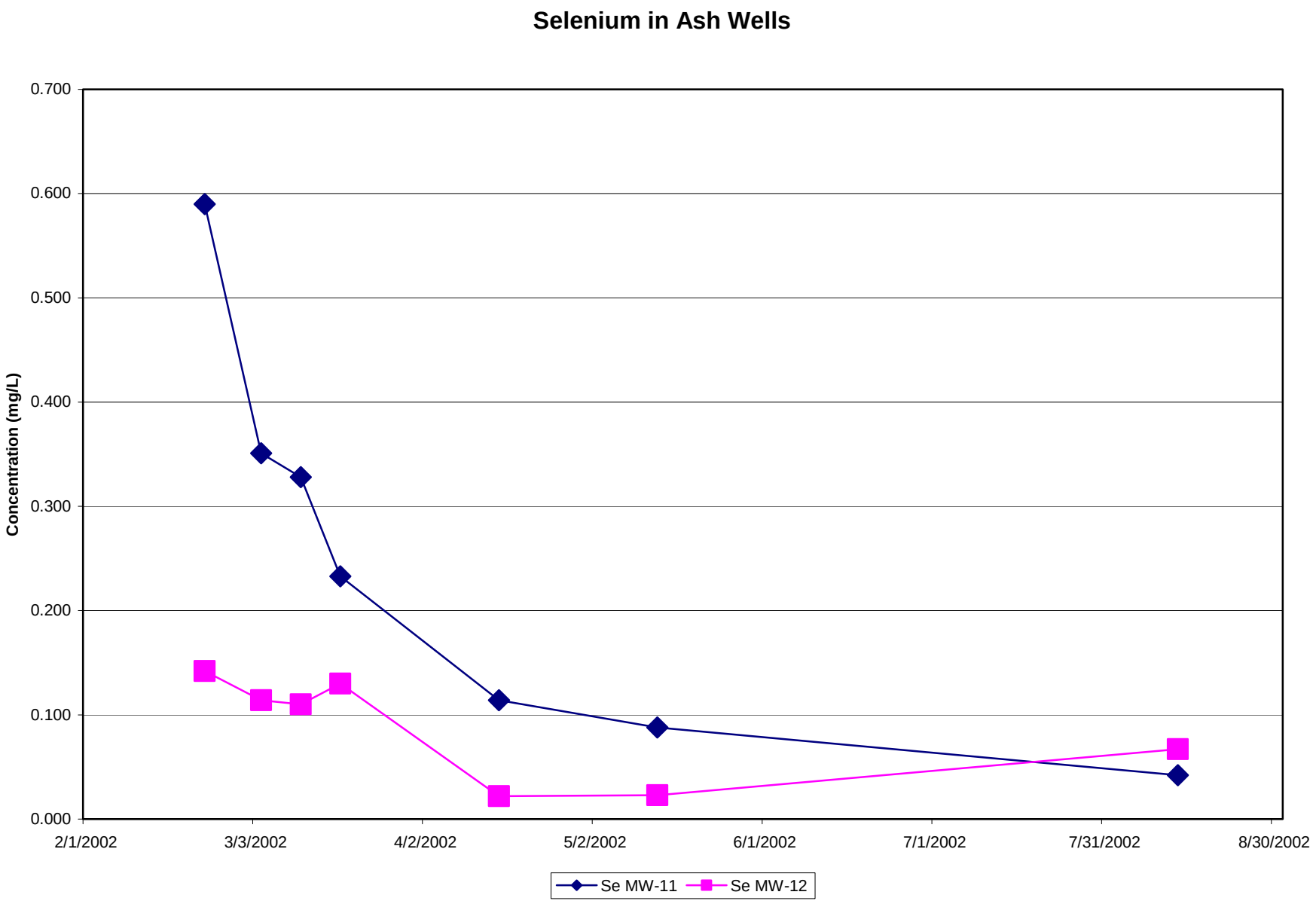
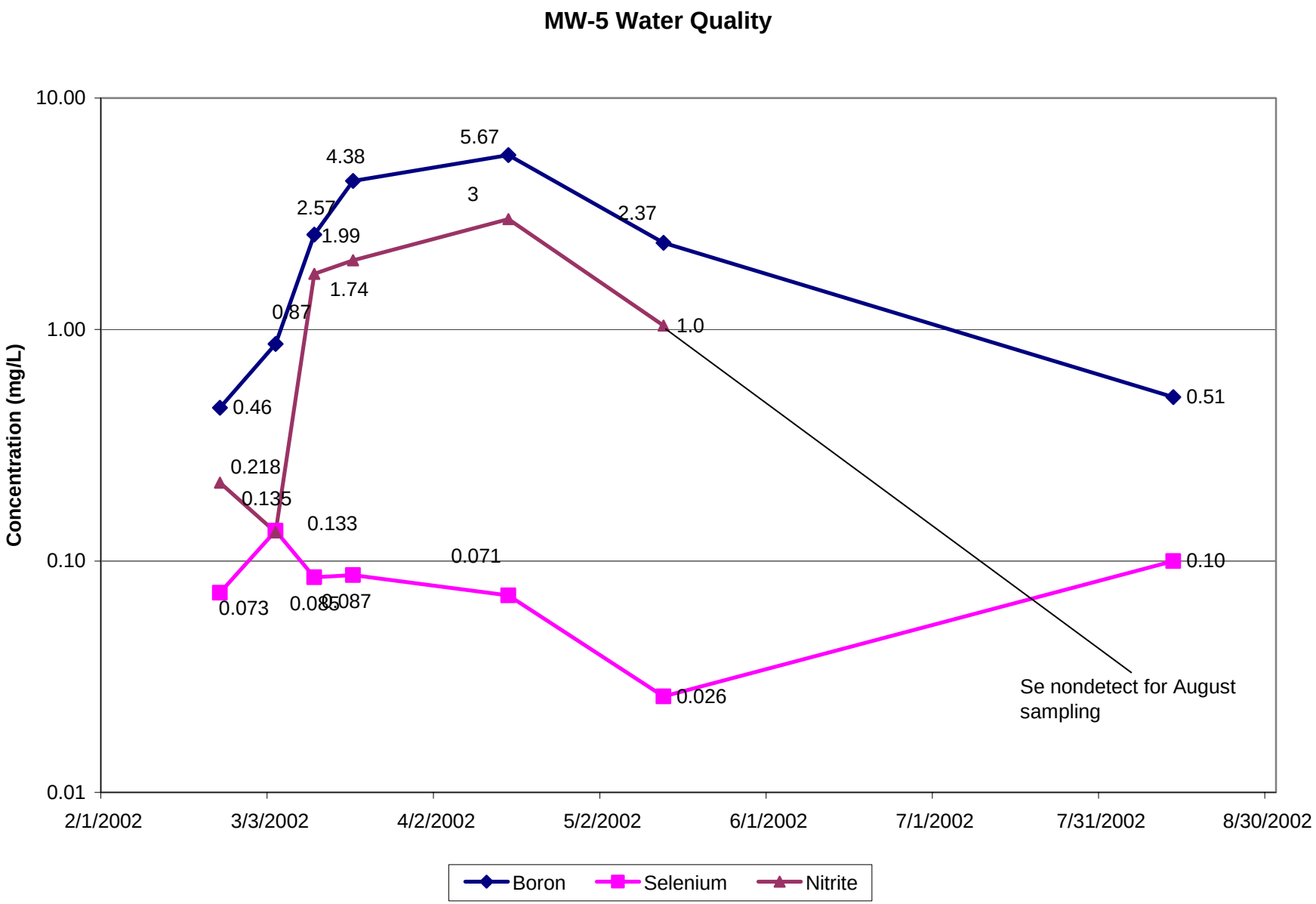
7/31/2002
8/20/2002
Boron MW-12
Boron - MW-11


Selenium in Ash Wells
Concentration (mg/L)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
2/1/2002
3/3/2002
4/2/2002
5/2/2002
6/1/2002
7/1/2002
7/31/2002
8/30/2002
Se MW-11
Se MW-12


MW-5 Water Quality
Concentration (mg/L)
10.00
1.00
0.10
0.01
2/1/2002
3/3/2002
4/2/2002
5/2/2002
6/1/2002
7/1/2002
7/31/2002
8/30/2002
0.46
0.87
2.57
4.38
5.67
2.37
0.51
1.99
1.74
3
1.0
0.218
0.135
0.133
0.071
0.073
0.085
0.087
0.026
0.10
Se nondetect for August sampling
Boron
Selenium
Nitrite

CCB LEACHING SUMMARY: SURVEY OF METHODS AND RESULTS[1]

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Abstract

The utilization of coal combustion by-products (CCB) as bulk fill and as mine backfill has raised questions about the potential contamination of surface and groundwater. A number of studies have addressed the release of various metal ions from CCB, but correlation of results has been difficult due to the multiplicity of methods and the variety of leachant solutions. Differences in the type of samples and sample size also have complicated the discussion. Leaching is related to the solubility of a specific compound and can be influenced by pH, temperature, complexation, and oxidation/reduction potential. A recent survey identified more than 100 leaching methods to remove soluble components from a solid matrix, including regulatory methods, standard methods, and those developed for a particular application. Regulatory tests and standard methods are not necessarily appropriate for leaching tests intended to simulate natural processes. Data obtained by different laboratories using standard or regulatory tests may be comparable (within an order of magnitude). Studies performed with different leaching methods do not necessarily produce comparable data, although researchers using different methods may arrive at similar conclusions. In the leaching studies surveyed, the disparity in leaching conditions, the duration of leaching, and the different samples make direct comparisons of results very difficult. However, many studies reached these general conclusions:

- than calcium, less than 50 percent of an element in CCB is labile, even in long-term tests;
- except for oxyanions, the solubility of cations in CCB increases with a decrease in pH;
- the alkalinity of the ash will affect its leachability; and
- the distribution of an element in solid phases (crystalline, amorphous, surface coating) may control its solubility.

Introduction

During the past 50 years, the use of coal to generate electricity has increased substantially, as has the generation of coal combustion by-products (CCB). In EPA's recent regulatory determination, it was acknowledged that CCBs are a nonhazardous materials and that increased utilization of these materials should be encouraged. However, environmental concerns about CCBs focused on the potential release of trace elements to surface and groundwater, particularly when the material is used as mine backfill. Estimating the release of metals from CCBs has been studied using a variety of methods, samples, and leachant solutions. Any attempt to integrate the results of disparate test protocols requires some discussion of leaching, the fundamentals, and the various methods. The results of CCB leaching studies can then be reviewed to determine if the results can be correlated to general conclusions.

Leaching Methods

The leaching behavior of all types of materials is related to several critical factors, including specific element solubility and availability or release potential. Solubility can be influenced by pH, complexation by inorganic species or dissolved organic matter, and reducing properties. A recent survey of the literature identified more than 100 leaching methods to remove soluble components from a solid matrix (Hesbach and Lamey, 2001). Several of these are regulatory methods, mandated to characterize materials; others are approved by organizations for establishing compliance to particular specifications. Many were developed for application to municipal solid waste or industrial wastes prior to use or disposal. Some are intended to mimic natural conditions while the intent of others is to obtain information about the nature of the extractable material within a particular solid. The methods vary in

[1]A more detailed discussion of the subjects discussed in this paper are included in "Fluid Extraction of Heavy Metals from Coal Ash," a dissertation submitted to the University of Pittsburgh in partial fulfillment of the degree of Doctor of Philosophy, April 2002.

the amount and particle size of leached sample, the type and volume of leachant solution(s), the leachant delivery method, and time. Most procedures are performed at ambient temperature, although a few decrease the time required to solubilize components by increasing the temperature. Although some methods have been developed for a specific type of material, most leaching methods have been applied to a variety of materials. The parameters for these methods are compared in Table 1.

Although there is a wide variety, leaching methods can be categorized in a number of ways. The first deals with whether the leaching fluid is a single addition (static extraction tests) or is renewed (dynamic tests). Methods are also characterized as (1) batch leaching, in which the sample is placed in a given volume of leachant solution; (2) flow through (column) systems; or (3) flow around systems for monolithic samples. Results are generally reported as a concentration, sometimes as the concentration in the leachant solution (mg/L) or as the concentration in the solid (mg/kg). In many methods, the liquid to solid ratio (L/S) is used to quantify the volume of leachant and the amount of solid sample, usually as mL/g or L/kg.

Summaries of many of the more commonly used leaching methods are given by Sorini (1997) and Wilson (1995). The International Ash Working Group (IAWG) based in Europe has done extensive work on the integration of a variety of tests into a comprehensive leaching system (Eighmy and van der Sloot, 1994; van der Sloot, 1998).

Leaching methods are categorized as static or dynamic methods. Within these categories, static methods are divided into batch and monolithic categories. Dynamic methods include column, serial batch, or sequential batch, although some methods are not uniquely defined within these categories. Due to the number of leaching methods, this discussion is not comprehensive. The intent is, rather, to identify commonly used leaching techniques.

Leaching Fundamentals[2]

Leaching Chemistry

As it applies to this study, leaching is the dissolution of a solid by an aqueous chemical solution. Leaching reactions are characterized as hydrolysis, caustic (alkaline), acidic, or oxidative reductive. In addition to water, acids and bases are commonly used as leaching agents. This process can be complicated by secondary reactions, such as precipitation, adsorption, or the formation of complexes. Although biochemical leaching may be important in natural processes and hydrometallurgy, it is not usually considered in regulatory or laboratory leaching tests.

The dissolution of mineral components and the behavior of dissolved components is controlled by the system variables, pH, eh, and the concentrations of the dissolved species (Demoupoulos, 1999). A chemical reaction involving dissolution and precipitation can be written as:

$$A_a B_{b(S)} \Leftrightarrow aA^{b+}_{(aq)} + bB^{a-}_{(aq)} \quad \textbf{Eq. 1}$$

where AB is the solid, A is the dissolved cation (metal), and B is dissolved anion (ligand). If the compound AB exists in solution, at equilibrium the reaction quotient, is equal to K, the equilibrium constant (Stumm and Morgan, 1996).

Reactions in solution are homogeneous reactions in one phase. Leaching involves heterogeneous reactions with at least two phases, liquid and solid. Since the reactant AB is a solid, its activity is considered fixed at unity and for this compound the equilibrium solubility product is:

[2]For a more thorough discussion of leaching chemistry refer to Demopoulos (1999), van der Sloot *et al.* (1998) and Stumm and Morgan (1996).

$$K_{sp} = \left[A^{b+}\right]^{a}\left[B^{a-}\right]^{b} \qquad \textbf{Eq. 2}$$

The solubility product is considered constant for varying compositions of the aqueous phase at constant temperature and pressure for a pure solid phase. If K_{sp} and the concentration (mol/L) of one of the species is known, it is theoretically possible to calculate the concentration of the other species. When the metal or the ligand is distributed in more than one mineral, solubility calculations become more complex. Solubility products, if known, can be used to estimate the relative solubility of several coexisting minerals.

Because reactants must diffuse across the liquid solid interface, the surface area of the solid is a variable. A non-homogeneous material, in which an element is distributed in more than one chemical compound or crystalline phase, also complicates the formulation of solubility equations. Competing reactions, secondary reactions, and precipitation also may complicate the interpretation of leaching results.

The shrinking core model that has been applied to a variety of solids leaching processes describes a reaction front starting at the surface of the particle of radius r and moving inward with a velocity v. The rate of reaction is a function of the distance the reaction front moves in time t.

$$R(t) = 4\pi p_r\left[r - \lambda(t)\right]^2 v \qquad \textbf{Eq. 3}$$

According to this model the reaction rate is greatest when the leaching solution is at the surface of the particle. Calculation of the reaction rate is more complex if the particle is not homogeneous, if more than one chemical reaction occurs, and if transport rates for reactants and products must be considered.

An adsorption/desorption model of intraparticle diffusion was developed by Chaiken (1992) to account for spatial heterogeneity of particle porosity and temporal changes in porosity due to leaching reactions.

$$\int(\lambda) = \frac{h}{\lambda\sqrt{\pi}} e^{-h^2(\ln\lambda/\ln\lambda)^2} \qquad \textbf{Eq. 4}$$

Leaching Methods

There are three types of leaching methods: (1) regulatory— those promulgated and approved by a regulatory agency to generate specific information for submission in a legal context; (2) standard methods are those adopted by a standards organization (ASTM, ISO) for a specific set of conditions and sometimes for specific materials; and (3) research methods developed for a particular objective. Most of this discussion deals with regulatory and standard methods, although examples of some commonly used research methods are included. Regulatory and standard methods are frequently used for research projects. However, results from different projects should be considered comparable only (1) if the method is appropriate to the problem studied; and (2) if the procedure is followed exactly.

Batch leaching methods are those in which a sample is placed in a given volume of leachant solution for a set period of time. Most of these methods require some type of agitation to insure constant contact between the sample and the leachant. At the end of the leaching period, the liquid is removed and analyzed. The most commonly used batch leaching methods are:

- the Toxicity Characteristic Leaching Procedure (TCLP),
- the Extraction Procedure Toxicity Test (EPTOX),

- the Synthetic Precipitation Leaching Procedure (SPLP),
- the Standard Test Method for Shake Extraction of Solid Waste with Water (ASTM-D3987), and
- the California Waste Extraction Test (WET).

The Availability Test for Granular Materials (NEN 7341) is a Dutch Standard leaching test (Van der Sloot *et al.*, 1994), the Leachate Extraction Procedure (LEP) is a procedure approved by the Canadian General Standards Board, and the Synthetic Groundwater Leaching Procedure (Hassett, 2000) is a draft ASTM procedure for long-term leaching.

In serial batch methods, a sample of waste is leached successively with fresh aliquots of the same leaching fluid. This method is intended to eliminate the effect of concentration on solubility and to simulate long-term exposure to the leachant solution. These methods include:

- EPA's Multiple Extraction Procedure (MEP),
- the Standard Test Method for Sequential Batch Extraction of Waste with Acidic Extraction Fluid (ASTM D 5284), and
- the Standard Test Method for Sequential Batch Extraction of Waste with Water (ASTM D 4793).

Column leaching tests are considered as simulating the flow of percolating groundwater through a porous bed of granular material. The flow of the leaching solution may be in either down-flow or up-flow direction and continuous or intermittent. The flow rate is generally accelerated when compared to natural flow conditions. However, it should be slow enough to allow leaching reactions to occur. A basis assumption in column leaching is that the distribution of the leaching solution is uniform and that all particles are exposed equally to the leachant solution. Precipitation or sorption within the column may affect the results.

The Standard Test Method for Leaching Solid Material in a Column Apparatus (ASTM D-4874) is intended to maximize the leaching of metallic species from a solid. The aqueous fluid passes through particles of known mass in a saturated up-flow mode. The Dutch Standard Column Test (NEN 7343) is also an up-flow application, and the Nordtest Column Method (NORDTEST) is similar to the Dutch Column test, except that column dimensions are optional**.** The up-flow column procedures are designed to insure that the leachant solution is equally distributed throughout the column. However, gravity flow columns also can be used to study leaching of porous media. Column experiments more closely approximate the flow conditions, particle size distribution and pore structure, leachant flow, and solute transport found in the field (Zachara and Streile, 1990). Column experiments can be conducted in both saturated and unsaturated conditions. Unsaturated conditions are usually intended to mimic vadose zone placement. Intermittent addition of a given volume of leachant solution at the top of the column can provide uniform distribution of the fluid and approximate a constant fluid front moving through the unsaturated column. Saturated columns are obtained by a constant fluid flux and allowing the fluid to pond at the top of the column. Variables, such as leachate collection, sampling frequency, leachant flow rate, and duration of the experiment are determined by the experimental objectives.

Sequential leaching tests use a single sample that is leached by a series of different leaching fluids. The constituents extracted with a particular leachant are associated with a particular mineral phase or chemical species. Speciation is considered one of the controlling factors in the potential release of cations to the environment. The USGS Sequential Leaching Method was developed as a rapid indirect method of determining the modes of occurrence of trace elements in coal (Palmer *et al.*, 1999). A Short Sequential Procedure uses two steps to assess the lability of heavy metals in soil particles (Maiz *et al.*, 2000). Like the later USGS sequential extraction procedure, Tessier (1979) uses a series of four extractant fluids to dissolve metals associated with particular ligand phases in a complex sample. A modified Tessier procedure uses aqua regia in place of hydrofluoric/nitric acid (Raksasataya *et al.*, 1996). A three-step sequential extraction procedure developed by the commission of the European Communities Bureau of Reference (Quevavller *et al.*, 1994) also has been modified (Raksasataya *et al.*, 1996) to include aqua regia digestion of the residual material.

Monolithic leaching methods are used to evaluate the release of elements from a material that normally exists as a massive solid, cement for example. They are frequently used to characterize the release of pollutants from stabilized waste materials. The release of an element is a function of the exposed surface area as opposed to the mass. Flow around systems relate solubility to the surface area of a particular volume. Flow through systems also consider the internal pore surface. And some systems take into account the rate of diffusion of the leachant solution into the

pores.

In static monolithic leaching, a particle of regular geometry and known surface area is immersed in a volume of leachant solution. The same leachant solution is sampled at defined intervals and replaced with fresh solution (Hoberg *et al.*, 2000). The flow through leaching test (Poon *et al.*, 2001) is used to characterize leaching from a waste that is more permeable than the surrounding material. The solid sample is placed in a flexible wall permeameter. The leaching solution is DI water at a mean flow rate of .0166 mL/min at a pressure of 400 kPa.

Bulk leaching generally refers to leaching large samples, either in a large column or in heaps. They are either industrial systems or used in a research setting to leach a nonhomogeneous sample with a large particle size and are not particularly applicable to fly ash. (ASTM Monolithic, ISO seawater)

The International Ash Working Group (IAWG) has designed a leaching protocol to quickly determine the total leachable elements in a material and to estimate metal release in a normal environmental setting (van der Sloot *et al.*, 1994; van der Sloot, 1998). An availability test is based on the extraction of fine-grained material at a L/S of 100 at a controlled pH of 4, which is assumed to be a lower pH limit found in natural environments. A second test at a pH of 8 is used to determine leachability of oxyanionic species. From the total acid consumption, the acid neutralization capacity of the material is estimated. Total elemental release as a function of time is estimated by leaching at different L/S values in a serial batch test. The release of contaminants is usually expressed in mg/kg leached against the L/S ratio.

Comparison of Leaching Methods

Several studies have attempted to compare different leaching methods, frequently in an attempt to correlate data from disparate techniques. Most comparisons were based on comparative release of particular elements by 2 or more specific procedures. Differences in such factors as test objective, leachant volume, sample size, and test duration were not considered.

In 1981, researchers at the Department of Energy/Los Alamos Scientific Laboratory (DOE/LASL) compared EPTOX with a procedure used at the laboratory (Heaton, *et al.*, 1981). The samples were coal preparation wastes. The LASL static leach procedure was similar to EPTOX and the release of RCRA elements was found to be comparable with both procedures.

The Electric Power Research Institute (EPRI) sponsored a round robin evaluation of TCLP and EPTOX (Mason and Carlile, 1986) that was intended to evaluate the reproducibility of the TCLP and compare the results to those obtained with EPTOX. Seven CCB samples were sent to each of three laboratories that performed duplicate determinations with both TCLP and EPTOX. For the individual procedures, most of the variability was related to consistent differences in the results from one of the three laboratories. When comparing the methods, the TCLP and EPTOX concentrations of 14 elements were comparable for approximately 60 percent of the determinations. Eighty-three percent of the concentrations determined with TCLP were equal to or greater then those determined with EPTOX.

In a report to EPRI (Zachara and Streile, 1990), static (batch) and dynamic (column) methods were compared. Based on a review of the literature, batch systems tend to be inexpensive, simple, and they generate chemical data for mechanistic applications. Column methods are more expensive and more operationally complex, but they generate results that reflect real systems subject to fluid flow and solute transport.

The Netherlands Energy Research Foundation (ECN) compared regulatory test procedures used in the United States, Canada, Germany, France, Switzerland, and the Netherlands (van der Sloot *et al.*, 1991). Although the effect of pH on release is established, the effects of changes in redox potential and the concentration of complexing agents, as well as the effect of temperature differences, are not known.

The European Commission on Normalization, through its technical committees, is addressing the integration of leaching methods for various materials. The committee on waste materials (CEN/TC292) addresses issues related to

disposal of wastes and also to by-products or secondary raw materials intended for reuse (van der Sloot *et al.*, 1998).

Leaching Methods Summary

Leaching can be described as the fluid extraction of a compound or element from a solid. It is an interactive process in which both leachant and solid variables control the results. The pH of the leachate, which is determined by the pH of the leachant and the alkalinity/acidity of the solid is generally recognized as a controlling factor. The effects of oxidation reduction potential, dissolution/precipitation equilibrium, complexation, temperature, and the concentration of dissolved CO_2 and O_2 is not addressed in most leaching methods.

Leaching methods include those to determine regulatory compliance, those approved by standards organizations, and methods developed for a particular objective. With exact duplication of regulatory or standard methods, there is a 60 to 80 percent probability that tests conducted by different laboratories with the same protocol will have comparable results. However, compliance tests and standard methods are not necessarily appropriate for leaching tests to simulate natural processes, obtain data on reaction mechanisms, or unravel complex solubility relationships. For these, it is necessary to select or develop a procedure that addresses the experimental objective, meets the procedural constraints, and produces data that is directly or functionally related to the problem being studied. Data obtained by different laboratories using standard or regulatory tests are probably comparable. Studies performed with different leaching methods do not necessarily produce comparable data, although researchers using different methods may arrive at similar conclusions.

Results of Laboratory CCB Leaching Studies

A number of researchers have addressed the release of captions, particularly heavy metals from coal combustion by-products (Reviews: Mattigod, Eary, EPRI). Many of these attempt to estimate the potential effects on groundwater if the CCBs are placed as bulk fills or used in mine remediation. Studies conducted during the last 25 years are summarized below. The disparity in leaching conditions, the duration of leaching and the different samples, make direct comparisons of results very difficult. However, the results of the individual studies can be correlated sufficiently to discern general trends. Leaching conditions for each study are summarized in Table 2, and results are summarized in Table 3.

RCRA Leaching Tests of CCB

The most common methods used to determine the environmentally "hazardous" characteristics of solid waste materials for RCRA purposes are TCLP and SPLP. Data on RCRA tests of CCB were obtained from surface mine permit files of the Pennsylvania Department of Environmental Protection (PADEP). Test results of 196 TCLP tests (Table 4) and 20 SPLP tests (Table 5) were reviewed (Kim and Cardone, 1997). There was one exceedence for mercury in the TCLP tests, and no exceedences in any of the SPLP tests. Approximately 33% of the values in the TCLP tests and approximately 75% in the SPLP tests were below detection limits.

Standard leaching protocols were used to determine the leachate concentrations from ash produced from various fuels including coal, waste coal, and petroleum coke (CIBO, 1997). For a total of 240 samples of fly ash, bed ash, and combined ash, one sample exceeded the RCRA limit for mercury (.29 mg/L) and one sample exceeded the RCRA limit for selenium (2.5 mg/L). In this sample population, the percentage of exceedences was less than one percent (0.8).

The results of both EPTOX and TCLP leaching tests on 17 samples of fly ash, bottom ash and FGD sledge are reported by EPRI (1987). In 34 tests, one sample exceeded the RCRA toxicity limit for arsenic and for chromium.

According to the results of the tests reviewed, less than one percent of CCB exhibit the characteristic of toxicity as determined by regulatory leaching tests.

Summary

There is a plethora of leaching protocols, regulatory, standard, and those commonly used for a specific purpose. The

research studies summarized used a variety of methods. In spite of the disparity of experimental conditions, some general conclusions are apparent.

- Almost all of the cations in CCBs, including the trace elements, are sparingly soluble at circumneutral pH.
- Most cations are more soluble in acid solutions.
- Those cations that form oxyanions are more soluble in basic solutions.
- The exceedence rate for RCRA metals as determined by regulatory leaching tests is less than one percent.

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Table 1. Comparison of method parameters for static leaching methods.

Method	Leachant	Sample size, g	pH	L/S	Results as	Time, hr
ASTM	Water	70		20	mg/kg	18
EPTOX	Water	100	5.0	20	mg/L	24
LEP	Water	50	5.0	20		24
SPLP	Water acidified with nitric and sulfuric acids	100	4.2	20	mg/L	18
TCLP	Acetic Acid or Acetate Buffer	100	2.88	20	mg/L	18
CA WET						
NEN7341						
LEP						
SGLP						

Table 2. Summary of Experimental Parameters for Laboratory Leaching Experiments

Reference	Leach Type	CCB	Sample Size	Leachant Solution	Volume/Flow Rate	pH	Time
Dreher *et al.*	Column	FBC+CSS		H_2O	1 pore volume/wk	>8	15 wk
	Batch	FBC+CSS		H_2O	L/S = 4:1	>8	3<>180 d
Dreesen *et al.*	Batch	ESP FA		0.1 M citric acid 1.0 M Hcl 0.001 to 1.0 M HNO_3 H_2O 0.1 M NH_4OH	L/S = 4:1		3 h
Dudas	Column	PC Fly Ash (Western Bituminous)	250 g	H_2O	124 L 245 L 421 L	> 12 to 8	2 yr max
Fishman *et al.*	Batch	"upstream" ESP FA "downstream" ESP FA		DI H_2O	L/S = 20:1	>8 <4	18 hr
Fleming *et al.*	Column	Coal FA MSW FA		Acetic Acid		3.0 4.1 6.8	
Griffin *et al.*	Batch	PC FA Char Slag		H_2O + NaOH H_2O + NaOH H_2O H_2O + HNO_3	10% weight to volume	8.8 8.0 4.0 2.7	3-6 months
Hequet *et al.*	Batch	3 FA	5 g	H_2O Acetic Acid/Acetate buffer	L/S = 10:1	>6.5 2 4.6	24 hr
Hjelmar	Lysimeter	2 FA	10-18 t	Rain/snow			7 yr
	Column	2 FA	8-16 kg	SP	17-145 mm/d	>11	

Reference	Leach Type	CCB	Sample Size	Leachant Solution	Volume/Flow Rate	pH	Time
	Serial Batch	1 FA		H_2O	L/S = 2.5, 5.8		5 d
Karapanagiota & Atalay	Batch	Coal FA	10 g	H_2SO_4	20 - 1900 mL	1	
		FBC FA				4	
Kim & Kazonich	Column	38 PC FA 2 non-utility FA 1 steel slag 5 FBC FA 1 BA 1 Weathered FA	1 kg	H_2SO_4	~130 mL/d to 230 mL/d	1.2	From 15 d to > 6 mo
				H_2O		6	
				Acetic Acid		2.88	
				SGW		6.7	
				SP		4.2	
				$FeCl_3$		1.95	
				$NaCO_3$		12.1	
Nathan *et al.*	Batch	4 FA	1 kg	H_2O	2, 10, 20	>10	18, 24 hr
				Acetic Acid	20	>4	18 hr
Nugteren *et al.*	NEN7343	1 FA		H_2O	L/S = 10:1	4	3 wk
Paul *et al.*	Batch	Class F Uox FGD Ox FGD		HAc H_2O	L/S = 20		18 hr
	Column			Groundwater	<100 mL/d	6$\pm$.2	~1 yr
Pritts *et al.*	TCLP	FGD + waste FBC + waste					
Querol *et al.*	Column	6 FA	2 g	H_2O	50 mL/hr		
	Batch	6 FA		DI H_2O	50 mL/g		24 hr
Rice *et al.*	Batch	FA, BA, Coal	10 g	H_2O	200 Ml		18 hr

Reference	Leach Type	CCB	Sample Size	Leachant Solution	Volume/Flow Rate	pH	Time
	Batch	3 FA		H_2O	L/S = 20/1		< 1 hr
	Column	4 FA		H_2O	0.75:1 - 15:1		64 d
Roy & Griffin	Batch	5 FA	1700 g	DI H_2O	17 L	varied	140 d
Seidel *et al.*	Batch	FA	varies	H_2SO_4	300 mL		24 hr
Seidel & Zimmels	Batch	FA		H_2SO_4	300 mL		12 d
Shabtai & Mukmenev	Batch	FA	70 kg	H_2O & H_2SO_4	230 L	0.9	2 hr
Steenari *et al.*	Batch	CFB		H_2O H_2SO_4	L/S = 16		10 x 24
Stewart *et al.*	Column	FA + coal refuse		SP	2.5 cm/4 d	4.6	4 yr
	Column	FA + coal refuse	varies	SP	2.54 cm/wk		3 yr
Talbot *et al.*	Batch	Ponded FA ESP FA	1 g	H_2O	L/S = 1000		~ 6 months
	Batch			H_2O		1 <> 12	1 wk
Teixeira *et al.*	EPTOX	PC FA		H_2O, HAc	16/1	5	24 hr
	INSA	PC FA	100 g	H_2O	3 x 1 L	>9	3 x 24 hr
	Column	PC FA	100 g	H_2O	20 L	>9	546 hr
Theis & Wirth	Sequential	11 FA		NH_4Oxalate			
				Hydroxylamine Hydrochloride			
				H_2O	200 g/L	varied	24 hr

Table 3. Summary of Laboratory Leaching Studies of CCB.

Reference	**Publication Date**	**Summary of Results**
Dreher *et al.*	1990	B, Ni, Mo, Se and Sr reported in alkaline leachate generated by FBC ash
Dreesen *et al.*	1977	Maximum extraction = 30% in strongly acid solution
Dudas	1981	Initial release of cations from simple salts, followed by dissolution of glassy ash matrix.
Eary *et al.*	1990	Trace elements acid soluble; pH controlled leaching of FA
Fishman *et al.*	1997	Ash spheres coated with soluble poorly crystalline aluminum potassium sulfate
Fleming *et al.*	1996	Acid leachable Cd, Cr, Al, Pb, Hg and Ag assumed to be present as oxides
Griffin *et al.*	1980	Concentration of Al, B, Be, Ca, Cd, Cu, Co, Mg, Mn, Ni, Si, Sr, and An increased at low pH; K, Mo and Na more soluble at high pH
Hequet *et al.*	1999	Cu and Zn absorbed from solution on FA, <1% Cu and <15% Zn released by subsequent leaching with H_2O, higher % released in acid, acetate buffer
Hjelmar	1990	Na and K leached initially; Ca dominates long-term leachate. Concentration decreases with increased L/S
Karapanagioti and Atalay,	1996	AMD metals absorbed by alkaline CCB>pH=4. Metals released at pH=1. Buffer capacity related to Ca in ash
Kim & Kazonich	2001	Solubility not a function of concentration in solid; solubility influenced by pH, <50% of metal extracted
Mattigod *et al.*	1990	Ca, Na, K released initially; negligible Fe, Mg, Si and Al released. Water releases <10% of Ca and Na;
Nathan *et al.*	1997	Release of heavy metals related more to source of coal than to pH of leachate
Nugteren *et al.*	1999	Washing FA with buffers reduced Cr, Mo, Sb, Se, and V leached from residues
Paul *et al.*	1994	Some elements absorbed from groundwater by CCB. ASTM was considered superior to TCLP
Querol *et al.*	2001	Water soluble major and trace elements more soluble in open

Reference	Publication Date	Summary of Results
Rice *et al.*	1999	pH of leachate is controlling factor, soluble aluminum potassium sulfate (APS) coating absorbed on glassy particles; Cd, Co, Cu, Mn, Ni, Pb, and Zn are acid leachable, As, Mo, and V soluble in alkaline leachates
Roy & Griffin	1984	Anhydrite controlled release of Ca; Al in equilibrium with mullite and insoluble hydroxide
Seidel *et al.*	1999	Calcium sulfate precipitation on particles inhibit the solubility of Al
Seidel and Zimmels	1998	30% of the Al and Fe in the ash leached, formation of porous layer of calcium sulfate inhibits solubility. 90% of the Ca, As, Cd, Cr, Cu, Hg, Pb and Zn were extracted at a pH <1
Steenari *et al.*	1997	80% of the Ca soluble in acid, less than 20% of K was leached from the fly ash samples
Stewart Stewart Stewart *et al.*	1995 1996 1997	Coal ash buffered acid formations from coal refuse. Alkalinity from CCB limits oxidation of pyrite in the coal refuse; metal release at low pH
Talbot *et al.*	1978	Fe, Al, Si - acid soluble; Ca, Mg, Na solubility not pH dependent below 10
Teixeira	1992	Ca & Mg acid and alkaline soluble; Na & K more soluble in alkaline solution. Mn, Ni, Co, and Cu soluble in acid; Mo, Cr, and V alkaline soluble. Trace element solubility < 20%
Theis & Worth	1977	Mullite, hematite and magnetite on the surface of amorphous particles controlled the release of trace elements. Except As, elements acid soluble.
Yaman & Kucukbayrak	1997	alkaline fly ash extract neutralized the sulfuric acid produced in the oxydesulfurization of Turkish lignite

Table 4. TCLP Results for 196 Tests of Fly Ash and Bottom Ash, PADEP Data.

	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
RCRA Limit	5	100	1	5	5	0.2	1	5
# <detection	79	63	133	111	121	167	111	146
Mean, mg/L	0.1	0.4	0.04	0.14	0.17	0.01	0.1	0.03
Max, mg/L	2.5	2.3	0.32	2	0.5	0.29	0.6	0.18
#Exceed RCRA	0	0	0	0	0	1	0	0

Table 5. SPLP Results for 20 Tests of Fly Ash and Bottom Ash, PADEP Data.

	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
RCRA Limit	5	100	1	5	5	0.2	1	5
# <detection	14	13	17	18	20	18	17	19
Mean, mg/L	0.18	0.3	0.002	0.04	NA	0.001	0.1	0.03
Max, mg/L	0.6	0.5	0.005	0.07	NA	0.002	0.2	0.03
#Exceed RCRA	0	0	0	0	0	0	0	0

WATER QUALITY
AT A COAL ASH FILLED SURFACE COAL MINE PIT IN INDIANA

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Abstract

Coal Combustion Products (CCPs) such as fly ash, bottom ash, and flue gas desulfurization (FGD) sludge are produced in large quantities as residues from the electric power plants using coal as a fuel. Only a few percent of the CCPs produced nationwide in the United States are placed in surface and underground coal mines. In Indiana, there are a number of active and inactive coal mines where mine filling with CCPs is permitted under Indiana Department of Natural Resources regulations. An inactive open-pit created by a surface mining operation offered a unique opportunity to haul and fill the pit with coal fly ash from a nearby power plant. Cinergy acquired the surface mined land from Peabody Coal in 1988 for the explicit purpose of placing about 1.45 million cubic yards (about 1.6 million tons) of coal fly ash to reclaim the land to its original topography and then to maintain the land as a wildlife habitat. From April of 1989 through the end of October 2001, Cinergy deposited approximately 1.6 million tons of CCPs to completely fill the open-pit created by the Peabody coal mining operations. There is a 5-ft soil cover and ground vegetation being planted to complete final grading and restoration of the site.

Cinergy has for the past 13.5 years carried out quarterly water quality monitoring by measuring a large number of parameters in the groundwater and surface water samples. In year 2001, a research project was initiated to (1) first synthesize and analyze available water quality monitoring data for the Cinergy site, and then (2) conduct additional field and laboratory research to assess aerial and temporal distribution of chemicals that could leach and potentially migrate in the groundwater down gradient of the ash fill.

This paper presents a summary of the monitoring and research project results on groundwater and surface water quality at the Universal Mine site now completely filled and reclaimed by the coal ash. The laboratory and field-scale leachate composition data from the Universal site indicates that sulfate, boron, and arsenic are the three constituents of interest leached at different concentrations and, therefore, would have the potential for migration in groundwater. All other monitored constituents are either not leaching at all or are leached at too low concentrations to be of any concern for impacting water quality.

The surface mining operations prior to the placement of coal ash, and also the presence of auger mined areas, resulted in acid mine drainage (AMD) conditions at the Universal site. The AMD water quality was characterized by high acidity; high concentrations of iron, manganese, and sulfate; and lack of alkalinity. The placement of coal ash, which is alkaline in nature, has resulted in significant improvement in the AMD water quality. Nearly all of the acidity has been neutralized and the water now has excess alkalinity. Iron, manganese, and sulfate all have been significantly reduced to lower concentrations as indicated by the long-term water quality monitoring data. Boron appears to be the only coal ash constituent showing leaching and migration in the down gradient water.

The continuing research is expected to provide a better understanding of the long-term water quality impacts and benefits associated with the CCPs mine filling operation. This research is particularly focusing on the leaching, attenuation, and fate of arsenic and boron in groundwater.

Introduction

More than 1.12 billion tons of coal are extracted annually from surface and deep mines in the United States (2001

data from U.S. Department of Energy). Most of the mined coal is combusted in utility boilers to generate electricity. In the year 2000, the U.S. electric utilities produced approximately 108 million tons of coal combustion products (CCPs). Coal fly ash constituted about 63 million tons or about 58 percent of the total CCPs. About 32 percent of the coal fly ash is used mostly for cement/concrete/grout, structural fill, and roadbase/subbase applications (ACAA, 2001). A very small quantity (less than 3 million tons annually) of coal fly ash is returned to mines; however, there is a large potential to use several million tons of CCPs for mine filling in a beneficial manner. But perceptions and lack of reliable scientific data continue to create obstacles in increasing the utilization of CCPs in active and inactive mines. In a regulatory determination on May 22, 2000, the U.S. EPA decided that the Agency will establish national regulations under Subtitle D of RCRA and/or upgrade SMCRA controls for CCPs used to fill surface and/or underground coal and other mineral mines in order to ensure protection of human health and the environment.

In 1988, Cinergy Corporation acquired and began filling with coal ash a final pit created by surface mining of coal at the Universal site in Indiana. Between April 1989 and the end of October 2001, Cinergy placed approximately 1.6 million tons of coal ash from a nearby power plant to completely fill the open-pit. Cinergy has been conducting quarterly monitoring of groundwater and surface water at the Universal ash fill site since early 1988. In 2001, Ish Inc. obtained funding from the U.S. DOE, Cinergy, EPRI, ACAA, and Ish Inc. to conduct additional field and laboratory research on the environmental processes affecting the water quality related to the placement of coal ash in the surface mine final pit at the Universal site. The laboratory research is being carried out at Purdue University.

This paper provides a tabular and graphical summary of water quality data developed by the compliance monitoring and the research project efforts. The paper also provides information on the composition of bulk ash and leachates generated in the laboratory and in the field. Although 34 parameters were typically measured in the water quality monitoring efforts, only a select few will be addressed in detail in this paper.

Site Description and Ash Placement Operations

The Universal coal mine site is located about 5 miles north-northwest of Terre Haute, Indiana in Vigo County. The site is adjacent to the eastern boundary of the Eastern Region Interior Province coalfields of Illinois and southwestern Indiana. These minefields have typically produced medium-to-high volatility bituminous coals of Pennsylvanian and Permian geologic age. Peabody Mining Company began and completed highwall mining operations at the Universal site along a north-south line in the mid-1980s creating a final pit which was approximately 1920 feet long, 325 feet wide, and 90 feet deep.

The geology of the premined consolidated strata consisted of a thin layer of fine clay overlain by an 18-inch thick coal seam that was overlain by shaley limestone, shale, and a thick deposit of loess. The exposed highwall at the Universal site showed a mantle of about 12 to 16 feet of pre-Wisconsin till and Wisconsin loess over the bedrock. The Universal site area is part of an upland landscape north of Coal Creek and west of the Wabash River. The upland rises about 100 feet above the Coal Creek flood plain and was well dissected before surface mining altered the topography.

PSI Energy, Inc. (now Cinergy Corporation) acquired a portion of the Universal mine site containing the final cut pit for the express purpose of coal ash deposition and surface mine reclamation. Indiana DNR issued a permit to PSI Energy to dispose fly ash/bottom ash from its nearby Wabash River Station to fill and reclaim the mine pit. The permit allowed for approximately 1.448 million cubic yards of CCPs to be disposed with ash deposit thickness ranging from 30 to 75 feet. The coal ash placement began sometime between March 13, 1989 and April 6, 1989 and was completed in October 2001.

The coal ash was hauled by tri-axle road-going trucks and placed dry in the mine pit. The coal ash was deposited in the mine pit until the height of the filled area corresponded to the approximate original topographic contour. A five-foot noncompacted soil cap and vegetation are being established as a final cover. The reclaimed mine pit land is to be maintained as a wildlife refuge.

Table 1 shows the annual tonnage of coal ash and coal gasification slag placed in the mine pit at the Universal site during the 13.5 years of mine filling operation.

Chemical Composition of Coal Ash and Leachates

Between May 1988 and December 2001, 25 samples of coal ash were collected and analyzed for total chemical concentrations and for 18-hours and 30-days leachate concentrations. Table 2 provides a statistical summary given by mean, median, maximum, and minimum values based on the measured concentrations for the bulk ash samples. Table 3 provides a statistical summary for the 18-hours and 30-days leaching tests completed on the same ash samples. Table 4 contains a statistical summary of field leachate composition data based on 17 samples collected and analyzed from leachate monitoring well MW-8.

The coal ash deposited at the Universal site contains aluminum, iron, potassium, calcium, magnesium, sulfate, sodium, and boron at average concentrations of greater than 240 mg/Kg. Manganese, zinc, barium, arsenic, vanadium, nickel, chloride, lead, chromium, copper, and fluoride are present in the average concentration range of 18 to 128 mg/Kg. Molybdenum, selenium, cadmium, silver, and mercury are found to range from non-detect to an average of about 5 mg/Kg. The coal ash is alkaline with an average pH of over 9 s.u., has a net neutralization capacity of about 17.6T/1000T, and contains about 5.8 percent total organic carbon.

The laboratory generated leachates as well as the field leachates all contained sulfate as the most abundant constituent that is released from the coal ash. Aluminum, boron, sodium, and calcium were the next most abundant constituents in the laboratory-generated leachates (tables 2-3). The field leachates, however, showed that calcium, sodium, chloride, boron, and potassium were the next most leached constituents (Table 4). The laboratory-generated leachates contained no silver, mercury, nickel, and lead. The field leachates contained no dissolved cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc. Field and laboratory leachates also showed arsenic with some variability in concentrations.

Time-series plots for pH, sulfate, boron, and arsenic in leachate monitoring well MS-8 are given in figures 1-4. These plots show that ash leachate has a pH of over 9 throughout the monitoring period of 1997-2001. The sulfate concentration in the ash leachate appears to be holding at about 1700 mg/L and boron is present at a concentration of about 45 mg/L. MW-8 monitoring data shows an initial increase in arsenic concentration in the ash leachate followed by a concentration ranging between 180 and 250 µg/L.

Water Quality Monitoring Program

Both groundwater and surface water are monitored on a quarterly basis for the compliance-monitoring program. The Universal site originally installed four groundwater monitoring wells (i.e., MW-1, MW-2, MW-3, and MW-4) in May 1988, approximately one year before the placement of coal ash began in April 1989. MW-4 is an up gradient well installed in the undisturbed bedrock formation and has been monitored for water level and water quality since May 1988 on a quarterly basis.

Monitoring well MW-1 was installed to the northeast side of the ash fill and had a long screen covering both the bedrock and the overlying spoil material. The MW-1 well has been replaced in December 2000 by two new wells designated as MW-1BR and MW-1UR. Monitoring well MW-2 was installed at the edge of the mine fill to the west presumably in the down gradient direction of the groundwater flow. This monitoring well was replaced by a new well MW-2A in 1997 that was properly screened in the mine spoil material to the west and down gradient of the ash fill. The original well MW-3 was installed to the south of the ash fill area, approximately 30-ft down gradient in the mine spoil material. This well was replaced by MW-3R in December 2000. In 1997, additional compliance wells MW-5, MW-6, and MW-7 were installed in the mine spoil material down gradient of the ash fill. In 1997, MW-8 also was installed in the ash fill to monitor chemical composition of the ash leachate. Therefore, the longest series of groundwater monitoring data is available from monitoring wells MW-1, MW-3, and MW-4, with a shorter time-series of data from monitoring wells MW-2, MW-2A, MW-5, MW-6, MW-7, and MW-8. The replacement wells MW-1BR, MW-1UR, and MW-3R are relatively new and have the shortest set of time-series data.

The Ish Inc. research effort has primarily focused on the south side of the ash fill area that covers the down gradient side for studying the groundwater flow and transport of leachate constituents. There are altogether 16 monitoring wells installed for the research project with the first 12 wells installed in March 2001 and the remaining four wells installed in October 2001. CB-9 is an up gradient well that compares in its location to the old up gradient well MW-

4. CB-1S and CB-1D are two leachate monitoring wells installed in the ash fill and screened at shallow and deep depths within the deposited ash. There are three additional spatial locations outside of the ash fill area, where a pair of monitoring wells have been installed to sample and analyze groundwater from shallow and deep zones. Shallow wells are screened in the mine spoil material. A limited amount of monitoring of these CB wells has been completed to date to generate preliminary results on the groundwater quality on the south side.

As part of the compliance monitoring effort, Cinergy also has been sampling and analyzing surface water from an old mine seep location since 1988. Cinergy has since then added five more surface water quality monitoring locations to its compliance monitoring program. These sampling locations are designated as North Pond, Ash Pit-Water Pond, Plug Seep, and two locations in the Coal Creek. In this paper, we will only present and discuss the mine-seep water quality data to depict the benefits and impacts of coal ash placement at the Universal site.

Table 5 provides a list of parameters that have been measured in the water quality samples collected in the groundwater and surface water monitoring programs at the Universal site.

Groundwater Flow

The water level elevation data from the 25 groundwater monitoring wells network suggest that the groundwater from the unmined east side of the ash fill area is flowing to the west into the ash that has resulted in an approximately 30-ft of saturated zone in the reclaimed mine pit. The groundwater then flows in a radial manner to the west, north, and south. This groundwater flow field implies that the old MW-4 and the new CB-9 are up gradient wells and that all other wells are hydraulically down gradient of the placed coal ash.

Groundwater Quality Results

Groundwater quality monitoring data from the wells MW-1, MW-2, MW-2A, MW-3, MW-4, MW-5, MW-6, and MW-7 were evaluated for time trends and changes in concentrations that may be related to the placement of ash. Since MW-3 and MW-4 wells data contain water quality measurements both before and during ash placement from 1988 through the end of 2001, we focused on presenting and discussing those data in this paper. The quarterly monitoring data for pH, acidity, alkalinity, manganese, iron, sulfate, chloride, boron, and arsenic are presented in Figures 5-13 as time-series plots. There are several observations that can be extracted from these time-series plots. The pH time-series plot (Figure 5) indicates that throughout the 13.5 years of monitoring period, pH in groundwater at down gradient well MW-3 is somewhat acidic compared to the near neutral pH in the up gradient well MW-4. Groundwater in well MW-3 contains about 200 mg/L of acidity, whereas MW-4 contains essentially no acidity (Figure 6). Both MW-3 and MW-4 groundwater contains over 350 mg/L alkalinity with MW-3 groundwater being more alkaline than MW-4 from the 1988 through 1998 time period. Both MW-3 and MW-4 have alkalinity of about 450 mg/L between 1998 through 2001 (Figure 7).

Figure 8 shows the time-series plot of manganese concentrations. The up gradient well shows no measurable amounts of manganese for the entire monitoring period, whereas MW-3 has shown manganese present in several mg/L concentration ranges. There appears to be a decrease in manganese concentrations in MW-3 groundwater over the 13-year monitoring period. These monitoring results indicate that dissolved manganese was present at about 5 mg/L level in groundwater down gradient of ash fill area before the ash was placed and, therefore, the observed manganese concentrations in MW-3 are not associated with the placement of ash in the mine pit.

Figure 9 shows the time-series plot of dissolved iron in groundwater at monitoring wells MW-3 and MW-4. Up gradient well MW-4 shows absence of dissolved iron in the groundwater, whereas the down gradient well MW-3 shows an average of about 20 mg/L. Dissolved iron at this elevated concentration was present in well MW-3 before ash placement. The monitoring data leads us to recognize that groundwater in the down gradient well MW-3 contains elevated dissolved iron concentrations that are <u>not</u> associated with the placement of coal ash in the mine pit.

Figure 10 shows the time-series plot of sulfate in groundwater at wells MW-3 and MW-4. The up gradient groundwater measured in MW-4 in an undisturbed geological setting has an average concentration of about 53 mg/L of sulfate, whereas the groundwater in down gradient well MW-3 screened in the mine-spoil material has sulfate concentrations in the range of 1500 mg/L. It is noted that sulfate was present at these elevated concentrations at

MW-3 in water samples collected before the ash placement and that subsequent to ash placement the sulfate level has not increased during 1989 through 2001. This time-series behavior leads us to conclude that even though sulfate is an ash leachate constituent, it has not impacted the down gradient groundwater at MW-3 at the Universal site.

Figure 11 shows the time-series plot of measured chloride concentrations in groundwater at MW-3 and MW-4. The average chloride concentration in the up gradient well MW-4 is about 11 mg/L, and the down gradient well MW-3 contains about 18 mg/L. Chloride in groundwater at these two wells is pretty low and requires no further discussion.

Figure 12 shows the time-series plot for boron concentrations in groundwater at wells MW-3 and MW-4. This plot indicates that the background well MW-4 contains an average concentration of about 0.4 mg/L of boron. The boron concentrations in groundwater at MW-3 do show an increase after early 1990 lasting through 1997 before showing a decrease during 1998 through 2001. The average boron concentration in groundwater at MW-3 is about 2.1 mg/L. Boron is a known leachate constituent associated with coal ash. The field-scale leachate monitoring data show that boron is present in the ash leachate at the site in over 40 mg/L concentrations. Therefore, it is inferred that the elevated boron concentrations in groundwater at MW-3 may be a result of ash leachate migration although there is an approximate 20-fold decrease in concentration between source and the down gradient monitoring well MW-3.

Figure 13 shows the time-series plot for dissolved arsenic in monitoring wells MW-3 and MW-4. The average dissolved arsenic concentration in the up gradient well MW-4 is 5 _µg/L with over 95 percent of the data showing below detection limit values. The measured arsenic in MW-3 shows an increase during the monitoring period 1989 through 1996 and then a large variability in concentrations measured during 1997 through 2001. The maximum measured concentration of arsenic in MW-3 was 35 _µg/L with about 43 percent of the data showing below detection limit values. The ash leachate data from MW-8 and data from the laboratory leaching tests showed arsenic concentrations to range from about 200 _µg/L to 300 _µg/L. Further research at the Universal site is now evaluating the release and migration of arsenic in groundwater to accurately describe the fate of leached arsenic from coal ash.

The groundwater quality monitoring data also show no significant differences in concentrations of barium, cadmium, chromium, copper, fluoride, lead, mercury, nickel, selenium, silver, and zinc. Sulfate is present at low levels in monitoring wells MW-4 and MW-1, but is found at concentrations between 500 to 2,000 mg/L in wells MW-2, MW-2A, MW-3, MW-5, MW-6, and MW-7. MW-3 contains higher levels of iron, manganese, and boron. Boron concentrations also are higher in groundwater at MW-1, MW-2, MW-2A, MW-5, and MW-6 compared to those found in wells MW-4 and MW-7. The pH in groundwater wells at the site generally falls in the range of 6.8 to 7.2 except for MW-3, which showed a slightly acidic pH of about 6.4.

Table 6 shows a list of wells and distances along an approximate flow path for these wells. CB-9 is the up gradient well, whereas CB3/CB7 wells pair is the furthest down gradient location of the monitoring wells on this flow path. Measured concentrations of sulfate, calcium, and boron as well as pH of groundwater samples collected in December 2001 and February 2002 have been plotted in Figures 10-13 as a function of distance along the groundwater flow path. The concentrations plotted at the 300 feet distance correspond to the ash leachate concentrations in monitoring wells CB-1S and CB-1D. The sulfate plot (Figure 14) shows that in the background well CB-9 (zero feet distance) there is a low level of sulfate, whereas sulfate concentrations in the leachate wells as well as in all other wells extending further down gradient are generally above 400 mg/L with the highest observed value of about 1500 mg/L. Most of these down gradient wells are screened in the mine spoil material.

The calcium concentrations plot in Figure 15 shows that there is a very low level of calcium in the up gradient well CB-9. The leachate wells (CB-15 and CB-1D) have about 650 mg/L calcium with all other down gradient wells showing a range from 100 mg/L to about 400 mg/L. Calcium is typically the ion pair present in sulfate containing water. Generally calcium sulfate and pyrite are involved in defining the geochemistry and the resulting concentrations of calcium and sulfate in groundwater at coal ash and coal mining sites.

Figure 16 shows the boron concentrations plot along the groundwater flow path in the south side of the Universal site. Similar to calcium and sulfate, boron concentrations are quite low in the background monitoring well CB-9. The ash leachate wells CB-1S and CB-1D show some variability between the two depths but contain between 30 to 80 mg/L of dissolved boron. The monitoring well CB-11, located about 15-ft or so outside of the ash fill area, shows boron at 15 to 30 mg/L that decreases to about 5 mg/L in well CB-10 located further down gradient. Boron concentrations in groundwater continue to decrease as one moves further down gradient to well pair CB-7/CB-3.

Figure 17 shows the plot of measured pH in groundwater along the flow path. Both the up gradient well CB-9 and the leachate wells CB-1S and CB-1D show alkaline pH in the range of 9 to 10 s.u. The down gradient wells installed in mine-spoil mostly show a near neutral pH to slightly acidic pH. Therefore, the groundwater pH at the Universal ash site is not affected by the alkaline pH of the ash leachate.

As we collect the longer term monitoring data on the groundwater quality along the flow path, additional evaluations will be completed and findings will be disseminated to interested audiences. The research effort will particularly focus on the leaching, attenuation, and fate of arsenic and boron at the Universal site.

Surface Water Quality

Acid mine drainage (AMD) was present at the Universal site. The AMD was caused by the oxidation of pyrites due to the coal mining operations. An old mine-seep is present to the southeast of the ash fill area. The mine-seep water flows through a surface channel into the Coal Creek located at least 1500 feet further south of the mine-seep area. This old mine-seep water has been quarterly sampled and analyzed for the list of water quality parameters shown in Table 5. We have prepared time-series plots for pH, acidity, alkalinity, manganese, iron, sulfate, chloride, and boron measured in the old mine-seep water since May 1988 through the end of 2001.

Figure 18 is the plot of pH that shows that prior to the coal ash placement, the mine-seep water was highly acidic (i.e., pH < 3.5) and has been completely neutralized to pH 7 by the coal ash deposit in the mine pit. The neutralization of the acidic pH is consistent with the alkaline chemical characteristic of the coal ash.

Figure 19 shows the time-series plot for measured acidity in the mine-seep water. The AMD water contained a large amount of acidity before the coal ash placement in the mine pit. Within one year of the ash deposition, the acidity in the mine-seep water has been nearly eliminated again because of the acid-neutralization capacity of the coal ash placed in the Universal mine pit.

Figure 20 is a time-series plot of measured alkalinity in the mine-seep water. This plot shows the absence of alkalinity during 1988 to 1990 followed by a gradual increase in alkalinity through the end of 2001. Therefore, the coal ash not only has neutralized acidity and increased pH of the groundwater feeding the mine seep, it also has generated additional alkalinity to provide further improvements to the water quality.

Figures 21 and 22 are the time-series plots of measured concentrations of manganese and iron, respectively, in the mine-seep water. Before the coal was placed in the mine pit, the mine-seep, an AMD water, was quite high in dissolved iron (over 100 mg/L) and manganese (over 7 mg/L). But, within a year of ash placement, both iron and manganese concentrations decreased significantly. The long-term monitoring further indicates that dissolved iron has continued to decrease to essentially a non-detect level with manganese also showing a gradual decrease to a concentration of below 2 mg/L in 2001. These decreases are due to the neutralization of acidity and increase in pH achieved by the alkaline ash. An increase in pH and alkalinity has precipitated the dissolved iron and manganese. It is also possible that the lack of oxygen may have stopped the generation of AMD.

Figure 23 is a time-series plot of sulfate concentrations measured in the mine-seep water. This plot shows a clear decrease in sulfate concentrations as a function of time. The sulfate levels of over 2,000 mg/L in 1988 are now reduced to about 1,500 mg/L in 2001. The initially high sulfate concentrations most likely were a result of pyrite oxidation that produced sulfate, iron, and acidic pH waters with low levels of calcium and other base cations in the water. The alkaline coal ash provided large amounts of calcium as well as alkalinity through the leachate. This ash leachate mixed with AMD waters and resulted in the precipitation of iron hydroxide(s) as well as gypsum, thereby creating the modified water quality of the mine-seep that is now low in iron and also sulfate compared to the original AMD waters. Therefore, even though sulfate is a coal ash constituent, in this case there is no distinguishable impact of sulfate on the water quality in the mine-seep.

Figure 24 shows a time-series plot of chloride measured in the mine-seep water. This plot shows a slow increasing trend in chloride concentrations, but the higher chloride levels are still less than about 100 mg/L in 2001.

Figure 25 shows a time-series plot of boron concentrations in the mine-seep water samples monitored since May 1989. For the first two years of monitoring, boron concentrations in the mine-seep water were less than 1 mg/L. Beginning in May 1991, the boron concentrations have been steadily increasing with the highest concentration of about 5 mg/L recorded in 2001. This time-series behavior and the documentation that coal ash leachate at this site contains over 45 mg/L of boron lead to the conclusion that boron contained in the ash leachate has contributed to elevating the boron concentration in the mine-seep water samples.

Summary and Conclusions

This paper provides a limited summary of monitoring results on water quality at a coal ash filled surface coal mine pit in Indiana. The more than 13.5 years of quarterly water quality monitoring data and the more recent extended spatial monitoring data provide insights on coal ash leachates and water quality changes when coal ash has filled and reclaimed a final cut mine pit at the Universal site. The monitoring data to date indicate that the alkaline coal ash leachate has been effective in improving AMD water quality that was present at the site. The coal ash leachate neutralized the acidic pH, increased alkalinity, essentially eliminated acidity, and significantly decreased manganese, iron, and sulfate concentrations. There were no indications of any other trace metals migration via the mine-seep. However, the coal ash leachate did increase significantly boron concentrations in the mine-seep water.

The groundwater quality data similarly show that coal ash leachate has not resulted in the leaching and migration of most of the trace metals contained in ash. Boron, arsenic, and sulfate are leached from the coal ash in different amounts. However, because of the presence of sulfate in groundwater in the spoil material, it is not feasible to discern the migration of sulfate contained in the coal ash leachate from the sulfate contributed by the mine spoil material. The limited data from the research effort does show that boron in the coal ash leachate has migrated out of the mine pit into the groundwater in the mine-spoil material. There is more than an order of magnitude decrease in boron concentration within 150-200 ft down gradient of the ash fill.

The continuing monitoring and the supplemental research at the Universal site will provide better understanding of benefits and impacts from the use of coal ash for mine filling in the next few years.

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Reference

ACAA, 2001. 2000 Coal Combustion Product (CCP) Production and Use (Short Tons). Alexandria, VA.

Ishwar Murarka has been addressing land and water environmental issues for more than 25 years. Murarka has worked as an environmental professional for Texas Instruments, Argonne National Laboratory, and Electric Power Research Institue (EPRI). After retirement from EPRI in 1998, Ishwar started Ish Inc. as an environmental consulting company specializing in investigating, evaluating, and developing strategies for the remediation of soils, groundwater, and sediments contaminated with metals and organics. He continues to offer consulting services to address environmental issues associated with the disposal and utilization of fossil fuel combustion by-products. He has served on the U.S. EPA's Science Advisory Board (SAB) from 1988 through 2001 in various capacities and continues to be a consultant to the SAB. He is most experienced with the scientific and regulatory deliberations on the management of fossil fuel combustion wastes and the former manufactured gas plant sites. He continues to perform research on leaching, attenuation, and environmental fate of metals and organic constituents. He holds a Ph.D. in Soil Science and Statistics from Oregon State University and an MBA from the University of Chicago. He was an NIH postdoctoral fellow in Biomathematics at North Carolina State University.

Table 1: Annual Tonnage Deposited in the Universal Mine Pit

Year	Coal Ash	Coal Gasification Slag
1989 270,364		0
1990 254,806		0
1991 0		0
1992 320,000		0
1993 0		0
1994 0		0
1995 75,194		0
1996 114,740		0
1997 95,387		0
1998 117,742		23,301
1999 54,368		14,113
2000 152,571		0
2001 151,335		0
TOTAL AMOUNT	**$1,607,507**	**37,414**

Table 2: Statistical Summary of Bulk Composition Data (mg/Kg) of Coal Ash Samples Placed in the Universal Mine Pit

Parameter	# of Samples	Median	Average	Maximum	Minimum
Aluminum	23 7,	150	7,373 13,	200	42
Iron	25 15,	700	15,935	27,500	86
Potassium	23 1,	200	1,271	2,700	ND
Magnesium	23 752		714	1,280	ND
Sulfate	25 455		526	2,000	55
Sodium	25 230		276	570	ND
Boron	25 223		241	455	ND
Calcium	4 5,	720	5,755	6,680 4,	900
Zinc	25 123		129	227	2.1
Barium	25 76		71 220		ND
Manganese	25 80		86 200		1.2
Arsenic	25 57		64 143		ND
Vanadium	23 42		45	71	ND
Nickel	25 40		40	77	ND
Chloride	25 24		41 270		ND
Lead	25 35		36	59	ND
Chromium	25 22		24	42	ND
Copper	25 21		21	41	ND
Fluoride	25 8		18	177	ND
Molybdenum	25 3.	7 4.	6	12 1.	9
Selenium	25 4.	1 4.	6 9.	8	ND
Cadmium	25 1.	0 1.	1 3.	2	ND
Silver	25 ND		0.18	1.6	ND
Mercury	25 0.	130	0.113	0.30	ND
Total Organic Carbon	25 52,	300	58,357 153,	000	5
pH*	22 9.	0 9.	1	10.6	7.5
Potential Acidity**	25 0.	3 2.	6	21.6	ND
Neutralization Potential**	25 17.	1 19.	8 48.	6	7.5

*Unit for this parameter is s.u
**Unit for these parameters is T/1000T
.ND = Non-detect

Table 3: Statistical Summary of Concentrations (mg/L) Measured in Coal Ash Leachates

Parameters		18-Hr Leachate		30-Day Leachate	
	# of Samples	Average	Median	Average	Median
Aluminum	23	3.43	2.9	2.73	2.6
Boron	25	2.65	2.3	3.39	3.1
Sulfate	25	135	31	56.8	47
Chloride	25	0.7	ND	1.34	1.1
Iron	25	0.67	ND	0.34	ND
Magnesium	23	0.5	ND	0.44	ND
Potassium	23	0.84	ND	0.78	ND
Sodium	25	1.45	ND	1.59	ND
Arsenic	25	0.285	0.26	0.301	0.31
Fluoride	25	0.225	0.23	0.285	0.29
Vanadium	23	0.18	0.21	0.23	0.27
Molybdenum	25	0.12	0.09	0.13	0.11
pH (standard units)	24	10.05	10.05	9.63	9.66
Barium	25	2	0.04	0.078	ND
Cadmium	25	0.0009	ND	0.0005	ND
Chromium	25	0.01	ND	0.01	0.011
Copper	25	0.008	ND	0.002	ND
Lead	25	0.002	ND	0.006	ND
Manganese	25	0.022	ND	0.004	ND
Nickel	25	0.002	ND	0.003	ND
Selenium	25	0.067	0.058	0.102	0.085
Zinc	25	0.043	0.02	0.018	ND
Silver	25	ND	ND	0.001	ND
Mercury	25	ND	ND	ND	ND
Sulfide	25	0.133	ND	0.077	ND

ND = Non-detect

Table 4: Summary Statistics for Measured Concentrations (mg/L) in MW-8 Leachate Water

Parameter	# of Samples	Mean	Median	Minimum	Maximum
Alkalinity	17	276.2	220	120	530
Boron	17	44.2	46	ND	56
Chloride	17	284.4	91	21	700
Sodium	17	190	120	ND	430
Sulfate	17	1,847	1,700	1,400	3,800
Total Organic Carbon	17	15.4	1.9	ND	110
Magnesium	17	6.6	6.9	ND	8.1
Molybdenum	17	1.7	1.6	0.96	2.3
Aluminum	15	0.38	0.44	ND	0.49
Arsenic	17	0.205	0.208	0.13	0.26
Sulfide	17	0.21	ND	3.4	ND
Barium	17	0.053	0.036	ND	0.35
Fluoride	17	0.007	ND	ND	0.12
Manganese	17	0.012	0.012	ND	0.023
Acidity	17	ND	ND	ND	0.0004
Cadmium	17	ND	ND	ND	ND
Chromium	17	ND	ND	ND	ND
Iron	17	ND	ND	ND	ND
Lead	17	ND	ND	ND	ND
Mercury	17	ND	ND	ND	ND
Selenium	17	ND	ND	ND	0.006
Silver	17	ND	ND	ND	ND
Zinc	17	ND	ND	ND	ND
pH (standard units)	17	8.96	9.2	9.5	6.9

ND = Non-detect

Table 5: List of Water Quality Parameters Monitored at the Universal Site

Acidity	Mercury
Alkalinity	Molybdenum
Aluminum	Nickel
Arsenic	ORP
Boron	Potassium
Cadmium	Selenium
Calcium	Silver
Chromium	Specific Conductivity
Copper	Sulfate
Fluoride	Sulfide
Hardness	Temperature
Iron	TDS
Lead	TSS
Magnesium	TOC
Manganese	Zinc
	pH

Table 6: List of Monitoring Wells and Approximate Linear Distances

Well I.D.	Distance (Feet)
CB-9	0
CB-1S 300	
CB-1D 300	
CB-11 450	
CB-10 480	
CB4 580	
CB-12S 680	
CB-12D 680	
CB-13 760	
CB-7 830	
CB-3 830	

Note: These distances are approximate and will be revised once the well locations have been surveyed.

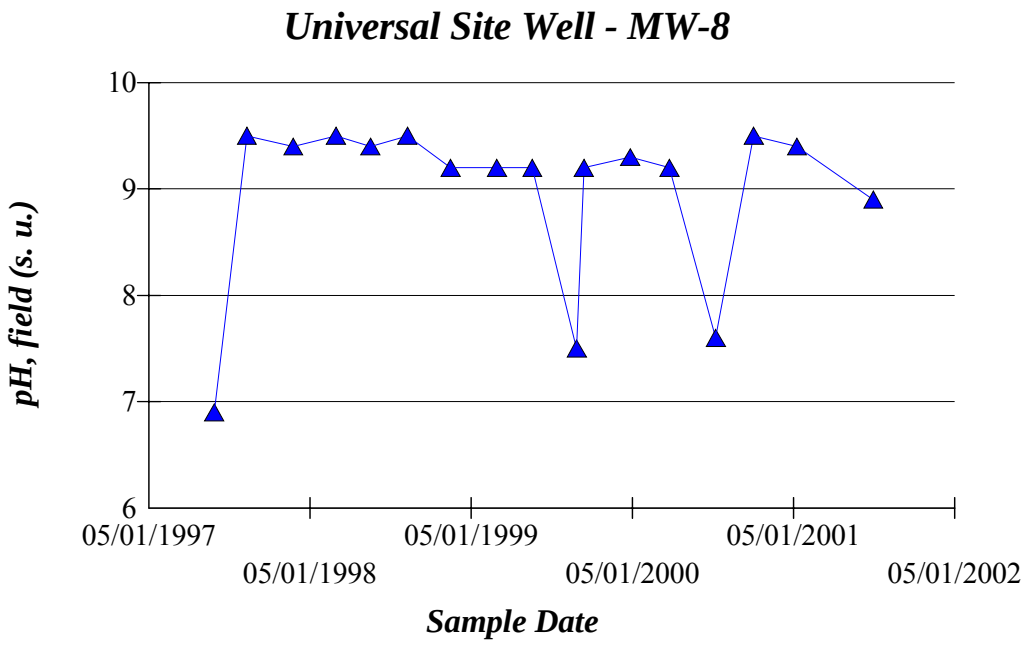

Figure 1. Time Series Plot of Measured pH in Field Leachate Samples

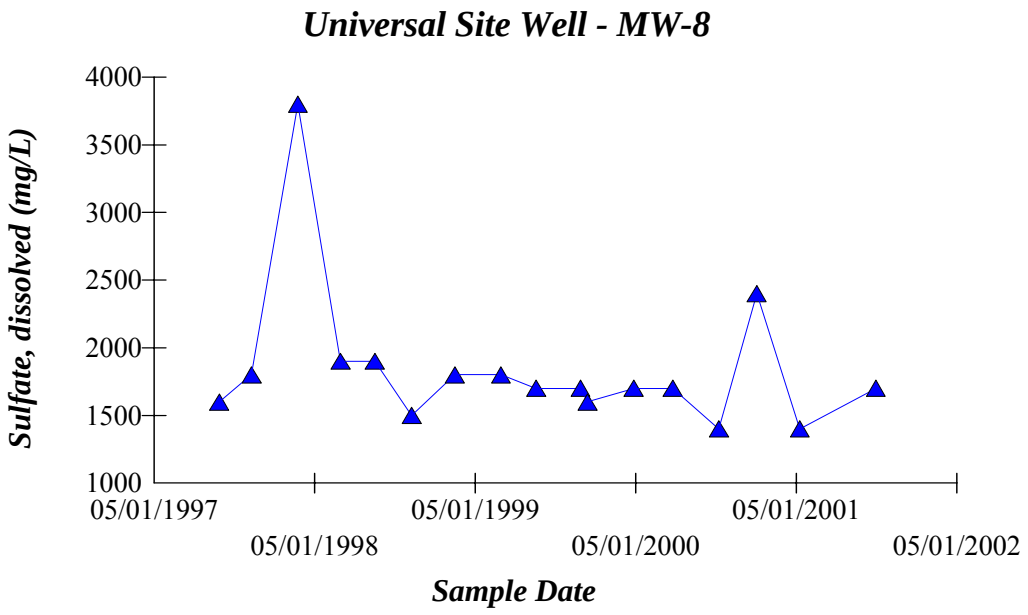

Figure 2. Time-Series Plot of Measured Sulfate Concentrations in Field Leachate Samples

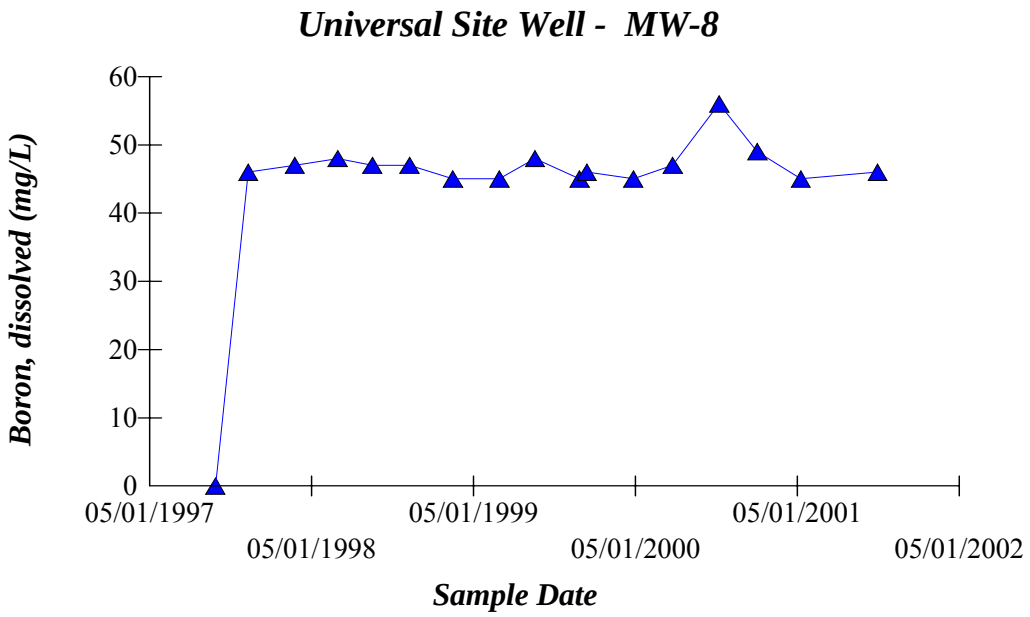

Figure 3. Time-Series Plot of Measured Boron Concentrations in Field Leachate Samples

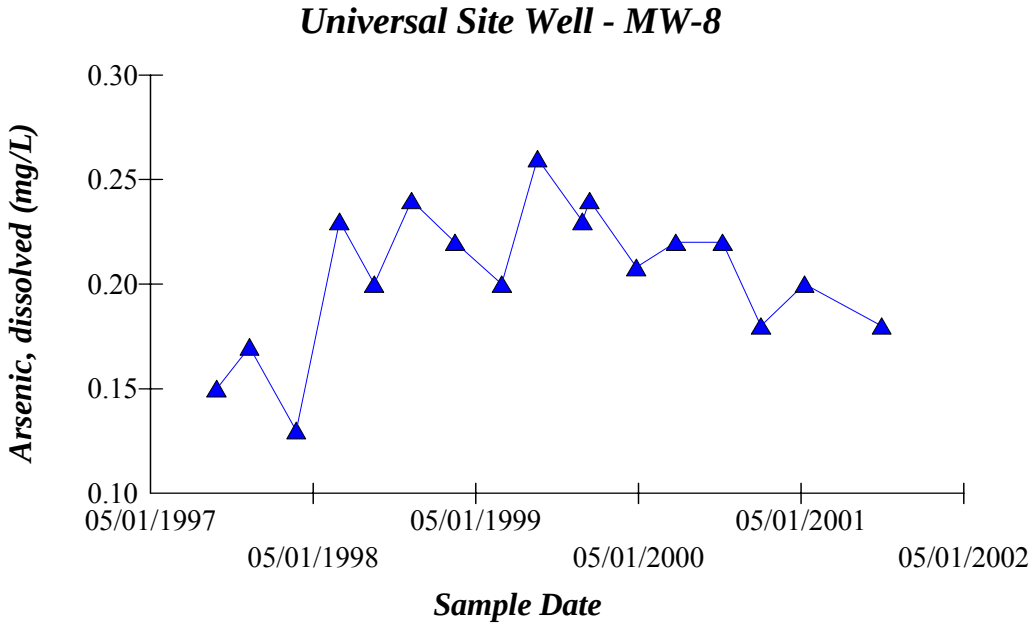

Figure 4. Time-Series Plot of Arsenic Concentrations in Field Leachate Samples

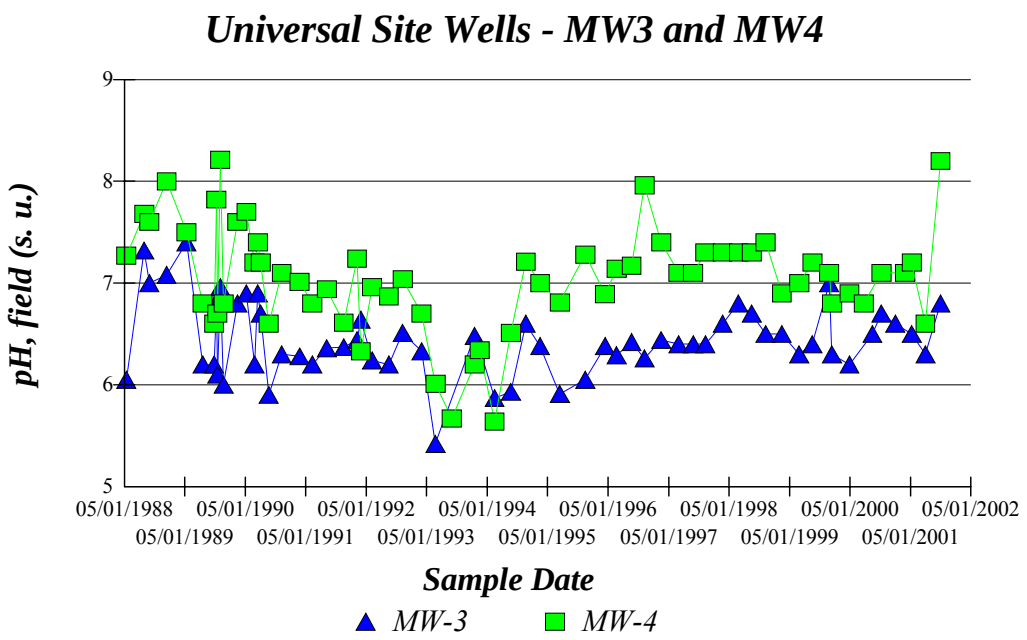

Figure 5. Time-Series Plot Showing pH Measured in Groundwater Samples

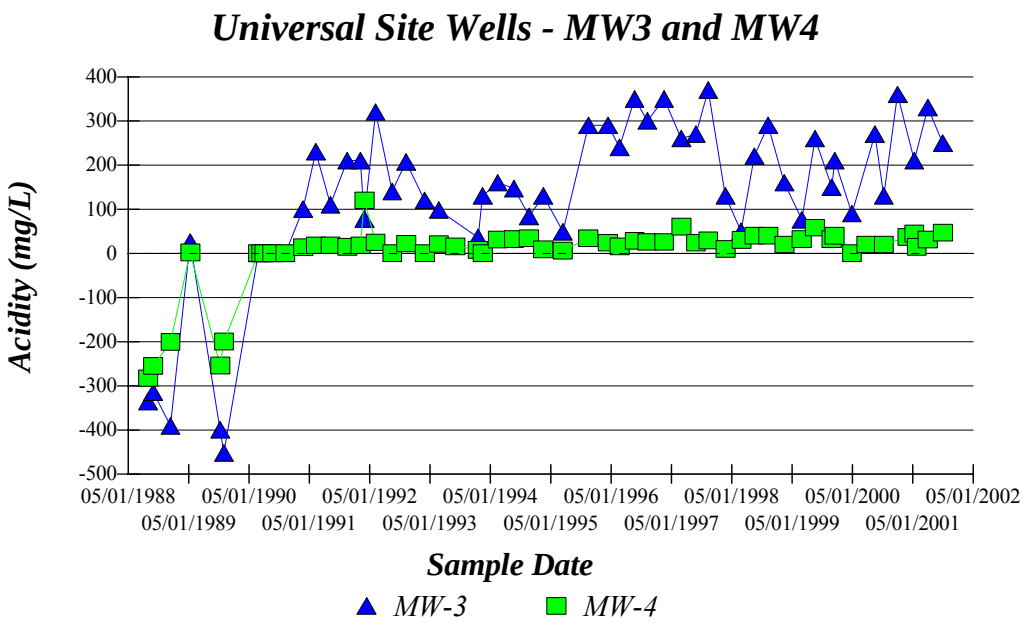

Figure 6. Time-Series Plot of Acidity Measured in Groundwater Samples

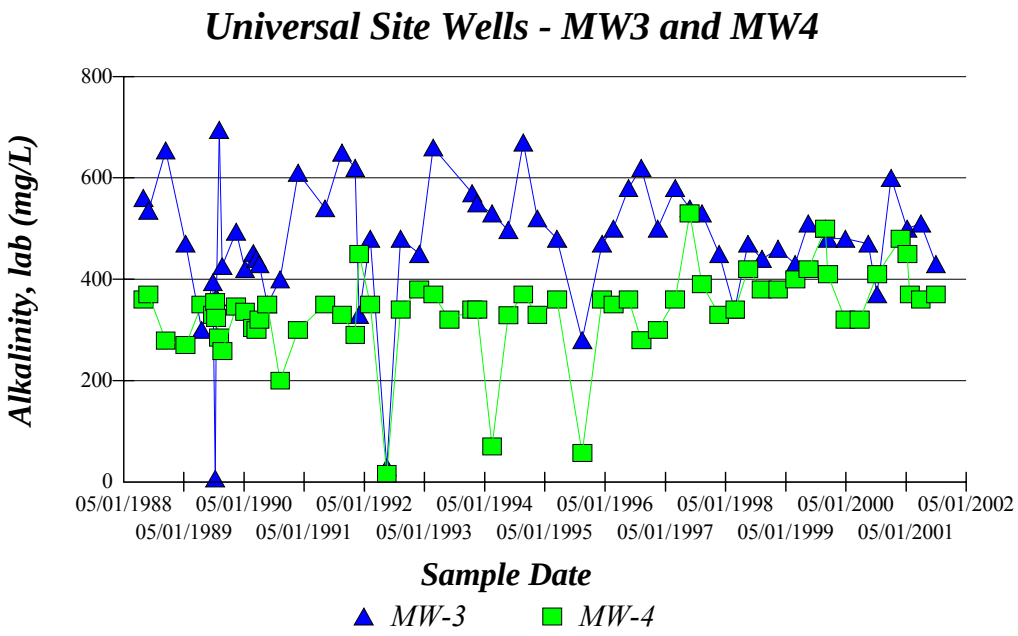

Figure 7. Time-Series Plot of Alkalinity Measured in Groundwater Samples

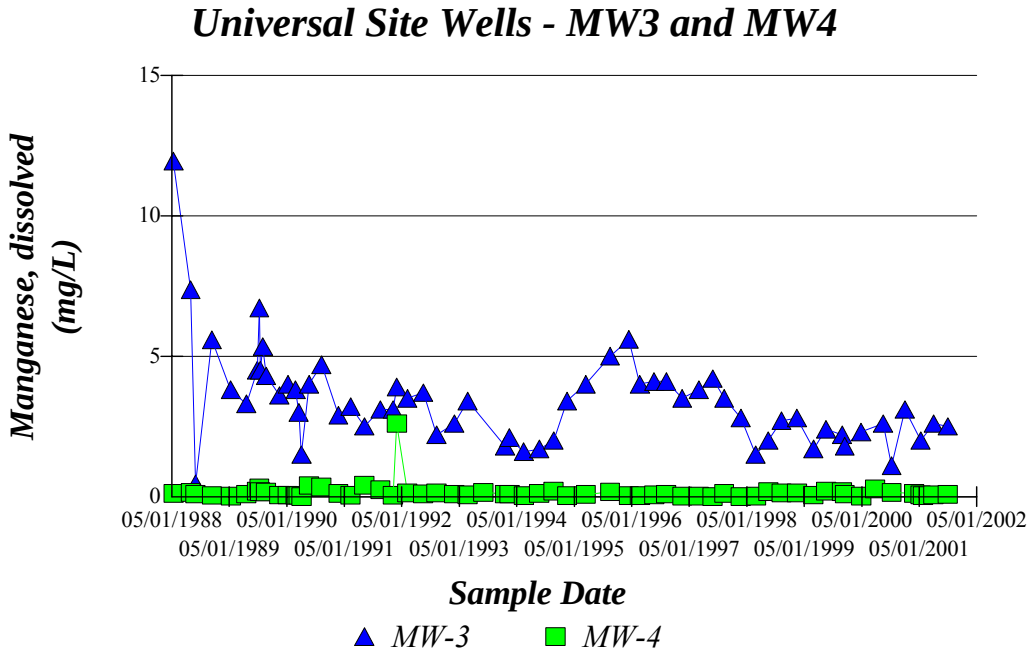

Figure 8. Time-Series Plot of Manganese Measured in Groundwater Samples

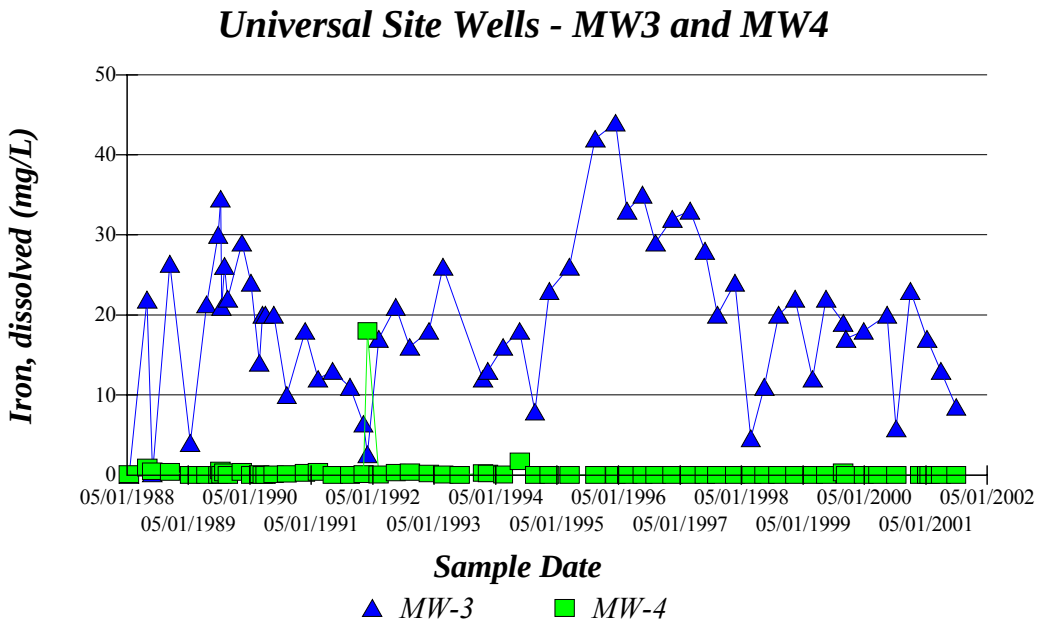

Figure 9. Time-Series Plot of Iron Measured in Groundwater Samples

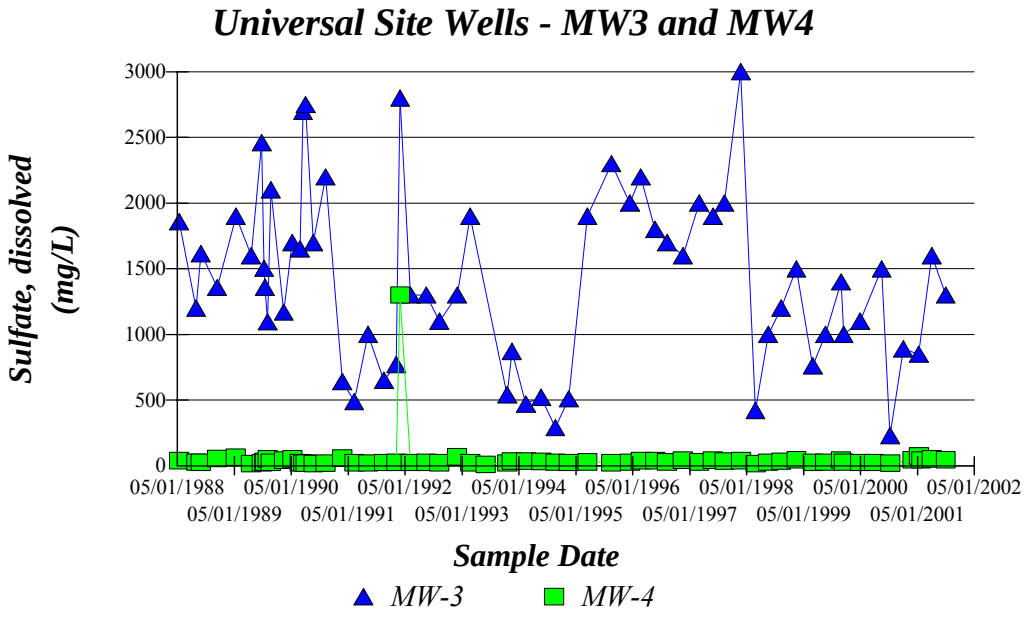

Figure 10. Time-Series Plot of Sulfate Measured in Groundwater Samples.

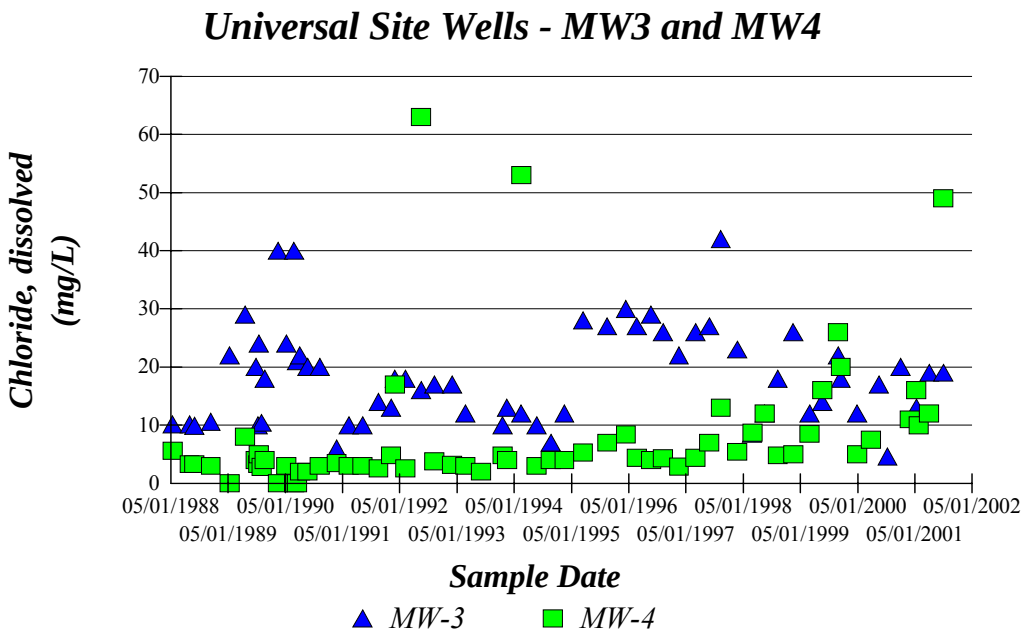

Figure 11. Time-Series Plot of Chloride Measured in Groundwater Samples

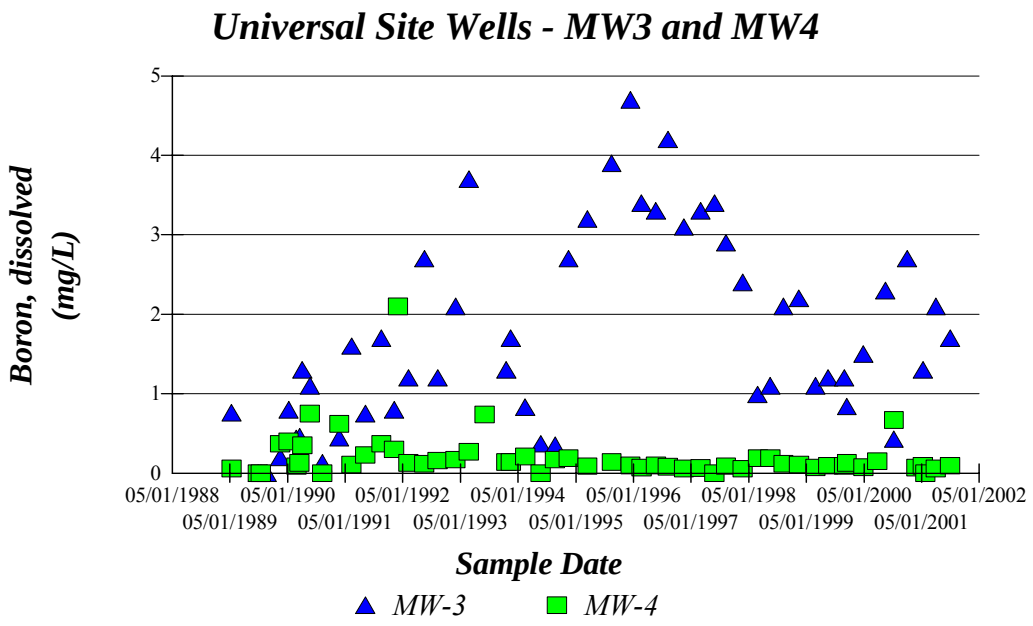

Figure 12. Time-Series Plot of Boron Measured in Groundwater Samples

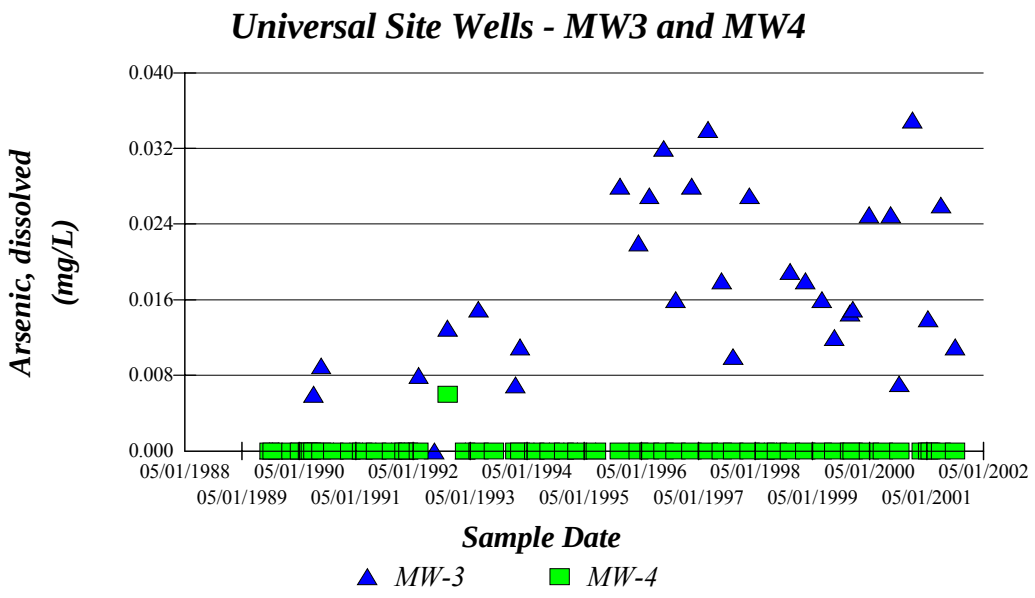

Figure 13. Time-Series Plot of Arsenic Measured in Groundwater Samples

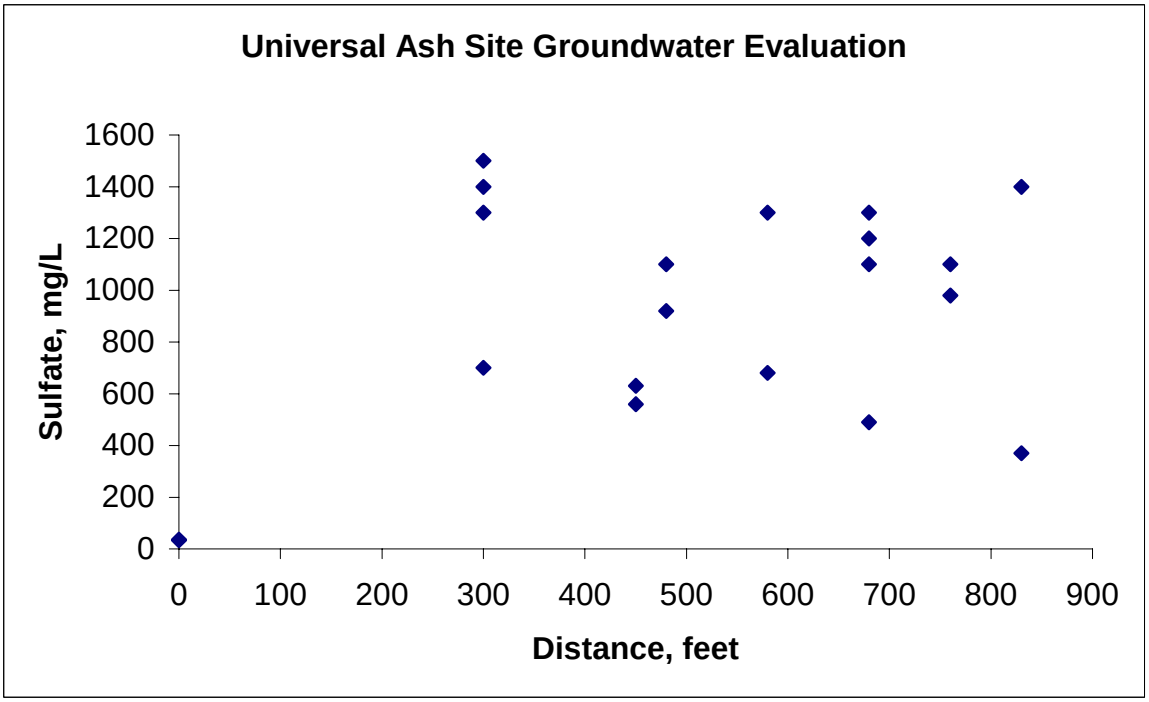

Figure 14. Plot of Sulfate Concentrations as a Function of Distance Along a Groundwater Flow Path

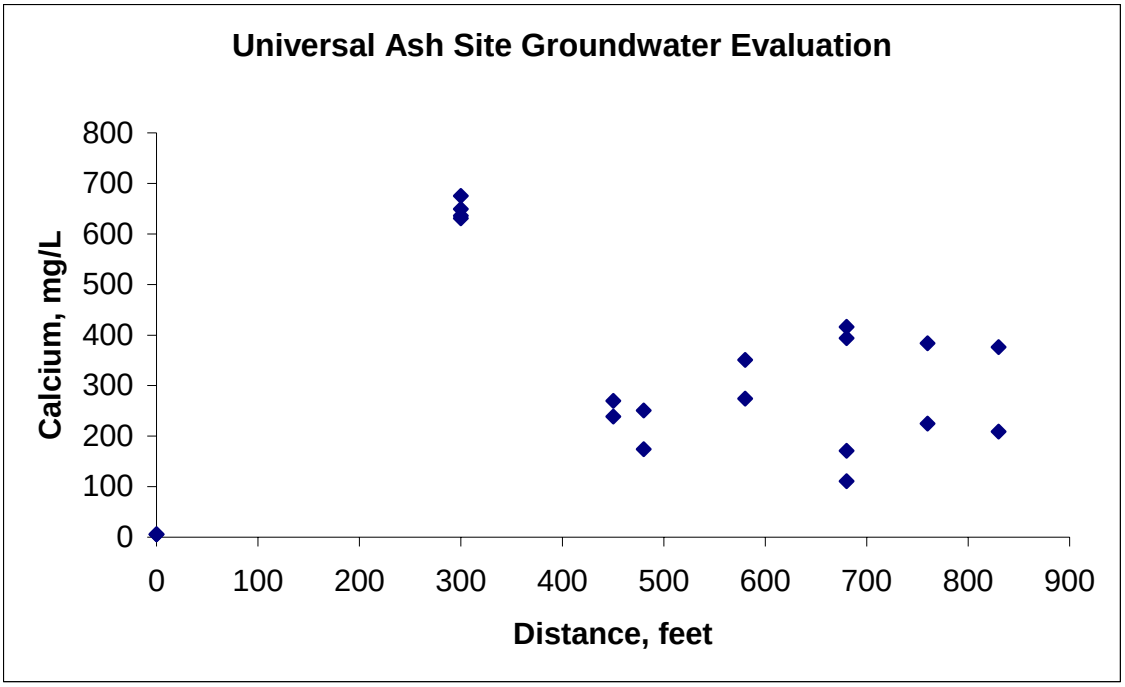

Figure 15. Plot of Calcium Concentrations as a Function of Distance Along a Groundwater Flow Path

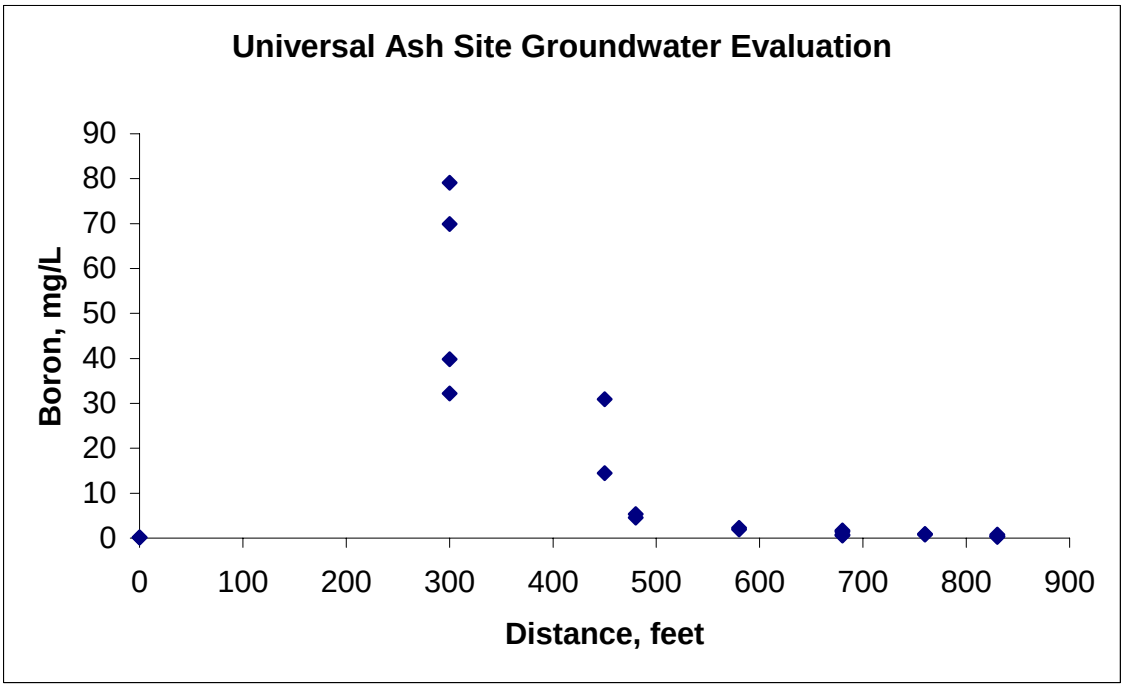

Figure 16. Plot of Boron Concentrations Along a Groundwater Flow Path

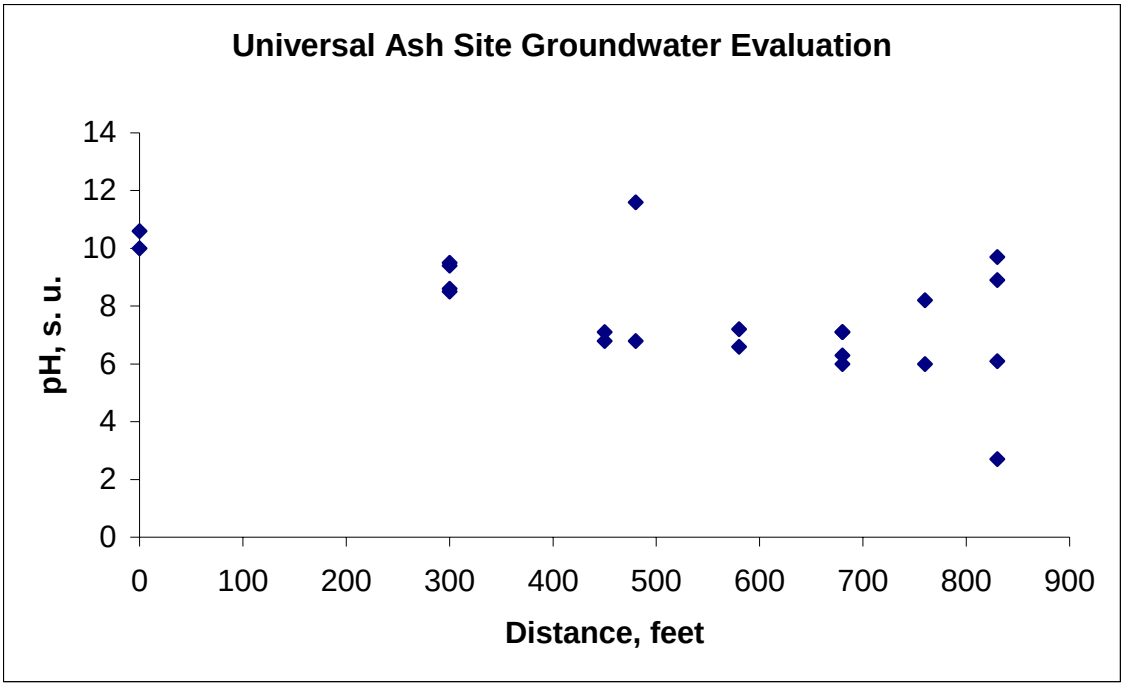

Figure 17. Plot of pH as a Function of Distance Along a Groundwater Flow Path

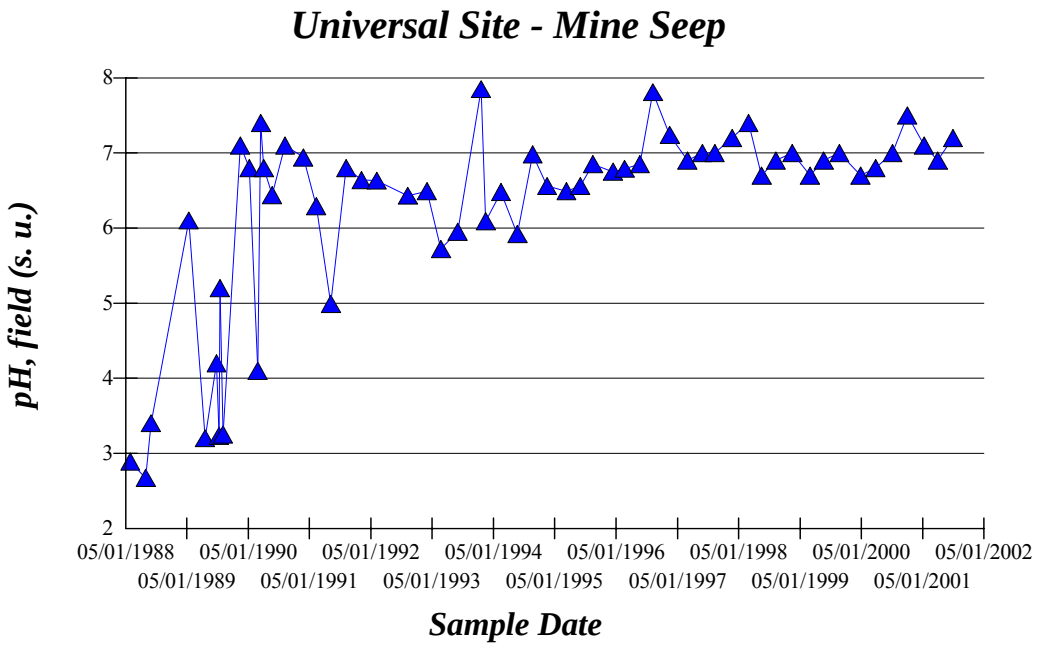

Figure 18. Time-Series Plot of pH Measured in Mine-Seep Water Samples

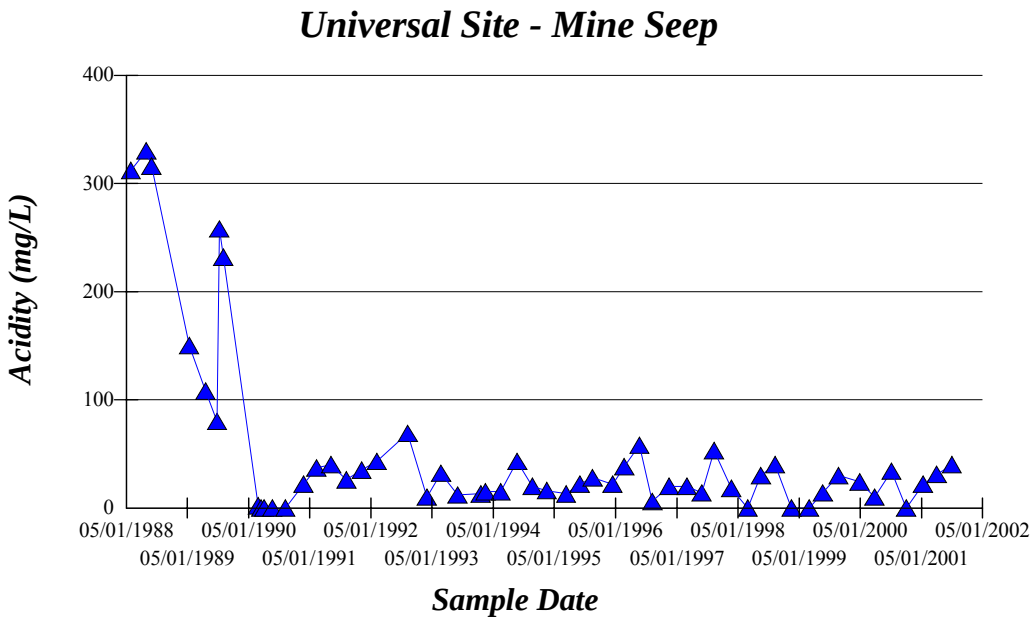

Figure 19. Time-Series Plot of Acidity Measured in Mine-Seep Water Samples

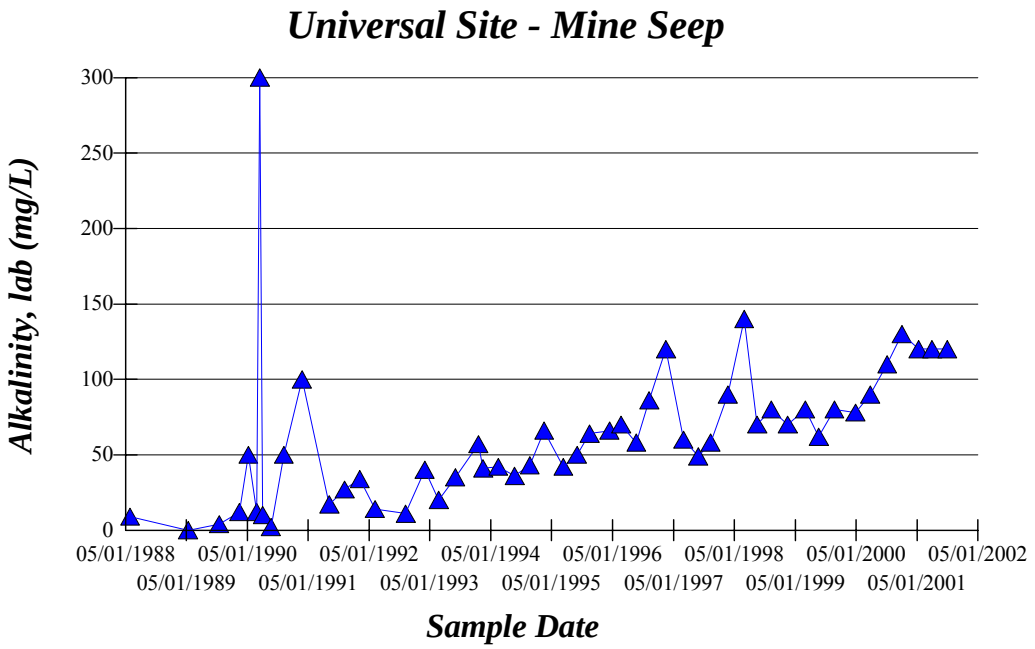

Figure 20. Time-Series Plot of Alkalinity Measured in Mine-Seep Water Samples

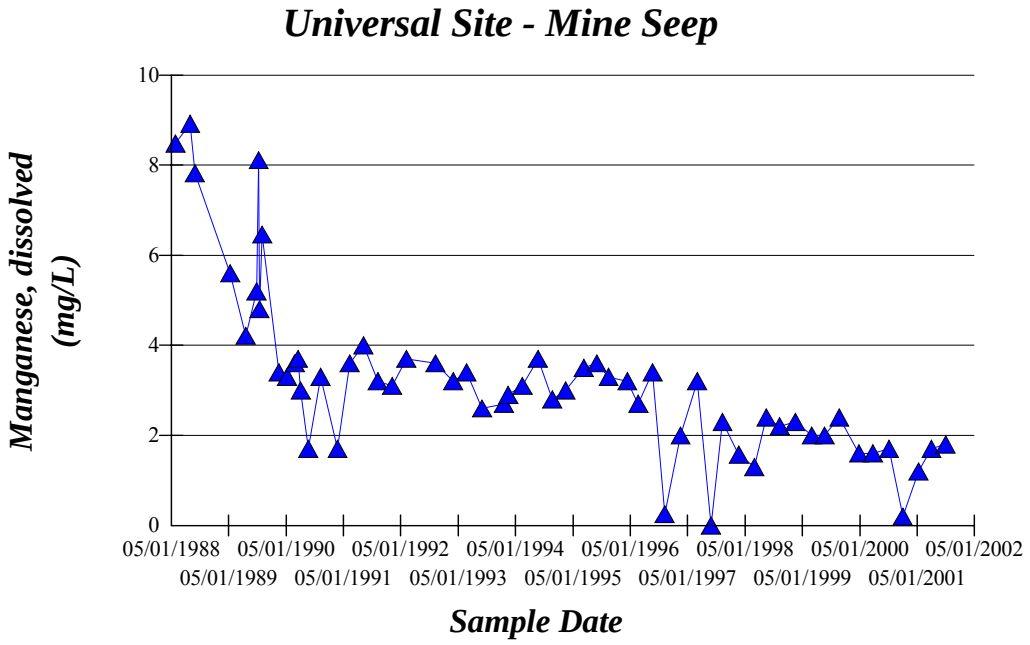

Figure 21. Time-Series Plot of Manganese Measured in Mine-Seep Water Samples

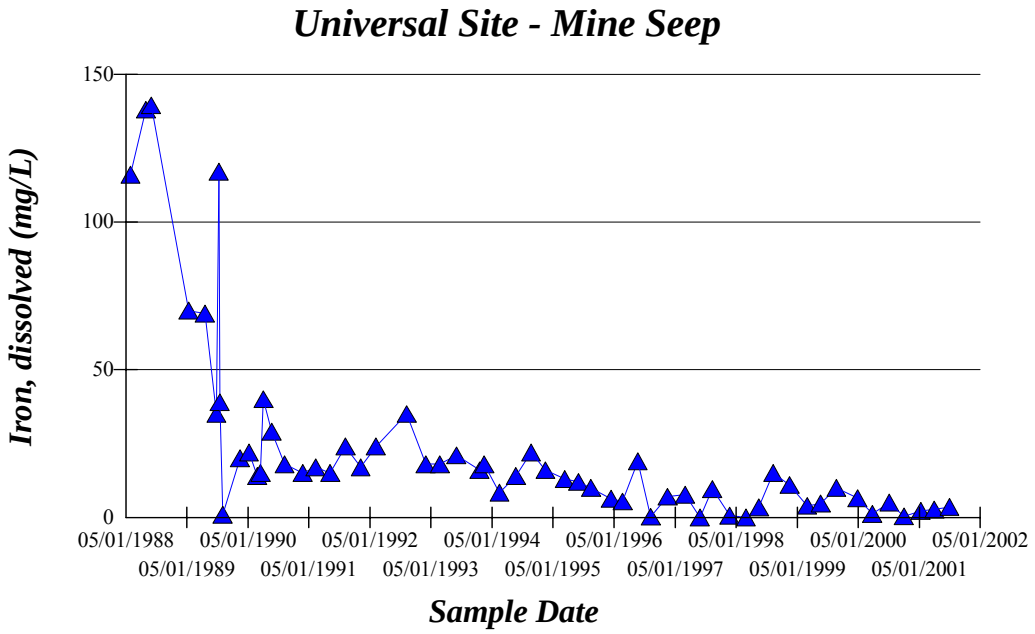

Figure 22. Time-Series Plot of Iron Measured in Mine-Seep Water Samples

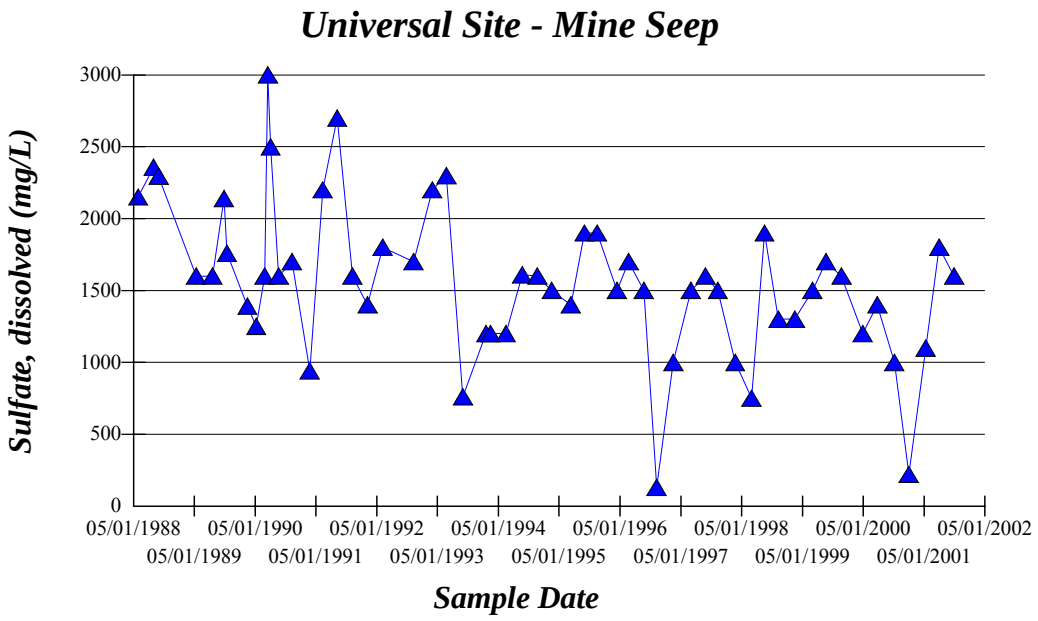

Figure 23. Time-Series Plot of Sulfate Measured in Mine-Seep Water Samples

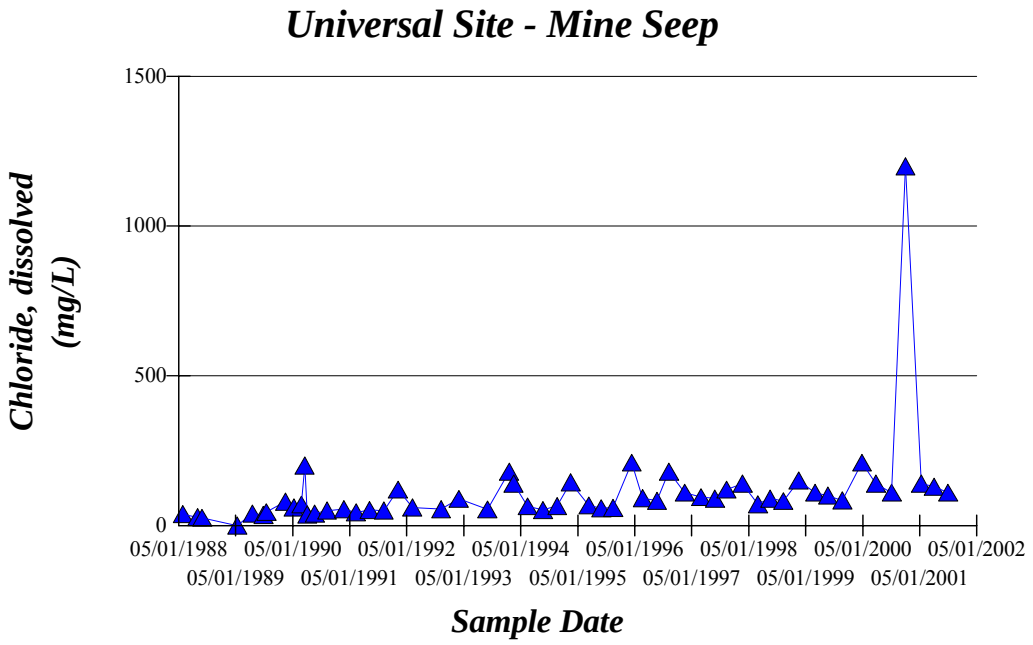

Figure 24. Time-Series Plot of Chloride Measured in Mine-Seep Water Samples

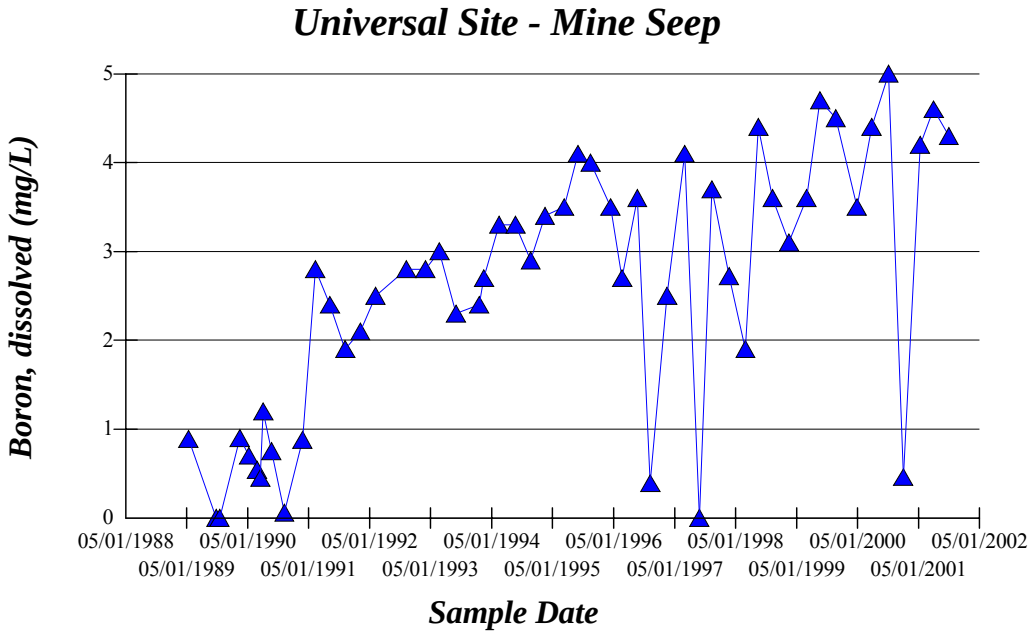

Figure 25. Time Series Plot of Boron Measured in Mine-Seep Water Samples

MINE PLACMENT OF COAL COMBUSTION PRODUCTS (CCPS) DATA COLLECTION AND RISK ASSESSMENT: MRAM – AN INTERNATIONAL AND INTERAGENCY COOPERATIVE PROJECT

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Abstract

In April 2000, the U.S. Environmental Protection Agency (EPA) issued its regulatory determination with respect to the disposal of coal combustion *by-products*, often called *combustion products or residuals*. The agency determined at that time that these residuals, while showing evidence of potential for risk to both human health and the environment, did not warrant treatment as hazardous wastes but rather should be managed in accordance with the provisions of Subtitle D of RCRA, in effect passing enforcement authority to the States.

As a part of that regulatory determination, EPA also stated that it did not, at that time, have enough data on mine filling practices to be able to pass judgment on the merits and protectiveness of that practice on a nationwide basis. The practice of mine filling is a common one, and various States have their own enforcement procedures on the books. Still, the varying geochemistries and hydrologies, and the varying wastes, together with past mining practices that have in many cases seriously damaged the local environment, make the practice controversial.

With the help of many agencies, private firms, special interest groups, and individuals, both in the United States and Canada, EPA began in 2001 a very wide ranging data collection effort aimed at determining what is happening at mine placement sites. To date, these have all been coal mining sites, but there is no reason why, in principle, these same coal combustion products might not be used at other non-coal mining sites scarred and damaged by mining. All would depend on the chemistries and of course on the economics of haul-back. The following have been leading players: EPA, DOE, DOI's Office of Surface Mining, the universities of West Virginia and North Dakota, representatives of Canadian utilities, several U.S. States and their representatives, U.S. industry represented by USWAG and CIBO, and a number of very experienced consulting firms as noted below.

With added funding, now MRAM II is underway. We are starting to analyze data of varying quality from some 65 sites, with knowledge of perhaps another 30-40 sites. We think, speaking only of coal mine sites, that upwards of another 500 or more sites might be candidates for this practice if protective practices may be clearly identified and the non-protective practices, where such may exist, also identified. All parties "own" these data; it is public information.

It is absolutely essential to appreciate that *perfection* is not the goal—temporal and spatial *improvement* is the goal.

Study Participants

This work would not be possible without the active participation of experts from all stakeholders having interest in mine placement of CCPs. The opinions of all those who have interest in this practice are invariably strong. Most believe the practice is "beneficial," but there are instances where such placement can result in worsening potential threats to both human health and the environment. However, all involved have one common interest: to study the many possible hydro/geochemistries sufficiently in order to determine just which circumstances are favorable and which are not.

From its inception, the MRAM project was envisioned by EPA as a cooperative venture. For it to achieve the objectives stated above, all stakeholders had to weigh in from the start. Despite differing views, some of which are

grounded in evidence and some in intuition ("How can we possibly make this polluting situation any worse than it is?"), all parties agreed that (1) prescriptive rules would be helpful; and (2) these would enable constructive dialogue on expanding this practice to as many sites as risks and economics will permit. While the U.S. EPA has the lead role, the following other agencies and individuals are participating: the U.S. departments of Energy (DOE) and Interior (DOI); the universities of West Virginia and North Dakota; representatives from Canadian utilities and mines located in the province of Alberta; several key U.S. states and their organized group representatives; U.S. industry represented by USWAG and CIBO; and several experienced consulting firms including IEC, DPRA**,** SAIC, Ish Inc., Tetra Tech, and Allison Geosciences. We are seeking to involve representatives from environmental groups as we continue our work.

The MRAM project

In the late spring of 2001, EPA began the MRAM project. MRAM is the acronym for "Mine-fill Risk Assessment/Modeling." MRAM is but one part of a broader EPA effort to collect information on mine filling practices in all of the States where this practice is allowed. What distinguishes MRAM from the other efforts is that MRAM targets quantitative waste and site specific chemical and hydrogeological data. It seeks to define and develop analytical relationships between the specific CCPs or residues placed in mine sites on the one hand, and the on-site spoils and hydro/geochemistry that will determine how the disposed wastes behave over time. (The other ongoing efforts are directed at reviewing State regulations, site visits and interviews, and searching for regulatory gaps at both the Federal and State level.)

Of course, chemical and other waste characteristics vary with the actual material being disposed; and equally obviously, how the material behaves will depend also on site and spoils characteristics. Three categories of data are being sought: (1) characteristics of the product wastes themselves, (2) site and spoils characteristics, and (3) whatever groundwater data may exist on any site where placement is occurring or has occurred. While the study embraces both surface and deep mines, it is expected the 2002 effort will be directed primarily at surface or open pit mines.

It is important to emphasize that EPA is not engaged in a "witch hunt" here. EPA acknowledges the many mine placement efforts that, at least to date, are showing site improvement either in measured contamination levels or in flow terms. But the geochemistry of these sites, while generally pretty well understood, is not documented as well as it might be for similar sites to be sought and studied. Conversely, examples where placement might not make sense typically involve (1) inadequate pH buffering; or (2) the placement of residues in situations where existing groundwater is worsened (in effect direct loading of contaminants to groundwater or loading via increased leaching).

Complicating this are the difficulties associated with measuring effects over time and over volumetric space (measuring temporal and spatial effects). Positive effects measured short-term can conceivably change dramatically as ash or site chemistries change with time; and, of course, subsurface flows, long-term, are exceedingly difficult to predict. Any placement "solution" is bound to be suboptimal for those reasons. Thus we have elected, for now, to be content with a simple "have we improved things insofar as we can determine with methods we have." We go as "long-term" as we can and ask that those who succeed us do the same.

The importance and relevance of SMCRA, the Surface Mining Control and Reclamation Act, cannot be overstated. This statute has for years been the underpinning of many coal mine reclamation projects. A special effort is being made, with the assistance of DOI's Office of Surface Mining, to determine where SMCRA and RCRA are supportive and where gaps may exist. Together the two statutes provide the primary legal basis for whatever Federal action may be taken.

The fundamental objectives of this project are to: (1) develop and publish protocols that permit wider use of protective practices and that explicitly discourage practices that are harmful; (2) document specific geochemical recipes for success or failure; (3) denote uncertainties; and (4) encourage wider usage of these residuals in mine land reclamation for any type of mine site (coal or non-coal) that might survive the analysis.

Data and Analysis

At the present time, we are beginning to assess data sets from 69 studies covering 55 sites in 9 states and Canada**.** Of these data sets, 40 are surface mines and 15 are deep mines. Certain of these data sets are far more comprehensive than others.

The initial data compilation includes mine type (surface or deep), climate designation, presence of acid mine drainage or not, placement above or below the water table, CCP type and composition, presence of cap and/or run on/run off controls, presence of liner or not, summary of groundwater data and quality, pH assessment, and any contaminant exceedances over toxicity thresholds. From this, when the database is completed, we expect to get a preliminary idea as to whether the site is currently presenting a problem or not. We would not, however, based solely on these data, be capable of explaining site phenomena.

We tabulate the following site characteristics: location, site dimensions, placement dates and purpose, nature of regulation and/or permitting, CCP type and additives if any, placement area and location within mine, soil/spoils characteristics, underlying stratigraphy and general topography, and, particularly, water table data. Here, we begin to seek insights particularly into the impact of key site characteristics (for example, soil and spoils chemistry and the presence of water in relation to locations of monitoring wells).

We also characterize the CCPs themselves. From our data to date, these wastes may contain the following: arsenic, barium, cadmium, chromium, lead, selenium, aluminum, cobalt, molybdenum, nickel, antimony, copper, mercury, zinc, silver, manganese, and iron. Some of these have primary drinking water toxicity thresholds and others do not. Finally, we array and statistically assess groundwater monitoring data for each contaminant and each site.

At time of writing of this paper, the methodology for achieving the objectives cited above is still in development. There are undoubtedly patterns of behavior between all the variables noted. The development of protocols enabling protective mine placement will necessitate careful study of these data sets. We may not have enough sites in our database. We may not have sufficient data from the sites for which we do have data. *In effect, we must ask whether we need to look further for more sites, while at the same time we seek to narrow our cases to a sufficiently prescriptive few. We must both broaden and narrow at the same time, as the methodology itself develops.*

Year 2002 Work Plan

As MRAM II begins, our plans include:

- Flesh out the data sets as much as possible to be sure we have sufficient data with which to fully understand a given site.
- Differentiate chemistries that appear promising from those that suggest problems.
- Develop rationale for nationwide recipes.
- Identify physical and mechanical fill practices by region and geology.
- Establish basic methodology for deep mines and non-coal mines.
- Investigate economics of haulback and funding options.
- Continue the comparative RCRA/SMCRA analysis to be sure we are using both statutes to their full advantage.

Andrew Wittner is employed in the Solid Waste Program of the U.S. Environmental Protection Agency at its headquarters in Annapolis, Maryland. He manages the risk assessment of wastes associated with fossil fuel combustion (mostly utilities and coal) and also the economics of risk mitigation. He is currently focusing on the use of these “ashes” in land reclamation. He managed both the groundwater and above ground risk analyses, the costing of risk mitigation alternatives, and the industry economic analyses that resulted in most recent final rule on fossil fuel wastes by EPA. He has degrees from Cornell and Columbia Universities and additional post graduate study in economics, engineering, and operations research.

MICROBIAL RELEASE OF MERCURY FROM COAL COMBUSTION BY-PRODUCTS (CCBs)

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Abstract

The research was directed toward understanding releases of mercury from microbial activity in fly ash under a disposal setting. Two samples were evaluated under six biological conditions. The releases of elemental and organomercury were evaluated.

The effect of biologic activity, although not of immediate interest in many disposal and use scenarios, will eventually become important as aging materials are infiltrated with water and become sites where microbes can live. The ability of mercury and mercury compounds to be methylated, becoming more toxic and likely to bioaccumulate, necessitated the study of microbial impacts on mercury in coal combustion by-products (CCBs).

Preliminary results were erratic and difficult to interpret. It appears that microbial action led to the formation of organomercury compounds, likely methyl-mercury, and the biological experiments as a whole emitted considerably more mercury than experiments performed with the same ash samples under dry conditions. The release of considerable levels of organomercury from the "sterile" controls suggests that sterility was not maintained. Biota tests are just beginning again using an improved apparatus. Another set of experiments is being conducted using aerobic and anaerobic conditions as before but without added electron acceptors. It is assumed that the CCBs being used will supply adequate supplies of these various electron acceptors.

Introduction

The Energy and Environmental Research Center (EERC) has been working on three primary tasks with the goal of determining the mechanisms of mercury release from coal combustion by-products (CCBs). These efforts were funded by the Coal Ash Resources Research Consortium (CARRC), the U.S. Department of Energy, and the U.S. Environmental Protection Agency (EPA) Center for Air Toxic Metals (CATM). The tasks focus on (1) the release of mercury from the CCBs in the range of ambient temperature to 600EC, (2) understanding releases of mercury from microbial activity in fly ash under a disposal setting, and (3) long-term release of mercury from CCBs at ambient and near-ambient temperatures. Results of tasks 1 and 3 are detailed elsewhere (REF). The work performed and under way for Task 2 is summarized here. Six CCB samples were selected for use in all tasks. These samples had been analyzed in previous CATM work and were shown to have higher-than-average mercury concentrations. It was deemed necessary to evaluate high-mercury-content samples in these tasks to ensure quality data. Utilizing the same samples for all tasks provided an opportunity to begin a hypothesis on the release of mercury from CCBs over a typical CCB life cycle.

The objective of Task 2 is to evaluate the effect of biota on mercury transformations and subsequent release to the groundwater through leaching or offgassing to the atmosphere. The experiments were designed to develop a preliminary understanding of releases of mercury from microbial activity in fly ash under a disposal setting. Two samples were evaluated under six biological conditions. The releases of elemental and organomercury were evaluated.

Experimental

Experiments to determine mercury release through microbial action on CCBs were conducted in an apparatus similar to that shown in Figure 1. The primary difference between the apparatus shown in Figure 1 and the actual

apparatus used was in the gas inlet system. In these initial experiments, constrictions in inlet tubing were used to control gas flow. This practice was inaccurate and required constant adjustment. The current apparatus is described as follows. A 250-mL Erlenmeyer flask fitted with a vacuum take-off adapter had its center inlet tube shortened to 6 cm below the standard taper. It had been found in previous experiments that tube plugging was a problem if ash-water slurry were allowed to contact the gas inlet tube during the course of the experiments. Gas inlet flow was regulated by directing inlet gas to the flasks through a section of fused silica gas chromatographic tubing, 0.32-mm I.D., approximately 60 cm long. It was found that the pressure drop through a section of tubing of these dimensions would allow a gas flow of approximately 2 mL per minute at an inlet pressure of approximately 10 psig.

Figure 1. Biological mercury apparatus.

Flow could be precisely controlled by adjusting either (1) tubing length or (2) inlet pressure. 100g of ash and 150 mL of a phosphate buffer were placed into each flask. After an appropriate gas purge (air for aerobic conditions and argon for anaerobic conditions), 100 FL of supernate from a homogenized wetland sediment slurry was added to each flask as a source of mixed bacteria.

Several conditions of microbial action were evaluated under aerobic and anaerobic conditions. Table 1 presents a summary of the most abundant types of microbial metabolism. In addition, a sterile control was used. In current and future experiments, specific electron acceptors are not being added, rather elements from the various fly ash samples are assumed to be present in sufficient concentrations to provide suitable electron acceptors.

Table 1. Types of Microbial Metabolism

Si Metabolism	Electron Donor Electron Acceptor	Product
1 Sul fate reducing	Glucose	Sulfate	Sulfide
2 Fermentative	Glucose	Glucose products	Mixed (acids, alcohols, etc.)
3 Nitrate reducing	Glucose	Nitrate	Nitrogen gas
4 Iron reducing	Glucose	Iron(III)	Iron(II)
5 Aerobi c	Glucose	Oxygen	Water
6 Sterile			

Results and Discussion

One set of experiments was performed using two fly ash samples. These samples, designated as 99-189 and 99-692, were used in a single set of microbial experiments. Both ash samples contained easily measured concentrations of mercury. Ash 99-189 was an alkaline fly ash from the combustion of Powder River Basin coal and petroleum coke. This ash was washed sequentially with distilled deionized water to somewhat reduce its alkalinity. This water washing reduced the concentration of mercury in this fly ash sample from 0.736 to 0.609 Fg/g of mercury. Fly ash sample 99-692 was a fly ash sample from the combustion of eastern bituminous coal and had a mercury concentration of 0.140 Fg/g

Mercury released was collected on two traps, which consisted of a gold-coated quartz trap followed by a carbon trap. The gold trap collected elemental mercury and the carbon trap collected organomercury. Tables 2 and 3 indicate the amount of mercury released from the biologically active fly ash samples. Biological activity was evident by effects on the fly ash samples and gold traps. Some fly ash samples were musty or moldy. Many gold traps exhibited color change.

Each sterile sample exhibited the largest percentage of total mercury release for the six conditions tested. Examination of the sterile samples along with the production of organic mercury provided evidence for microbial contamination. This likely happened because several of the tubes became plugged during the course of the experiments, requiring the apparatus to be partially disassembled to restore gas flow.

Table 2. Results for Fly Ash 99-189

Conditions	Elemental Hg, ng	Organic Hg, ng	Percentage of Total Hg
O_2	81	0.90	0.134
Fe	103	78.90	0.299
NO_3	95	685.00	1.28
Ferm.	99	0.17	0.163
SO_4	158	43.30	0.33
Sterile	116	1,375.00	2.45

Table 3. Results for Fly Ash 99-692

Conditions	Elemental Hg, ng	Organic Hg, ng	Percentage of total Hg
O_2 1.96		0.12	0.015
Fe 3.16		0.30	0.025
NO_3 5.08		0.06	0.037
Ferm. 1.05		0.11	0.008
SO_4 0.77		0.36	0.008
Sterile 9.23		0.08	0.067

Conclusions

Although the amounts of mercury given off during the course of the various biological experiments were somewhat confusing, it is important to note that the total mass of mercury given off in each experiment was still relatively small. The unfortunate, although somewhat inevitable, conclusion drawn is that organomercury compounds were also formed through biological action. It is likely that methyl-mercury was formed, but this may be confirmed in current experiments. Overall, the biological experiments released between 0.008 and 2.45 percent of the total mercury as a combination of elemental and organomercury. In nonbiological experiments, between 0.001 and 0.03 percent of the total mercury was released. Biological contamination of sterile experiments resulted in production of organomercury compounds. Because of this problem, future experiments will not attempt sterility. Instead,

deprivation of the glucose nutrient will be used as a control.

Experiments are currently under way in triplicate using an improved setup to reevaluate the release of mercury from biologically active CCBs. The results from these experiments will be available in about one year.

References

Center for Air Toxic Metals 2001 Annual Report; Annual Report of the Center for Air Toxic Metals, organized and administered through the University of North Dakota Energy and Environmental Research Center; U.S. Environmental Protection Agency Contract No. R 827649-01; Energy and Environmental Research Center: Grand Forks, ND, March 2002.

David J. Hassett is a Senior Research Advisor at the Energy and Environmental Research Center (EERC) of the University of North Dakota. He also serves as the Fuels Analyst for the State of North Dakota. He has authored or coauthored more than 200 publications and holds a patent entitled "Enhanced Ettringite Formation for the Treatment of Hazardous Liquid Wastes," U.S. Patent 5,547,588. He is presently involved in several research projects. His principal areas of interest and expertise include the application of analytical chemistry to address environmental issues associated with trace element occurrence, transport, and fate; coal combustion by-product management; groundwater quality; and air quality. The most recent research focus has been on trace element transformations during coal conversion processes and interaction between groundwater and coal conversion solids as related to the leachability of trace elements. Additional areas of expertise include hydration reactions of coal conversion solid residues as well as organic synthesis, radiochemistry, x-ray spectrometry, analytical chemistry, and vegetable oil diesel fuels. In 1985, he presented his research on vegetable oil diesel fuels as a member of a People to People Biomass Utilization Delegation to the People's Republic of China and, in 1998, was an invited keynote speaker at the 15th Conference on Clay Mineralogy and Petrology held in Brno in the Czech Republic. He has laboratory experience with infrared spectroscopy, gas chromatography, neutron activation analysis, atomic spectroscopy (atomic absorption and inductively coupled argon plasma), thin-layer chromatography, ultraviolet and fluorescence analysis, x-ray fluorescence spectroscopy, nuclear magnetic resonance spectroscopy, ion chromatography, laser spectroscopy, and capillary electrophoresis. He holds a B.S. in Chemistry and Mathematics from Winona State University in Minnesota.

Debra F. Pflughoeft-Hassett is a Research Manager in Residuals Research at the Energy and Environmental Research Center (EERC) of the University of North Dakota. Her principal areas of interest and expertise include utilization and characterization of coal combustion by-products (CCBs), waste management, and environmental impacts of CCB use and disposal. She has worked on the development of databases containing characterization information on CCBs and on the development of chemical characterization protocols. She has expertise in applying analytical chemistry, mineralogical and geological data, and engineering testing to demonstrations and field projects utilizing CCBs. She has participated extensively as an investigator on research investigations of CCB characterization, groundwater contamination, sediment attenuation, leaching characterization, and chemical fixation of trace elements. She participates as a principal researcher and project manager on several investigations of the characterization, utilization, and disposal of CCBs, and currently manages the research effort of the Coal Ash Resources Research Consortium (CARRC) and other CCB research at the EERC. She is the director of the Western Region of the Combustion By-Products Recycling Consortium and is a member of several professional organizations including: the North Dakota Academy of Science; represents the EERC in the American Coal Ash Association; and the American Society for Testing and Materials Committee on Environmental Assessment. She serves on the steering committee for the U.S. Department of the Interior Office of Surface Mining Coal Combustion By-Product Information Network and participates in the U.S. Environmental Protection Agency's Mine Fill Research and Analysis/Modeling (MRAM) Project. In addition, she has coauthored more than 60 publications. She received her B.S. in Chemistry from the University of North Dakota in 1982.

ENVIRONMENTAL PERFORMANCE OF CCPs

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Abstract

Large quantities of coal combustion products (CCPs) are produced in the United States by electric power plants. Coal is burned in conventional boilers as well as in fluidized bed combustion units; both of them produce fly ash, bottom ash (bed ash), and flue gas desulfurization (FGD) sludge. The American Coal Ash Association (ACAA) has developed annual statistics on the disposal and utilization of the CCPs nationwide. Approximately 30% of the generated CCPs is utilized and the remaining 70% is disposed in landfills and impoundments. More than 25 years of research, development, and monitoring efforts by many entities have produced a large body of knowledge on the characteristics and environmental performance of disposed and utilized CCPs.

In this paper, we provide a descriptive summary of the nature of impacts particularly on groundwater quality in the vicinity of the disposal and use facilities. Insights into the leaching, attenuation, and environmental fate of inorganic constituents of interest have been summarized.

Introduction

Coal combustion products (CCPs) are residues of coal burning in utility boilers and fluidized bed combustion units to produce electricity. Coal is a widely distributed fossil fuel available in the United States. More than 1.12 billion tons of coal are extracted annually from surface and deep mines in the United States (2001 data from U.S. Department of Energy). The vast majority of this annual production of coal is burned to produce electricity. Combustion of coal produces fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) sludge collectively named as CCPs. The American Coal Ash Association reported that in the year 2000 the U.S. electric utilities produced about 108 million tons of CCPs. About 30% of the CCPs is used in cement/concrete, structural fill, roadbase/subbase, snow and ice control, blasting grit, roofing granules, and in the wallboard production. Approximately 70% of the CCPs is land disposed in landfills and impoundments.

The land disposal of CCPs has been a subject of regulatory discussion at the Federal level under the Resource Conservation and Recovery Act (RCRA). In 1980, the Bevill amendment to RCRA exempted the fossil fuel combustion residues from the Subtitle C (hazardous waste) of RCRA pending the outcome of the U.S. EPA determination. RCRA required that the U.S. EPA conduct studies and determine if the fossil fuel combustion wastes should be regulated under Subtitle C of RCRA. The U.S. EPA studies and determination were to be based on the actual management practices for CCPs and the risks to human health and the environment from those management practices. In 1988, EPA submitted its first report to Congress and on August 9, 1993 made the first regulatory determination declaring that the disposal in landfills and surface impoundments of coal fly ash, bottom ash, boiler slag, and the FGD sludge did not require a Subtitle C regulation under RCRA. The U.S. EPA made its second regulatory determination on March 22, 2000, in which the Agency announced that national regulations under Subtitle D of RCRA would be developed to address the management of CCBs in surface impoundments and landfills. In addition, the Agency stated that regulations under Subtitle D of RCRA and/or possible modifications to existing regulations under SMCRA are warranted when CCPs are used to fill surface or underground mines. This second determination reaffirmed that the CCPs do not require to be regulated under the Subtitle C of RCRA.

As a result of national regulatory interest during the last 20 years, large amounts of effort were placed in developing characterization data, groundwater monitoring results, and risk assessments for the CCPs placed in landfills and impoundments. The Electric Power Research Institute (EPRI) developed a significant portion of the technical information that was relied upon by the U.S. EPA in making its regulatory determination. EPRI work emphasized studies on the leaching and attenuation chemistry of metals found in CCPs. EPRI studies also completed several field-scale monitoring and characterization studies of land disposal facilities where CCPs were placed by the power plants. This paper contains a summary of knowledge on leaching, attenuation, and fate of metals and soluble salts in

the subsurface environment associated with landfills and impoundments used to manage CCPs.

CCP Composition and Environmental Performance Factors

Coal fly ash, bottom ash, and slag composition are dominated by aluminum and silica that are also the primary constituents of soils and geological materials. The FGD sludge composition is dominated by calcium and sulfur. All coal combustion products contain metals in trace amounts. The CCPs also contain significant amounts of calcium, magnesium, iron, and sulfur. Boron is a common constituent present in moderate amounts in the CCPs. The four types of CCPs vary in particle size and in their leaching potentials for the various chemical constituents contained in them. Therefore, the environmental performance factors are typically associated with pathways and receptors for the constituents of concern found in CCPs. RCRA regulates eight metals under its toxicity characteristic rule. These metals are barium, arsenic, selenium, chromium, cadmium, mercury, lead, and silver and they are present in CCPs in varying concentrations.

Other constituents in CCPs that provide an assessment of environmental performance include boron, sulfate, vanadium, nickel, zinc, molybdenum, and manganese. The groundwater pathway, where release and migration of constituents in CCPs disposed in landfills and impoundments would take place, is one of the major concerns of regulators in order to assess risks/impacts; therefore, attention has been placed on developing technical information on leaching of target chemicals. Similarly, studies have been completed to examine retardation or attenuation of metals in groundwater to understand the potential extent of migration of leached constituents. Results from both laboratory and field studies are available on the leaching and attenuation processes in reports and open literature papers.

Coal ash has the potential to produce leachates that contain measurable concentrations of chemicals of concern. Therefore, in the next subsection, a qualitative description is given to convey the nature of leaching and the impacts associated with leachate migration at CCP management facilities.

Observations Regarding Environmental Performance

Generally silica, aluminum, calcium, magnesium, and iron contained in the CCPs do not pose leaching and groundwater quality impact potentials at CCP containing landfills and impoundments. However, for the western coal ash where leachate pH can be highly alkaline (above pH 10), the aluminum concentrations in the leachates can be also quite high. The increased aluminum levels are reflective of the increased solubility of aluminum at high pH conditions.

Barium is one of the regulated RCRA metals and is also present in the CCPs. Leaching test results from numerous samples of CCPs covering a large number of power generating facilities indicate that barium in CCP leachates are below regulatory standards and that leachates from naturally occurring soils in the United States also contain comparable levels of barium in solution.

Mercury and silver are regulated RCRA metals but are present in CCPs in extremely low concentrations. Available laboratory and field-scale data strongly suggest that leaching and migration of these two metals contained in CCPs are not likely to occur. Therefore, mercury and silver in CCPs pose no risk to the environment from landfills and impoundments where the CCPs are disposed.

Cadmium is another regulated RCRA metal and is present in low concentrations in CCPs. Available laboratory and field measurements indicate that very low concentrations of cadmium can be found in leachates. However, the majority of the data indicates that the cadmium concentrations in the CCP leachates are well below all applicable regulatory standards on water quality.

Similar to mercury, silver, and cadmium, both lead and chromium seldom leach from CCPs and, therefore, do not migrate in the groundwater near CCP management facilities. Lead and chromium in CCPs are typically present in solid phase compounds that have very low dissolution and leaching potentials for the two metals. While these observations provide the most likely performance of these five metals in CCPs, there are some extreme situations

(e.g., very acidic pH, very alkaline pH) where increased leaching for these metals can occur.

Arsenic is found in CCPs at low to somewhat high concentrations. Laboratory and field measurements have shown that leachates from CCPs can contain low to moderately high concentrations of arsenic. However, most of the arsenic is present as arsenic (V) species that is relatively low in toxicity compared to arsenic (III) species. Acidic to near neutral coal ashes generate leachates with arsenic concentrations ranging from 300 ug/L to about 800 ug/L. Occasionally the leached arsenic has resulted in localized increases in groundwater concentrations down gradient of the CCP disposal unit. However, available literature also indicates that arsenic has high attenuation potential thereby its potential to migrate in groundwater is greatly reduced. U.S. EPA in its regulatory determination in 2000 noted that there exists a potential for arsenic impacts on groundwater quality in the very long-term.

Selenium is another RCRA regulated metal. Low concentrations of selenium can leach from CCPs and can migrate short distances in groundwater. However, the leaching potential for selenium in CCPs is somewhat higher under alkaline conditions (i.e., when pH is greater than 10). The environmental chemistry of selenium is complex because selenium in CCPs is present in two valence states. The presence of both types of selenium species in the CCP leachates makes it difficult to predict the migration potentials. However, selenium does attenuate moderately well through adsorption onto soil/aquifer material.

Boron and molybdenum are relatively soluble constituents present in CCPs. Leachate concentrations for boron can range from under 1 mg/L to over 100 mg/L. Boron in leachate shows a very small potential for retardation/attenuation by soils/aquifer material. In the field and laboratory studies, boron has been found in elevated concentrations in groundwater at the CCP management sites. In fact, boron is often used as an indicator of leachate migration from landfills and impoundments used to manage CCPs.

Molybdenum is also a soluble constituent and leachate concentrations usually are below 2 mg/L. But molybdenum has been observed in elevated concentrations in groundwater at ash disposal as well as ash use sites.

Sulfur, commonly present as sulfate of calcium, magnesium, or sodium, is highly soluble and often is abundantly present in the CCPs. Field-scale studies and monitoring of groundwater have shown that sulfate concentrations in leachates and groundwater can be in the range of 200 to 2,500 mg/L. Similar to boron, sulfate is not subject to chemical attenuation and, therefore, is quite mobile in groundwater. Both boron and sulfate are, therefore, often times used as indicators of leachate migration from landfills and impoundments used to manage CCPs.

Metals such as nickel, vanadium, copper, and zinc are found in CCPs as well as in soils. Leaching tests do show some release of these constituents as a result of dissolution by the water contacting the CCPs. However, available monitoring data do not show migration and groundwater quality impacts associated with these constituents in CCPs.

At some CCP management facilities, manganese has shown increased concentrations in monitoring wells. Leaching tests show low to moderate potential for manganese release from CCPs at concentrations that can explain the observed increases in groundwater concentrations of manganese. Therefore, the relationship between CCP management facilities and elevated manganese concentration in down gradient groundwater is not clear.

The increasing use of NO_x control technologies at power plants is expected to result in increased concentration of ammonium in coal ash. Limited amounts of available data do indicate that leachate generated from the ammoniated ash will contain significant amounts of ammonium. Depending on the soil and aquifer conditions, the ammonium in leachate is likely to convert to nitrate that could migrate in groundwater without attenuation resulting in elevated concentrations of nitrate and/or ammonium in down gradient groundwater.

Summary and Conclusions

The foregoing description provides a qualitative summary of leaching and effects on groundwater for a number of metals and soluble salts contained in CCPs. No effort was made to present in this paper a quantitative summary of available data on the release and migration of constituents of concern to present the knowledge on the environmental performance of CCPs when disposed in landfills and impoundments.

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Dr. Ishwar Murarka has been addressing land and water environmental issues for more than 25 years. Dr. Murarka has worked as an environmental professional for Texas Instruments, Argonne National Laboratory, and Electric Power Research Institute (EPRI). After retirement from EPRI in 1998, Ishwar started Ish Inc. as an environmental consulting company specializing in investigating, evaluating, and developing strategies for the remediation of soils, groundwater, and sediments contaminated with metals and organics. He continues to offer consulting services to address environmental issues associated with the disposal and utilization of fossil fuel combustion by-products. He has served on the U.S. EPA's Science Advisory Board (SAB) from 1988 through 2001 in various capacities and continues to be a consultant to the SAB. He is most experienced with the scientific and regulatory deliberations on the management of fossil fuel combustion wastes and the former manufactured gas plant sites. He continues to perform research on leaching, attenuation, and environmental fate of metals and organic constituents. He holds a Ph.D. in Soil Science and Statistics from Oregon State University and an MBA from the University of Chicago. He was an NIH postdoctoral fellow in Biomathematics at North Carolina State University.

Session 5

CCB Regulatory Direction

Session Chairperson:
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Springfield, Illinois

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Truett Degeare, U.S. Environmental Protection Agency, Washington, D.C.

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Descriptions of State of Colorado Regulatory Programs Associated with Coal Combustion Waste (CCW) Mine Placement
Dave Berry, Colorado Division of Minerals and Geology, Denver, Colorado

The Disposal of Power Plant Waste in Mines: Public Health, Environmental, and Regulatory Concerns
Lisa Evans, Clean Air Task Force, Boston, Massachusetts

The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines
Kimery Vories, Office of Surface Mining, Alton, Illinois

OVERVIEW OF U.S. ENVIRONMENTAL PROTECTION AGENCY COAL COMBUSTION WASTE (CCW) MINE FILL ISSUES

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Abstract

The U.S. Environmental Protection Agency is developing national regulations under the RCRA statute for the management of coal combustion by-products (CCB). The regulations will address the management of CCBs in surface impoundments, landfills, and by mine placement. The regulations are a consequence of EPA's regulatory determination for fossil fuel combustion wastes, which was issued on May 22, 2000. The presentation will describe the history and basis of the determination decision, and then focus on activities concerning development of the mine placement regulations.

Introduction

We've heard much of SMCRA (Surface Mining Control and Reclamation Act), the Federal legislation providing for regulation of coal mines. Now, I briefly want to consider RCRA, the Resource Conservation and Recovery Act.

The Resource Conservation and Recovery Act

Congress enacted RCRA in 1976, just months prior to enacting SMCRA.

- RCRA amended the Solid Waste Disposal Act of 1965, which is the fundamental Federal legislation on solid waste issues.
- RCRA addresses a broad spectrum of materials as solid wastes, some of which aren't even solid.
- As its name indicates, RCRA deals with conservation and recovery of our resources.
- Importantly, RCRA also establishes a Federal system to oversee how the nation deals with some of the most noxious materials. The two key RCRA subtitles are C (hazardous waste) and D (solid waste).

RCRA Subtitle C

- Provides for identification of "hazardous wastes," designates which materials will be regulated as "hazardous."
- Provides for cradle-to-grave regulation of hazardous waste practices; comprehensive regulations spanning generation, storage, transport, processing, treatment, and disposal.
- Establishes Federal regulatory program, including Federal permits, inspections, and enforcement with option for States to implement.
- States have opportunity to demonstrate regulatory program equivalence to the Federal program and receive EPA authorization to implement in lieu of a Federal program. Most States have received authorization.

RCRA Subtitle D

- Provides for more limited regulation of solid wastes not identified as hazardous.
- Regulatory focus is disposal, including Federal prohibition on "open dumping." Defined as disposal in a fashion not complying with Federal disposal standards.
- Because there are not Federal permits, Federal disposal standards under Subtitle D are self-implementing or are implemented through State permits. This means facility owners/operators either comply with the Federal standards with little flexibility or comply with State permits that can provide site-specific flexibility.

- RCRA provides for citizen suits to help enforce standards.

For a few specific wastes, including coal combustion wastes (CCW), RCRA includes special provisions:

- Statute exempts CCW from regulation as hazardous wastes under Subtitle C pending specific EPA actions.
- EPA was required to conduct a special study of CCW and issue a Report to Congress. EPA was then required to issue a Regulatory Determination stating how CCW is to be regulated.
- The Report to Congress was issued in March, 1999, and the Regulatory Determination was published following an opportunity for public comment in May, 2000.

For the 130 million tons/year of CCW, EPA's decision in Regulatory Determination said:

- Continue exemption from Subtitle C;
- Develop Subtitle D regulations for disposal (landfill, impoundment) (80million tons/year); and regulate mine fill (10 million tons/year) under RCRA Subtitle D and/or SMCRA.
- Remaining 40 million tons/year (beneficial uses such as soil amendment, road, road/base, waste stabilization, cement and concrete, wallboard) continue unregulated.

Regulation developments for disposal (landfill and surface impoundments) and mine fill currently are on separate tracks.

- For disposal, much of the data collection and analysis efforts have been completed.
- For mine fill, EPA is still in the information-gathering and assessment mode.

Mine Fill

- This is placement of CCW in or on land from which minerals have been or are being extracted.
- Coal or non-coal mines.
- This is a relatively new, but increasing practice. It is now estimated at 10 million tons per year with some 250 mines involved.
- The practice disposes of the CCW but also puts the CCW to beneficial use.

Mine Fill Benefits

- Improve disturbed mine lands
- Abate acid mine drainage
- Avoid development of greenfield CCW facilities

According to its Regulatory Determination, EPA's primary concern is for potential adverse impacts on groundwater

- Possible placement into useable groundwater
- Subsequent inflow/outflow of groundwater, with possible adverse impacts on users and uses.

The Regulatory Determination acknowledged EPA's lack of information on <u>PRACTICES</u> and <u>CONTROLS</u> for mine fill.

Complexities of Practices

- Mine Fill is a relatively new practice that lacks long-term monitoring data.
- Mine sites often contain otherwise non-potable groundwater.
- Mine sites not amenable to groundwater flow due to tight fireclay and cementitious nature of CCW.
- Large expanses of disturbed land with variable, site-specific hydrogeology and CCW characteristics; also
- Variety of placement practices (e.g., intermix with spoil, spread/compact as liner to isolate spoil, place in bulk).

Complexities of Controls

- Both Federal and State controls may apply.
- For permitted coal mines only: Surface Mining Control and Reclamation Act (SMCRA) controls apply through Federal Office of Surface Mining or approved State permit programs.
- For abandoned coal and non-coal mines: other State controls apply, such as solid waste permit programs.

EPA is engaged in information collection to fill information needs on practices and controls.

- Learning about practices conducted at mine sites and how State agencies ensure compliance with regulatory controls.
- Working with Office of Surface Mining and "SMCRA" State agencies through Interstate Mining Compact Commission (IMCC) and with "RCRA" State agencies through Association of State and Territorial Solid Waste Management Officials (ASTSWMO).

Information gathering should provide foundation for RCRA Subtitle D and/or SMCRA controls that will:

- Allow for beneficial placement of CCW at mines.
- Protect against adverse impacts on groundwater, both near- and long-term (i.e., post-closure).
- Provide flexibility for site-specific determinations.
- Avoid undesirable disruptions to existing, protective regulatory programs.

Form more information on EPA investigation concerning Coal Combustion Wastes, see the following EPA Internet web site: www.epa.gov/epaoswer/other/fossil/

Truett V. Degeare (P.E) has been with the Federal solid waste program since 1968 and with the U.S. Environmental Protection Agency since its formation in 1970, serving in various staff and management positions. Principal areas of contribution: development of Federal regulations on incineration and land disposal of solid waste; technical assistance to State, local and Federal agencies and other countries; development and implementation of program to authorize State hazardous waste regulatory agencies; and development of regulatory approaches for wastes from mining and minerals processing, from production of crude oil and gas, and from production of energy from fossil fuel combustion. He holds a B.S. in Civil Engineering from Missouri School of Mines and Metallurgy and an M.S. in Sanitary and Public Health Engineering from Oklahoma State University.

STATE/FEDERAL INITIATIVE ADDRESSING MINE PLACEMENT OF COAL COMBUSTION WASTES

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Abstract

Beginning in May of 2001, the Interstate Mining Compact Commission (IMCC) has sponsored a series of meetings between State and Tribal representatives and representatives from the Federal government including the Environmental Protection Agency, the Office of Surface Mining, the U.S. Geological Survey, and the Department of Energy. The purpose of these meetings has been to discuss potential adjustments to existing State and Tribal regulatory programs relating to the placement of coal combustion waste (CCW) into surface and underground mines. The meetings have been in response to EPA's Regulatory Determination on Wastes from the Combustion of Fossil Fuels published on May 22, 2000 and, more specifically, the finding that regulations under Subtitle D of RCRA and/or possible modifications to existing regulations established under SMCRA are warranted when CCW is used to fill surface or underground mines. State and Tribal regulatory programs are in varying stages of maturity with regard to the placement of CCW in mines. Some are well established and have rich experience to share, while others are in the initial stages of development. Over the course of the past year, the States and Tribes have had the opportunity to learn from one another about existing approaches that are being used and potential enhancements to their programs. Discussions have focused on the various operational, environmental, and economic issues associated with the practice of placing CCW in mines, including how States and Tribes can adjust or improve current regulatory practices, identify existing or potential regulatory gaps, and examine the impacts of various Federal regulatory proposals on the content and implementation of existing State and Tribal programs. This presentation will report on the progress of State/Federal discussions concerning placement of CCW in mines and the expected next steps in terms of potential State/Tribal or Federal regulatory adjustments.

Introduction

The focus of our attention this afternoon is on the direction that we may see the U.S. Environmental Protection Agency (EPA), the Federal Office of Surface Mining (OSM), and the States take with respect to the regulation of coal combustion by-products (CCBs). Consequently, my remarks will be from a policy perspective, not a technical one. My objective is to provide you with an overview from the States' viewpoint about where we are in the regulatory development process and, more specifically, about a State/Federal initiative to inform one another about our existing regulatory approaches and what the future might hold.

IMCC Forum on CCB Rulemaking Related to CCB Placement at Mine Sites

Following EPA's publication of its Notice of Regulatory Determination on Wastes from the Combustion of Fossil Fuels in May of 2000 (at 65 Federal Register 32214), the member States of the Interstate Mining Compact Commission (a multi-State governmental organization representing the natural resource and environmental protection interests of its 20 member States) suggested to both EPA and OSM, in the U.S. Department of the Interior, that an intergovernmental forum would serve as a valuable mechanism to initiate discussions between State and Federal governments concerning next steps pursuant to the regulatory determination. This suggestion followed on the heels of a resolution adopted by IMCC in May of 2000 affirming the appropriateness and effectiveness of State regulations and policies for the safe handling, recycling, beneficial use, and placement of coal combustion by-products. The resolution also supported the management of CCBs without the application of Federal RCRA Subtitle C requirements. The IMCC States were particularly focused on EPA's finding that, although CCBs or coal combustion wastes (CCW) did not warrant regulation under Subtitle C of the Resource Conservation and Recovery Act (RCRA) as "hazardous waste," the agency had determined that national regulations under Subtitle D of RCRA are warranted when these wastes are disposed in landfills or surface impoundments, and that regulations under Subtitle D and/or possible modifications to existing regulations established under the Surface Mining Control and

Reclamation Act (SMCRA) are warranted when these materials are used as fill in surface or underground mines. IMCC was especially concerned about the latter "mine placement" aspects of the determination given the significant interplay between approved State regulatory programs under SMCRA and any potential adjustments to the national SMCRA regulations (that serve as a template for State regulatory programs).

IMCC CCB All Government Meeting, May 15-16, 2001

Both EPA and OSM saw the value of proceeding in this manner and the first intergovernmental forum on mine placement of CCBs was held on May 15 and 16 in St. Louis, Missouri. The forum was open to all States, not just IMCC member States, and also involved tribal government representatives. Other Federal participants included the U.S. Geological Survey and U.S. Department of Energy. The forum began with several presentations from EPA, OSM, and State representatives regarding current mine placement practices and regulatory programs. These presentations also allowed attendees to hear about current issues and problems being encountered in the mine placement of CCBs in anticipation of the potential development of a new regulatory approach by EPA. One of the key objectives of the forum was to engage State and Federal representatives affected by a potential mine placement rule in an open discussion about current challenges being encountered in the field. The goals of the discussion were to identify potential regulatory gaps, anticipate potential interagency jurisdictional conflicts, and discuss implementation concerns associated with any new rule. A key outcome of the forum was the establishment of an ongoing dialogue among the States, Tribes and Federal representatives concerning the various operational, environmental, and economic issues associated with the practice of mine placement of CCBs. A copy of the notes from the meeting can be found at EPA's website: www.epa.gov/epaoswer/other/fossil/index.htm.

IMCC CCB State and Tribal Government Meeting August 13, 2001

The intergovernmental forum was followed by a meeting of the States and Tribes on August 13 and 14 in St. Louis. Among the issues discussed were: characterization methods and tests for CCBs; placement requirements; use of liners; closure requirements; site characterization and volume restrictions; definition of beneficial use versus classic disposal; the need for Federal regulations, guidelines, or policies; and which Federal agency should take the lead: EPA or OSM. The outcome of this meeting was the development of a draft discussion outline that contains the basic position of the States/Tribes concerning the regulation of CCB placement at mine sites. The outline has served as the basis for continuing discussions with EPA and OSM regarding the need for national regulations given the adequacy of existing State and Tribal regulatory programs. A copy of the outline is available on EPA's website. The outline addresses categories of coal ash management; coal ash management principles for beneficial use; coal ash regulatory principles for beneficial use; disposal/placement at mine sites other than beneficial use; and conclusions. Among the conclusions drawn by the States were the following:

- Approved beneficial use determinations by the States preclude the need for further waste regulation by EPA or OSM.
- Experience at the State level in implementing existing State and Federal laws substantiates the adequacy of the existing regulatory structure.
- Comprehensive Federal regulations will be difficult to implement from a nationwide perspective due to differences in regional geology, climate, ash composition, and other factors.
- State data and information supports these conclusions and are available for review.

Throughout the discussions on mine placement of CCBs, the States and Tribes have attempted to reflect the input and positions of the various departments and/or agencies within each State that have jurisdiction over this matter. This often includes the mining regulatory agencies within the departments of Natural Resources or Environmental Protection; the solid waste regulatory agencies within the departments of Environmental Protection, Environmental Quality, or Health; and the water quality regulatory agencies within the departments of Environmental Protection or Environmental Quality. IMCC also has coordinated its efforts with the Association of State and Territorial Solid Waste Management Officials (ASTSWMO), which has been active for many years on this issue and has begun to consider potential guidelines for nonhazardous industrial waste management that may serve as a model for potential guidance in the CCB mine placement arena.

IMCC CCB All Government Meeting November 14-16, 2001

In preparation for the second State/Federal dialogue, the States requested that EPA make available for State and Tribal review two draft documents which the agency had been developing: "Regulation and Policy Concerning Mine Placement of Coal Combustion Waste in 26 States" and "Mine Placement of Coal Combustion Waste – State Program Elements Analysis." Copies of both draft documents were provided to the States in early November and are available from EPA. These documents provide a detailed overview of State regulations and policy (under both mining and solid waste programs) concerning CCB mine placement, with an emphasis on coal mines. The reports summarize the elements of existing State programs that are applicable to CCB mine placement, including:

- administrative program elements (i.e., permitting and public participation);
- planning and enforcement program elements (i.e., reclamation plans, site characterization and restrictions, and special requirements related to acid mine drainage);
- waste characterization and monitoring program elements (i.e., required chemical analyses, groundwater and surface water monitoring);
- design and operational program elements (i.e., groundwater table restrictions, compaction, interim cover, fugitive dust controls, and erosion/surface runoff controls); and
- closure and post-closure program elements (i.e., final cover, revegetation, financial assurance/bonding, and post-closure site utilization restrictions).

These reports by EPA are dynamic documents and their accuracy and completeness will change as States continue to provide information to the agency concerning current State regulatory program requirements. Since the initial release of the reports, several of the States, including some that were not represented in the early drafts of the reports, have provided updates, clarifications, and new information to EPA in an effort to improve the nature and usefulness of the reports. In addition, EPA is incorporating changes to the reports based on site visits and interviews that the agency is conducting in various States. In the final analysis, the States and Tribes are hopeful that these reports will assist all of the parties to the discussion (EPA, OSM, the States, and Tribes) in determining (1) what the agreed-upon program elements should be for the regulation of mine placement of CCBs, and (2) how effectively the States and Tribes are currently implementing those elements. The need for additional national guidance or regulation should emerge from our continuing discussion of these reports.

The second State/Tribal/Federal meeting took place on November 14 and 15 in San Antonio, Texas. Among the topics discussed at the meeting were:

- an explanation and status report on EPA's Minefill Risk Assessment/Modeling (MRAM) Project and its relationship to EPA's Coal Ash Regulatory Program;
- a presentation on the State of Illinois' Data Management System for Mine Placement Activities;
- review and discussion of EPA's Draft Reports mentioned above;
- an overview of EPA's program of site visits and interviews with individual State agencies that regulate mine placement of CCBs; and
- review and discussion of the States' outline on coal ash management, including:
  - the topics of use of coal ash (beneficial use versus disposal);
  - principles for beneficial use of coal ash;
  - the effectiveness of existing state regulatory programs (both coal and noncoal); and
  - interagency cooperation and coordination, both within the States and within the Federal government.

A copy of the meeting notes is available at EPA's website, noted above.

IMCC All Government Meeting April 15-16, 2002

The most recent meeting of State/Tribal/Federal government representatives was held April 15 and 16 in Golden, Colorado in conjunction with OSM's technical interactive forum on "Coal Combustion By-Products and Western Coal Mines." At that meeting, representatives received updates on the MRAM project, EPA's State program reports, and EPA's site visits. The State of Indiana provided an overview of its CCB database and how the State is using this data to effectively monitor and regulate mine placement of CCBs. EPA and OSM presented more detailed responses to the States' outline on coal ash management, which were helpful in informing the ongoing debate and clarifying EPA's and OSM's positions and concerns. Finally, and perhaps most valuable to our on-going discussions, the participants spent time reviewing EPA's mine fill regulatory concerns, primarily from a RCRA perspective. This discussion was most promising in terms of bridging the gap between how the States currently operate under the respective SMCRA and RCRA programs and what EPA is anticipating based on its understanding of those RCRA elements that it believes should be applicable to mine placement of CCBs. As the States attempt to

continue informing the debate on these issues, we anticipate building on the good work that EPA has undertaken to date in its two State regulatory program reports and the valuable efforts OSM has made to articulate the SMCRA regulations that apply to CCBs. We then hope to engage in an analysis of what the State could do to supplement the current permitting information and data that we collect and analyze as part of our SMCRA or other non-coal programs by specifically addressing those RCRA elements that appear to be different or that require additional information or approaches.

State Concerns about CCB Rule Making

Over the course of the State/Federal discussions, the States/Tribes have consistently articulated the following concerns to EPA and OSM, several of which remain to be addressed or resolved within the context of continuing State/Tribal/Federal government debate:

- SMCRA appears to serve as an adequate and effective baseline for any type of regulatory analysis concerning mine placement of CCBs. In this regard, we see the SMCRA permit serving as the platform for CCB mine placement at coal mines. For non-coal mines, we believe that the existing State permitting framework, which is often RCRA-based, is adequate.
- It is essential to examine the effectiveness and comprehensiveness of existing State/Tribal programs before adding additional regulatory requirements.
- There is a need to coordinate among all applicable statutes/regulations that impact the regulation of mine placement of CCBs, including SMCRA, RCRA, the Clean Water Act, and the Safe Drinking Water Act. There is a sense that many of the necessary regulatory requirements are already in place in the context of these statutes and their respective regulatory programs.
- There is an absolute need for flexibility to accommodate differences among the States related to geology, climate, ash characterization, and agency operation.
- There needs to be consideration given to both coal and non-coal sites and the differences between them (possibly a segmented approach).

As a final product in the area of regulating mine placement of CCBs, the States are hoping to strike a balance between existing State regulatory program requirements and any gaps that may be defined and justified. To date, although there are differences among the States in the way they regulate mine placement of CCBs, in terms of sharing jurisdiction among several State agencies, relying primarily on the SMCRA program for mine placement at coal mines, and differentiating between beneficial use and classic disposal, there has been little evidence of major gaps that require filling through new national regulations under either SMCRA or RCRA. And in those States that do not have well defined programs for mine placement of CCBs, it is usually because they have not had to deal with its beneficial use or disposal within their borders. Even in those States, a comparison of their programs with States who actively regulate mine placement of CCBs demonstrates that most, if not all, of the program elements are in place and would likely operate effectively when needed.

The few areas within State programs that have been shown to need some degree of shoring up can best be addressed through intergovernmental discussions, such as are occurring at the present time. Through a benchmarking type of approach, States can identify areas in their programs that would benefit from fine tuning, and this can be accomplished by patterning these areas after other State programs. If and when specific regulatory gaps are found to exist in a significant majority of State programs, then it would be appropriate to consider national guidance from EPA and/or OSM. However, all of EPA's program analyses to date do not yet justify the need for such guidance, and OSM has stated on numerous occasions that it believes State programs are adequate (at least as far as SMCRA programs for CCB mine placement at coal mines are concerned). Interestingly, in those States without SMCRA regulatory programs (i.e., the non-coal States), their solid waste programs tend to play a more active role from a regulatory perspective, and these States have structured their RCRA programs to address mine placement of CCBs from coal mines that are used beneficially or disposed of within their borders.

Conclusion

As we continue to pursue the ultimate resolution of this regulatory challenge, the States look forward to a continued effective working relationship with EPA and OSM as we seek to design an appropriate approach to the regulation of mine placement of CCBs.

Greg Conrad is the Executive Director of the Interstate Mining Compact Commission (IMCC), a multi-State governmental organization representing 20 mineral producing States, since 1988. He is responsible for overseeing issues of importance to the States in the legislative and regulatory arenas. Prior to joining IMCC, Greg served for nine years as senior counsel with the American Mining Congress, which is now part of the National Mining Association. Greg has spoken and presented papers at conferences hosted by such organizations as the Eastern Mineral Law Foundation, the Conference of Government Mining Attorneys, the Colorado School of Mines, the Office of Surface Mining, the National Mining Association, the Environmental Law Institute, and State government groups. He has written extensively on mining issues for professional journals and magazines. Greg holds degrees from Michigan State University in business administration and from the University of Detroit School of Law.

Resolution

BE IT KNOWN THAT:

WHEREAS, the Environmental Protection Agency (EPA) is required by law to make a determination as to the applicability of Resources Conservation and Recovery Act (RCRA) Subtitle "C" hazardous waste regulations to coal combustion by-products (under the Bevill Amendment); and

WHEREAS, based upon a preponderance of technical evidence, a wide variety of commentors, including business and environmental leaders, and Federal, State, and local government officials, have urged EPA not to designate coal combustion by-products as hazardous; and

WHEREAS, States have effectively managed the handling of coal combustion by-products through regulations and/or policy appropriate to the level of risk they present without the need for further Federal rule making; and

WHEREAS, coal combustion by-products are widely employed in beneficial uses such as mine site reclamation including stabilization, acid mine drainage prevention/remediation, and soil amendment; and

WHEREAS, a number of private companies are using waste coal as fuel — and in the process are utilizing coal combustion by-products for cleaning up abandoned mine sites and waste coal piles at no cost to the taxpayer; and

WHEREAS, a decision by EPA to regulate coal combustion by-products as hazardous would jeopardize these beneficial uses and inhibit environmental cleanup without a commensurate reduction in environmental risk; and

WHEREAS, the Interstate Mining Compact Commission represents the natural resources and environmental protection interests of its member States, and is composed of the Governors of said States who act as Commissioners;

NOW THEREFORE BE IT RESOLVED:
That the Interstate Mining Compact Commission (IMCC) affirms the appropriateness and effectiveness of State regulations and policies for the safe handling, recycling, beneficial use, and placement of coal combustion by-products; and

That the IMCC supports the management of coal combustion by-products without the application of Federal RCRA Subtitle "C" requirements.

Issued this 10th day of May, 2000

ATTEST:
Executive Director

FEDERAL LEGAL AND REGULATORY ISSUES AFFECTING THE PLACEMENT OF COAL COMBUSTION PRODUCTS IN MINES

Jim Roewer
Utility Solid Waste Activities Group
Washington, DC

Abstract

The U.S. Environment Protection Agency (EPA) has twice affirmed the nonhazardous regulatory status of utility Bevill wastes, or wastes from the combustion of coal and other fossil fuels: on August 9, 1993 EPA, and, most recently, on March 22, 2000.

Notwithstanding the fact that the agency did not make a finding that the management of coal combustion products (CCPs) in mines was in fact causing environmental harm, EPA announced, as part of the March 2000 regulatory determination, its intention to develop national regulations, under the Resource Conservation and Recovery Act (RCRA) or the Surface Mining Control and Reclamation Act (SMCRA) addressing the placement of CCPs in mines. EPA is in the process of information gathering to support regulatory decision-making and has scheduled formal proposal of regulations addressing mine placement of CCPs by March 2003; final rule would be published by August 2004.

This presentation will address the Federal legal and regulatory implications of the placement of CCPs in mines—current status and the development of future standards. In addition the legal/regulatory role of consensus standards addressing CCP utilization in mine applications will be discussed.

Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act (RCRA) establishes a regulatory regime for solid and hazardous wastes, ensuring their proper management to protect human health and the environment. As solid wastes, coal combustion products (CCPs) are subject to RCRA; however, CCPS, along with other high-volume, low-toxicity wastes (i.e., mining wastes, cement kiln dust, oil and gas exploration wastes) were identified as meriting special evaluation by EPA.

In 1978, EPA recognized that large volume wastes generated from the combustion of coal by electric utility power plants could require special treatment under the Resource Conservation and Recovery Act (RCRA). In October, 1980, Congress passed the Bevill Amendment to RCRA that restricted EPA's ability to regulate fly ash, bottom ash, boiler slag, and flue gas emission control waste generated from the combustion of coal or other fossil fuels as hazardous waste. The Bevill Amendment directed EPA to produce a report on the sources, volumes, management practices, and most importantly, an assessment of the potential danger to human health and the environment from wastes generated by the combustion of coal and other fossil fuels. Congress also directed EPA to make a regulatory determination six months after this report was to be issued:

> *[T]he Administrator shall, after public hearings and opportunity for comment, either determine to promulgate regulations under this subtitle [subtitle C] … or determine that such regulations are unwarranted.* (RCRA § 3001(b)(3)(C)).

In February, 1988, EPA published a Report to Congress (RTC) titled "Wastes from the Combustion of Coal by Electric Utility Power Plants." The RTC recommended preliminarily that high volume coal combustion wastes not be regulated as hazardous wastes under Subtitle C of RCRA, but indicated that EPA intended to consider whether low volume wastes exhibiting hazardous characteristics should be so regulated. In spite of the clear language of the Bevill Amendment, EPA never followed the RTC with a regulatory determination.

In 1991, a group called the Citizens Interested in the Bull Run, Inc. filed suit against EPA based on the absence of a final regulatory determination. The Court ordered EPA to make its final regulatory determination in two phases, one by August 1, 1993, for the four high volume waste streams from coal combustion (e.g., fly ash, bottom ash, boiler slag, and flue gas desulfurization wastes) and a second one by October 1, 1999, for all "remaining" utility fossil fuel combustion wastes—wastes from the combustion of oil and gas, wastes from coburning of coal with solid waste, and CCPs when comanaged with other utility waste streams.

On August 9, 1993, EPA published the phase one regulatory determination that concluded that regulation of the four large volume CCPs as hazardous was "unwarranted" under RCRA Subtitle C (58 Fed. Reg. 42466).

A second Report to Congress (RTC II) on the remaining utility Bevill wastes, "Wastes from the Combustion of Fossil Fuels," was issued on March 1, 1999. In RTC II, EPA identified areas of concern involving the specific management practices of coal combustion products, especially agricultural applications, mining applications, beneficial use applications, and the management of mill rejects or pyrites comingled with coal combustion products.

RTC II specifically recommended that:

- disposal of coal-fired comanaged wastes should remain exempt from RCRA Subtitle C;
- most beneficial uses of coal-fired comanaged wastes should remain exempt from RCRA Subtitle C;
- oil combustion wastes managed in lined units do not warrant regulation under RCRA Subtitle C;
- beneficial uses of oil combustion wastes should remain exempt from RCRA Subtitle C; and
- the Subtitle C exemption for natural gas combustors should remain in effect.

Each of these recommendations rests on well-documented Agency findings tied to "real world" data that show that:

- these wastes rarely exhibit the characteristics of hazardous waste;
- the trend among electric utilities is to install more environmental controls at waste management facilities, including liners, covers, and groundwater monitoring;
- there are few documented cases of proven damage to the environment caused by fossil fuel combustion wastes, and these few cases all involve older, unlined management units, most of which no longer are receiving combustion wastes, and at which there were no adverse human health effects;
- electric utility companies have achieved an outstanding record of environmental regulatory compliance, with no major enforcement cases involving solid or hazardous waste at a utility facility in the five year period between 1992 and 1997; and
- States have developed a comprehensive body of regulations applicable to the waste management units in which utilities store and dispose of combustion wastes.

With regard to mine placement of CCPs, RTC II made no specific recommendations. In spite of finding no indications of environmental damage from mine placement activities, EPA indicated a general concern with placement of these materials in contact with the water table. EPA recognized that

> *under ideal circumstances, placement of wastes in mines should present no increased risks to human health and the environment relative to landfills. In fact, minefills could result in net environmental benefits relative to conventional landfills through avoided development of Greenfield space for UCCW disposal, improvement of disturbed mine lands through contouring, revegetation and reduced infiltration to mine workings, and abatement of acid mine drainage through neutralization and diversion.* (RTC II at 3-51).

However, EPA identified data gaps that it intended to address and therefore did not reach a firm recommendation.

On May 22, 2000, EPA concluded the Phase II Bevill regulatory determination, stating that fossil fuel combustion wastes "do not warrant regulation under Subtitle C of RCRA," thereby retaining the Bevill exemption under RCRA § 3001(b)(3)(C) (65 Fed. Reg. 32214). This determination reaffirmed the 1993 determination for coal combustion wastes and extended it to oil and gas combustion wastes as well as low volume wastes comanaged with high volume coal combustion wastes. Along with the nonhazardous Bevill Determination, EPA announced that it will develop national standards under RCRA Subtitle D to address coal combustion wastes disposed in landfills and surface impoundments or placed in mines. EPA provided an unqualified endorsement of all beneficial uses other than mine placement, and the Subtitle D regulations will not address those activities. In sum, EPA stated that

> *[a]fter considering all of the factors specified in RCRA Section 8002(n), we have decided . . . , that the decisive factors are trends in present disposal and utilization practices (Section 8002(n)(2)), and the current and potential utilization of the wastes (Section 8002(n)(8)), and the admonition against duplication of efforts by other federal and state agencies*. (65 Fed. Reg. 32217).

EPA acknowledges the potential benefits of mine placement, but is concerned that an alleged lack of adequate regulatory oversight could result in damage to human health and the environment. The bases for the determination to regulate mine placement under Subtitle D include:

- the potential to present a danger to human health and the environment "under certain circumstances"; and
- few States have comprehensive programs that specifically address the unique circumstances of mine filling.

Although EPA identified no damage cases related to mine placement, it remains concerned about placement of coal combustion wastes in contact with groundwater, but offers no explanation of the nature of its concern. The agency has expressed a concern that government oversight is necessary to ensure that mine placement of CCPs is conducted in a manner appropriate to protect human health and the environment.

Surface Mining Control and Reclamation Act (SMCRA)

In its effort to develop nonhazardous waste regulations applicable to mine placement, EPA will consider whether RCRA Subtitle D, the Surface Mining Control and Reclamation Act (SMCRA), or a combination of the two authorities would be most effective. Significantly, EPA acknowledges that SMCRA is "expressly designed to address environmental risks associated with coal mines." (65 Fed. Reg. 32217, 32232)

SMCRA establishes stringent national standards for coal mining and reclamation. In recognition of diverse mining conditions across the United States, the Congress intended that each individual State become the primary regulator to implement the regulatory program, in lieu of relying on a Federal agency to do so. The Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSM) is the Federal agency that oversees the work of the State agencies that are enforcing the Federal coal mining laws. Once a State regulatory agency receives authority from OSM to implement SMCRA, it has the option to enforce the Federal standards or to promulgate more stringent State standards.

It is important to recognize that SMCRA is not the only law with which a mine operator must comply; the Clean Air Act, the Clean Water Act, the Federal Coal Mine Safety and Health Act, the Endangered Species Act, the Fish and Wildlife Coordination Act, and the National Historic Preservation Act can all impact the permitting of any coal mining activity, including the mine placement of CCPs.

Regulations promulgated under SMCRA address permitting of mine operations, including;

- public participation elements;
- planning and enforcement, including site characterization and CCP-specific issues;
- waste characteristics, including surface and groundwater monitoring and CCP analysis; and
- design and operational elements, including closure and post-closure considerations.

OSM has encouraged the State regulatory authorities to develop initiatives to utilize CCPs in both the abandoned mine lands reclamation and in active mine reclamation, and many States have adopted policies or guidelines for the use and the management of CCPs at mine sites. These State policies or guidelines are implemented during the permit review process for an active mine site or in the design phase for abandoned mine site.

Industry's View of Mine Placement of CCPs

The electric utility industry supports the regulation of CCPs as federal nonhazardous wastes as determined by EPA as a result of the regulatory process established by the Bevill Amendment to RCRA. And the industry supports the regulation of CCP management under State regulatory authority. In addition, mine placement of CCPs should be regulated under SMCRA, with the specific regulatory authority exercised by State regulators.

If the agency establishes regulations addressing either CCP disposal, or the mine placement of CCPs, such measures should be performance-based standards that fill any defined gaps in State regulations rather than prescriptive Federal standards that overlay or supplant existing State programs. In the May 22, 2000 regulatory determination, EPA referred to language in the Bevill amendment admonishing against the imposition of regulations that would be a "duplication of efforts by other Federal and State agencies (65 Federal Register 32217)." It is critical that the agency not waste time and resources to develop duplicative regulations and instead rely on OSM and State regulatory authorities to ensure that CCP mine placement activities continue to be conducted in a protective manner.

James Roewer is the Executive Director of the Utility Solid Waste Activities Group (USWAG), where he is responsible for overall program management, including the addressing of solid and hazardous waste and toxic substance issues on behalf of the utility industry. He serves as the Chairman of ASTM Subcommittee E50.03 on Pollution Prevention/ Beneficial Use, and as a member of the Steering Committee of the Combustion By-Products Research Consortium. He has served as Senior Environmental Manager in the Energy Policy Department of the National Rural Electric Cooperative Association (NRECA); Environmental Scientist in the Natural Resources Section of EEI; Manager, State and Local Government Relations with the American Society of Mechanical Engineers; and Research Assistant with the Science Unit of the Illinois Legislative Research Service. He holds a Masters of Science in Environmental Science from the School of Public and Environmental Affairs at Indiana University, and a B.A. in Biology from Wittenberg University.

INDUSTRY PERSPECTIVE ON CCP REGULATORY DIRECTION

Janet Gellici
Western Coal Council
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Abstract

This presentation will provide an overview of industry's perspective on the regulation of coal combustion products (CCPs), including a discussion of how CCP regulation is likely to impact the long-term viability of coal as an energy fuel source. I will address the need for a balanced, integrated approach to CCP regulation that acknowledges the environmental and economic soundness of the continued use of site and region specific approaches on a State-by-State basis. The presentation will further highlight the interactive effects of enhanced beneficial uses of CCPs and land filling of CCPs.

The Western Coal Council

The mission of the Western Coal Council is to advance the development and utilization of western coal as an economic, abundant, and environmentally sound fuel source. Our primary objectives are advancing the marketing and management capabilities of our member companies and to promote the professional development needs of our individual members. In our advocacy efforts, we address political and public audiences and support the efforts of the National Mining Association, Edison Electric Institute, and American Coal Ash Association. Our educational objectives involve providing market intelligence and technical information and providing a forum for the lawful exchange of information among utility coal industry executives. We currently have 115 corporate members that span the entire coal chain from production through consumption. We have coal traders and brokers among our members as well as railroads, trucking companies, and ports and terminals. We believe the coal support service companies are a vital part of our business including laboratories, equipment providers, and ash marketers. This year we will celebrate our 20th anniversary, part of which will be the transition from a western regional association to a national business association. In June of this year, we will change our name to the American Coal Council. The reason for this change is that a lot of the western and eastern markets are converging. What happens in West Virginia and Kentucky affects the coal market in Wyoming. We feel this will advance our business and education objectives. Our vision is to be the business voice of the utility/coal industry. It is our plan to continue to support a special interest group, the American Coal Ash Association that is dedicated to addressing ash issues.

The National Energy Policy

The current administration's national energy policy addresses three critical needs:

- the need for a diverse fuel supply to meet the nation's energy demands;
- the need for a secure fuel supply, that translates into a need to use our domestic resources including fossil, nuclear, and renewables; and
- the need to ensure that this energy is affordable for all segments of our society.

All of these needs are being supported by an increased demand for electricity nationally. Our economic health is tied to our ability to meet these needs. The Energy Information Administration has projected the national electricity capacity through 2020 (Figure 1).

A diverse, secure, and affordable source of fuel to power our electric utilities will help us insure that we will be able to continue to prosper and grow our economy and that we can achieve this while maintaining the highest environmental standards in the world. It takes a lot of money to install the environmental controls that the industry requires. Some of that money needs to come from economical fuel sources like coal. EIA's projections continue to show a major role for coal into the year 2020 (Figure 2). This load will be shared more and more with natural gas, nuclear, and renewables, but coal will continue to provide a foundation for our electric fuel needs in the coming decades.

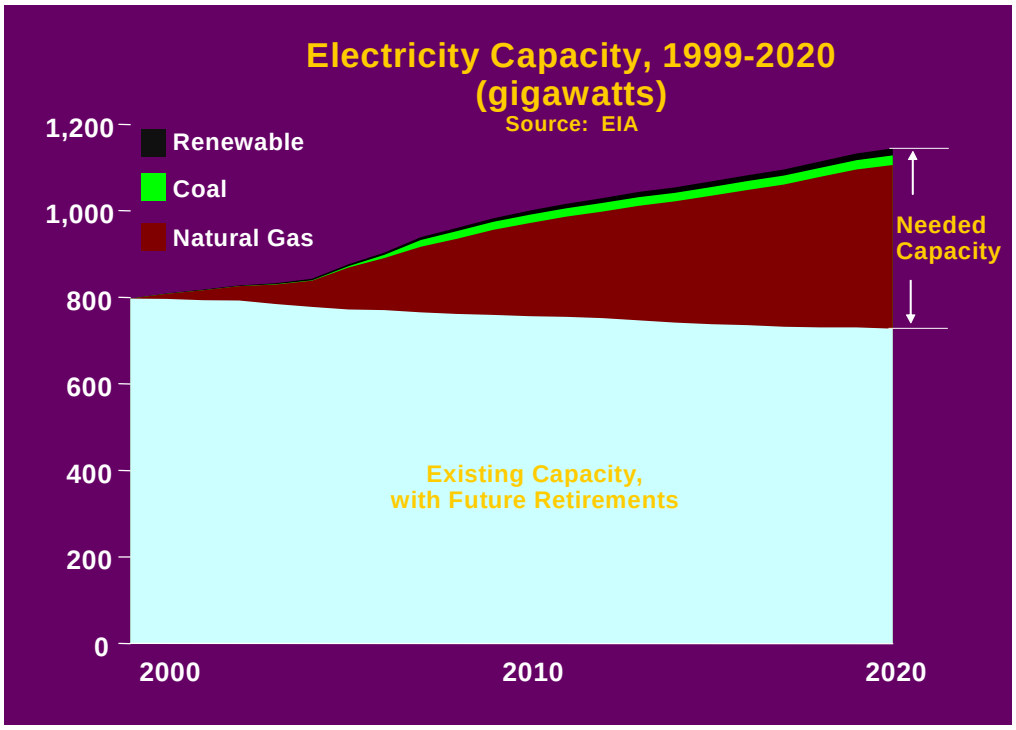

Figure 1. Energy Information Administration National Electricity Capacity Projections

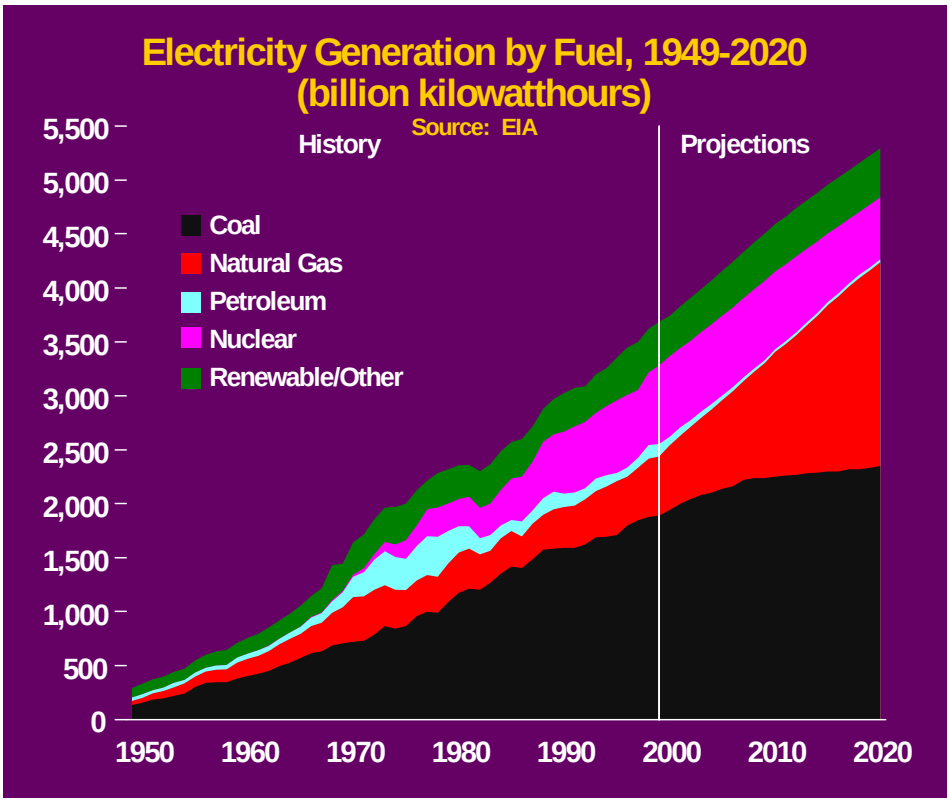

Figure 2. EIA Projection of Electric Generation by Fuel Type through 2020.

One of the reasons for this is that coal has been and will continue to be an affordable fuel for electric generation. Coal prices have been historically less volatile than the other fuel sources. EIA projects that coal will continue to maintain this price stability into the future (Figure 3).

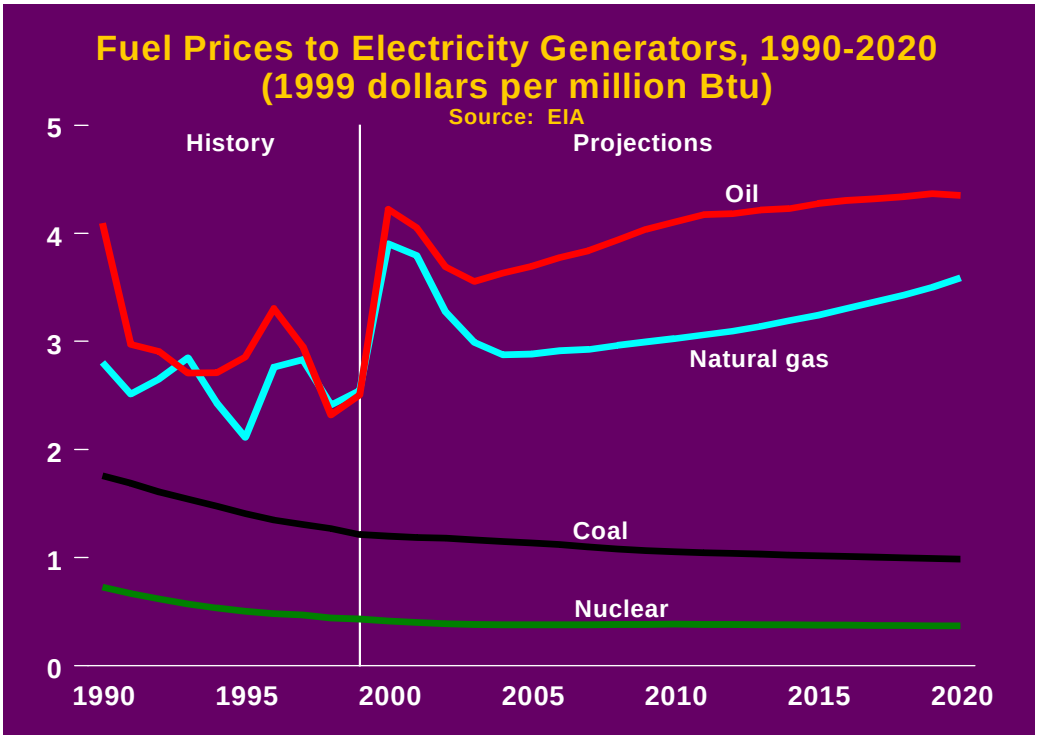

Figure 3. EIA Projection of Fuel Prices for Electric Generation through 2020.

Coal Fired Generation

What does the future hold for coal generation in the future? Based on 1998 data EIA has detailed the state specific cost of electricity compared to the percentage of electricity generated by coal (Figure 4). This data was developed prior to the California energy crisis. The areas in red show high electric cost and low utilization of coal show up as the areas that are particularly vulnerable to periods of energy shortage and high cost. Consumers in these areas are bearing the brunt of policy decisions in those States to not use energy fueled by coal.

What does the future hold? EIA projects that 95 percent of the new electric generation capacity through 2005 will be fueled by natural gas (Figure 5). This is setting up a future reliance on a limited and price volatile fuel source that is more expensive and less available than coal power. Following the California energy crisis, there was an increase in the announcement of new coal fired energy sources. Prior to the crisis, RDI showed 6,200 megawatts of proposed new coal fired generation capacity. Immediately following the crisis, that figure jumped to 34,000 megawatts. Today, post Enron scandal, we are still looking at about 16,000 megawatts of proposed new coal fired generation capacity.

What is ahead for new coal fired generation? The National Energy Policy and EIA foresee coal playing a crucial role in our energy needs in the future. The price of natural gas and the ability of electric generation companies to secure investment funding also will determine if new coal fired electric generation proceeds. The outcome on the current dialog on carbon dioxide and multi-pollutant regulation will affect decisions on the construction of new coal fired power plants. Currently, more and more of our coal suppliers are publicly owned. This means we are seeing increasing shareholder demands for profitable returns impacting the supply and availability of coal and the ability of companies to invest in new coal fired generation. Deregulation and consolidation in the electric utility industry is putting increased pressure on generators to effectively manage risk that will factor into future fuel choice decisions. Finally, coal suppliers and consumers will be increasingly concerned about costs and risk exposure. Industry is scrambling to secure at least some predictability of these factors.

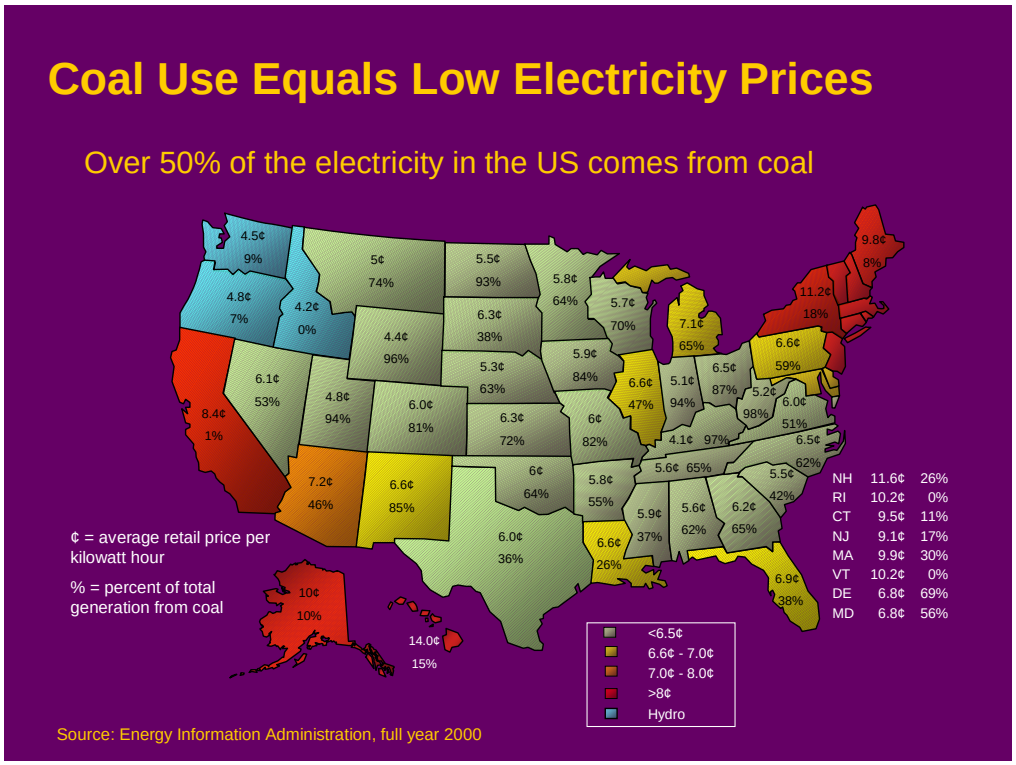

Figure 4. EIA data on the State specific cost of electricity generation and the percentage generated by coal.

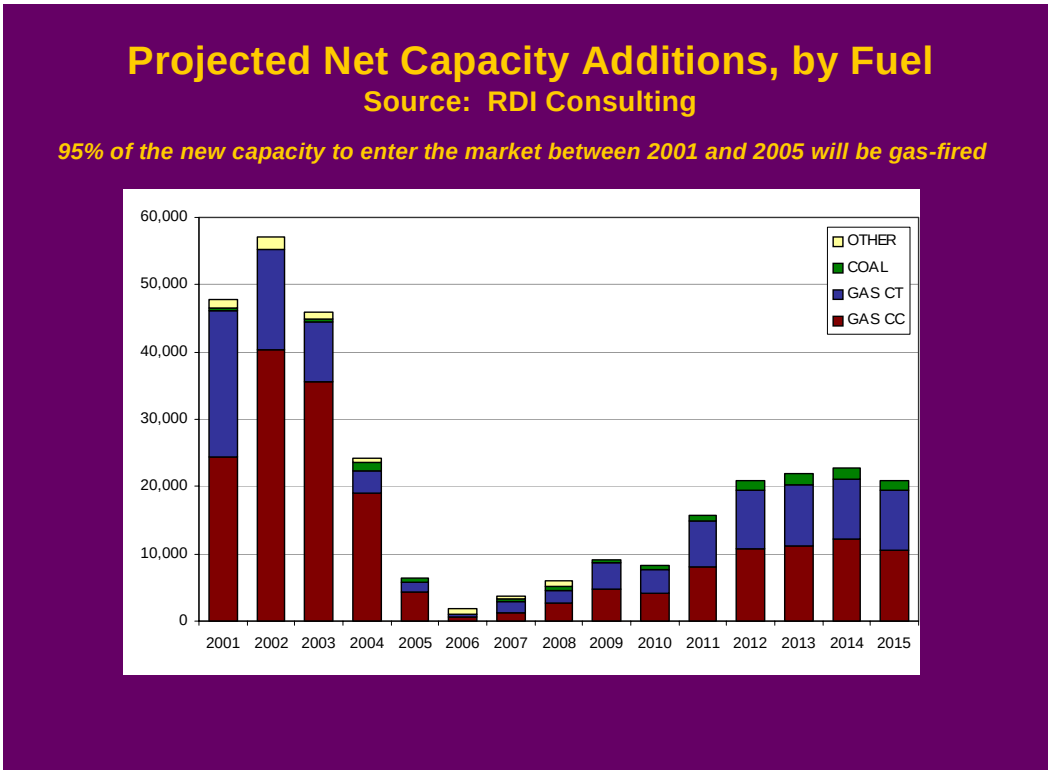

Figure 5. RDI projection of proposed new electric generation by fuel type.

How do CCPs Factor into These Concerns?

This is important primarily in the area of economic viability and environmental compliance. CCPs can contribute favorably to a coal or electric utility bottom line. This will become increasingly important in the new marketplace that is dominated by shareholder scrutiny and cost/benefit analysis. CCPs also can offer significant environmental benefits. The increased utilization of CCPs as products supports industries' environmental stewardship goals as well. Many factors are taken into consideration when a company is deciding on whether or not to build a power plant and what fuel to consider. CCPs are increasingly a part of that equation. Companies will take into account national and State regulations regarding ash disposal and utilization. What does environmental compliance add to the cost of the project? They also will take into account whether or not there is a local market for the CCPs. Will I as a generator be able to recycle CCPs in such a way that it will contribute positively to the environmental ledger? CCPs can be used in many beneficial applications. Among those I include land filling and backfilling as well as the development of construction products and as an admixture. The use of CCPs in the place of cement has been demonstrated to reduce carbon dioxide emissions. This type of use also reduces the energy that is used to make cement. We also see CCPs being used to improve product durability and strength and to reduce project and product cost.

What Needs to be Done to Improve the Use of CCPs?

We need to educate users (architects, engineers, and policy makers) about the benefits of CCPs. We need incentives (possible tax and financial incentives) to get the architects, engineers, and project managers to use CCPs. We need more favorable CCP building codes and less prescriptive standards on product specifications. We need to educate people about the U.S. EPA comprehensive procurement guidelines as well as greater compliance with these guidelines. These guidelines mandate the use of the highest degree of green products, including CCPs. We need to think about these materials not as a waste or as a by-product but as a valuable resource for meeting our investment and environmental goals. Finally, we need clearly defined roles for Federal and State regulation for CCPs. SMCRA establishes minimum Federal performance standards for surface coal mining and reclamation. The States establish permitting guidelines that are responsive to unique local conditions. This is how it should be.

Janet Gellici is currently Executive Director of the Western Coal Council where she has been employed since 1982. The Western Coal Council is an alliance of coal, utility, trading, and transportation companies advocating a partnering, non-adversarial approach to business relationships. The WCC's primary goal is to advance the development and utilization of western coal as an economic, abundant, and environmentally sound fuel source. Programs and activities are designed to advance the marketing and management capabilities of Association members, which include coal and pet coke suppliers, consumers, transportation companies, coal and power traders, ports and terminals, and coal support service firms. The WCC, a 501(c)(6) trade association based in Denver, has more than 110 corporate members.

She independently produces the Annual Coal Market Strategies conference in association with the WCC and Edison Electric Institute. This event addresses strategic, economic, legislative, and regulatory issues impacting the utility-coal industry. She also serves as Executive Director of the Coal Trading Association, an organization that promotes coal trading capability and liquidity in the United States. As part of this effort, the Association developed an industry standard Master Coal Purchase and Sale Agreement to facilitate efficient trading of coal products and to increase market liquidity. In 1998, she was appointed by the Secretary of Energy to serve on the National Coal Council, an advisory group to the Secretary. She is a member of the American Society of Association Executives, serves on the Board of Directors of the Colorado Society of Association Executives, and is a member of the Institute of International Education. She earned her MBA from Regis University and is a graduate of the University of Iowa with a degree in Journalism.

NORTH DAKOTA REGULATORY PERSPECTIVE

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Abstract

In the past 21 years, North Dakota developed modern standards and facilities for management of solid waste, including coal combustion waste. With eight major energy facilities, North Dakota's requirement address location restrictions, operating criteria, facility design, groundwater monitoring and corrective action, closure and post-closure care, and financial assurance. The State solid waste program has worked with the industry to investigate and solve past disposal issues and develop solutions to waste issues. The State also has cooperated in developing guidelines and procedures for coal combustion by-product utilization. The talk will describe North Dakota's history, experience, and standards for managing coal combustion waste.

Introduction

The Division of Waste Management includes the Solid Waste Program, the Hazardous Waste Program, and the Underground Storage Tank Program. The Division of Solid Waste is one of four divisions within the North Dakota Department of Health dealing with environmental issues. The other environmental divisions include Air Quality, Municipal Facilities (water supply and waste water facilities), and the Division of Water Quality. All divisions administer programs approved by the USEPA, some of which are partially funded by the USEPA. All divisions also administer Programs that are not funded by the USEPA.

In the past 21 years, North Dakota developed modern standards and facilities for management of various types of solid waste including coal combustion waste. With eight major coal-fueled energy facilities within the State, North Dakota's requirements address location restrictions, operating criteria, facility design, groundwater monitoring and corrective action, closure and post-closure care, and financial assurance. The State's Solid Waste Program has worked with the energy industry to investigate and solve past disposal issues and develop long-term solutions. The North Dakota Solid Waste Management Rules for coal combustion waste disposal follow the general model of the Resource Conservation Recovery Act Subtitle D criteria for municipal waste; however, the specific requirements are tailored for North Dakota's geology and the coal combustion waste materials.

Current coal combustion waste disposal sites are carefully constructed with compacted clay liners or composite liners, they control surface water run-on and runoff and have leachate drainage systems. The State's permit process includes a multi-agency review and embraces public review and comment.

Indiscriminate disposal of coal waste into surface mines has not occurred for 20 years; however, many of the permitted landfills are located within carefully constructed facilities that were once part of surface mines. Thick sequences of clay-rich soils associated with North Dakota's coal mines, when properly segregated and conditioned, make excellent material for liner and final cover construction. Other facilities located outside of mine areas have similarly been constructed and/or upgraded to meet modern standards.

While every State in the country has old waste sites that needed upgrading, closure, and/or remediation, North Dakota's coal fired electric plants have discontinued unsuitable waste management practices. In April 2000, when the USEPA was considering regulating coal combustion waste as a hazardous waste through Subtitle C of the Resource Conservation and Recovery Act (RCRA), the State of North Dakota informed EPA's administrator Carole M. Browner that "The States' regulatory program for these power plant wastes meet all the requirements of an effective program and yet does not bridle the industry with unnecessary paper work and regulation."

The Department also has cooperated in developing guidelines and procedures for coal combustion by-product utilization. As the lead North Dakota agency in promotion of recycling and waste reduction, the North Dakota Department of Health recognizes that many of these waste products, if properly characterized, utilized, and handled can reduce the country's reliance on valuable natural resources, conserve energy, and reduce the cost of waste management practices. At the same time, the State's Ash Utilization guidelines place strong emphasis on the protection of human health and the environment.

Background

The Solid Waste Program, receives no Federal money for regulating nonhazardous solid waste disposal including: municipal solid waste landfills (Subtitle D of the Resource Conservation Recovery Act), inert waste landfills which deal with construction and demolition waste as well as bottom ash and coal fired boilers, nonhazardous industrial waste generated through manufacturing and industrial activities, and special waste generated by the energy and oil industries.

The Solid Waste Program oversees approximately 224 permitted disposal facilities and 316 waste transport permits and responds to spills, emergencies, and incidences of public concern regarding solid waste. The 224 permitted disposal facilities include 14 municipal solid waste landfills, 182 inert waste landfills, 20 special waste landfills (17 of which are for the coal industry), and eight surface impoundments, most of which are for the energy industry.

Coal combustion waste is by far the largest waste generated in North Dakota. Approximately 9,900 tons per day of coal waste is generated compared to about 1,400 tons per day of municipal solid waste, approximately 100 tons per day of industrial waste, and about six tons per day of hazardous waste. Coal combustion waste generated in the State includes fly ash, flue gas desulfurization (FGD) waste, coal gasification waste, and bottom ash (also may be classified inert waste). The State has eight energy facilities centered in the central part of the State: (1) Basin Electric, Antelope Valley Station north of Beulah, ND; (2) Basin Electric Leland Olds Station near Stanton, ND; (3) Dakota Gasification Company north of Beulah, ND; (4) Great River Energy, Coal Creek Station near Underwood, ND; (5) Great River Energy Stanton Station; (6) Montana Dakota Utilities, Heskett Station north of Mandan, ND; (7) Minnkota Power Cooperative, Milton R. Young Station near Center, ND; and (8) Ottertail Power Cooperative Coyote Station, south of Beulah, ND.

North Dakota currently has four active lignite mines. The Freedom Mine, owned by North American Coal Corporation is located north of Beulah, ND and provides coal to the nearby Basin Electric Antelope Valley Station and the Great Plains Synfuels Plant owned by Dakota Gasification Company, as well as the Leland Olds Station. The Beulah Mine, owned by Dakota Westmoreland Corporation, supplies coal to the nearby Coyote Station as well as by rail to the MDU Heskett Station located near Mandan, ND. The Center Mine, owned by BNI Coal Ltd., supplies coal to the nearby Milton R. Young Station. Finally the Falkirk Mine, owned by North American Coal Corporation, supplies lignite to the Great River Energy Coal Creek Station. Specific information on North Dakota's lignite industry can be found at the North Dakota Lignite Energy Council's web site at www.lignite.com. Disposal facilities exist in both mine settings and non-mine settings. Three plants have waste facilities in both abandoned mine settings and non-mine settings. Three plants have waste facilities in both recent (post-reclamation law sites) mines and non-mine settings. One plant has all its waste facilities in a recent mine. One plant has all its waste facilities in a non-mine setting.

History of Coal Combustion Waste Regulation

In the late 1970s and early 1980s, as new, larger plants and new scrubber technology meant more waste, the North Dakota Department of Health began active regulation of energy wastes as allowed under its 1976 solid waste rules. Coal combustion waste was classified as "residue" and was allowed to be disposed under permits called "special use" permits. In the early 1980s, the North Dakota Department of Health's Solid Waste Program began more active regulation of energy waste and required formal permitted sites for disposal of such materials. The practice of "dumping" in mine spoils ceased in the early 1980s. Some sites were in geologically unsuitable locations and/or had inadequate engineering. The Department began (1) evaluating disposal site geology and hydrogeology, (2) requiring increased engineering controls, and (3) requiring various operational standards and groundwater monitoring for facilities.

A number of surface impoundments were located on river alluvial plains or in glacial outwash gravel deposits. Other sites, in sandy soils or adjacent to nearby alluvial valleys and wetlands, posed groundwater and surface water contamination hazards. The Department began to work with companies to close or upgrade unsuitable operations or facilities in unsuitable locations. The Department instituted a multi-agency review process utilizing (1) the solid waste staff, (2) the Division of Water Quality within its Department, (3) the North Dakota Geological Survey, and (4) the North Dakota State Water Commission. For sites in active mines, the Mine Reclamation Division of the North Dakota Public Service Commission also reviewed permits.

In the 1980s, new landfills and some surface impoundments were constructed under permits from the Department. Clay liners and clay covers began to be utilized for coal waste. Better control of surface water within landfills was instituted. Groundwater monitoring of all permitted facilities was initiated. Corrective action and closure of polluting facilities were emphasized.

In 1992, the Department revised its solid waste rules, responding in part to the revisions in the Federal rules for solid waste disposal facilities, found in 40 CFR Parts 257 and 258. The Department also proposed rules updating the requirements and the regulatory framework for virtually all classes of solid waste management within the State. The rules were further revised in succeeding years with the latest revision in 1999.

In 1994 and 1995, the last unlined surface impoundment for fly ash and bottom ash was upgraded with a composite liner and the facility was changed to manage only bottom ash (inert waste). Thus, by the mid-1990s, facilities in North Dakota were up to modern design standards.

North Dakota Solid Waste Management Rules for Special Waste

The North Dakota Solid Waste Management Rules, Chapter 33-20 of the North Dakota Administrative Code (NDAC) written pursuant to North Dakota Century Code, Chapter 23-29, include appropriate standards for various types and sources of solid waste. Coal combustion waste is called "special waste" which is defined in the State law as:

"Special waste means solid waste that is not a hazardous waste regulated under Chapter 33-20.3 and includes waste generated from energy conversion facilities; waste from crude oil and natural gas exploration and production; waste from mineral and ore mining, beneficiation, and extraction; and waste generated by surface coal mining operations. The term does not include municipal waste or industrial waste."

The criteria for special waste disposal facilities include:

- Location Standards
- Operation Requirements
- Design Requirements
- Groundwater Monitoring/Corrective Action Requirements
- Closure/Post-closure Requirements
- Financial Assurance Requirements

Location Standards

Section 33-20-04.1-01 NDAC, general location standards for solid waste management facilities states, "No solid waste management facility may be located in areas which result in impacts of human health or environmental resources or in an area which is unsuitable because of reasons of topography, geology, hydrogeology, or soils. Sites for new or for lateral expansions of land treatment units, surface impoundments closed with solid waste in place, municipal waste landfills, industrial waste landfills, and special waste landfills must minimize, control, or prevent the movement of waste or waste constituents with geologic conditions and engineered improvements. Sites should be underlain by materials with low permeability to provide a barrier to contaminate migration."

This section further states: "The following geographic areas or conditions must be **excluded** in the consideration of a site:

(1) where the waste is disposed within an aquifer;

(2) within a public water supply designated wellhead protection area;
(3) within a 100-year flood plain;
(4) where geologic or man-made features, including underground mines, may result in differential settlement and failure of a structure or other improvement on the facility;
(5) on the edge of or within channels, ravines, or steep topography whose slope is unstable due to erosion or mass movement;
(6) within woody draws; or
(7) in areas designated as critical habitats for endangered or threatened species of plant, fish or wildlife."

Section 33-20-04.1-01 NDAC also describes some **avoidance** areas that should not be used for developing solid waste facilities. Avoidance areas include sites over or immediately adjacent to glacial drift aquifers; sites within 1000 feet from a down gradient drinking water supply well; sites closer than 200 feet from surface water or a wetland; final cuts of surface mines; and sites closer than 1000 feet from parks.

The listing of final cuts of surface mines as an avoidance area does not necessarily preclude use of such sites. The State has some facilities that have been constructed in final cuts of surface mines; however, the primary concern is separation of disposed waste from any remaining lignite seams, which locally can be groundwater aquifers and sources of drinking water. Remaining coal can be a pathway for leachate migration. Some final cut sites have been permitted where adequate clay is backfilled to elevate the base of the disposal operation well above the top of any remaining coal seam and a clay liner is used to minimize the potential for leachate migration. All permitted sites are carefully engineered and monitored.

Operation Requirements

Chapter 33-20-04.1 NDAC, the general performance standards also contain many of the operational requirements for solid waste facilities.

Requiring trained operators for solid waste facilities ensures that the people actually operating the facility know what is necessary to maintain the facility in compliance with the State's solid waste management rules and to minimize impacts on the environment. The State emphasizes that without adequately trained operators, many of the safety, siting, or design features can be rendered useless if facility operators are not aware of the basic principals and requirements to properly operate the system.

Storm water run-on/runoff controls and the surface water requirements are designed to minimize the potential for surface water and groundwater degradation. Simply put, keeping the landfill area as dry as possible, keeping water out of the site, and controlling any water that runs off of the waste or off any contaminated areas are crucial elements in solid waste facility design and operation. A solid waste management facility may not cause a discharge of pollutants into waters of the State unless such discharge is in compliance with the requirements of the North Dakota Pollutant Discharge Elimination System (NDPDES) pursuant to State rules.

Similarly, solid waste facilities must comply with the State's air quality rules. Fine particulate waste such as fly ash, can create dust problems that must be controlled. Some power plants utilize a pug mill to add adequate moisture to such waste so as to control dust emissions. Some facilities moisten the surface of the ash. In some special cases, incompatible wastes have been mixed resulting in emissions. When these cases arise, the Department has pursued appropriate actions with the regulated community.

The operating rules also require control of access to the site, which is not normally a problem with special waste facilities that are located in rural industrial settings. Most power plants and mines have adequate gates and fences. Solid waste facilities also are required to have signs at the entrance or in a nearby location for pertinent information so that employees or contractors know who to contact in the event of an emergency, or should there be problems evident at the facility. Solid waste facilities also are required to be routinely inspected by the owner/operator in addition to inspections by the State.

A "Plan of Operation" to be approved as part of the permit review process must describe how the facility will be operated. The Plan of Operation includes a description of waste acceptance and handling procedures, inspection activities, contingency actions, leachate removal system operation and maintenance, safety procedures, implementation of closure activities and a description of what waste will be accepted at the facility, as well as what

types of waste will not be accepted at the facility.

Solid waste management facilities are required to keep records detailing the facility's operation, any compliance problems or deviations from the operation's plan, records on groundwater and surface water monitoring, facility inspection logs, construction and closure activities, etc. Solid waste management facilities are required to submit an annual report to the Department.

The operational requirements also require facilities to have access to adequate equipment to operate the facility. This can include waste equipment, earth moving equipment, construction equipment, pumps, and other devices needed in the daily operation. Facilities must have adequate access roads so that waste transportation equipment can arrive safely at the site and have adequate cover material to conduct covering activities as required in their operation. Solid waste facilities must maintain appropriate earthen material on or near the site unless removal is authorized by the Department. Periodic surveying/inspection is necessary to ensure proper filling in accordance with the plan.

The North Dakota Solid Waste Management Rules emphasize orderly landfill development through "Sequential Partial Closure," which means bringing discrete, usually adjacent portions of a disposal facility to elevation and grade in an orderly, continually progressing process as part of the operations of the facility for facilitating closure. This requirement helps keep waste as consolidated as possible. Consolidation of wastes (1) minimizes surface water and eventual groundwater pollution, and (2) reduces leachate generation, reducing dust and reducing operation requirements, thereby reducing the cost of waste management facilities.

Solid waste management facilities must carefully control run-on and runoff from waste management areas to avoid concentration of water on or in waste and thus reduce the amount of leachate generated. The State has found leachate in some landfills to be quite high in total dissolved solids and in some facilities it may have a high pH and contain heavy metals. Leachate removal systems, if required for specific landfills, must be operated and maintained as necessary, and landfills cannot accept excessive amounts of liquids unless approved by the Department.

Finally, the operation requirements for solid waste management facilities require suitable plant growth material (SPGM), which is normally the soil A and upper B horizons, must be identified and quantified in a soil survey before facility construction. SPGM must be removed and stock piled and maintained for later use in closure. North Dakota State law requires a registered professional soil classifier be used to perform soil classification and survey activities.

Design Requirements

Subsection 2 of Section 33-20-4.1-01 general location standards states:

"Sites for new or for lateral expansions of land treatment units, surface impoundments closed with solid waste in place, municipal waste landfills, industrial waste landfills, and special waste landfills must minimize, control, or prevent the movement of waste or waste constituents with geologic conditions and engineered improvements. Sites should be underlain by materials with a low permeability to provide a barrier to contaminant migration."

Most sites are located in geologically suitable areas. Landfills and surface impoundments for special waste also have engineered clay liners or composite liners. Clay liners are generally 4-feet thick and are constructed in 6-inch layers with each layer compacted and tested. Increasingly, composite liners, with a thinner layer of clay (usually 2 feet) overlain by a synthetic layer (high density polyethylene or "HDPE") are being utilized. The hydraulic head on a surface impoundment is such that waste constituents can migrate through even a 4-foot compacted clay liner in a relatively short amount of time. Most surface impoundments have composite liners.

Recently, the Heskett Station in Mandan, ND evaluated its landfill lining system and found it would save space and money by utilizing a composite liner. Working with the State, MDU found that a composite system consisting of an HDPE layer underlain by 6 inches of compacted clay would result in less potential leachate migration than a simple 4-foot compacted clay liner. The savings in 3 ½ feet of volume in the landfill should result in substantial savings for the company.

The Heskett Station landfill utilizes sand from their fluidized bed as part of a drainage or leachate collection layer in the landfill. Some other special waste landfills in North Dakota utilize bottom ash, a sand-like glassy material, as a

drainage layer above the liner system to keep the waste dry.

The State has found that the construction and quality assurance/quality control measures are critical in obtaining a liner that meets the specifications. Obtaining low hydraulic conductivity from compacted clay is different from compaction for roads and structures. For compacted clay liners or for the compacted clay portion of a composite liner, soil characterization, moisture control (2-5% wet of optimum) and compaction is critical. Quality assurance/quality control testing, on each 6-inch lift, is also critical for liner construction. The solid waste program has developed *"Guideline 5 - Quality Assurance for Construction of Landfill and Surface Impoundment Liners and Caps and Leachate Collection Systems"* (copies available by request or reference the Department's web site) for facility construction and documentation. Liners also must be adequately protected after construction and during operation to ensure integrity.

Groundwater Monitoring/Corrective Action Requirements

All special waste facilities permitted in North Dakota have groundwater monitoring programs. The first phase of monitoring is detection monitoring, which requires semiannual monitoring of at least one up gradient and two down gradient monitoring wells. More wells and/or increased sampling may be required as part of the permit. The groundwater parameters include general water parameters plus appropriate heavy metals. The State does not require analysis for volatile organics or other organic constituents from coal fired plants as such materials are not found in the waste. The owner/operator of a solid waste facility is required to perform an annual statistical analysis of its groundwater monitoring results to determine if a statistically significant increase has occurred.

In the event of a statistically significant release, the owner/operator must notify the Department and must evaluate the nature and extent of the release. The owner/operator also must evaluate potential remedial measures and, when requested, conduct a public meeting to be held with interested and affected persons. Assessment monitoring may be conducted on an increased scheduled and for an increased number of parameters than detection monitoring. Similarly, additional wells may be necessary to determine the nature and extent of a potential release.

Based on the assessment of any groundwater release, appropriate corrective action measures may be necessary. The corrective action measures must be adequate to attain the groundwater protection standards as negotiated with the Department and must control sources of the release.

Closure/Post-Closure Requirements

All solid waste facilities must have a closure plan approved by the Department as part of the permit process. The final cover of all facilities must be designed and constructed to ensure the quality and integrity of the final cover. Sites must be designed and closed to minimize erosion and optimize drainage so that surface water cannot infiltrate the buried waste material. The final cover on landfills and surface impoundments closed with waste in place must have a minimum slope of at least 3 percent and may be allowed up to 15 percent. Solid waste facilities can be closed with steeper slopes above 15 percent if they can demonstrate that soil loss can be carefully controlled. State rules do not allow closed landfill slopes to exceed 25 percent grade.

Recent experience shows that closing landfills with closure slopes approaching 20-25 percent are difficult due to erosion. Given the finite amount of soil cover over a closed solid waste management unit, the State's rules do not allow closed solid waste management units to be used for cultivated crops, heavy grazing, buildings, or any other use that might disturb the protective vegetation in soil cover. For slopes exceeding 15 percent up to 25 percent, steeper slopes must be justified as being stable. Erosion cannot exceed one 100th of one percent of the final cover per year.

Solid waste management owners/operators must conduct post-closure activities required as part of their permit and the solid waste rules for a minimum of 30 years after closure of the facility. Owners/Operators must maintain the final cover and leachate collection systems and continue to monitor groundwater and surface water. If contamination, excessive erosion, leachate buildup, or other problems arise, the owner/operator is required to conduct corrective action, as necessary. The post-closure period can be extended by the Department, as necessary.

Financial Assurance Requirements

Solid waste disposal facilities are required to have financial assurance as specified in Chapter 33- 20-14 NDAC. The owner/operator must ensure that funds are adequate to cover the costs of closure and post-closure care and that the funds will be available in a timely fashion whenever needed until the owner/operator is released from the financial assurance requirement by the Department. A detailed estimate must reflect the cost of hiring a third party to close the largest area of a solid waste management unit ever requiring final cover at any time during the active life of the facility. Financial assurance provisions must be adjusted annually for inflation or for design changes. Financial assurance may be required for corrective action during the facilities active operation or during the post-closure period, if necessary.

Five mechanisms for financial assurance are allowed under the ND Solid Waste Management Rules. These mechanisms include (1) trust fund, (2) surety bond, (3) letter of credit, (4) insurance, and (5) financial test and corporate guarantee. Most utilities use the financial test and corporate guarantee.

Solid Waste Permit Process

The State's review process (see attached flow diagram), includes a preliminary evaluation to screen sites that are not intrinsically suited for development as solid waste facilities before significant time and effort has been spent on design and site investigation work. Pre-applications utilize existing information such as county groundwater and geologic studies, soil surveys, topographic maps, aerial photographs, nearby surface water and well information, etc.

The multi-agency site suitability review required under the State rules includes review by two divisions in the North Dakota Department of Health: the divisions of (1) Waste Management and (2) Water Quality. In addition, the North Dakota Geological Survey and the North Dakota State Water Commission review sites for site suitability. Finally, for sites located within mined areas, the North Dakota Public Service Commission, Division of Mined Land Reclamation reviews proposed facilities for site suitability and for accordance with the mine plans.

The Department coordinates issues with local planning, zoning, and health officials interested in such issues. The permit process includes opportunities for public comment. An applicant for a solid waste management facility must publish a notice for a new or renewed permit twice in the local newspapers. After a thorough review, if the facility appears acceptable and in accordance with the State rules, the Department prepares a review document and draft permit and publishes a notice in the local county paper and nearby daily newspapers. A 30-day public comment period is allowed to receive testimony. If sufficient interest is expressed by the public, the Department will conduct a hearing and receive testimony.

Coal Combustion By-Product Utilization

The Department has worked with a number of energy companies as well as with some food processors utilizing coal as a fuel to develop beneficial uses for coal combustion by-products or ash. The Department's attached *"Guideline 11 - Ash Utilization for Soil Stabilization, Fill-In Materials and Other Engineering Purposes"* is a straightforward 4-page document that summarizes the Department's approach to product utilization. In essence, the proposed uses for coal combustion by-products must reasonably demonstrate that the proposed use will not adversely impact the environment. The project's potential impact to surface water, groundwater, air, and soil quality should be evaluated.

Background information on the source, quality, and quantity of ash as well as appropriate analysis must be provided. The Department is pleased to review existing information, especially leach testing information; however, some leach methods are more appropriate than others. One primary Department interest is determining what initial runoff might be from a site should a heavy rainfall event occur. Trying to simulate actual natural conditions in a laboratory is difficult; however, we have utilized a synthetic precipitation leachate procedure Method 1312, modified by reducing the solution to a solid ratio of 4:1. The Department also found good results with the ASTM Method D-3987 modified utilizing a solution to a solid ratio of 4:1. The Department also has reviewed results utilizing the synthetic groundwater test and other methods that attempt to simulate a waste's interaction with the environment. The Department finds it beneficial to try to model or conduct a laboratory simulation before the trial project to try to replicate field conditions.

The beneficial reuse of coal combustion by-products is gaining acceptance in North Dakota. For many years, fly ash

has been a commonly used admixture for cement, especially the fly ash generated by the Coal Creek Station located near Underwood, North Dakota.

Ash is routinely used as a partial replacement of cement by the North Dakota Public Service Commission Abandoned Mine Lands program for grout filling of abandoned mined projects. MDU-Heskett Plant has received approval to utilize some of their waste as an admixture for a controlled flowable fill in engineering settings. One or two sugar beet companies have been approved to utilize some of their ash for stabilization of sugar beet piling sites and other stabilization projects. Stabilization of mine roads and other roads also has been studied. The Department is recently evaluating the use of coal combustion products for stabilization of livestock feedlots.

Use of bottom ash, a sand-like product, for winter traction and now replacing salt and sand has been accepted in North Dakota and other States. Bottom ash is also being marketed for abrasives and sand blast medium.

Steve Tillotson has been employed since 1980 by the North Dakota Department of Health. He is currently the Assistant Director of the Division of Waste Management and manages the State Solid Waste Program that includes permitting, compliance, and planning issues; the promotion of waste reduction and recycling; toxic materials reduction; and various educational programs. He holds a Bachelor's Degree in Geology/Earth Science and a minor in History from North Dakota State University with postgraduate studies in Environmental Science at the University of Minnesota.

GUIDELINE 11 - ASH UTILIZATION FOR SOIL STABILIZATION, FILLER MATERIALS AND OTHER ENGINEERING USES

North Dakota Department of Health - Division of Waste Management
Telephone 701-328-5166 ● Fax 701-328-5200 ● Website
www.health.state.nd.us
Rev: 04/01

Attachment: Parameters and Methods for Assessing Leachability* of Fly Ash and Runoff from Fly Ash Utilization Sites in North Dakota (Parameters may be reduced based upon review.)

North Dakota Department of Health is working with a number of power plants, coal-fined boiler operators, coal mines, and other entities wishing to utilize waste materials such as coal-fired fly ash and/or bottom ash for engineering purposes. Some projects such as road stabilization, underground mine stabilization, controlled strength flowable fill, and other uses have been reviewed and approved by the Department based on an evaluation of the material's engineering and environmental properties. Persons proposing use of waste materials for beneficial reuse need to demonstrate that the material will be beneficially used without adversely impacting the environment.

Beneficial reuse must be carefully considered to ensure it is not simply *"use constituting disposal"* or *"sham recycling."* Proposers should be familiar with the state's environmental laws and rules, including the North Dakota Solid Waste Law, Chapter 23-29 North Dakota Century Code (NDCC); the North Dakota Solid Waste Management Rules, Article 33-20 North Dakota Administrative Code (NDAC); as well as the state's Water Pollution laws, Chapter 61-28 NDCC, which includes Section 61-28-06 which states in part:

> "It shall be unlawful for any person:
>
> a. To cause pollution in any waters of the state or to place or cause to be placed any waters in a location where they are likely to cause pollution of any waters of the state . . . "

The Department needs to review important aspects of any proposal, including, but not limited to, the ash quality and quantity, the proposed use of the ash, site characteristics, potential receptors, how the material will be handled, contingency plans in case adverse environmental conditions arise, how the site will be monitored to ensure environmental protection, what will be done when use of the material is completed, any local health or zoning issues, site closure and reclamation, etc. At a minimum, any proposal should address the following:

1. **Background information on the source, quality, and quantity of the ash** including the generator of the ash; the type of facility, the boilers, the pollution control equipment, etc., used in generating and collecting the ash; the source and the type of fuel used in the process; the variability of the ash; whether it is a mixture of other materials or waste streams, how it is stored and handled prior to any disposal or use, and any other information necessary.

2. **Analysis of the ash,** including both existing information and, as necessary, some leach analysis. Information that might be provided would include mineralogical properties and total analysis plus an assessment of the environmental leachability of the ash materials. At a minimum, an ash leach test on one or more representative samples utilizing either: (1) a

modified EPA Synthetic Precipitation Leaching Procedure (SPLP) Method 1312, with a *solution to solid ratio 4:1*, or (2) A modified ASTM D-3987 procedure with a *solution to solid ratio of 4:1*. A list of chemical parameters is attached to this memorandum. The detection limits for analysis must be substantially below the safe drinking water standards.

3. **A discussion and details on the proposed use of the ash**, including any admixtures, fill materials, soil, etc., should be provided. Information that is essential for review includes a description of the actual beneficial use; the mix ratio and design lift thickness; type and quality of fill materials, moisture levels, compaction, and engineering properties (including the strength and durability of materials), and what the material will be covered with, assessment of weathering, material breakup, etc., should be provided.

4. **A laboratory simulation** of the environmental properties of the proposed use should be addressed. Laboratory simulation testing to replicate field conditions determine leachability of the material as-placed should be provided. Upon discussion with the Department, a field simulation test should be agreed upon that will be adequate to determine any impact on the environment from initial waste placement, and any impact through continued weathering, mechanical abrasion, erosion, field runoff, etc. Various simulation tests have been approved by the Department, including kinetic tests simulating infiltration of water through fill materials.

   One publication that has been utilized for evaluating ash utilization in a mine setting is the publication *"Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Mine Sites in British Columbia"* by Dr. William A. Price, Reclamation Section, Energy and Minerals Division, Ministry of Employment and Investment, Bag 5000, Smithers, British Columbia, V0J2N0. Other information is available in Departmental files or may be proposed by the applicant based on the conceptual field application. Laboratory simulation of the field application methods might also entail testing of the materials due to its fate in the environment through weathering, breakup, erosion, abrasion, excavation, etc.

5. **The site characteristics**, including soils, topography, geology, hydrogeology, groundwater quality, surface water conditions and flow, vegetation, etc.

6. **Potential receptors**, including nearby communities, residences, parks, natural areas, neighboring land use, waterways, site drainage, groundwater conditions and quality groundwater wells, and any other information necessary to assess potential impacts to health and the environment.

7. **Description of the material handling and conceptual construction**, including transport and storage of materials, placement of materials, equipment, construction techniques, moisture application and monitoring, mixing, testing, etc., as well as controls and monitoring of windblown dust, stormwater and/or any ponded water must be described.

8. **The proposal should address reasonable contingencies** such as discontinuance of the application methods, cleanup of the site should environmental damage occur, final disposal of placed materials after the life of the project, etc.

9. **Approval by any local health, environmental, and permitting authorities** must be obtained before the project is conducted. Any Departmental approval is contingent upon and does not supersede compliance with all local environmental, health, and building code requirements.

10. **Monitoring of surface, groundwater, air, and soil** may be required.

11. The proposer should provide routine reports on construction and operation progress, monitoring results, final construction details and, for ongoing projects, periodic re-analysis of the ash material on an annual basis or, more often, under the following circumstances:

    a. The process generating that waste changes, such as the installation of different boilers, burners, pollution control equipment, or any other process change which might influence the character of the waste being utilized;

    b. In the event that the raw material or type of fuel changes; and

    c. Any other changes or variances which may influence the characteristics of the ash/product or the mixture used in the construction project.

This outline is provided for guidance purposes only. Additional requirements or conditions may be stipulated by the Department, dependent on the particular application, site characteristics, or other regulatory requirements.

Should you have any questions regarding these matters, please feel free to contact the Department at (701) 328-5166. More information on the state's environmental laws and rules are available at our Website www.state.nd.us

North Dakota Department of Health - Division of Waste Management

Parameters and Methods for Assessing Leachability* of Fly Ash and Runoff from Fly Ash Utilization Sites in North Dakota (parameters may be reduced based upon review)

a. Basic water parameters:

(1) Appearance (including color, foaming, and odor)
(2) pH[1]
(3) Specific conductance[2]
(4) Temperature

b. General geochemical parameters:

(1) Ammonia nitrogen
(2) Total hardness
(3) Iron
(4) Calcium
(5) Magnesium
(6) Manganese
(7) Potassium
(8) Total alkalinity
(9) Bicarbonate
(10) Carbonate
(11) Chloride
(12) Fluoride
(13) Nitrate + Nitrite, as N
(14) Total phosphorus
(15) Sulfate
(16) Sodium
(17) Total dissolved solids (TDS)
(18) Total suspended solids (TSS)
(19) Cation/anion balance
(20) Sodium Adsorption Ratio SAR)

c. Heavy Metals:

Group A:

(1) Arsenic
(2) Barium
(3) Boron
(4) Cadmium
(5) Chromium
(6) Lead
(7) Mercury
(8) Selenium
(9) Silver

Group B:

(10) Antimony
(11) Beryllium
(12) Cobalt
(13) Copper
(14) Nickel
(15) Thallium
(16) Vanadium
(17) Zinc

d. For Fly Ash waste analysis, naturally occurring radionuclides:

(1) Gross Alpha Particle Radioactivity (pCi/1)
(2) Radium 226 and 228 (pCi/1)
(3) Uranium

*Ash leach test on one or more representative sample(s) using a **modified** EPA Synthetic Precipitation Leaching Procedure (SPLP) method 1312 with a **solution to solid ratio of 4:1. A modified ASTM D-3987 procedure with a solution to solid ratio of 4:1 may also be used.** Laboratory detection limits must be substantially below the level of any state or federal drinking water standard or goal.

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DESCRIPTIONS OF STATE OF COLORADO REGULATORY PROGRAMS ASSOCIATED WITH COAL COMBUSTION WASTE (CCW) MINE PLACMENT

Presented by Dave Berry
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Abstract

Two surface coal mines in the State of Colorado receive coal combustion wastes (CCWs). The CCWs that are placed into these mines consist of boiler fly ash, boiler bottom ash, and scrubber sludge. These CCWs are generated by two coal burning power stations that also are situated within Colorado. Regulatory approval of CCW placement into areas within these two coal mines was coordinated between agencies within the Colorado Department of Natural Resources, the Colorado Department of Public Health and Environment, and the local county governments.

Introduction

Two surface coal mines in Colorado receive coal combustion wastes (CCWs). These mines are the Trapper Mine and the Keenesburg Mine. The Trapper Mine is an active coal-producing operation. The Keenesburg Mine, a former coal-producing operation, is in reclamation.

The Trapper Mine is situated near the city of Craig, in Moffat County, Colorado, and is permitted and operated by Trapper Mining Company of Craig, Colorado. The Keenesburg Mine is situated near the city of Keenesburg, in Weld County, Colorado, and is permitted and operated by Coors Energy Company of Golden, Colorado.

Boiler fly ash, boiler bottom ash, and scrubber sludge are being placed into the Trapper Mine. These CCWs are generated by the Yampa Project power station in Craig, Colorado, which is operated by Tri-State Generation and Transmission Association, Inc.

Boiler fly ash and boiler bottom ash are being placed into the Keenesburg Mine. These CCWs are generated by the Coors Brewery power station in Golden, Colorado, which is operated by Trigen – Colorado, L.L.L.P. As the Coors power station uses a baghouse instead of scrubbers, scrubber sludge is not generated at the Coors power station.

Current Regulatory Schemes

The regulation of the placement of CCWs into coal mines in Colorado is coordinated, primarily through two State agencies, in conjunction with local county governments. The two State agencies involved are the Colorado Department of Natural Resources and the Colorado Department of Public Health and Environment.

Within the Colorado Department of Natural Resources, the Division responsible for approving this activity at coal mines is the Division of Minerals and Geology, more specifically the Coal Program (DMG). The DMG is a State Regulatory Authority as recognized by the US Office of Surface Mining, Reclamation, and Enforcement under the Federal Surface Mining Control and Reclamation Act of 1977.

Within the Colorado Department of Public Health and Environment, the Division responsible for approving this activity is the Hazardous Materials and Waste Management Division, more specifically the Solid Waste Unit (SWU). The SWU is the State's RCRA (the Federal Resource Conservation and Recovery Act of 1976) authority (it

should be noted that the US EPA in April, 2000, chose to not declare CCWs as hazardous wastes).

Approval by SWU for placement of CCWs at the Trapper Mine and the Keenesburg Mine occurred in conjunction with the boards of County Commissioners for Moffat and Weld Counties, respectively. Trapper Mining Company and Coors Energy Company applied for a Certificate of Designation (CD) for a Solid Waste Disposal facility from the county governments where the coal mines that receive the CCWs are situated. The county governments then coordinated their review of the CD applications with the SWU. The SWU subsequently recommended approval of the CD applications to the Moffat and Weld County government agencies, who then in turn approved the solid waste disposal facilities. Disposal of non-CCW mining-related solid wastes occurs at the Trapper Mine CCW placement area.

Weld County required, in conjunction with a Certificate of Designation, that the Coors Energy Company obtain a Site Specific Development Plan and Special Use Permit (USR), in accordance with the Weld County Code. The local permit allows for the disposal of fly ash, bottom ash, mine waste rock, and demolition debris from on-site structures such as the shop/office building at the facility. Disposal of non-CCW mining-related solid wastes is not approved in the facility USR or CD. An amendment to the USR and CD would be required prior to disposal of non-CCW mining-related solid wastes.

Though placement of CCWs at the Keenesburg Mine now occurs on private land, CCW placement at one time occurred on land leased from the State of Colorado. Placement of CCWs at the Trapper Mine coincidentally currently occurs on land leased from the State. In both cases, the mining permittees had to obtain approval for placement of CCWs on State lands from the State Board of Land Commissioners (SBLC). The SBLC is another agency within the Colorado Department of Natural Resources.

Basic Approach to Performance and Operating Standards

Standards for the design, construction, operation, maintenance, and closure of municipal solid waste disposal facilities within Colorado are established by the SWU. These municipal disposal facility standards may be applied to CCW placement facilities at coal mines at the discretion of the SWU, depending upon the nature of the CCW placement site.

DMG requires coal mining permittees that propose to operate CCW placement areas within coal mines to comply with certain applicable environmental performance standards of the Colorado Surface Coal Mining Reclamation Act (the Act) and the Regulations of the Colorado Mined Land Reclamation Board for Coal Mining (the Regulations).

DMG coal mining and reclamation environmental standards that may apply to CCW placement operations within coal mines address:

- salvaging of topsoil and subsoil from the CCW area for use in reclamation;
- protection of salvaged soils from wind and water erosion;
- protection of air quality at the CCW placement site during operation;
- protection of surface water quality and quantity at and around the CCW placement site during and after operation;
- protection of groundwater quality and quantity at and around the CCW placement during and after operation;
- replacement of at least four feet of non-toxic soil over CCW materials;
- re-establishment of a positive-draining reclamation topography of approximately original elevation; and
- re-establishment of a self-sustaining, diverse vegetative cover that leads to a beneficial post-mining land use of the CCW area.

State Enforceability

DMG has State enforceability for the activities approved through the DMG coal mining and reclamation permit. The SWU has some enforceability of the standards set by the SWU for CCW facilities. The counties have some enforceability of their approvals of the applications for Certificates of Designation for the CCW facilities.

Citizen Enforceability

Citizen enforceability of CCW placement in Colorado coal mines can be coordinated initially with DMG. DMG may request assistance from the SWU and county agencies if any citizen enforcement issues lie more squarely within the jurisdiction of those agencies.

State's position on beneficial uses of CCWs related to mine placement, including use at Abandoned Mine Land (AML) sites

While DMG has no official position on beneficial uses of CCWs related to mine placement, DMG has approved placement of CCWs at two surface coal mines in Colorado. DMG has no official position on the placement of CCWs at AML sites.

Nature of Disposal Practices

At the Keenesburg Mine, fly ash and bottom ash are end-dumped from haul trucks. A row across the pit is prepared for receipt of ash by formation of a berm across the pit. This is to prevent uncontrolled run-out of ash across the floor of the pit. The dump piles are leveled by a grader, bulldozer, or front-end loader. The ash is then sprayed with water. The ash is covered every other day by a thin layer of mine spoil cover material. After successive layers of ash and spoil bring the surface elevation to levels where the final cover will be placed, another row is started across the pit.

At the Trapper Mine, fly ash and bottom ash are end-dumped from haul trucks. Scrubber sludge is transported to the disposal area via mixer trucks.

Pre-placement Site Characterization/Assessment Acceptance/Rejection Criteria

The DMG has no specific acceptance/rejection criteria for CCW placement sites. Based upon the proposed location of the CCW placement facility within a coal mine, DMG would utilize applicable siting and environmental protection standards set forth in the State coal mining and reclamation act and regulations. Some of the State coal mining regulations that could form the basis for a potential denial of a proposed CCW placement site at a coal mine could include, but not be limited to, those addressing the proximity of the CCW site to a residence, a public facility, or a public road; the location of the CCW site in an area deemed unsuitable due to its difficulty in achieving reclamation; the location of the CCW site being proposed within an alluvial valley floor; and the location of the CCW site being proposed within an area listed on the National Register of Historic Places.

Groundwater Assessment (Pre-Use Monitoring, Modeling)

Groundwater assessment for CCW sites within the Trapper and Keenesburg Mines occurred via the baseline geologic and groundwater quality and quantity data gathering required by the State's coal mining and reclamation laws and regulations. The period of time requested by DMG for groundwater baseline data gathering is typically 12 months. However, the State Solid Waste regulation typically requires eight quarters of background data.

Trapper Mining Company has provided additional groundwater modeling at DMG's request, including simple evaluations of potential of cross-strata migration of CCW leachate, the potential for surface water/groundwater interaction, and the travel time of the CCW leachate.

Acid/Base Accounting

There were no pre-use acid/base accounting assessments conducted specifically for the CCW placement sites at the Trapper and Keenesburg mines. However, the permittees for both of these mines submitted chemical analyses of the overburden, interburden, and underburden materials. This was to demonstrate to DMG the acid-forming, toxic-

forming, or alkalinity-producing potential of these materials as required by the DMG laws and regulations.

Floodplain Assessments

The CCW placement sites at the Keenesburg and Trapper mines are located outside of floodplains. As such, there were no pre-use floodplain assessments required by the DMG. The DMG would likely not approve any future proposals for CCW placement sites in floodplains, due to the potential for surface water and alluvial groundwater contamination.

Seismic Assessments

The CCW placement sites at the Keenesburg and Trapper mines are situated within areas from which coal has been extracted under the DMG coal-mining permit. As such, the CCWs are being placed below grade and are not at risk for being transported off-site in the event of significant seismic events such as earthquakes or large surface mining blasts.

DMG laws and regulations do, however, have seismic safety construction factors associated with impoundment embankments of a certain size. If an application were submitted for a CCW impoundment and that impoundment had an embankment of a certain size, the DMG might need to consider those seismic safety factors in its review of the proposal.

Surface Water Assessments (Pre-Use Monitoring, Modeling)

As with the groundwater assessments, all pre-use surface water quality and quantity assessments for CCW placement at the Trapper and Keenesburg mines were conducted in accordance with the DMG laws and regulations pertaining to coal mining and reclamation. The period of this baseline surface water data gathering is typically 12 months.

The permittee for the Trapper Mine has provided additional modeling of the potential for surface water/groundwater interaction. This was provided after the approval of the CCW placement activity, during review of the mine operation's permit.

Soil and Geologic Assessments

Soil and geologic pre-use assessments were conducted in accordance with the requirements of the DMG laws and regulations for coal mining and reclamation. These included descriptions of regional stratigraphy and structural geology, geochemistry of the coal overburden for acid-generating potential, determinations of aquifer locations and extents, and assessments of suitability of soils for use as in reclamation and as a cover over the CCWs.

Public Notice/Approval and Environmental Justice Issues

Public notice of the applications for the Certificates of Designations from the county governments were addressed at that level. Public notice of the approvals for the CCW placement within the coal mines were addressed by the DMG in conjunction with the public notice requirements described in the DMG laws and regulations.

There were no environmental justice issues raised during the DMG approval processes. Approval of the existence and location of CCW sites within counties occurs at the county government level. It is possible that approval of CCW placement areas by DMG within previously approved coal mines may have reduced any potentially negative environmental justice issues that might have been raised for these sites had the CCW placement areas been proposed in other locations within Colorado.

Waste Characterization Methods, Analytes, and Frequency

Toxics Characteristics Leaching Procedure (TCLP) tests are conducted on the CCWs being placed into the Keenesburg Mine. Analytes measured include arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, and Gross Alpha and Gross Beta. These tests are conducted annually, with tests also run whenever the source of the coal to the Coors Brewery power plant changes.

There are currently no TCLP tests required of the CCWs being placed into the Trapper Mine.

Acceptance/Rejection Criteria

There are no pre-established acceptance or rejection criteria pertaining to CCW characterization at either the Trapper or Keenesburg mine.

Construction and Placement Criteria

At the Keenesburg Mine, pits were reclaimed to an elevation 5 feet above the groundwater table. Clay material was then placed in the pits. CCW disposal cells are then covered with 6 feet of overburden soils and two feet of sandy topsoil. Thin overburden soil layers are placed on the layers of CCWs every other day. The width of the CCW layers is controlled by the placement of overburden soil berms across the floor of the pit.

At the Trapper Mine, CCW placement is limited to pre-approved locations selected so as not to hinder the reconstruction of approximate original topography.

Placement Methods (Layering, Piling, Intermixing with Spoil, etc.)

Layering is used at both the Keenesburg and Trapper mines.

Air Emission (Dust) Limits/Standards, Required/Acceptable Practices

Air Pollution Emission Notices (APENs) are in effect at both the Keenesburg and Trapper mines. These are maintained by the mining permittees in accordance with requirements established by the Air Pollution Control Division of the Colorado Department of Public Health and Environment.

Groundwater Protection Limits/Standards, Required/Acceptable Practices (e.g., Liners, Protective Distance Above Water Table)

Standards for groundwater protection in the State of Colorado are established by the Water Quality Control Commission of the Colorado Department of Public Health and Environment.

At the Keenesburg Mine, CCWs are placed into pits after clay is placed at the bottom of the pits. CCW placement occurs five feet or more above the water table.

CCWs at the Trapper Mine are placed into an unlined pit constructed within backfilled coal mine spoil. CCW placement is limited to areas above projected groundwater saturation levels.

Surface Water Protection Limits/Standards, Required/Acceptable Practices (e.g., Stream Diversion, Contouring, etc.)

Operations at both the Keenesburg and Trapper mines are designed so that surface water runoff stays within the CCW placement pits during active disposal. There are no specific CCW surface water standards associated with the NPDES permits issued by the Water Quality Control Division to the mines.

At the Keenesburg Mine, the finished grades of the reclaimed cells are shaped to develop a positive drainage off of the reclaimed cell areas to minimize infiltration of precipitation. Temporary perimeter ditches have been installed uphill of the CCW placement area to prevent overland runoff from washing across the active CCW placement area.

At the Trapper Mine, the CCW placement area is within a former coal excavation pit. This pit disturbed some natural ephemeral drainage channels. CCWs are restricted from being placed within 50 horizontal feet of these re-established drainages.

Cover Material (Daily, Intermediate, Final) and Revegetation

At the Keenesburg Mine, CCWs are covered by a thin layer of overburden materials every other day. The final cover layer is six feet thick, overlaid by an additional two feet of sandy topsoil. Revegetation requirements are the same as for the other parts of the coal mine.

There is no daily requirement for cover placement at the Trapper Mine. CCWs are covered by a five-foot thick layer of mine spoils, and are then overlaid by topsoil. Revegetation is the same as for the other parts of the coal mine.

Quantity and Placement Restrictions

There is no quantity restriction for CCW placement into the Keenesburg Mine. Placement must allow the cover requirements to be met, and must be placed in a clay-lined area at least five feet above the water table. CCWs generated at the Trigen power plant must come from only pre-approved sources of coal.

CCWs at the Trapper Mine are placed at the daily rate of generation from the Yampa Project power station (about 1500 cubic yards/day). CCWs must be placed in the pit above the projected eventual groundwater saturation elevation and must be located at least 50 horizontal feet from any reconstructed drainage channels.

Monitoring Requirements
Groundwater (Well Design and Placement, Analytes, Frequency)

At the Keenesburg Mine, groundwater monitoring is accomplished by six wells, one up gradient and five down gradient from the CCW placement cells. Samples are tested for: alkalinity, bicarbonate, carbonate, chloride, hydroxide, sodium absorption ratio, specific conductance, sulfate, pH, arsenic, barium, cadmium, calcium, hardness, iron, lead, magnesium, manganese, molybdenum, selenium, sodium, and total dissolved solids.

At the Trapper Mine, groundwater monitoring well design and sampling requirements are the same as for the rest of the coal mine.

Surface Water (Sampling Points, Analytes, Frequency)

There are no specific surface water sampling points, analytes, or sampling frequency requirements for the CCW placement activity at either the Keenesburg or Trapper mine. Surface water runoff from the CCW placement area is designed at both mines to be retained within the placement area.

Availability of Data to Public

All data associated with surface and groundwater monitoring is available to the public at the DMG offices and at the mine offices.

Closure Requirements

At the Keenesburg Mine, CCWs must be covered with six feet of coal overburden materials, then an additional two feet of topsoil. The replaced topsoil must be revegetated in accordance with the approved revegetation plan for the rest of the mine. The DMG would retain its regulatory jurisdiction until the permittee received approval of a Phase III bond release application.

At the Trapper Mine, CCWs must be covered by five feet of coal overburden materials, then an additional amount of topsoil. The replaced topsoil must be revegetated in accordance with the approved revegetation plan for the rest of the mine. The DMG would retain its regulatory jurisdiction until the permittee received approval of a Phase III bond release application.

Post-Closure Requirements
Monitoring, Reporting, Record Keeping

In Colorado, coal mine reclamation is not released from DMG jurisdiction until all revegetation standards are met and until at least ten years following the reclamation have passed. During these ten years, DMG requires monitoring of surface and groundwater quality and quantity, and of revegetation success. Reporting of this information is usually provided by coal mining permittees in Annual Hydrology Reports and Annual Reclamation Reports. The DMG and the permittees keep these annual reports on file until the DMG terminates jurisdiction.

Colorado Solid Waste regulations, however, prescribe 30 years post closure water monitoring. This is subject to change based upon a demonstration that water quality over a shorter period of time has not varied significantly.

Maintaining Integrity of Final Cover

Maintenance of the final cover, such as protecting it from wind and water erosion, ensuring the revegetation of the cover is successful, and protecting the revegetation from noxious plant infestation, is required by DMG.

Subsequent Use Restrictions

Use of the reclaimed CCW areas at both the Keenesburg and Trapper mines must be in accordance with the approved post-mining land uses approved for the rest of the reclaimed portions of the mine.

Corrective Action/Remediation

This is the same as for the rest of the mine-related disturbances.

Financial Assurance

The Solid Waste Unit (of the Colorado Department of Public Health and Environment Hazardous Materials and Waste Management Division) requires some form of financial assurance, and deems this requirement as being met by the coal mine reclamation bond.

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THE DISPOSAL OF POWER PLANT WASTE IN MINES: PUBLIC HEALTH, ENVIRONMENTAL, AND REGULATORY CONCERNS

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Abstract

The use of power plant waste as mine fill raises many significant environmental and regulatory issues. When power plant waste is placed in mines, hazardous constituents, such as arsenic, chromium, selenium, and cadmium, can leach from the waste to contaminate ground and surface water. It is the responsibility of the US Environmental Protection Agency to develop regulations under the Resource Conservation and Recovery Act to ensure that such damage does not occur. In the absence of stringent safeguards, power plant waste disposal in mines is likely to cause irreparable harm.

Introduction

Power plant waste (PPW)[1] is the second largest solid waste stream in the United States. Coal plants generate a waste stream of chemicals surpassing that created by pulp and paper mills, chemical manufacturers, petroleum refineries, and textile mills *combined*. Yet Federal standards for PPW disposal are conspicuously absent. While Section 1003 of the Resource Conservation and Recovery Act (RCRA) requires EPA to ensure that solid waste does not pose a danger to the environment or human health, EPA has no Federal standards in place to protect the nation's water from the toxic contaminants contained in the 115 million tons of PPW generated annually. One disposal practice that is becoming increasingly prevalent is the placement of PPW in surface and deep mines.[2] Whether justified for amelioration of acid mine drainage (AMD) in eastern coalfields or as a method of cheap disposal in western regions, this practice threatens the nation's water and public health. Inconsistent State regulation of PPW disposal in mines allows the placement of large quantities of waste without adequate site characterization, waste characterization, documentation, public notice, isolation, groundwater monitoring, closure requirements, financial assurance for closure, or corrective action requirements. While it has been suggested that PPW mine fill be regulated under provisions of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), use of SMCRA provisions alone would be grossly inadequate to address the threats posed by disposal of this waste. Unless Federal RCRA authority is exercised in a timely and decisive manner, it is likely that this waste disposal practice will cause irreparable environmental harm throughout the United States.

The Threshold Issue: The Nature of the *Waste*

At the heart of this issue is that PPW is an *industrial solid waste* containing significant quantities of hazardous constituents.[3] Because it is a waste, the regulation of PPW falls squarely within the purview of RCRA. Disposal of PPW in coal mines is subject to the criteria contained in 40 CFR Part 257, *Criteria for Classification of Solid Waste Disposal Facilities and Practices.* Furthermore, the mine into which PPW are permanently disposed is a *landfill*.[4]

Only RCRA has the authority and regulatory framework to address the particular problems presented by solid and hazardous waste. It is undeniable that this waste, when exposed to groundwater, leaches its hazardous constituents.[5] This leaching process may take decades, but at site after site, the evidence is clear that significant quantities of toxic constituents will exit a deposit of PPW, often severely impacting ground and surface water, threatening public health and destroying wildlife habitat.[6] Consequently, it is essential that the ultimate disposal of this waste in mines be governed by the safeguards contained in RCRA which are intended specifically to protect human health and the environment from potentially harmful waste. Using any other regulatory scheme, such as SMCRA, is an inadequate substitute. To date, the Office of Surface Mining (OSM) has never addressed waste issues with the specificity that this issue deserves.

As a regulatory matter, the labeling of this waste is also significant. PPW has been called a "by-product" in the context of this forum. In many States, the disposal of this "by-product" in mines is classified as beneficial use, exempting it from the regulations governing the disposal of any type of solid waste. Nevertheless, removing "waste" from its name is merely a marketing tool. While sound environmental policy encourages the safe reuse of solid waste, beneficial use must be demonstrated to be genuinely *beneficial.* Such is not the case with all PPW mine fill projects. With the exception of certain AMD applications and carefully planned reclamation projects, PPW mine fill is often simply an inexpensive, but potentially dangerous disposal practice. Furthermore, the financial benefits of this disposal method accrue only to the utilities and mine operators. A great financial burden falls upon the communities whose land, water, and health are adversely affected by the waste disposal.

In EPA's March 5, 2000 Draft Notice of Regulatory Determination on Wastes from the Combustion of Fossil Fuels, EPA determined that PPW would be regulated under Subtitle C of RCRA when land disposed or when used to fill surface or underground mines. EPA exempted from Subtitle C regulation PPW that was "beneficially used" for purposes such as waste stabilization and beneficial construction applications in cement, concrete, concrete products, roadbed, and wallboard. Concerning mine fill, EPA stated that a beneficial use exemption was *not* appropriate because "when not done properly, mine filling has the potential to contaminate groundwater to levels that could damage human health and the environment."

In EPA's final Notice of Regulatory Determination on Wastes from the Combustion of Fossil Fuels (65 FR 32214, May 22, 2000), EPA retreated from this position and proposed that mine fill be regulated under Subtitle D of RCRA, not Subtitle C. Yet EPA reiterated its concerns regarding mine fill and these concerns still distinguish it from other "beneficial" uses of PPW. Specifically EPA stated in the Final Determination that "...we cannot reach definitive conclusions about the adequacy of mine filling practices employed currently in the United States and the ability of government oversight agencies to ensure that human health and the environment are being adequately protected." (Id.at 32228.)

In the Final Determination, EPA raises two very legitimate areas of concern. The first is that mine filling practices might be lacking in some very basic safeguards. To this point, EPA listed three primary concerns: (1) the inadequacy of groundwater monitoring data to determine post-fill groundwater impacts, (2) the inadequacy of site characterization and the need to match mine chemistry to waste chemistry to avoid an increase in hazardous metal releases, and (3) the risk of placing PPW in direct contact with groundwater in both underground and surface mines.

Secondly, EPA raised in the Final Determination, but did not answer, the critical question of whether RCRA regulation of PPW mine fill under Subtitle D is necessary or whether modification of existing regulations under SMCRA would be sufficient. This paper addresses both the concerns raised by EPA regarding the potential adverse environmental impacts of PPW mine fill and the question of the most effective regulatory approach to PPW disposal in mines. By examining environmental problems posed by use of PPW in mines, including the concerns raised by EPA, and by demonstrating how none are currently adequately addressed under SMCRA, this paper advocates a strong RCRA role in developing federal regulations.

Placement of PPW in Groundwater at Mine Fill Sites

The placement of PPW directly in contact with groundwater in surface and deep mines is a practice that concerns EPA, State regulators, and environmental groups. The likelihood that hazardous constituents will leach from PPW is greatly increased when the waste is placed into groundwater. Several of EPA's most recent proven damage cases are sites where PPW was placed in mines with exposed groundwater.[7]

RCRA regulations clearly prohibit the placement of a waste in a manner that would cause Federal drinking water standards in an underground drinking water supply to be exceeded. In contrast, SMCRA's requirements to protect groundwater have been interpreted by the Office of Surface Mining (OSM) in a vague if not contradictory manner that does not guarantee the degree of protection ensured by RCRA regulations. For example, the standard leaching test on a typical sample of PPW yields results indicating that this waste meets SMCRA's definition of a "toxic forming material," which is "earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are detrimental

to biota (life) or uses of water." (30 C.F.R. Section 710.5) Yet nowhere in SMCRA, its regulations, or in OSM guidance is there any explanation or numerical standard that can be used to apply this definition in the field. Furthermore, SMCRA regulations employ confusing language that requires "contact (of water) with toxic producing deposits" to be either "prevented," "removed," or "minimized" without explaining what such deposits are or which of these directives should be applied in any particular case. (30 U.S.C. Section 1265(b)(10)(A)) The result is mine filling programs throughout the United States that range from those isolating PPW many feet above water tables to those allowing millions of tons of toxic-forming PPW to be dumped directly into groundwater aquifers that are being used as private and public water supplies.[8]

Lack of Groundwater Monitoring at Mine Fill Sites

The Clean Air Task Force and Hoosier Environmental Council have reviewed groundwater monitoring programs at active and inactive mines in Indiana, Illinois, Ohio, Kentucky, West Virginia, Pennsylvania, Texas, North Dakota, and New Mexico and found, without exception, that none of the groundwater monitoring at these sites approaches the standard level of groundwater monitoring undertaken at RCRA solid or hazardous waste disposal facilities.

PPW mine filling operations typically employ a few to a half dozen monitoring wells to cover waste disposal areas of a few hundred to several thousand acres in size. Many of the monitoring programs at these mine filling operations are not even monitoring for PPW contaminants and/or have made little effort to establish pre-disposal baseline water quality that can be credibly used to gauge post-disposal water quality impacts. Indeed at many inactive mines used as PPW fills, there is no monitoring at all because OSM and states fail to require such monitoring at abandoned mine reclamation projects.[9]

In EPA's May 2000 Determination on Wastes from the Combustion of Fossil Fuels, the agency expressed concern over the lack of groundwater monitoring at PPW landfills and surface impoundments. EPA pointed out that 62 percent of PPW surface impoundments lack groundwater monitoring systems. We support EPA's concern about the lack of monitoring and liners at PPW landfills and surface impoundments and the need for RCRA controls. Nevertheless, we believe it follows logically that this concern should extend to the much greater quantities of PPW placed in mines, sometimes directly in contact with groundwater. Given the uncertainty admitted by the agency regarding the release of PPW contaminants from mine fills, the millions of tons of waste involved, and the potential for harm to ground and surface water, we feel RCRA controls are absolutely essential.

Lack of Post-Closure Monitoring, Financial Assurance, and Corrective Action Requirements at PPW Mine Fill Sites

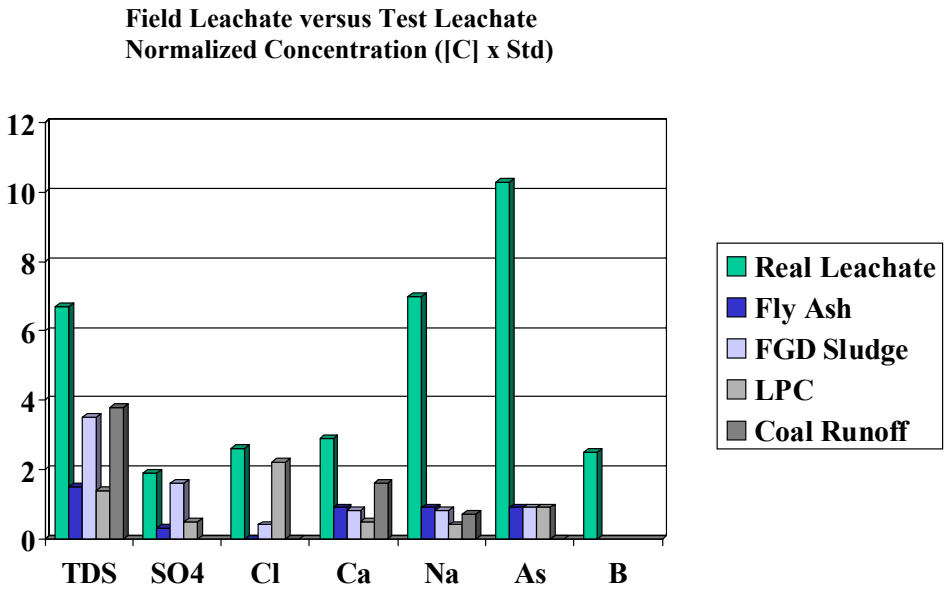
Without exception, OSM and State mine regulatory officials interpret the requirements of SMCRA to mean that groundwater monitoring at mine fills need only take place through the final release of mine reclamation bonds. This typically occurs within three to eight years after mining when surface revegetation requirements are met and mine operators have demonstrated that the post-mine groundwater recharge capacity exists. Thus, given the slow and usually unpredictable rate of groundwater resaturation around mine fills, monitoring is stopped many years if not decades before down gradient flows of groundwater, much less plumes of PPW contaminants, would even be detectable from these sites. PPW will potentially be of concern for far longer than the post-closure liability period for the disposal area.[10]

Unless the bonds are held for much longer periods, no financial assurance is available to address groundwater damages. Furthermore, mine reclamation bonds are valued at levels so low that they would never cover the costs of post-closure monitoring or remediation of a contaminated PPW mine fill site. Currently, reclamation bonds are frequently found to be inadequate to cover remedial activities at mine sites *without* PPW disposal. When one adds to a mine large quantities of waste containing hazardous constituents, there is little likelihood that bonding could cover cleanup costs. In addition, groundwater monitoring programs at PPW mine fills are not designed with a numeric standard or concentration of pollution that could constitute a corrective action standard. Consequently there is no definitive trigger for cleanup activities. The irrefutable reality is that the environmental safeguards in place at PPW mine fills do not remotely approach the safeguards in place at PPW landfills regulated under State solid waste regulations and State solid waste plans approved by EPA under RCRA.

Failure to Accurately Assess the Leaching Potential of PPW

A study of PPW in Indiana by J.R. Boulding indicates that PPW does contain high enough concentrations of leachable toxic contaminants to warrant environmental concern.[11] Proper characterization of the wastes prior to disposal is critical. One significant finding of the Boulding report is that neither the Toxicity Characteristic Leaching Procedure (TCLP) nor extraction procedures provide a complete assessment of the leaching potential of PPW. Long-term leaching tests, conducted until equilibrium has been achieved for each element of concern, using a leaching solution that simulates natural groundwater, would give a more accurate depiction of potential groundwater contamination.[12] As illustrated in Table I, the predicted leachate as indicated by standard laboratory tests and actual field leachate generated by PPW can vary by orders of magnitude.

Table 1. Fern Valley Disposal Area



While RCRA regulations still employ the TCLP for many purposes, RCRA regulations governing post-closure monitoring and corrective action provide an essential safety net. If PPW generates leachate that exceeds the standard predictive leaching test, RCRA-imposed groundwater monitoring wells and post-closure monitoring requirements will detect the migration of the contaminated leachate. The RCRA wells and monitoring will ensure that early detection of hazardous constituents will occur and corrective action measures can be imposed in a timely manner. Under SMCRA, on the other hand, groundwater monitoring would likely have ended long before the leachate showed the impacts of the PPW contamination. Obviously, it would be better to use a leachate test that more accurately predicts the behavior of PPW and to employ a risk assessment approach to PPW-filled mine sites.[13] But the fact remains that given the difficulty in predicting the leaching behavior of PPW in mines, a RCRA regulatory framework that provides for long-term monitoring and corrective action offers critical safeguards.

Lack of Restrictions for Post-Reclamation Use of Property

In contrast to landfills, there are no onsite restrictions for future use of mine fill properties. PPW mine fills can cover large areas up to several thousand acres. There is no State mine fill program or SMCRA requirement that obligates a mine operator to post a notice that disposal of PPW has even occurred at a mine fill, no matter how large the scale. In addition, unlike landfill caps which are designed to inhibit water penetration, mine bond release requirements compel mine operators to demonstrate that final cover soils are *not* too compacted to prevent productive growth of crops and/or trees. (30 U.S.C. Section 1265(b)(19)-(20)) Long-term mine reclamation performance standards explicitly require operators to demonstrate that the post-mine land uses will be equal to or greater than pre-mine land uses. (See 30 U.S.C. Section 1265) This means that mine owners who mine on land that previously supplied water and was used for farming or grazing must be able to rehabilitate the land for these

purposes after mining is completed. Whether such land use on areas of PPW mine fill is safe and appropriate is a critical question not currently being addressed by OSM under SMCRA.

This raises the basic question of the appropriateness of using solid waste for reclamation activities under SMCRA. The purpose of SMCRA was to ensure that land disturbed by mining is returned to its original shape and use or is improved for better uses. (30 U.S.C. Section 1265) Disposing of huge quantities of solid waste in surface and deep mines can only be seen as antithetical to this purpose. Useable, reclaimed land demands sources of clean water. The jury is still out on whether PPW ameliorates AMD and genuinely improves water quality. In other circumstances, where AMD is not present, or worse, where the groundwater underlying mines is alkaline, as in western coalfields, it is likely that PPW will adversely affect water quality.

The public health implications are immense. After mines are filled with PPW, there is a risk of public exposure to water from wells drilled in or near these waste deposits. Unlike RCRA, SMCRA does not define a "solid waste boundary," beyond which hazardous constituents cannot migrate without mitigation. (See 40 CFR Section 257.3-4) SMCRA anticipates that after mining and filling, when revegetation is complete, the land and water will be usable. This will not be the case, as evidenced by leaching of contaminants at PPW mine fill sites that have made onsite water unsafe for human consumption.[14]

Lastly, there is an oft-repeated fallacy that the groundwater down gradient of existing mine sites is either already unusable or is not currently used for human consumption. This is patently false and reveals an unacceptable arrogance on the part of State and Federal regulators. Often groundwater in rural areas is the lifeblood of the community, and public water supplies are simply unavailable.[15] Should groundwater be contaminated by a mine fill, the economic and social costs to such a community would be devastating. While populations affected by individual mine sites may be small in number, due to the isolated locations of the mines, this cannot mean that the value of the water resources and historic way of life of the affected community is so small as to be an inconsequential cost of PPW disposal.

Conclusion

In summary, SMCRA was enacted to stop the abuses of coal mining on surrounding environments and communities and compel reclamation of surface mined lands to the same productive uses that occurred on them before the mining. The framers of SMCRA did not contemplate the use of this law to allow the cheap dumping of massive quantities of industrial wastes. Rather, they enacted RCRA to ensure the responsible disposal of these wastes.

EPA cannot continue to allow States to implement mine fill programs without Federally mandated standards. Federally enforceable standards under RCRA are necessary to ensure that the same level of protection extends to every coal-mining state. In the absence of such standards, States will continue to practice "one-downmanship" wherein coal mines offer cheap disposal options to coal purchasers, prompted by weak, industry-boosting "beneficial" use exemptions. The coming decade will bring a substantial increase in coal burning in the United States, significant increases in amounts of PPW, and an increase in the toxicity of PPW resulting from more stringent controls on power plant stack emissions. As the quantity of PPW increases, so will the pressure to find cheap disposal solutions. It is critical therefore for EPA to set national standards that guarantee safe reuse and disposal of these hazardous wastes.

Citations

(1) This paper uses the term "power plant waste" or "PPW" instead of the term "coal combustion by-product" or "CCB" because the subject of these proceedings is a solid *waste* under Federal law. In addition, the term "coal combustion waste" is avoided because it implies that the waste consists only of the wastes strictly resulting from coal combustion. The term "power plant waste" correctly reflects the fact that the waste commonly contains numerous additional wastes, both hazardous and nonhazardous, generated at a coal-burning plant including coal pile runoff, coal mill rejects and waste coal (pyrites), air heater and precipitator washes, wastewater treatment sludges, and boiler chemical cleaning wastes. See Notice of Regulatory Determination on Wastes from the Combustion of Fossil Fuels, May 22, 2000, 65 FR 32214 at 32220.

(2) Use of the term "disposal" for PPW placement in mines is consistent with the definition of disposal in RCRA. According to Section 1003(3) of RCRA, disposal is defined as "the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters." (42 U.S.C 6903(3))

(3) See 40 CFR 258.2.

(4) See 40 CFR 257.2.

(5) Among the hazardous constituents contained in PPW are 17 toxic chemicals including arsenic, mercury, cadmium, chromium, selenium, aluminum, antimony, barium, beryllium, boron, copper, lead, manganese, molybdenum, nickel, vanadium, and zinc. These contaminants have been shown to cause birth defects, cancer, and neurological damage in humans, and similar damage to wildlife.

(6) As of the date of this forum, EPA has acknowledged 18 proven damage cases caused by PPW. According to EPA, proven damage cases are "those with exceedences of primary MCLs [maximum contaminant levels] or other health-based standards in groundwater or surface water off-site or at a distance from the waste management unit sufficient to conclude that they could cause human health concerns." See Draft Assessment of Candidate Damage Cases Involving Fossil Fuel Combustion Waste, December 2001. In addition, EPA acknowledges four "ecological" damage cases where adverse impacts to surface water from PPW has caused significant damage to wildlife and their habitat.

(7) The following four proven damage cases involved the placement of PPW in gravel mines or pits. At three sites, ground and/or surface water was contaminated by heavy metals, and the migration of that groundwater off-site at levels above the maximum contaminant levels posed a threat to human health (City of Beverly/ Vitale Fly Ash Pit, Massachusetts; Virginia Power Yorktown Power Station Chisman Creek Disposal Site, Virginia; WEPCO Cedar-Sauk Landfill, Wisconsin). At the remaining site, a health-based standard for boron was exceeded in drinking water wells (WEPCO Highway 59 Landfill, Wisconsin).

(8) See, for example, the mine fill practices employed at the following mine sites, Farmersburg Mine, Indiana; Elkhart Mine, Illinois; Center Mine, North Dakota; and Prides Creek Mine, Indiana.

(9) For example, under Pennsylvania law, when PPW is used as fill at an abandoned mine site, there is *no* requirement for groundwater monitoring. Given the large amount of PPW that can be permitted at these sites, the number of abandoned mine sites in Pennsylvania, and the frequency of acid mine drainage at Pennsylvania mine sites, there is potential for environmental degradation. See 25 PA Code Section 287.664. In addition, PPW in Pennsylvania enjoys a beneficial use exemption for use as "structural fill" where, again, no groundwater monitoring requirements apply. See 25 PA Code Section 287.661.

(10) For example, the Clean Air Task Force examined at random five permits involving PPW mine fill in Pennsylvania. For two of the five permits, groundwater monitoring ceased after only three years.

(11) Boulding, J.R. 1991 Disposal of Coal Combustion Waste in Indiana: An Analysis of Technical and Regulatory Issues. Hoosier Environmental Council, Indianapolis, Indiana.

(12) In the paper entitled "Long-term Monitoring and Evaluation of Water Quality Changes from Utilization of Coal-Ash to Fill a Surface Coal Mine" by Ishwar P. Murarka and Thomas Bailey, published in conjunction with the 2001 International Ash Utilization Symposium, the authors demonstrate that leachate concentrations vary significantly when 18-hour leachate tests of PPW are compared to 30-day leachate tests. Contaminant levels of several hazardous constituents are substantially higher in 30-day leachate tests.

(13) The paper entitled, "Assessing the Water Quality Impacts of Fly Ash Structural Fill Projects," by Joseph E.

Bonnetti, Ph.D. and Gary F. Brendel, reviews TCLP and Synthetic Precipitation Leaching Procedure (SPLP) tests, and finding them deficient, suggests adoption of risk assessments to assess potential environmental impacts at fly ash utilization sites. This approach would take into account project specific considerations such as volume and composition of PPW, rates of infiltration, constituent migration and attenuation, existing groundwater quality, and present and future groundwater uses.

(14) See "Long-term Monitoring and Evaluation of Water Quality Changes from Utilization of Coal-Ash to Fill a Surface Coal Mine" by Ishwar P. Murarka and Thomas Bailey. Groundwater and surface water at the Universal PPW mine fill site has been rendered unsafe for human consumption, yet this mine site has been used as an example of successful use of PPW fill.

(15) The pending mine fill permit for the Farmersburg, Indiana surface mine, which could potentially permit the placement of 22 million tons of PPW in a massive strip mine, could potentially severely impact a community of farmers who rely on groundwater to sustain their farms and livestock.

Lisa Evans is an environmental attorney and legal consultant for the Clean Air Task Force. The Clean Air Task Force is a national environmental project whose mission is to tighten State and Federal regulations to reduce smog, soot, haze, acid rain, toxic pollution, and climate change. She previously worked as an Assistant EPA Regional Counsel in Region I as well as an attorney for the Massachusetts Department of Environmental Management. She is also the author of six nonfiction books on nature and national parks. She holds a J.D. from the University of California, Berkeley and a B.A. from Cornell University. She is a founding member of two Massachusetts nonprofit environmental organizations on whose boards she currently serves.

Appendix I

February 26, 1999

EPA-SAB-EEC-COM-99-002

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Subject: Waste Leachability: The Need for Review of Current Agency Procedures

Dear Ms. Browner:

The Science Advisory Board's Environmental Engineering Committee (EEC) has prepared this commentary to call your attention to the need to review and improve EPA's current waste leachability testing procedure, i.e., the Toxicity Characteristic Leaching Procedure (TCLP). This review involves two related issues. First, the TCLP is applied too broadly. Second, leach tests, including the TCLP when used to characterize toxicity, can be improved by accounting for additional parameters.

In 1990, EPA promulgated the TCLP as a method to characterize the toxicity potential of wastes using a particular worst-case scenario. In addition to its use as a waste classification test, regulators and industry are using the TCLP more broadly. The TCLP may be inappropriate in some of these broad applications.

The SAB raised may science issues to the Agency in its 1991 commentary, *Leachability Phenomena.* Many of these scientific issues remain current and, in some cases, affected Agency programs. For example, the Agency's reliance on a single scenario has caused some difficulties for the Agency's hazardous waste regulation programs. The Agency has had two significant legal challenges to the TCLP and its application in particular settings. An enclosure to the current letter also presents recommendations on leach test parameters and field issues. It is time to make improvements.

In the first case, [1] Edison Electric Institute challenged the application of TCLP for making hazardous waste classifications of mineral processing wastes, arguing that these wastes are never disposed in a municipal solid waste (MSW) landfill. While upholding the use of a generic mismanagement scenario, and noting that EPA is not obligated to tailor the TCLP to typical mismanagement conditions, the court concluded that the toxicity characteristic rule must bear "some rational relationship to mineral wastes in order for the Agency to justify the applications of the toxicity test to those wastes.[2]"

In a more recent instance, the use of the TCLP to determine compliance with a waste treatment standard was successfully challenged. In that case, [3] spent aluminum podiners were treated and disposed in a monofill, which had conditions very different from those anticipated by the TCLP test. Landfill conditions such as high alkalinity, monofilling of waste, and very low ratios of leachate to waste (or liquid to solid) were important to waste leachability. Examination of the monofill leachate showed significantly higher concentrations of certain contaminants than those predicted by the TCLP test. When aluminum manufacturers challenged application of the TCLP in this setting, the court vacated this TCLP application. The court cited the language in the earlier EEI case, the Agency's failure to relate the TCLP test conditions to the actual field conditions, the significant difference in the field conditions, and the fact that waste contaminants were leaching at a much higher rate than predicted by the TCLP test.

These cases support the view that EPA needs greater flexibility in waste leach testing, and that EPA's leach testing needs to account for more leaching parameters because they affect actual leaching of contaminants from waste in the field.

The current state of the science supports, even encourages, the development and use of different leach tests for

different applications. To be most scientifically supportable, a leaching protocol should be both accurate and reasonably related to conditions governing leachability under actual waste disposal conditions.

The science supports consideration of scenarios other than the municipal solid waste scenario on which the TCLP currently relies for determining whether wastes meet the toxicity characteristic. When the leach testing is applied in a regulatory program to characterize toxicity, it may be appropriate for other applications, such as site remediation or waste treatment evaluation. For some applications it may be better to use the worst-case scenario likely to be encountered I the field. When a leachability test is used to assist with an environmental assessment of a particular location, it may be more appropriate for the test to be both waste and site specific. While this approach may require more case-specific analysis, it should yield more reasonable results.

The Committee's single most important recommendation is that EPA improves leach test procedures, validate them in the field, and then implement them. The Agency recognized this need in 1990 when it stated, in the TCLP final rule, that "the present" TC revisions are only the first step in a long-term strategy to refine and expand the hazardous waste identification program." The EEC's 1991 commentary, *Leachability Phenomena*, recommended improvements to leach test procedures. EPA has not used these recommendations to revise the TCLP or to develop other Agency sanctioned leaching protocols.

The Committee recognizes the difficulty to developing different leach tests for different applications while at the same time retaining sufficient consistency and commonality to be both workable and logical. Maximum use should be made of a conceptual model followed by an analogue model with good statistical rigor. Nevertheless, the Committee recommends that the Agency study the TCLP testing procedure – and its various applications – and then generate improved leach test procedures. The Committee is confident that leach test procedures can be improved within the constraints of the regulatory environment and the operational needs of available laboratory procedures.

The multiple uses of TCLP may require the development of multiple leaching tests. The result may be a more flexible, case-specific, tiered testing scheme or a suite of related tests incorporating the most important parameters affecting leaching. Applying the improved procedure(s) to the worst-case scenario likely to be encountered in the field could ameliorate many problems associated with current procedures. Although the Committee recognizes that these modifications may be more cumbersome to implement, this type of protocol would better predict leachability.

Many parameters that affect the leachability of contaminants in the field are not addressed in the current TCLP. Indeed, it would be difficult to accommodate all the parameters affecting leaching into a single protocol. However, the most important of these parameters should be considered. Although the Committee does not offer any advise to the Agency, at this time, on which parameters will be most important to consider for the various applications, the Enclosure discusses many of these parameters and their effects. Because this is a large undertaking, the EEC suggests that EPA first upgrade the primary uses of the TCLP and then address ancillary uses of the test.

The EEC would be happy to assist the Agency in providing consultation on specific issues germane to the revision of the Agency's leaching protocols. We look forward to the response of the Assistant Administrator for the Office of Solid Waste and Emergency Response.

Sincerely,

Signing for the Science Advisory Board:
Dr. Joan Daisey, Chair,
Dr. Hilary Injang, Chair,
Environmental Engineering Committee
Dr. Domenico Grasso, Chair
Leachability Subcommittee (Head of Dept. of Civil & Environ. Eng., Univ. of Connecticut, Storrs, CT)

Enclosure A

1. **Background:** The Resource Conservation and Recovery Act (RCRA) defines hazardous wastes as solid wastes that may pose a substantial present or potential hazard to human health and the environment when improperly managed. The Agency promulgated characteristics that classify wastes as hazardous by virtue of their inherent properties (45 FR 33084). In this final rule, the Agency established two criteria for identifying hazardous waste characteristics: (1) The characteristic should be capable of being defined in terms of physical, chemical, or other properties which cause the waste to meet the statutory definition of hazardous waste and (2) the properties defining the characteristic must be measurable standardized and available testing protocols." Under this rule, the potential for certain wastes to leach significant concentrations of toxic substances is a defining characteristic. In order to identify wastes that may exhibit such leaching behavior, the Agency, at present, uses the TCLP.

The TCLP results from EPA's efforts to improve upon the earlier Extraction Procedure (EP) Toxicity Characteristic (EPTC). The major shortcomings of the EPTC were its inaccuracy when applied to organic constituents and the lack of useful benchmarks for determining toxicity levels. The Hazardous and Solid Waste Amendments (HSWA) in 1984 directed EPA to make changes in the testing procedure to predict the leaching potential of a waste more accurately. To better address the leaching behavior of organic compounds, EPA replaced the EPTC with TCLP. The TCLP, like EPTC, assumes a worst-case mismanagement scenario involving co-disposal in a MSW landfill.

Two difficulties with the TCLP are: (1) the TCLP does not account for the many parameters that affect leaching and (2) the TCLP has been applied in situations where it is not appropriate. The latter is important because a test designed to predict leaching in MSW landfills may over- or under-predict leaching potential in other scenarios. Given the broad-based application of TCLP, scientific issues related to its appropriateness, as a predictor of leaching must be addressed in the general context of its use. Section 4. addresses leach test parameters in some detail.

This commentary focuses on issues associated with the TCLP regarding the breadth of its application and the need to account for a wider range of parameters. The 1991 EEC commentary, *Leachability Phenomena* (EPA-SAB-EEC-92-003), identified concepts and principles that should be incorporated into any analytical protocol that is aimed at assessing contaminant leaching potential from wastes.

More specifically, *Leachability Phenomena* recommended an Agency-wide effort to:

- Study and better understand mechanisms controlling leachability,
- Develop better conceptual models for waste management scenarios
- Evaluate stresses affecting long-term contaminant release potential
- Develop a variety of contaminant release tests and test conditions to assess potential release of contaminants from sources of concern
- Improve mathematical models to complement laboratory tests of leachability
- Field test leach tests before being broadly applied

Ideally, testing procedures bear a rational relationship to the actual conditions under which waste is managed and consider the many parameters that affect the leaching behavior of contaminants from a waste. The TCLP does not address all parameters and scenarios. As a result, the TCLP is more accurate in some applications than in others.

Where important parameters are not considered and the scenario does not relate to actual disposal conditions, decisions based on the test results may not protect the environment or human health. *Leachability Phenomena* pointed out that "prior to developing or applying any leaching tests or models, the controlling mechanisms must be defined" and "an understanding of how they (directly or indirectly) influence release and environmental fate should be established." *Leachability Phenomena* stated, "any extrapolation of a set of conditions or stresses appropriate for one purpose should not be applied to another without reasonable verification of relevance." Moreover, such extrapolation must be scientifically and legally defensible.

The remainder of this enclosure describes the TCLP test and its recent uses, discusses leach test variables in light of both waste classification and risk assessment, and presents issues pertinent to waste management in the field that should impact the development and implementation of an appropriate test. Finally, any EPA leaching test must insure statistically rigorous methods for sample acquisition and analyses that minimize uncertainty and maximize the likelihood of accurate and representative results.

2. **Description of the Toxic Characteristics Leaching Procedure:** The Toxicity Characteristics Leaching Procedure (TCLP) is a batch test developed by the EPA in response to deficiencies in the Extraction Procedure (EP).[6] Many of the assumptions used in developing the EP are retained. For example, the TCLP models co-disposal of industrial wastes with municipal solid waste in a sanitary landfill. The model assumes 5 percent industrial waste and 95 percent municipal waste.[7] However, the TCLP has important differences from the EP.

The TCLP specifies a procedure for liquid wastes, which are those with less than 0.5 percent dry solid material and for wastes containing greater than or equal to 0.5 percent dry solid waste. For liquid wastes, the waste is filtered through a 0.6-0.8 μm glass fiber filter. The liquid after filtration is defined as the TCLP extract. For wastes containing greater than or equal to 0.5 percent dry solid waste, the liquid must first be separated and stored for later analysis. The solid phase may then undergo size reduction.[8] The EP required particle size reduction where the waste could not pass through a 9.5 mm sieve or has a surface area of less than 3.1 cm^2/gm. This requirement is retained by the TCLP. However, where the EP allowed the use of the Structural Integrity Procedure (SIP) for monolithic wastes, the TCLP does not. The SIP accounts for the effects of waste material physical durability on contaminant leachability. In the TCLP, the waste must be ground or milled until it passes a 9.5 mm sieve.

While the EP used only one extraction fluid, the TCLP uses two. A pH 2.9 acetic acid solution is used for moderately to highly alkaline wastes and pH of 4.9 acetate buffer solution is used for all other wastes.[9] The TCLP also uses two types of extraction vessels. For volatile compounds, a zero headspace vessel is used while bottles are used for non-volatile compounds.[10] The TCLP specifies rotary agitation in an end over end fashion at 30 ± 2 rpm. The extraction period for the TCLP is set at 18 hours.[11] The extraction fluid is filtered using a 0.6-0.8 μm glass fiber filter. [12] Unless multiple phases will form on combination, the extraction fluid is combined with the initial liquid phase. The combination is then analyzed. Otherwise, the liquids are analyzed separately and then mathematically combined to give a volume-weighted average concentration.[13]

3. **Uses of TCLP:** Although promulgated as a test of the toxicity characteristic of contaminants in a waste, TCLP has found a variety of other applications. For example, TCLP has been used in administrative delisting procedures, as an end point test for clean-up standards and as a source term (often implying an infinite source) for risk assessments/site closure modeling.

The appropriateness of employing TCLP for these and other uses is questionable because the TCLP does not account for the variety of processes that can affect leachate quality, quantity, and migration. Not all of these factors are equally important in every situation, of course, which makes guidance particularly important. The Committee recommends that the EPA consider issuing a policy statement on the appropriate use – and limitations – of the TCLP and/or other leaching tests. EPA should also consider developing guidance on the relative importance of each parameter as it pertains to particular applications (such as waste delisting petitions, source term estimates, etc.).

4. **Leach Test Parameters**

a. Kinetics: The TCLP is based on an extraction time of 18 hours. This time frame was arbitrarily chosen and does not necessarily bear any relation to an equilibrium state. Moreover, the point at which the system is poised in relation to equilibrium will be variable. For some constituents, the 18-hour extraction period could approximate the time to equilibrium. However, for others, it could be years away. Moreover, mass transport domains governing batch leaching in the TCLP are physically quite different from flow regimes experienced in the field. Some solid matrices display a long period of slow release that may be more relevant to the protection of health and the environment than the early, fast release. This slow release may or may not persist above the regulatory levels. For some constituents, the TCLP may not measure this slow release. Consequently, the extensibility of TCLP data to developing an understanding of the mobility of contaminants in the field is tenuous. However, as the *Leachability Phenomena* document pointed out, in the majority of contaminant release cases, the equilibrium situation does not apply with the result that rate limiting chemical and physical reactions are more important to the analysis.[14]

> Therefore, quantifying the kinetics of release is of significant importance. Determining the controlling mechanisms for the scenario and selecting appropriate testing periods should improve the accuracy of the leach test(s).

b. Liquid/Solid Ratio: The TCLP uses a 20:1 liquid to solid ratio. This ratio was chosen for analytical and

administrative procedural purposes. In the field (in either MSW landfills or natural environments), liquid to solid ratios can vary significantly depending upon conditions. Variables such as weather, climate, and infiltration rates as well as hydrological impacts of engineered systems can result in substantial deviations from this ratio. Furthermore, if saturation is experienced, the relative solubility of some constituents may be suppressed.

It is especially important to consider such variables where the leach test is being used to predict behavior in the field.

c. pH: The TCLP assumes that, in the MSW landfill scenario, the disposal venue (not the waste) governs the leaching fluid chemistry. The two current TCLP leaching fluids cannot account for the full diversity of wastes and waste management conditions. As a result, the TCLP does not always accurately predict the concentrations of various constituents that will actually be found in leachates. For example, a recent study indicated that pH values of MSW leachates (pH 6-8.5) were generally higher than pH values used in the TCLP.[15] This difference in pH was thought to cause the higher than predicted concentrations of regulated metals that form ox anions (e.g. Sb, As, Mo, Se, V) in MSW leachate. Many contaminants do not leach from waste matrices.

The treatment of alkaline wastes is another difficulty because the TCLP may underestimate the leaching potential of such wastes. First, continuous long-term contact with an acidic medium may exhaust the alkalinity thus increasing the leaching potential of an alkaline waste. Second, the leachability of certain waste constituents may increase under alkaline conditions.

Similarly, aggressive simulated MSW leachate (i.e. TCLP fluids) may significantly over predict the availability and mobility of contaminants in natural settings. It is doubtful that any test will address the full diversity of conditions at sites at which wastes are managed. Modeling is another way to address this difficulty.

Addressing such situations, in which field chemical conditions are not well represented by the TCLP[16] should result in improvements to the leach test procedure(s).

d. Colloid Formation: Colloids may be formed during the end-over-end agitation required by TCLP testing. The forces exerted during the agitation process may overcome the adhesion or cohesion forces of some constituent particles. This aggressive agitation can dislodge or otherwise create colloidal particles, which may pass through the filtering process and subsequently be analyzed as part of the extract. Hydrophobic organics and metals can preferentially bind to these colloidal particles. The detached colloidal particles in the extraction fluid may result in an over-prediction of the aqueous phase of the constituent by the TCLP[17].

Colloidal phase constituents may not be representative of field speciation and should be treated differently from dissolved constituents in risk analyses. An appropriate and representative solid/liquid separation procedure should be incorporated into the revised testing procedures.

e. Particle Size Reduction: TCLP particle size reduction requirements may not represent field condition. The TCLP requires that solids must be reduced in size to pass a 9.5 mm sieve before the waste is mixed with the extraction fluid. This reduction in size increases the specific surface area of the particles, which increases the leaching potential. Monolithic wastes have a lower leaching potential due to physical stabilization and the resultant increase in the length of the diffusion pathway from waste into the leachate. Additionally, some processes also provide for chemical stabilization by binding heavy metals in insoluble hydroxide and other complexes.[18] Consequently, reductions in leachability that derive from solidification/stabilization associated with monolithic wastes are ignored.[19]

Leachability Phenomena recommended that low strength wastes should be milled. Moderate strength wastes should be tested sequentially as they are gradually reduced in particle size. High strength wastes could be agitated "as is." Further, the commentary asserted that wastes agitated "as is" will break up leaving only stronger portions intact.[20] This "as is" agitation may more accurately represent the conditions in which the waste exists.

Reduction in particle size also affects testing of volatile compounds. Although the use of the zero headspace extractor vessel (ZHE) reduces the loss of volatiles during sample preparation procedures, particle size reduction of a waste containing volatiles will result in losses before the waste is introduced into the ZHE. The problems with particle size reduction were discussed in the proposed rule in which the TCLP was introduced. EPA concluded that the advantages of particle size reduction outweighed the potential problems. In light of the comments above, the Committee recommends that EPA revisit the issues of volatile loss and/or increases in constituent solubility.

f. Aging: At present, the TCLP protocol requires that wastes be tested at the time of generation. Should significant time elapse from time of generation to time of disposal, chemical, or physical transformations may take place compromising the validity of TCLP results as a predictor of leachable concentrations.

Similarly, if a leach test is used for risk assessment purposes, it should accommodate transformations that may be expected over the time frame of model predictions. The Agency should address aging considerations in its revised protocol.

g. Volatile Losses: The volatility of the waste may result in losses during the leaching procedure and analysis. The EPA requires the use of a zero-headspace extraction vessel (ZHE) when testing volatiles. However, as discussed above, sample handling(e.g. particle size reduction) may also result in loss of volatile compounds. Additionally, when addressing volatile compounds, the most important pathway for release to the environment may not be leachability. The mass release through volatile losses must be considered in these cases.

h. Interaction with Other Wastes: The TCLP assumes municipal solid waste leachate governs leachate chemistry and rate of release. However, many other scenarios are possible, some of which may lead to an increase in the leachability when compared to the standard generic case.

Leachability Phenomena pointed out that, in the presence of co-solvents, solubility of the constituents in the organic phase rather than aqueous phase may control the leachate concentration.[21] Similarly, surfactants may also mobilize hydrophobic contaminants. Testing procedures and analyses of results should address the issues associated with the presence of co-solutes in either a waste classification or risk assessment scenario.

5. **Related Field Issues**

a. Multiple Phases: At some contaminated sites, residually trapped mixtures of hydrocarbons exist that take the form of non-aqueous phase liquids (NAPL). The release of chemicals into ground water is affected by both the dissolution of the NAPL mixture and desorption from the soil matrix.[22] The multi-component release from the residually trapped mixture must be considered to accurately predict contaminant concentrations. When testing a multi-component NAPL mixture with the TCLP, the more soluble fraction will dissolve first, yielding an inaccurate portrayal of the behavior over a longer period of time. Similarly, precipitation and dissolution reactions may bias TCLP results away from what may be observed in the field. Procedures to accommodate the potential presence of multiple phases should be developed.

b. Field Validation of the Test: The 1991 EEC commentary, *Leachability Phenomena,* suggested that leach tests should be field validated before broad application. By simulating field conditions with appropriate test variables, more accurate and precise results can be achieved.[23] The TCLP was not intended to be representative of in-situ field conditions but rather of a generic MSW landfill worst-case scenario. There should be means of reconciling any leach test results with expected or observed field leachate concentrations. The use of an appropriate model would be helpful in this regard. Modeling and/or monitoring could help in defining such field conditions, and then provide a framework for possible use of the TCLP results within a site-specific risk assessment framework. Consequently, should the ultimate disposal scenario for either risk classification or risk assessment be significantly different than the MSW landfill case, field validation of any revised protocol may be necessary.

Wastes sampled from different locations at the same site could yield different results. The contaminants themselves could also be different from one area of a site to another. This heterogeneity could affect concentrations in the leachate and interactions between co-disposal wastes. For either the waste classification case or the risk assessment case, a rigorous statistically based sampling protocol to account for representativeness and to minimize uncertainty should be developed and adopted.

NOTICE

This report has been written as part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the EPA, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use.

THE SURFACE MINING CONTROL AND RECLAMATION ACT: A RESPONSE TO CONCERNS ABOUT PLACMENT OF COAL COMBUSTION BY-PRODUCTS AT COAL MINES

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Abstract

The use and disposal of Coal Combustion By-Products (CCBs) (i.e., fly ash, bottom ash, flue gas desulfurization material, and fluidized bed combustion material) at coal mines has become an area of intense interest, research, activity, and controversy during the last decade. The U.S. DOI, Office of Surface Mining (OSM) was created in 1977 as part of the Surface Mining Control and Reclamation Act (SMCRA) to provide minimum levels of protection concerning public health, safety, and the environment, and balance this with the need for a viable U.S. coal supply. Since May of 1994, OSM has taken an active role in encouraging and promoting technological advances, research, and technology transfer related to the use and disposal of those material residues remaining after the combustion of coal to produce electric power.

Currently, there are less than 2 percent of the CCBs that are produced in the United States that are placed back at less than 2 percent of the mines sites where they originated. Most of the uses to date have been extensively researched. This research indicates that the placement of these materials on the mine site usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards. It also can be used to improve the economics of mining when used as a non-toxic fill within the spoil area prior to grading and final reclamation. Beneficial uses include: (1) a seal to contain acid forming materials and prevent the formation of acid mine drainage; (2) an agricultural supplement to create productive artificial soils on abandoned mine lands where native soils are not available; (3) a flowable fill that seals and stabilizes abandoned underground mines to prevent subsidence and the production of acid mine drainage; (4) a construction material for dams or other earthlike materials where such materials are needed as a compact and durable base; and (5) a non-toxic, earthlike fill material for final pits and within the spoil area.

The recycling of these materials into useful products has attracted a great deal of interest as a raw material for basic construction products off the mine site. Concerning CCB placement at coal mine sites, some environmental groups believe the use of these materials places an unacceptable risk on public health and environmental quality. This paper will attempt to provide a response to public criticism concerning the relative adequacy of SMCRA programs that protect public health and the environment when CCBs are placed at a SMCRA permitted mine site.

A Brief History of U.S. Environmental Protection Agency (EPA) Rule-making on CCBs Related to Their Use and Disposal on Coal Mine Sites

In October of 1980, Congress temporarily exempted from regulation, under Subtitle C of the Resource Conservation and Recovery Act (RCRA), certain large volume fossil fuel wastes (FFW) and then directed the U.S. EPA to conduct a detailed and comprehensive study of fossil fuel wastes based on eight study factors.

On August 9, 1993, the U.S. EPA made a regulatory determination that the four large volume FFWs do not warrant regulation as hazardous under Subtitle C of RCRA. EPA commits to a schedule to complete the report to congress for the remaining wastes.

In its decision on May 22, 2000, the U.S. EPA determined that national regulations under Subtitle D (Solid Waste) of the Resource Conservation and Recovery Act (RCRA) [and/or possible modifications to regulations under the Surface Mining Control and Reclamation Act (SMCRA)] were warranted when these wastes are used to fill surface

or underground mines. EPA believes this is necessary so that CCBs will be consistently managed across all waste scenarios. EPA expects to have a proposed rule out under Subtitle D of RCRA (Solid Waste) in 2003 and a final rule by 2004.

Purposes of SMCRA

The purposes of SMCRA are given in the Act as follows, 30 U.S.C. 1202:

- Establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations.
- Assure that the rights of surface landowners and other persons with a legal interest in the land or appurtenances thereto are fully protected from such operations.
- Assure that surface mining operations are not conducted where reclamation as required by the Act is not feasible.
- Assure that surface coal mining operations are so conducted as to protect the environment.
- Assure that adequate procedures are undertaken to reclaim surface areas as contemporaneously as possible with the surface coal mining operations.
- Assure that the coal supply essential to the Nation's energy requirements, and to its economic and social well-being is provided and strike a balance between protection of the environment and agricultural productivity and the Nation's need for coal as an essential source of energy.
- Assist the States in developing and implementing a program to achieve the purposes of the Act.
- Promote the reclamation of mined areas left without adequate reclamation prior to the enactment of the Act and which continue, in their unreclaimed condition, to substantially degrade the quality of the environment, prevent or damage the beneficial use of land or water resources, or endanger the health or safety of the public.
- Assure that appropriate procedures are provided for the public participation in the development, revision, and enforcement of regulations, standards, reclamation plans, or programs established by the Secretary or any State under the Act.
- Provide a means for development of the data and analyses necessary to establish effective and reasonable regulation of surface mining operations for other minerals.
- Encourage the full utilization of coal resources through the development and application of underground extraction technologies.
- Stimulate, sponsor, provide for, and/or supplement present programs for the conduct of research investigations, experiments, and demonstrations, in the exploration, extraction, processing, development, and production of minerals and the training of mineral engineers and scientists in the fields of mining, minerals resources, and technology, and the establishment of an appropriate research and training center in various States.
- Wherever necessary, exercise the full reach of Federal constitutional powers to insure the protection of the public interest through effective control of surface coal mining operations.

Response to Concerns about the Placement of Fly Ash, Bottom Ash, Flue Gas Desulfurization Material, and Fluidized Bed Combustion Ash at SMCRA Mine Sites

Concern #1: Mine filling (with CCBs) is not adequately addressed by SMCRA.

RESPONSE: There is no exemption for any coal combustion by-product placed at a SMCRA mine site from any of the permitting requirements and environmental performance standards contained in SMCRA. When the use or disposal of coal combustion by-products happens at surface coal mines, State and Federal coal mining regulators are involved to the extent that SMCRA requires[2]:

- the mine operator to ensure that all toxic materials are treated, buried, and compacted, or otherwise disposed of, in a manner designed to prevent contamination of the ground or surface water;
- making sure the proposed land use does not present any actual or probable threat of water pollution; and
- ensuring the permit application contains a detailed description of the measures to be taken during mining and reclamation to assure the protection of the quality and quantify of surface and groundwater systems, both on and off-sites, from adverse effects of the mining and reclamation process also to assure that rights of present users of such water are protected.

Any disposal of coal combustion by-products at mine sites must be in accordance with SMCRA standards, State and

Federal Clean Water Act requirements, and with applicable State solid waste disposal requirements. The States differ in their regulatory requirements for disposal of coal combustion by-products as solid waste. Trace element concentrations in coal combustion by-products vary according to where the coal was mined and how it was processed. Chemical and physical site characteristics differ by region. Accordingly, State regulatory programs that allow use or disposal must be designed to handle those differences.

Based on the extensive body of research [1,3] that has been focused on this issue over the last 20+ years that has shown many positive environmental effects and no negative effects, the author concludes that SMCRA is providing adequate protection of public health, safety, and the environment.

Concern #2: These materials (CCBs) are wastes containing significant quantities of hazardous constituents.

RESPONSE: Research[4] has shown that less than 1 percent of these materials have the potential to leach hazardous constituents (According to nationwide analysis by the U.S. Department of Energy with only two out of 288 sources, or 0.7 percent, of the CCBs tested demonstrated the potential to leach trace elements at levels that would be classified as hazardous).

Concern #3: Only RCRA has the authority to address the problems presented by solid and hazardous waste.

RESPONSE: Although no regulatory authority can contradict RCRA, many other State and Federal regulations can and do apply to the handling of wastes or recycled materials. RCRA is not exclusive. It is interesting to note that all of the few examples of potentially hazardous constituents contaminating ground or surface water produced from these materials were produced under the regulation of the U.S. EPA that implements RCRA and none under the U.S. OSM that regulates SMCRA.

Concern #4: These materials, when exposed to groundwater, leach hazardous constituents.

RESPONSE: Research[4] has shown that less than 1 percent of these materials have the potential to leach hazardous constituents based on laboratory testing with the TCLP method. Based on U.S. EPA groundwater monitoring of more than 1,000 wells at electric utility CCB disposal areas nationwide, the data has demonstrated that only 12 of those wells have produced water at levels considered hazardous and none from SMCRA mine sites. All of the SMCRA water monitoring data I am aware of to date, indicate that placement of these materials at SMCRA mine sites does not produce groundwater that has hazardous constituents and in most cases is environmentally beneficial.

Concern #5: The leaching process may take decades, but significant quantities of toxic constituents will exit a deposit of these materials, often severely impacting ground and surface water.

RESPONSE: The SMCRA permitting process is designed to prevent both the acceptance of any CCB materials that have the potential to harm public health or the environment and the placement of materials in such a manner on the mine site that they would have the potential to leach toxic levels of constituents. The SMCRA mining and reclamation plan is designed to ensure that the placement of the material will not have the potential to contaminate either the ground or surface water. The SMCRA water-monitoring plan is designed to demonstrate that the SMCRA permitting and planning process has been successful in protecting the environment both during and after mining.

The author would agree that in some hydrogeologic settings it may take decades to restore the long-term water table at a mine site (specifically in the arid Western United States). The chemical nature of these CCB materials, however, is such that any constituents leached from them will leach very rapidly at first and then be reduced to barely detectable levels. This means that water-monitoring data will quickly identify the worst possible leachate characteristics that could be expected from placement of these materials at a mine site. Based on the extensive body of research [1,3] that has been focused on this issue over the last 20+ years that has shown many positive environmental effects and no negative effects, the author concludes that SMCRA is providing adequate protection of public health, safety, and the environment.

Concern #6: The use of these materials as mine fill threatens to cause problems more severe than the conditions it was intended to ameliorate (i.e., reduce acid mine drainage).

RESPONSE: Recent studies by the U.S. Geologic Survey[5] have successfully utilized magnesium to calcium ratios and sulfur-isotope ratios as tracers on pressurized fluidized bed combustion (PFBC) by-product placed in an abandoned coal mine to mitigate the effects of acid mine drainage. The study demonstrates that the application has been environmentally beneficial both in dramatically decreasing the effects of acid mine drainage and that any remaining trace elements in the groundwater are due to acid mine drainage and not leachate from the PFBC.

Concern #7: The standard leaching test on a typical sample of these materials yields results indicating that these materials meet SMCRA's definition at 30 CFR 701.5 of a "toxic forming material" which means "earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are detrimental to biota (life) or uses of water." Yet nowhere in SMCRA, its regulations, or in OSM guidance is there any explanation or numerical standard that can be used to apply this definition in the field. Furthermore, SMCRA regulations employ confusing language that requires "contact (of water) with toxic producing deposits" to be either "prevented," "removed," or "minimized" without explaining what such deposits are or which of these directives should be applied in any particular case. The result is mine filling programs throughout the United States that range from those isolating these materials many feet above water tables to those allowing millions of tons of toxic forming materials to be dumped directly into groundwater aquifers that are being used for private and public water supplies.

RESPONSE: Most of these materials would not meet the SMCRA definition of toxic forming material because most of them have leachate characteristics in the same range as non-toxic native soil materials. Less than 2 percent of these materials have the potential to produce toxic levels of leachate. Because leachate tests are required as part of the SMCRA permit applications, the permit can not be approved until the operator demonstrates that the placement of the material in question on the mine site will not cause or contribute to contamination of the ground or surface water.

SMCRA language is not confusing. SMCRA requirements differ from RCRA requirements, however, because they are based on performance standards rather than design standards. By using performance standards, which are minimum levels of environmental protection, SMCRA allows for each State regulatory authority to develop methods and techniques that are most appropriate for the climate, geology, geography, and other site conditions that occur locally. It also allows the operator to design the site-specific mining and reclamation techniques that maximize the operator's efficiency and still insure the appropriate level of environmental protection. The result is that each State is allowed to develop a program specifically suited to its needs to protect the environment based on local conditions while maintaining a uniform national level of environmental protection. This result is supported by all existing scientific research and water monitoring which finds no evidence of damage to public health or environment due to the placement of these materials at SMCRA mine sites and in most cases actual improvement of ground or surface water quality. In those cases where they are used as soil amendments on abandoned mine projects, both researchers and State AML programs report improved plant growth.

Concern #8: Groundwater monitoring programs at active and inactive mines in Indiana, Illinois, Ohio, Kentucky, West Virginia, Pennsylvania, Texas, North Dakota, and New Mexico have been reviewed and found that, without exception, none of the groundwater monitoring at these sites approaches the standard level of groundwater monitoring undertaken at RCRA solid or hazardous waste disposal facilities.

SMCRA is different from RCRA in that SMCRA uses minimum environmental performance standards that allow adaptation to site specific conditions while RCRA applies uniform engineering design standards without regard for local site conditions. Each uses different methods to achieve the same end of protection of public health and the environment. SMCRA requires that water monitoring plans at a SMCRA mine site, including those where placement of these materials takes place on the mine site, must be designed to protect the current and approved post-mining land use and to protect the hydrologic balance and to comply with existing State and Federal Water Quality laws and regulations. The final proof is that there is no credible evidence that SMCRA has not protected the public or the environment where these materials have been placed at a SMCRA mine site. All of the scientific evidence to date shows that placement of these materials at SMCRA mine sites has either been environmentally beneficial or has had no negative effect.

Concern #9: At many inactive mines used as fills for these materials, there is no monitoring at all because OSM and the States fail to require such monitoring at abandoned mine reclamation projects.

RESPONSE: At SMCRA abandoned mine land projects, the State Regulatory Authority is required to apply for a NPDES permit under the Clean Water Act. If the State Clean Water Authority requires an NPDES permit, then the project must obtain the permit and comply with any applicable monitoring or water quality requirements. A recent study by Ralph Haefner of the U.S. Geological Survey [5] conducted testing and monitoring to determine the impact of placing CCBs at an abandoned mine land reclamation site contaminated by acid mine drainage. This study proved that water quality after application of the CCBs was greatly improved following CCB placement at this site and that any remaining potentially toxic elements were a result of the historic acid mine drainage and not due to leachate from the CCBs.

Concern #10: In EPA's May 2000 Determination on Wastes from the Combustion of Fossil Fuels, the agency expressed concern over the lack of groundwater monitoring at (electric utilities not covered by SMCRA) CCW landfills and surface impoundments. EPA pointed out that 62 percent of (electric utilities not covered by SMCRA) CCW surface impoundments lack groundwater monitoring systems. The commenter supports EPA's concern about the lack of monitoring and liners at (electric utilities not covered by SMCRA) CCW landfills and surface impoundments and the need for RCRA controls. The commenter believes it follows logically that this concern should extend to the much greater quantities of these materials placed in mines, sometimes in direct contact with groundwater.

RESPONSE: It is not valid to compare utility fossil fuel waste disposal sites where toxic leachate has occurred with SMCRA mines sites where toxic leachate has not occurred, as they differ significantly in terms of regulatory requirements, geology, geography, hydrology, characteristics of materials placed, and reclamation practices.

Electric Utility CCB Disposal Facility

Electric utility disposal sites where toxic leachates have occurred are typically characterized by:

- geographic placement in a floodplain;
- a geologic setting of alluvial sand and gravel usually close to a river;
- groundwater that is plentiful and of high quality;
- all types of fossil fuel wastes are placed in these facilities in a wet slurry without any chemical characterization of the material;
- reclamation is accomplished with a shallow layer of fill over the area and revegetated; and
- the Clean Water Act usually covers the area during operation and State Solid Waste regulations at disposal (Figure 1).

SMCRA Mine Site CCB Placement

CCB placement at mine sites typically is characterized by:

- a geographic placement in an upland position;
- a geologic setting of bedrock sandstone, shale, and limestone underlain by an impermeable fire clay below the lowest coal seam that was mined;
- groundwater is limited and of poor quality;
- only those CCBs that are leachate tested and approved in the SMCRA permit are allowed for placement on the mine site;
- reclamation is accomplished with a deep layer of spoil over the area followed by topsoil and then revegetated; and
- at all phases, the placement is regulated by the environmental protection permitting and performance standards of SMCRA, which include the requirements of the Clean Water Act and applicable State Solid Waste program requirements (Figure 2).

TYPICAL UTILITY CCB STORAGE/DISPOSAL AREA

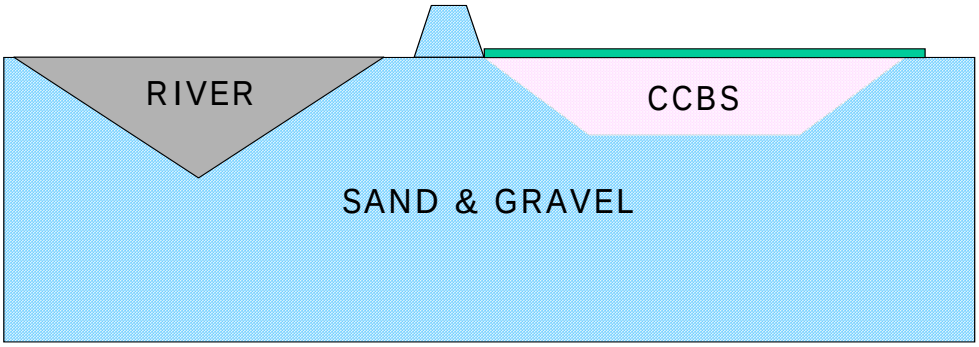

Figure 1. Typical cross-section of an electric utility disposal site where toxic leachate has occurred.

TYPICAL CCB FILL AT MINE

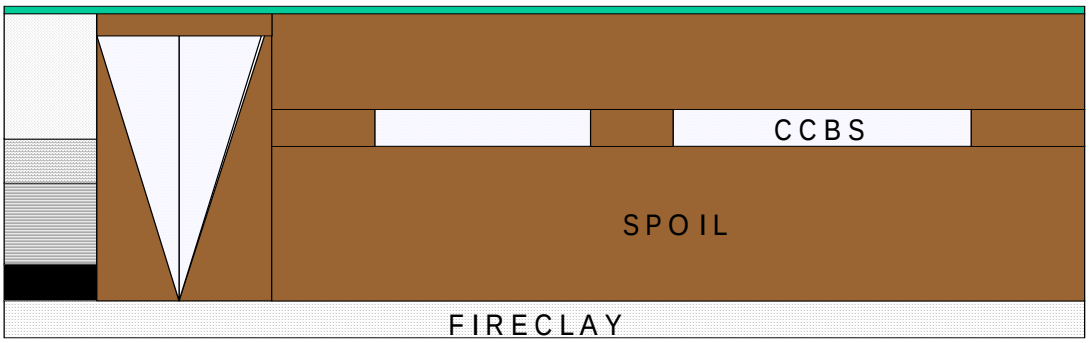

Figure 2. Typical cross-section of CCB placement at a reclaimed coal mine site.

According to the U.S. Geological Survey and the American Coal Ash Association [6], in 2000 the total production of these materials was 98.2 million metric tons. Of that total, 29.1 percent was recycled as commercial products and 1.55 million metric tons or 1.6 percent was placed at mines sites. The remaining 69.6 million metric tons or 70.9 percent was placed in surface impoundments of landfills under the control of the electric utility industry. Neither logic nor simple arithmetic would support the claim that much larger quantities of these materials are placed at mine sites than by electric utilities in surface impoundments or landfills.

Concern #11: Without exception, OSM and State mine regulatory officials interpret the requirements of SMCRA to mean that groundwater monitoring at mine fills need only take place through the final release of mine reclamation bonds. This typically occurs within three to eight years after mining when surface revegetation is met and mine operators have demonstrated that the post-mine groundwater recharge capacity exists. Thus, given the slow and usually unpredictable rate of groundwater resaturation around mine fills, monitoring is stopped many years if not

decades before down gradient flows of groundwater, much less plumes of fossil fuel waste contaminants, would even be detectable from these sites. Without the bonds being held for much longer periods, no financial assurance is available. Furthermore, the commenter has yet to find a mine reclamation bond valued at a level that would cover the costs for post-closure monitoring or maintenance of a mine fill placement site nor has the commenter found a groundwater monitoring program at such a site with a numeric standard or concentration of pollution that could constitute a corrective action standard.

RESPONSE: OSM has not provided any interpretation of the SMCRA requirements for duration of performance bonds other than the plain language of 30 CFR 800.13(a)(1) that performance bond liability shall be for the duration of the surface coal mining and reclamation operation and for a period which is coincident with the operator's period of extended responsibility for successful revegetation provided in 816.116 or until achievement of the reclamation requirements of the Act, regulatory programs, and permit, whichever is later. At a minimum, 30 CFR 816.116(c) requires the period of extended responsibility for successful revegetation after the last year of augmented seeding.... And in areas with more than 26 inches of annual precipitation for five full years and in areas with less than 26 inches of annual precipitation for ten full years. In practice, OSM has found that most operators do not achieve a Phase III release until long after this minimum time period. In the year 2000 OSM annual report, OSM records that there were 4,530,710 acres under SMCRA permit. In that same year 63,071 acres, or 1.4 percent of that acreage, received a full Phase III bond release. At that rate of release, it would take almost 72 years to release the remainder of the acreage currently under permit.

What is important, concerning SMCRA performance bonding duration, is that SMCRA requires that the bond not be released until all of the reclamation requirements of the SMCRA, including protection of water quality, is achieved. To date, there has been no scientific evidence to support the claim that water monitoring, where these materials are placed at a mine site, needs to be longer than that required for proof of revegetation success. If such evidence were eventually produced, then SMCRA would require that the bond be maintained until the minimum performance standards were met regardless of the time it took.

The argument that a determination of potential water quality contamination cannot be determined until the volume of groundwater has reached complete resaturation is not scientifically valid. Research to date[1,3], indicates that release of leachable trace elements from CCBs placed at mine sites is not at levels that: (1) threatens public health or the environment, (2) takes place very quickly when placed in contact with water, (3) cannot be quickly absorbed by the surrounding spoil materials (usually dominated by clay and silt sized particles produced by shale rock in the overburden), and (4) that any long-term leachate from these materials at SMCRA mine sites does not pose any threat to public health or the environment.

Concerning the bond amount, no value for post closure monitoring and maintenance of the placement sites can be assessed when the best science available indicates that none will be necessary. Concerning a numeric standard for water quality, SMCRA requires that water monitoring plans at a SMCRA mine site, including those where placement of these materials takes place on the mine site, must be designed to protect the current and approved post-mining land use and to protect the hydrologic balance and to comply with existing State and Federal water quality laws and regulations. SMCRA is based on performance standards rather than design standards. By using performance standards, which are minimum levels of environmental protection, SMCRA allows for each State Regulatory Authority to develop methods and techniques which are most appropriate for the climate, geology, geography, and other site conditions that occur locally. It also allows the operator to design the site-specific mining and reclamation techniques that maximize the operator's efficiency and still insure the appropriate level of environmental protection. The result is that each State is allowed to develop a program specifically suited to its needs to protect the environment based on local conditions while maintaining a uniform national level of environmental protection. This result is supported by all existing scientific research and water monitoring which finds: (1) no evidence of damage to public health or the environment due to the placement of these materials at SMCRA mine sites; (2) in most cases, actual improvement of ground or surface water quality; and, (3) in the cases where they are used as soil amendments, improved plant growth on the surface.

Concern #12: In contrast to (RCRA) landfills, there are no on-site restrictions for future use of mine fill properties. Placement of these materials at mine sites can cover large areas up to several thousand acres. The commenter has yet to find a State mine fill program or OSM requirement that obligates a mine operator to post a notice that disposal

of fossil fuel waste has even occurred at a mine fill, no matter how large the scale.

RESPONSE: SMCRA requires mining and reclamation plans, including those incorporating placement of these materials at the mine site, to be proposed, reviewed, and approved as a part of the permitting process. SMCRA requires at 30 CFR 773.13 that all permit applications, significant revisions, and renewals of all permits be advertised in local newspapers and copies of the application materials be made available to the public. All SMCRA permitting documents, except for certain proprietary information, are a matter of public record. Since SMRCA also requires that the pre-mining capability of the land be restored following mining and reclamation, there is no need for on-site restrictions.

Conclusion

OSM has been extensively involved with the development and distribution of technical information related to the beneficial placement of CCBs at coal mine sites. Because of the complexity of the issues involved and the importance of protection of public health and the environment during surface coal mining and reclamation, OSM is very supportive of additional research into the potential environmental effects of CCB placement at coal mine sites. The author's assessment of the 20+ years of research on the subject to date indicates that the placement of these materials on SMCRA mine sites usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards or as a non-toxic fill to reduce reclamation costs. Any additional Federal regulation of CCB placement at SMCRA mine sites, however, should be based on sound scientific evidence that the existing regulatory framework is not adequate.

References

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[3] Kim, A. G., W. Aljoe, and S. Renninger. 2001. Wastes from the Combustion of Fossil Fuels: Research Perspective on the Regulatory Determination. U.S. DOE National Energy Technology Laboratory, Pittsburgh, Pennsylvania. 21 p.

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[5] Kalyoncu, R.S. 2001. Coal Combustion Products-Production and Uses. IN: Proceedings of the 18th International Pittsburgh Coal Conference. Session 34 Coal Combustion By-Products Utilization I. Newcastle, New South Wales, Australia.

Kimery Vories is a Natural Resource Specialist with the Office of Surface Mining since 1987. He is chairperson of several multi-agency, multi-interest group steering committees that hold forums, publish proceedings, and manage Internet Websites on mining and reclamation issues related to the technical aspects of Coal Combustion By-Products, Prime Farmland Reclamation, Reforestation, and Bat Conservation. He has been professionally employed in coal mining and reclamation since 1979 with 37 related professional publications. He serves on: (1) the National Steering Committee for the Combustion By-Products Recycling Consortium; and (2) the Technical Program Committee of the International Ash Utilization Symposium at the University of Kentucky. He holds a BA and MA in Biology/Geology from Western State College of Colorado with an additional three years Post MA Graduate work in Ecology and Reclamation at the University of Massachusetts and Colorado State University.

WHERE DO WE GO FROM HERE?

FORUM PARTICIPANT RECOMMENDATIONS

At the conclusion of the forum on April 18, 2002, the participants provided the following recommendations concerning issues or concerns deserving attention and efforts by the Coal Combustion By-Products Steering Committee.

1. Need to make an effort to have members of the environmental community represented at future meetings.

2. Need to include more data from the electric utilities that have been gathering this type of data for decades.

3. Need to have data from more long-term groundwater monitoring efforts.

4. Would like to see more in depth case studies that show the complete project, how it was done, how it was monitored, pre- and post-project land use, and the results for both successful and unsuccessful projects.

5. Need to see more data from non-coal mining projects, such as placement in quarries and in sand and gravel operations.

6. Need to see case studies for how the States evaluate and make decisions on approval of permits for placement of CCBs at mine sites. How is a determination made on where to place monitoring wells and how many and what kind?

7. How does a State determine that a CCB placement area is ready for Phase III bond release under SMCRA?

8. Would like to see a presentation of data from the Savanna River Ecology Lab on the environmental impacts of toxic leachate from ash ponds at a large electric utility.

9. In an acidic environment, how does the State use acid-base accounting to ensure that trace elements in the CCB material are not leached due to acidity in the environment?

10. Need to evaluate how future pollution controls will impact placement of CCBs.

11. Need to compare and contrast how the different States handle CCBs.

12. Need to evaluate how future fuels (mixing coal with other fuels) will impact placement of CCBs.

SURVEY RESULTS
CCBs AND WESTERN COAL MINES:
A TECHNICAL INTERACTIVE FORUM
PARTICIPANT COMMENTS AND RECOMMENDATIONS

CATEGORY OF PARTICIPANTS	# OF REGISTRANTS	% OF REGISTRANTS
TOTAL REGISTRATION	129	
TOTAL COMPLETING THE SURVEY	35	100
LEVEL OF SATISFACTION WITH THE FORUM		
EXTREMELY SATISFIED	12	35
VERY SATISFIED	22	65
SATISFIED	0	0
DISSATISFIED	0	0
VERY DISSATISFIED	0	0

COMPLIMENTS:

1. **Inviting an environmental speaker was a good idea!**
2. **Very good!**
3. **I thought this was a very good forum with a lot of good planning going into the development!**
4. **Forum was very well presented.**
5. **All speakers were very knowledgeable on their topics.**
6. **Very good discussions and great opportunity to talk with representatives from all groups.**
7. **Good Job!**
8. **Very good format! The presentations addressed a broad range of issues.**
9. **Events like this are critical if we hope to advance the science and find safe ways to manage and use this waste stream.**
10. **Well done! Well organized!**
11. **Very effective interactive discussion was very helpful!**

WHERE DID THE PARTICIPANTS COME FROM?
AND
WHO DID THEY REPRESENT?

PARTICIPANT AFFILIATION	# OF REGISTRANTS	% OF REGISTRANTS
State Agency	25	19
Electric Utility	24	19
Consultant	19	15
Mining	14	11
OSM	12	9
University	7	5
USGS	7	5
U.S EPA	5	4
Environmental Group	4	3
Native American	4	3
DOE	3	2
CCB Organization	3	2
Other	2	1

REGIONAL REPRESENTATION	# OF REGISTRANTS	% OF REGISTRANTS
WEST	64	50
EAST	33	26
MID-CONTINENT	31	23
INTERNATIONAL	1	1

PARTICIPANT RATING ON USEFULNESS OF TALKS
4.0=EXCELLENT; **3.0**=GOOD; **2.0**=FAIR; **1.0**=POOR

SESSION 1 CCBs: THE BASICS

PRESENTER	AVERAGE RATING	RATING RANGE
Rustu Kalyoncu	**2.4**	**4-1**
Ann Kim	**3.1**	**4-2**
Gretchen Hoffman	**3.0**	**4-2**
Bruce Boggs	**3.2**	**4-2**
Debra Pflughoeft-Hassett	**3.1**	**4-2**
Susan Thorneloe	**2.8**	**4-1**
OVERALL SESSION 1 AVERAGE	**2.9**	

SESSION 2 TESTING AND TERMINOLOGY

PRESENTER	AVERAGE RATING	RATING RANGE
Howard Humphrey	**2.8**	**4-1**

LeRoy Jacobs	**3.2**	**4-1**
David Hassett	**3.6**	**4-1**
Andrew Stewart	**3.1**	**4-1**
Ralph Haefner	**3.5**	**4-1**
Russell Hill	**3.3**	**4-1**
OVERALL SESSION 2 AVERAGE	**3.3**	

SESSION 3 WESTERN MINING APPLICATIONS/CASE STUDIES

PRESENTER	AVERAGE RATING	RATING RANGE
Andy Young	**3.3**	**4-2**
Gordon Criswell	**3.2**	**4-2**
Karl Koehler	**3.4**	**4-2**
Darrell Holmquist	**3.0**	**4-2**
Dianne Stockdill	**3.1**	**4-1**
Rick Holbrook	**2.8**	**4-1**
OVERALL SESSION 3 AVERAGE	**3.1**	

SESSION 4 ENVIRONMENTAL IMPACTS TO GROUNDWATER

PRESENTER	AVERAGE RATING	RATING RANGE
Joby Adams	**3.4**	**4-2**
Ann Kim	**3.3**	**4-2**
Ishwar Murarka	**3.1**	**4-2**
Andrew Wittner	**2.7**	**4-1**
David Hassett	**3.0**	**4-1**
Ishwar Murarka	**3.4**	**4-2**
OVERALL SESSION 4 AVERAGE	**3.2**	

SESSION 5 CCB REGULATORY DIRECTION

PRESENTER	AVERAGE RATING	RATING RANGE
Truett Degarre	**2.8**	**4-1**
Greg Conrad	**3.2**	**4-1**
Jim Roewer	**3.3**	**4-1**
Janet Gellici	**3.2**	**4-2**
Steve Tillotson	**3.5**	**4-1**
Dave Berry	**3.0**	**4-1**
Lisa Evans	**3.1**	**4-1**
Kimery Vories	**3.7**	**4-2**
OVERALL SESSION 5 AVERAGE	**3.2**	

SUGGESTIONS FOR IMPROVEMENT

APPLICATIONS OF CCBS AT ABANDONED MINE LANDS
- Need more information on applications on AML sites.

APPLICATIONS OF CCBS AS PRODUCTS
- Need more information on implications for concrete applications and concrete products.

CCB CHARACTERIZATION AND LEACHING
- More information on CCB chemical characterization.
- The first session on CCB Basics was much too basic for the audience and could have been reduced or eliminated.
- Need more scientific data on leaching of CCBs.
- What is the rational for requiring 50 years of water monitoring.

CCB PLACEMENT AT NON-COAL MINES
- Application and permit review process on CCB disposal at non-SMCRA mine sites.

ECONOMICS

- What are the economics of ash disposal and who pays?
- How does CCB disposal cost relate to total energy cost for electricity from coal?
- More on economics of CCB use and disposal.

INTERACTIVE DISCUSSION

- Have a social reception every evening of event for better discussion.
- Have a round table discussion on regulatory issues.
- Attendance at social reception would have been better if it was held the evening after topics on regulatory issues.
- More time for interactive discussion.

OTHER

- There was a lot of overlap in some presentations.
- Have the field trip in the middle of the forum followed by the talk on the site so it is still fresh.
- I got the most out of seeing what the other States were doing on CCB placement.
- Some overheads were unreadable.
- Having never been to Colorado I would have liked to have had an opportunity to see the mountains.
- Need a glossary sheet of terms and abbreviations for those that are unfamiliar with the terminology.
- Will there be such a forum in the Eastern United States?
- It will be critical to spread this data out to as many stakeholders as possible if any meaningful change is to come of these efforts.
- Need more engineering issues like analysis of mechanical stability and engineering design.
- It would have been better to hold the forum in downtown Denver so you would not need a rental car to get around.
- Need more funding opportunities for CCB projects.
- Dependence upon audience use of microphones was cumbersome.
- Have all speakers stand on podium for presentations.
- More case studies that balance successes and failures.
- Combine first two sessions and have more case studies.
- Consider 45-minute talks rather than 25 minutes for a more relaxed format.
- Several people missed the end of Session 5 because of needing to depart prior to the end of the forum.
- Need earlier adjournment time on last day.

PUBLIC PARTICIPATION

- Larger environmental input is needed from non-government organizations.
- A professional debate between environmental scientists and CCB scientists.
- Invite members of the public and allow them to present their ideas.
- What the public thinks and their level of awareness is important.
- The public is irritated by activists and suspicious of big companies. We believe that industry can be understood and that a clear welcoming of the public with the right tone would make a huge difference to the welfare of industry.
- Environmental technical experts should be included at future forums so their "scientific" questions could be discussed.
- While not everyone appreciated the environmental groups, I was glad they were there. We may not always agree, but we must listen to each other.
- I would have liked to see environmental groups present.
- Have an entire forum or session presented by the environmental community.

REGULATORY ISSUES

- Have discussion of legal, regulatory, and policy issues at beginning of forum to establish a context for CCB characterization, use, and disposal talks.
- More legal issues with attorneys.

Appendix

APPENDIX 1: RECORDED DISCUSSIONS

Edited by
Kimery C. Vories
USDI Office of Surface Mining
Alton, Illinois

The following are the edited discussions that took place at the end of each speaker presentation and at the end of each topic session. The actual comments have been edited to translate the verbal discussion into a format that more effectively and efficiently communicates the information exchange into a written format. The organization of the discussion follows the same progression as that which took place at the forum. A topical outline has been developed to aid in accessing the information brought out in the discussions.

The topic of each question is shown in alphabetical order in **bold.** The individual speaker questions are listed in outline format under the appropriate topic session and presentation title. Questions during the twenty-minute interactive discussion are listed at the end of the session in the following format.

SESSION # AND TOPIC AREA
1. Presentation Title
   - **Subject of question or comment**

SESSION #: INTERACTIVE DISCUSSION
Subject of question or comment

OUTLINE OF DISCUSSION TOPICS

SESSION 1: COAL COMBUSTION BY-PRODUCTS: THE BASICS
1. History of CCB Production and Use with an Overview of Applications
   - **CCB use by type of fly ash**
   - **Increasing public education**
2. Physical and Chemical CCB Characteristics
   - **Effect of low NO_x burners on CCB composition**
3. Fly Ash Utilization in the Western United States
   - **Use versus sales**
4. Innovative CCB Uses in Mine Fill and Related Applications
5. ASTM Standard to Support Mine Application of CCBs
   - **Agency participation in E-50**
6. Potential Effects of Mercury Controls on CCBs
   - **Annual rate of mercury emissions**
   - **Impact of mercury controls on CO_2 emissions**

SESSION 1 INTERACTIVE DISCUSSION
Applicability of CERCLA to CCBs
Applicability of "cradle to grave" concept to CCBs
CCBs as "foreign" materials

SESSION 2: TESTING AND TERMINOLOGY
1. CCB and CCP Terminology
   - **ASTM terms for wet materials**
   - **Environmental comments on ASTM Standards**
   - **Usefulness of classification of fly ash by lime content**
2. Chemical and Physical Testing of Coal Ash Products
3. Evaluating CCBs for Environmental Performance: Performance Based Measurement Systems
   - **Ability of soils to attenuate leaching**
   - **Determination of best leaching method**
   - **Long-term leaching prediction**

- **Worst case leaching method**

4. Evaluation of Physical Properties and Engineering Performance of CCBs in the Laboratory and the Field
5. Environmental Tracers of Leachate Derived from Pressurized Fluidized Bed Combustion By-Products in an Abandoned Coal Mine Setting
   - **Beneficial use of CCBs to reclaim AML sites in appalachia**
   - **Tissue analysis of vegetation**
   - **Unsuccessful application of CCBs at Pennsylvania sites**
6. QAQC and Variability of CCBs Relating to Mine Applications

SESSION 2: INTERACTIVE DISCUSSION

Availability of commercial methods for determining forms of mercury
Determining chemical forms of mercury
Importance of liquid to solid ratios in measuring leachate
Laboratory leachate methods as predictors of field conditions
Method for measuring boron
Obtaining representative samples of CCBs
Valid uses for column leaching methods

SESSION 3: WESTERN MINING APPLICATIONS/CASE STUDIES

1. Ashes to Ashes: Returning CCBs to the Ground at the Navajo Mine
   - **Distance traveled by leachate and its quality**
   - **Duration of monitoring**
   - **Saturated zone thickness**
2. Coalstrip Steam Electric Station/Coal Combustion By-Products Disposal
   - **Cost of lined pond**
   - **Duration of monitoring**
   - **Saturated zone thickness**
3. Hydrologic Monitoring and CCB Placement at Trapper Mine
   - **Alternatives to a monofill**
   - **Duration of monitoring**
   - **Number of down gradient CCB monitoring wells**
   - **Number of monitoring wells**
   - **Permit required**
     a. **Permit restrictions**
     b. **Problems resulting from wet ash**
     c. **Quantity of CCBs disposed**
     d. **Time required for leachate to reach monitoring wells**
     e. **Time that disposal area is open**
4. Mitigation of Abandoned Underground Coal Mines/High Groundwater Table Case Study
   - **Long-term stability**
   - **Percent of fly ash used**
   - **Project financing**
   - **Project liability**
5. Monitoring and Environmental Evaluation of CCB Disposal Activities at Great River Energy
   - **Are maps included**
   - **Cost of the system**
   - **Number of man hours**
   - **Software used**
6. Disposal on Tribal Lands Under Federal Regulations

SESSION 3: INTERACTIVE DISCUSSION

Conditions for release of performance bond
OSM oversight of State CCB permitting process
Physical characteristics of CCBs required by OSM
Post mining land use at Navajo mine
Potential for livestock to drink water from CCB disposal area
Statistical analysis of Great River Energy database
Surface drainage around disposal area

SESSION 4: ENVIRONMENTAL IMPACTS TO GROUNDWATER

1. Use of CCBs to Reclaim a Water Filled Quarry
2. Leaching Summary
   - **Studies under redox conditions**
3. Indiana Water Quality at a Mine Site
4. Mine Filling Using CCPs Data Collection and Risk Assessment: An Interagency and International Effort
5. Microbial Study Results
   - **Future testing of sorbents**
   - **Heat produced by microbes**
6. Environmental Performance of CCBs
   - **Down gradient concentrations of arsenic and boron**

SESSION 4: INTERACTIVE DISCUSSION

Benefit of California wet test for leachate
CCB placement failure stories
EPA MRAM number of mines with data
EPA MRAM statistical analysis
Universal site discharge of leachate waters
Varra site degree of success
Varra site duration of water monitoring
Varra site geological similarities between mine site and test site
Varra site impact of CCB disposal on St. Vrains River

SESSION 5: CCB REGULATORY DIRECTION

1. EPA Perspective
   - **EPA reclamation of federal AML lands**
   - **Rule making on CCBs related to SMCRA**
   - **Rule making schedule for CCBs**
   - **State field tour selection process**
   - **Tribal primacy under RCRA**
2. State/Federal Initiative Addressing Mine Placement of Coal Combustion Wastes
   - **Duration of IMCC initiative**
   - **IMCC perspective on need for additional RCRA rules on mining**
   - **Recent IMCC results**
3. Legal Aspects of CCB Beneficial Use in Mining
   - **Clean air task force lawsuit**
   - **CCB/mining damage cases**
   - **Regulation of non-coal mines**
4. Industry Perspective
5. North Dakota Regulatory Perspective
6. Descriptions of State of Colorado Regulatory Programs Associated with Coal Combustion Waste (CCW) Placement
   - **Soil/overburden handling**
7. Regulation of Coal Combustion Waste at Mine Sites: Environmental Concerns
   - **Agreement on meaning of terms**
   - **Effect of CCB placement on pre-existing toxicities**
   - **Environmental protection as good business**
   - **Federally enforceable standards**
   - **Protection of future land use**
8. The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines

SESSION 5: INTERACTIVE DISCUSSION

Adequacy of water monitoring for damage case determination
Adequacy of water monitoring under SMCRA
CCB placement at abandoned mine lands
Land use at CCB disposal area in North Dakota

National federal rules relative to site specific design standards
Need for recording CCB placement on deeds
Policy on CCB placement relative to coal as a fuel
Requirement for meeting EPA rules at AML sites in Illinois
Tracer tests for water monitoring

DISCUSSION BY SESSION

SESSION 1: COAL COMBUSTION BY-PRODUCTS: THE BASICS

1. History of CCB Production and Use with an Overview of Applications. Rustu Kalyoncu, USGS Minerals Information Team, Reston, Virginia

Question: **(CCB use by type of fly ash)** Has there been any effort to collect CCB use data based on the type of fly ash?

Answer: I don't know because the American Coal Ash Association collects this data.

Question: **(Increasing public education)** The public seems to know very little about the use of coal ash. How can the general public be educated about the science, engineering, and economic benefits to using this material?

Answer: The environmental community is "gun shy" about this issue because of mistakes made in the past. As a material scientist, I believe that coal combustion products from coal ash are good and the U.S. EPA is fishing when they try to put addition restrictions on the use of these materials. Concerning education of the public, the USGS has an excellent education program at its headquarters in Reston, Virginia. They frequently have open houses and extensive science fairs where they invite school children, teachers, and the public to participate. They have booths, visual aids, presentations, and answer questions. I think they do an excellent job and would recommend that other government agencies do something similar. We also have much of this information on the Internet and have publications called fact sheets written for the public.

2. Physical and Chemical CCB Characteristics. Ann Kim, U.S. DOE, National Energy Technology Laboratory, Pittsburgh, Pennsylvania

Question: **(Effect of low NO_x burners on CCB composition)** Are you seeing any literature on changes in the composition in CCBs due to low NO_x burners?

Answer: It is not in the literature. There just has not been enough research done in this area.

Comment: Low NO_x burners result in a higher carbon content in the residue that makes it not suitable for cement and concrete applications. Pennsylvania State University has developed a method for separating the unburned carbon from these materials such that the carbon has a high surface area and can be sold. There might be a slight increase in coarseness because of the increase in carbon but there are no other changes in its composition.

3. Fly Ash Utilization in the Western United States. Gretchen K. Hoffman, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

Question: **(Use versus sales)** Can you explain what you mean by using a percentage of a product and selling a marketable commodity?

Answer: It could be used in the coal mine where it came from or ash marketers could sell it.

4. Innovative CCB Uses in Mine Fill and Related Applications. Bruce Boggs, ISG Resources, Inc., Salt Lake City, Utah

5. ASTM Standard to Support Mine Application of CCBs. Debra Pflughoeft-Hassett, Energy and Environment Research Center, University of North Dakota, Grand Forks, North Dakota

Question: **(Agency participation in E-50)** In the development of the TCLP test for leachate analysis at ASTM there was extensive development by the government agencies that helped to get it through the consensus process and made it more acceptable as a tool for the regulatory process. Do you have any agency participation on E-50?

Answer: EPA has been involved in a number of the standards being developed in E-50 from storage tanks through Phase I and Phase II property assessments. There does need to be greater agency involvement in this subcommittee.

6. Potential Effects of Mercury Controls on CCBs. Susan Thorneloe, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina

Question: **(Annual rate of mercury emissions)** I have seen some EPA literature that reported 75 tons of mercury from coal burning in the United States per year. Your slide shows 39 tons of mercury, has there been a change?

Answer: The slide I showed that reported 39 tons of mercury was the projection for the year 2010 after mercury control technology would be in place.

Comment: The 75 tons was reported many years ago and USDOE now has data that shows that after the application of scrubbers to many power plants that current mercury emissions are around 40-50 tons.

Question: **(Impact of mercury controls on CO_2 emissions)** Western coals primarily emit elemental mercury and the only technology that is currently available for its removal is activated carbon. The use of this technology results in such high carbon levels that the CCBs are unusable in the concrete market. In your analysis of mercury removal, are you evaluating the resulting increase in CO_2 that would be produced because of the inability to use fly ash for concrete?

Answer: EPA is studying this issue and will be evaluating changes in CO_2 consumption related to mercury removal.

SESSION 1 INTERACTIVE DISCUSSION

Comment: **(Applicability of CERCLA to CCBs)** CERCLA does apply to the clean up of a disposal area that is contaminating the environment, including when the contamination comes from CCBs. Although it is a safety net, funding is a problem. The solution, however, is to handle the disposal of CCBs in such a manner that the issue of damage to the environment and the implementation of CERCLA does not happen.

Comment: **(Applicability of "cradle to grave" concept to CCBs)** Concerning the "cradle to grave" concept for CCBs, we need to remember that the "cradle to grave" concept is applied under RCRA for hazardous wastes. This would not apply to CCBs because they are not hazardous wastes. As such, it should not be expected that utilities should apply the "cradle to grave" concept for disposal of CCBs.

Comment: The charge of RCRA is to dispose of these materials, be they hazardous or solid wastes, in a way that is safe and protective of human health and the environment.

Question: **(CCBs as "foreign" materials)** Are CCBs an area of special concern where we are introducing a "foreign" material into the mining environment?

Answer: The idea that CCBs are "foreign" rather than "natural" because they are modified by combustion and are a special concern when they are placed back into the "natural" mine environment is not valid. This is because the mine environment is not natural, resulting from the process of excavation, blasting, loading, transport, mixing, replacement, compaction, reshaping, etc. The entire mine environment is "man made" and our concern should be whether or not that man made environment will be as productive as the natural environment it replaced and be just as protective of environmental quality.

SESSION 2: TESTING AND TERMINOLOGY

1. CCB and CCP Terminology. Howard Humphrey, American Coal Ash Association, Syracuse, New York

Question: **(ASTM terms for wet materials)** What is the correct term when a venturi mixer is used to produce a mix of FGD fly ash and scrubber sludge?

Answer: The ASTM does not yet address terms for wet materials.

Question: **(Environmental comments on ASTM Standards)** Is there a way for environmental groups to provide comment on the ASTM guide for use of CCB as structural fill?

Answer: You would need to participate in the ASTM E- 50 task force. Even as a non-member of ASTM you can submit comments to Jim Roewer of USWAG who is the chairman of that group. He has just indicated that he will send you that draft so that you can provide comments.

Comment: **(Usefulness of classification of fly ash by lime content)** You have mentioned that the Class C and Class F fly ash designations are important in concrete. I think it is also important in evaluating fly ash in other applications like determining if an ash is cementitious (based on lime content) when used for waste stabilization or soil stabilization.

2. Chemical and Physical Testing of Coal Ash Products. LeRoy Jacobs, Wyoming Analytical Laboratories, Golden, Colorado

3. Evaluating CCBs for Environmental Performance: Performance Based Measurement Systems. David Hassett, Energy and Environment Research Center, University of North Dakota, Grand Forks, North Dakota

Question: **(Ability of soils to attenuate leaching)** The National Research Council did an evaluation of attenuation several years ago and predicted a low to moderate attenuation potential in soils for contaminants you find in coal ash. How well do you think this applies to coal ash disposal sites?

Answer: You cannot apply something like this generally. There are some soils that are highly attenuating and some that are virtually non-attenuating. This is why I said that a well-characterized site is essential. I would not want to rely on a study like that any more than I would rely on just speculation about how something might leach.

Comment: **(Determination of best leaching method)** ASTM needs to develop a protocol for how to select the most appropriate leaching method.

Question: **(Long-term leaching prediction)** How does the time period of a leaching test relate to assuring EPA that the material will not become hazardous over hundreds to thousands of years?

Answer: I don't think you can extrapolate the results from a leaching test out to hundreds or thousands of years. Also, just because a material produces leachate does not mean it is bad. A controlled release is how the environment protects us from itself and ourselves. I think that modeling with respect to groundwater flow and understanding the rate of release is the only way to project how these materials will behave in the field over time. You have to combine laboratory testing and groundwater modeling.

Question: **(Worst case leaching method)** You said that acid leaching of CCBs is not a worst case for field conditions. Why not?

Answer: If you leach with an acid, you cannot assume that it is leaching more anilities than an alkaline leach. Quite often an alkaline leaching will strip more of certain anilities than an acidic leaching.

4. Evaluation of Physical Properties and Engineering Performance of CCBs in the Laboratory and the Field. Andrew Stewart, Power Products Engineering, Eden Prairie, Minnesota

5. Environmental Tracers of Leachate Derived from Pressurized Fluidized Bed Combustion By-Products in an Abandoned Coal Mine Setting. Ralph Haefner, U.S. Geological Survey, Columbus, Ohio

Question: **(Beneficial use of CCBs to reclaim AML sites in appalachia)** Do you think that all of the AML sites in Appalachia would benefit from a similar reclamation process with fly ash?

Answer: That is a very big question. In Ohio, a big issue is that the cost of landfilling of this material is less expensive than the cost of trucking the CCBs to an AML site. This was a very expensive project. We expended a lot of resources and time on the education and public relations necessary to get approval to do this project. We definitely need to put a lot more effort into educating people on the benefits of using these materials. The ideal would be to see these materials being used beneficially.

Question: **(Tissue analysis of vegetation)** What type of vegetation was planted at the site and did you analyze the plant tissue for contamination by the site?

Answer: Red Fescue and Alfalfa were planted at the site. Ohio State University analyzed the plant tissue from the site and that information has been summarized in EPRI reports, but I don't remember the results.

Comment: **(Unsuccessful application of CCBs at Pennsylvania sites)** I come from Pennsylvania where I know of at least 80+ AML sites that have been reclaimed using these materials. Based on my observations, many of these sites are not working properly.

6. QAQC and Variability of CCBs relating to Mine Applications. Russell Hill, Boral Material Technologies, Inc., San Antonio, Texas

SESSION 2: INTERACTIVE DISCUSSION

Question: **(Availability of commercial methods for determining forms of mercury)** If EPA were to require that, following the implementation of mercury controls on utility stack emissions, a utility report mercury levels by specific form would you be able to say with any confidence that we could do that?

Answer: Probably, as long as the speciation includes oxide formation. Because if it is elemental mercury, it is fairly easily determined by gold amalgamation. By transforming using some other chemical techniques in the gold amalgamation, you can determine the salt formation that would include oxides of mercury. You would do a total mercury and then subtract the two to get a difference. It is still, however, a very difficult thing to do.

Comment: The Energy and Environment Research Center at the University of North Dakota has tried to speciate mercury compounds that were put on ash and were absolutely unsuccessful. In theory you should be able to do it but what happens in practice is that during the process of speciation your form of mercury changes. You might think you get a good measurement but you aren't. I have answered this question extensively on a peer-reviewed paper I wrote. There are a lot of people who think that you can speciate forms of mercury on ash, and I have challenged those people who think that it can be done to tell me how, without result.

Question: **(Determining chemical forms of mercury)** After mercury controls are put in place, is there a way that we can determine what form the mercury (mercury chloride or mercury oxide) is in the ash?

Answer: There is mercury speciation down at ppm and below levels. However, measurement of mercury and mercury salts at tens of ppm level is very difficult because these forms of mercury are very volatile. The special transform infrared spectroscopy is one way but it is not very sensitive. You can do ICP mass spec and look at the different chemical species that are present and try to make some educated guesses. There are some analytical techniques that claim to be able to do it but I have not seen any real good data on speciation of mercury.

Question: **(Importance of liquid to solid ratios in measuring leachate)** Concerning the 20 to 1 liquid to solid ratio for batch laboratory extractions, can you give an explanation what you might have against a 4 to 1 or 8 to 1 ratio?

Answer: Environmental groups who want to prove a point often propose those different ratios. I do not think that leaching methods should be used to prove a point; instead, they should be used to get accurate measurements. The point here is that if we standardize the ratio, use it to make these measurements, then I don't have a problem with changing the ratio as long as everyone uses the same ratio. But if you change the ratio and just use a different ratio

for coal ash then it is not valid.

Comment: If you just look at the science and you are dealing with an area that has been filled with ash, the water that occupies the pore space is not anywhere near a 20 to 1 ratio. There are chemicals that are in limited supply and when you dilute to a 20 to 1 ratio you will not get a reasonable estimate of what the leachate will be under field conditions. I am concerned that depending upon the application and the existing field conditions you may need to be flexible on the ratio that you use in order to get a more relevant answer as to how the material will leach rapidly in the first flush of pore water.

Comment: I am not sure that in this situation the ratio you use matters as much as you suggest. When you talk pore volume you are usually talking about column leaching, which is a dynamic situation. I really don't have a problem with using a different liquid to solid ratio to get better science.

Question: **(Laboratory leachate methods as predictors of field conditions)** It has been stated that the liquid used in a leachate test should closely approximate the liquid that the materials will be leached with in the field. If this is the case, how are the environmental groups not using good science when they use ratios that approximate those found in the field?

Answer: I was talking chemistry not proportions. I am saying the TCLP method uses the wrong kind of water for a leachate test of CCBs in a disposal area. Distilled or de-ionized water would more closely approximate the rainwater that the material will be leached by in the field. People quite often want to use a laboratory-leaching test as an accurate predictor of what will leach in the field, and this is what I consider to be invalid. The problem is that laboratory-leaching tests are not adequate predictors, by themselves, of what leaching conditions will take place at CCB placement areas in the field. We have determined that, in most cases, laboratory leachate methods will show a much higher concentration of leaching than will actually take place in the field. I use the synthetic groundwater leaching method in order to reduce the error caused by using acetic acid and use long-term leaching in order to obtain hydration reactions. I do not think that a laboratory leaching method will ever, by itself, be predictive of actual leaching conditions in the field. All the leaching method will tell is the amount of relatively easily mobilized constituents in the material. The next step to assessing potential field leaching conditions would be to determine approximate liquid to solid ratios that you find on a mine site. In North Dakota or other parts of the arid west, we would not have enough liquid to work with. You could not duplicate this in the laboratory in any meaningful way. In many cases in North Dakota, we have so little water you never produce a leachate at all.

Comment: One of the important reasons for using a 20 to 1 liquid to solid ratio in measuring potential leachate is the mass of data that has already been accumulated in the literature using this ratio and the use of this ratio in evaluating what is actually happening in field conditions. This is good science but it can't be used in a regulatory context. We cannot use these tests as a predictor of field conditions, but we do have the results of testing at many locations where you can compare the actual results of field leaching with a consistent laboratory test method.

Question: **(Method for measuring boron)** What is the best method for determining the boron concentration in groundwater ash leachate, and what is a legitimate detection limit?

Answer: There are a couple of methods. Boron can be done at a moderate detection limit on a ICP mass spec although they are using a boral silicate glass when they do that so that you can get some contamination from that. You could get in the ppb range with this method. When you are doing a very low detection limit on boron you have problem with Pyrex contamination where you do your sample preparation work. So you have to be careful that you prepare your sample in plastic or Teflon. There is also a wet method that involves a distillation of mentholated boron that can be a colorimetric method that can give you a very low detection limit. Boron is a difficult element to measure. You could get in the ppb range with this method.

Question: **(Obtaining representative samples of CCBs)** How do you obtain a sample of ash in order to insure that it is representative of the material that will be used?

Answer: Typically, ASTM C618 designates a group of different classifications for sampling. There is a grab sample that is a random sample that could be pulled from a process line or a truck or rail car. You have regular samples that represent one lot of material that would be a composite sample of numerous grab samples that would be taken from a truck or rail car. You can then have a composite sample that would represent an average of multiple trucks or rail

cars. Your process control would be done on the basis of the grab sample or the regular sample. Your quality assurance testing can be done on a composite sample. One of the things that increases our comfort level, that we are really getting representative data, is that you have a long history of the performance of a particular process stream generated at a particular facility. We look for trends in the data over time, in order to assure us that a specific quality of material is being produced. This assumes that the plant is running in a controlled manner with consistent fuels. If these parameters change, then you need a much more conservative measurement.

Question: **(Valid uses for column leaching methods)** It has been stated that column leaching is not an ideal method but that there are applications that are acceptable. Where would column leaching be applicable?

Answer: Column leaching would probably be applicable when you are using non-alkaline ashes. It has a lot of applications in research. The reason is does not have application in environmental performance is due to the rate at which the columns are run. When people try to use this with a monolith of material in order to get a measurement of what is happening to the mass of material, you do not get flow through the material but flow around the material.

SESSION 3: WESTERN MINING APPLICATIONS/CASE STUDIES

1. Ashes to Ashes: Returning CCBs to the Ground at the Navajo Mine. Andy Young, BHP Navajo Coal Co., Fruitland, New Mexico

Question: **(Distance traveled by leachate and its quality)** On the down gradient wells, has leachate water from the disposal area reached the wells at the boundary of the lease and, if so what is its quality?

Answer: In this area, the water has been moving through the ash for 15 years. We believe the water has moved into the mine spoils and has reached the wells at the lease boundary but we don't see the elevated levels of arsenic and boron that we see in the ash itself.

Question: **(Duration of monitoring)** What is the time period from the latest placement of ash to how long the groundwater monitoring will continue, and how many wells are in place to monitor down gradient impacts of this disposal area?

Answer: In the area I showed on the slide, there were 11 wells. We have other wells at the mine but they are all dry. Of these 11 wells, there are some up gradient, some immediately down gradient of the disposal area, and then some at the boundary of the lease area. This site has been monitored since 1995, and monitoring will be continued until bond release, which will be at least 10 years after revegetation has been established.

Question: **(Saturated zone thickness)** You state that 1.6 million tons of CCBs have been placed at this mine since 1974, adding up to about 30+ million tons. How thick is the disposal and is there a saturated zone?

Answer: It can be placed to around 75 to100 feet of thickness. In the area I showed on the slides, the saturated zone was about 40 to 50 feet thick.

2. Coalstrip Steam Electric Station/Coal Combustion By-Products Disposal. Gordon Criswell and Jim Parker, PPL Montana, Coalstrip, Montana

Question: **(Cost of lined pond)** Did you say that the paste technology was less expensive than using lined ponds?

Answer: Yes. If we were to attempt to line this pond, the estimate would be around $30 million.

Question: **(Evidence that mitigation was necessary)** What did you find in the surface or groundwater that made you conduct mitigation measures?

Answer: It varies. In our groundwater monitoring program, we look for specific pond water signature constituents and combinations of constituents and trends. Specifically we look for sulfate, boron, and calcium/magnesium ratio. Unimpacted water has a higher levels of calcium than magnesium. If the water becomes impacted by CCB leachates, the magnesium level will climb to higher levels than the calcium.

Question: **(Free water in paste)** In your pond design, will you have any free water behind the dam?

Answer: The 5 percent of free water that I showed when compared to the 75 percent free water that we have now is so little that with the amount of evaporation we have we are not sure that there will be any water remaining.

3. Hydrologic Monitoring and CCB Placement at Trapper Mine. Karl Koehler, Trapper Mining, Inc., Craig, Colorado

Question: **(Alternatives to a monofill)** Did you consider backfilling versus a monofill?

Answer: We have not considered any alternatives other that what we are currently using.

Question: **(Duration of monitoring)** How long will you monitor them?

Answer: We will monitor until at least 10 years after vegetation has been established. The State has some discretion as to how long after that they may require monitoring related to the ash disposal. On one site, we expect to monitor for at least 16 years and much longer for other areas.

Question: **(Number of down gradient CCB monitoring wells)** How many of the total wells are down gradient from the ash disposal area?

Answer: About one third of the 34 wells are down gradient from the CCB fill areas.

Question: **(Number of monitoring wells)** How many monitoring wells do you have?

Answer: We have about 34 monitoring wells.

Question: **(Permit required)** Did you have to obtain a permit for this disposal?

Answer: Yes. The details are explained in a later talk.

Question: **(Permit restrictions)** Were there any restrictions placed in the permit on disposal?

Answer: The disposal methods are part of our mining permit and we must stick with what we have approved in the permit.

Question: **(Problems resulting from wet ash)** Do you have problems trying to get around on these ash piles during rain or snow events?

Answer: We have short-term problems and may have to blade a roadway after a rain so that the trucks can travel over the area.

Question: **(Quantity of CCBs disposed)** How many tons of CCBs do you dispose of at your mine?

Answer: Our current rate of disposal is 400,000 to 450,000 tons per year. We have been disposing of CCBs at this mine since 1984 but not at that rate.

Question: **(Time required for leachate to reach monitoring wells)** How long will it take for leachate to reach the monitoring wells?

Answer: The water has already reached the wells in the adjacent spoils. It has not yet reached the wells that are most down gradient.

Question: **(Time that disposal area is open)** How long does a pit stay open before you cover it?

Answer: It will take about 6 years.

4. Mitigation of Abandoned Underground Coal Mines/High Groundwater Table Case Study. Darrell Holmquist, CTL Thompson Inc., Denver, Colorado

Question: **(Long-term stability)** What is the long-term stability of these sites after treatment? Do you expect any continued subsidence in the future?

Answer: We are very positive that the project will stop subsidence in the areas that are grouted. The difficulty is being able to tell from the surface whether or not all of the area you intended to grout underground actually were filled. We do test drilling to confirm that the area has been filled. Any future subsidence would be very minor in comparison with what is happening prior to treatment.

Question: **(Percent of fly ash used)** What percent of fly ash do you use in your mix?

Answer: We don't know. When we first started this type of project we specified the amount of fly ash to use in the contract and ran into trouble because the contractor was not able to achieve the level of strength required. Now we specify the level of strength and let the contractor figure out how much fly ash he has to use in the mix to achieve the correct result.

Question: **(Project financing)** How was the project financed?

Answer: This project was financed through the Abandoned Mine Land program. The costs have been running between $250,000 to $300,000 per surface acre.

Question: **(Project liability)** Who would be liable if the project fails to prevent subsidence?

Answer: The State of Wyoming has a mine subsidence insurance program. Any home that is undermined is eligible for enrollment in that program. Structures under this plan would be covered from the effects of mine subsidence whether or not they were grouted.

5. Monitoring and Environmental Evaluation of CCB Disposal Activities at Great River Energy. Diane Stockdill, Great River Energy, Underwood, North Dakota

Question: **(Are maps included)** Do you use any mapping, or are you just looking at charts and tables.

Answer: The first step was charts and tables but mapping is definitely one of the things we want to add.

Question: **(Cost of the system)** What did it cost to develop the system?

Answer: Under $25,000.

Question: **(Number of man-hours)** How many man-hours did it take to develop this system and how many hours to maintain it?

Answer: The data was already in an Access database. The new system that we added was just to be able to query that database. It took about two months for the consultant to set up the system. The data is entered at the lab as it always has been.

Question: **(Software used)** What off the shelf software did you use to run the data management system?

Answer: It was a Microsoft product that we used.

6. Disposal on Tribal Lands Under Federal Regulations. Rick Holbrook, Office of Surface Mining, Denver, Colorado

SESSION 3: INTERACTIVE DISCUSSION

Question: **(Conditions for release of performance bond)** Concerning the issue of performance bond release at the Navajo mine and whether or not the down gradient wells will be monitoring for a sufficient length of time so that water from the disposal area will come in contact with these wells: Will bond release be made only after there has been sufficient monitoring of water that has actually reached those wells from the disposal area or will it be possible to release the performance bonds without ever monitoring water from the disposal area?

Answer: Mining at the Navajo mine began in 1963 and ash disposal in pits and ramps began in 1974; that would preclude regulation by SMCRA because it was done prior to SMCRA becoming law. For any area where CCBs have been permitted for disposal that are regulated under SMCRA, there is no groundwater. Therefore, there will be no groundwater monitoring results because there is no groundwater. In addition, for any area of the Navajo mine where there is groundwater, there is no use of that water. In practice, OSM is going to look at the monitoring data and try to evaluate trends. We will be evaluating the result of the reclamation on a material damage basis. If it is determined that material damage would occur at level 10, the premining condition was a level 1, and the post-reclamation level is 6, OSM would interpret that as no material damage because it did not change the potential use of the water. OSM is obligated to look at the likelihood that there would be a potential for generation of a water quality that would prohibit its premining use. OSM defines material damage through the process of the Cumulative Hydrologic Impact Assessment done at the time of permit approval. We would look at what the water is being used for and what the standards are for that use. In the case of the Navajo mine, the water is being used for nothing, the backgroundwater quality is of such poor quality that it is not useable, and there is very little to no water over most of the mine. At Black Mesa and the Kayenta Mine the groundwater has a pristine water suitable for drinking water. The issue there is to protect both the structural integrity of the aquifer and the quality of the water to maintain its use as drinking water. At these mines, we will not release bond until OSM has hydrologic data that demonstrated that its water quality and quantity was stable and still useable as drinking water.

Question: **(OSM oversight of state CCB permitting process)** How does OSM evaluate State performance on CCB placement permits where the State is the regulatory authority?

Answer: OSM confers with the State and evaluates how they are implementing their program. OSM looks at a sample of permits and evaluates how they were done. It is not rigorous and does not attempt to second-guess the State. It primarily compares the results the State is achieving on the ground and how that relates to the permitting process and levels of enforcement. OSM is involved in the final bond release and must give its concurrence at that point.

Question: **(Physical characteristics of CCBs required by OSM)** What physical characteristics of the ash are required on Federal lands regulated by SMCRA?

Answer: Does the ash cement, will it settle, and does it need compaction? Attributes that relate to how the material should be handled. There is no microscopic evaluation. The permittee analyzes the material for trace elements, grain size, and distribution in order to determine potential for dust, and permeability.

Question: **(Post mining land use at Navajo mine)** What is the post mining land use?

Answer: Grazing. There were several independent studies that were done with respect to rooting depth for the native vegetation in the area in order that there would not be any potential for the vegetation to contact CCBs that might represent a plant toxicity. These studies determined that 10 feet of cover over the ash was sufficient.

Question: **(Potential for livestock to drink water from CCB disposal area)** Is there any potential for livestock to drink water contaminated by CCBs at the Navajo mine?

Answer: No. The livestock drink water that has runoff from the surface of the reclaimed area and collects in ponds. The ash disposal areas do not generate water.

Question: **(Statistical analysis of Great River Energy database)** Concerning the data management system developed at Great River Energy in North Dakota, do you have any ability to perform statistical analysis?

Answer: We do not have that capability currently, but want to add it eventually.

Comment: There are software packages available that would provide for data management and statistical analysis of groundwater.

Question: **(Surface drainage around disposal area)** At the Trapper Mine, you showed surface drainage ditches on both sides of the CCB disposal area, do you normally crown the disposal area so that surface water does not collect on the disposal area?

Answer: Yes, we will crown or slope the final disposal area so that water will flow away from the area.

Comment: At the Trapper Mine, we try to place all of the CCBs above the water table. We divert surface areas away from these areas.

SESSION 4: ENVIRONMENTAL IMPACTS TO GROUNDWATER

1. Use of CCBs to Reclaim a Water Filled Quarry. Joby Adams, Colorado Groundwater Resource Service, Fort Collins, Colorado

2. Leaching Summary. Ann Kim, U.S. DOE National Environmental Technology Laboratory, Pittsburgh, Pennsylvania

Question: **(Studies under redox conditions)** In all of these studies, there seems to be an absence of redox conditions. Do we always assume that there are oxidizing conditions in groundwater conditions?

Answer: There may not be oxidizing conditions for all groundwater situations but very few studies considered redox conditions.

3. Indiana Water Quality at a Mine Site. Ishwar Murarka, Ish Inc., Sunnyvale, California

4. Mine Filling Using CCPs-Data Collection and Risk Assessment: An Interagency and International Effort. Andrew Wittner, U.S. Environmental Protection Agency, Annapolis, Maryland

5. Microbial Study Results. David Hassett, Energy and Environment Research Center, University of North Dakota, Grand Forks, North Dakota

Question: **(Future testing of sorbents)** Are you going to be testing the release of mercury from some of the possible sorbents like activated carbon or wet scrubbing?

Answer: Yes.

Question: **(Heat produced by microbes)** The microbial experiments have the potential to produce heat. Was there a change in temperature and did you try to measure it?

Answer: The microbial studies has such a limited glucose supply that they did not have the potential to grow at a rate that would have given off enough heat to change the temperature. I do not believe the temperature changed, but I did not measure it.

6. Environmental Performance of CCBs. Ishwar Murarka, Ish Inc., Sunnyvale, California

Question: **(Down gradient concentrations of arsenic and boron)** Your data indicated that arsenic leached from the ash. What concentration of arsenic did you find in the groundwater down gradient from the Indiana Universal disposal area?

Answer: The up gradient water above the disposal area had about 5-6 ppb of arsenic. The levels below the disposal

area showed a lot of variability but were either very low on not detectable. In addition when you look at boron you find that significant amounts are leaching from the disposal area but it begins to attenuate within 100 feet of the disposal area and has attenuated to 1 ppm or become not detectable by the time it reached our last monitoring point.

SESSION 4: INTERACTIVE DISCUSSION

Question: **(Benefit of California wet test for leachate)** California has a sodium citrate leach as well as a TCLP leach for fly ash. How would you compare these two test methods?

Answer: I don't think the sodium citrate leach is going to leach any more trace elements than the TCLP. Most of the trace elements in fly ash are acid leachable. The California wet test, which uses a sodium citrate buffer, does not have a very low pH. I believe this method was developed primarily for municipal landfills. I do not see any advantage in its use. California does not produce any coal ash.

Question: **(CCB placement failure stories)** I have seen three CCB placement success stories at this forum. I come from Pennsylvania with what I believe is a story about a CCB placement failure. Why have we not seen any stories about CCB failures?

Answer: This site is not in the MRAM database. Pennsylvania will obtain the data from this site and give it to EPA for inclusion in the database.

Question: **(EPA MRAM study: Number of mines with data)** How many mines are you collecting CCB leachate data from for the EPA MRAM study?

Answer: We think that there are about 100 mines that actively receive CCB materials. We currently have data on CCB leachate monitoring for 65 mines.

Question: **(EPA MRAM statistical analysis)** Will EPA be doing statistical analysis on the data they are collecting in their MRAM study?

Answer: The data will be placed on an Excel spreadsheet that will allow statistical analysis. Once we determine that the data is representative, we will be looking at probabilities, regression analysis, and averages. How useful this analysis will be is yet to be determined. Based on the risk assessments we have done so far I am not convinced that statistical analysis in necessary. A concern I have is the long-term preservation of groundwater aquifers for future use.

Question: **(Universal site discharge of leachate waters)** Has the Universal site in Indiana been discharging unregulated flow from pits contaminated with arsenic and boron leachate from the disposal area?

Answer: The Universal site is regulated by an NPDES permit where the company has to report the levels of parameters required by the permit to the Indiana Clean Water program prior to discharge.

Comment: The NPDES permit issued by Indiana does not require the measurement of arsenic and boron with the result being that surface impoundments contaminated by leachate from the disposal area can and do exceed the limits for these parameters when pumped into adjacent dry stream beds that have no water for dilution. It is not responsible for the State of Indiana to issue NPDES permits for discharge of waters contaminated by ash leachate without discharge limits for trace elements that are known to leach from these materials at potentially toxic levels.

Question: **(Varra site degree of success)** Is it premature after only two months of water samples to call the Varra Colorado site a success?

Answer: The term of the project is one year. The trends in data that we see so far closely parallel what we found in the laboratory column experiment. It is a success to us in that it shows we can predict what will happen in the field based on what we are finding in the laboratory. There is still a lot of data to be collected in order to assess the long-term impact. The question of what type of monitoring will be done after one year is yet to be determined, as that will be determined by the Colorado Health Department at that time.

Question: **(Varra site duration of water monitoring)** How long have you actually been monitoring water at the Varra Colorado site?

Answer: We placed the ash in late February of this year. We took our first water quality sample one week after placement. We sampled weekly for the first month and have just completed our first monthly sample so we have a total of 5 samples over two months.

Question: **(Varra site geological similarities between mine site and test site)** On the geology of the disposal area near the St. Vrains River, it appeared that there was a large amount of soil that you were putting the fly ash into. How did the geology of the test area compare to the geology of the area that you want to place the fly ash in the mined out pit?

Answer: At the mine pit, the depth to shale is about 30 feet while the depth to shale at the test area is about 5-6 feet. The gravel material above the shale area is the same with the exception of the depth to shale. We predict that at the mine area the greater depth of gravel material would provide even better bypass characteristics than we find at the test area. The theory being, if you can get the groundwater to bypass the disposal area it will reduce the potential for generating leachate from the ash.

Question: **(Varra site impact of CCB disposal on St. Vrains River)** Concerning the Colorado Varra site by Joby Adams for the disposal site in alluvium along the St. Vrains River, are you measuring water quality of water in the river above and below the disposal area?

Answer: The water that comes in contact with the disposal area does not come from the St. Vrains River but flows from up gradient of the disposal area through a trench around the disposal area and then into the St. Vrains River. This flow takes about 7 years to get from the disposal area to the river. We have monitoring wells down gradient from the disposal area but due to the hydrology of the area we do not believe there will be any impact to the St. Vrains River.

SESSION 5: CCB REGULATORY DIRECTION

1. EPA Perspective. Truett Degeare, U.S. Environmental Protection Agency, Washington, D.C.

Question: **(EPA reclamation of Federal AML lands)** In the West, there is a large amount of abandoned mine lands on Federal land administered by Federal agencies. How is this handled?

Answer: Regrettably, Super Fund and CERCLA handle that. This is more of a backward looking statute while RCRA is more a forward-looking statute. There have been actions under CERCLA looking at sites like this.

Question: **(Rule making on CCBs related to SMCRA)** In the upcoming EPA rule making on CCBs, will this apply to SMCRA permits?

Answer: EPA is working with OSM to figure that out, but we don't have the answer yet.

Question: **(Rule making schedule for CCBs)** What is EPA's schedule for CCB rule making both for landfills and for mining?

Answer: The current schedule is that the proposed rules will come out in the spring of 2003 and the final rules a year later.

Question: **(State field tour selection process)** In the State CCB and mining field tours that EPA is currently conducting, how does EPA select the States with sites that you visit?

Answer: We began by looking at the States that had the larger number of mines where CCB placement was going on and the extent of coal mining in the State. When we talk to the State, we ask for their input on what mine sites might be the most appropriate to visit.

Question: **(Tribal primacy under RCRA)** In the West, there is also a lot of land on Indian reservations. Have any of the Indian reservations been given authority under RCRA to regulate CCB placement or landfills on their land?

Answer: Under RCRA that is a very difficult situation. EPA has worked with the tribal nations and we are encouraging them to adopt the RCRA regulations and some (i.e., North Carolina) have done so. We cannot really authorize them to have primacy under RCRA.

2. State/Federal Initiative Addressing Mine Placement of Coal Combustion Wastes. Greg Conrad, Interstate Mining Compact Commission, Herndon, Virginia

Question: **(Duration of IMCC initiative)** How much longer do you think this process will take?

Answer: We are making great progress and our most recent meeting provided real breakthroughs that should inform the continuing discussions. The ball is really in the court of IMCC to take EPA to the next level of understanding.

Question: **(IMCC perspective on need for additional RCRA rules on mining)** Does IMCC think that EPA should issue new regulations concerning the placement of CCBs at mine sites?

Answer: IMCC believes that is still an open issue with remaining work to be done in terms of bringing EPA up to speed about how different States regulate this issue, especially the dynamics between SMCRA and RCRA.

Question: **(Recent IMCC results)** Can you share any of the thoughts that have come out of the most recent IMCC meeting?

Answer: In general, IMCC obtained a much better understanding of EPA's specific concerns about CCB placement at mine sites from a RCRA perspective and their perception of regulatory gaps in existing State programs.

3. Legal Aspects of CCB Beneficial Use in Mining. Jim Roewer, Utilities Solid Waste Activities Group, Washington, D.C.

Comment: **(Clean Air Task Force lawsuit)** As a clarification, the lawsuit filed by the Clean Air Task Force was lost on procedural grounds not on the basis of substantive arguments.

Comment: **(CCB/mining damage cases)** You made the statement that there were no CCB/mining damage cases. As a clarification, EPA did add three damage cases that pertained to placement of CCBs in gravel pits. It is the position of the Clean Air Task Force that the only reason that there are so few mining damage cases is because of the failure to adequately monitor these sites.

Question: **(Regulation of non-coal mines)** How are quarries and non-coal mines regulated concerning CCB placement?

Answer: I believe this is one of the regulatory gaps that EPA needs to investigate because SMCRA would not address this. There may be, however, State mining authorities and programs that do address these issues.

4. Industry Perspective. Janet Gellici, Western Coal Council, Arvada, Colorado

5. North Dakota Regulatory Perspective. Steve Tillotson, North Dakota Waste Management Division, Bismarck, North Dakota

6. Descriptions of State of Colorado Regulatory Programs Associated with Coal Combustion Waste (CCW) Placement. Presented by Dave Berry; Authors Thomas A. Kaldenbach, Bryon G. Walker, and Daniel I. Hernandez, Colorado Division of Minerals and Geology, Denver, Colorado

Question: **(Soil/overburden handling)** Please explain what you mean concerning your soil/overburden conservation and redistribution program?

Answer: Valley fill does not apply to situations in Colorado. All of the topsoil is salvaged prior to mining during the initial stage of disturbance and stored in stockpiles or in large mines it is immediately hauled for replacement to another part of the mine. In terms of spoil and overburden conservation, typically at the large pit mines we have storage of spoil ridges directly adjacent to the open pit. It will be replaced into the pit during final reclamation after any CCB placement has occurred. The final step is to replace the topsoil.

7. Regulation of Coal Combustion Waste at Mine Sites: Environmental Concerns. Lisa Evans, Clean Air Task Force, Marblehead, Massachusetts

Question: **(Agreement on meaning of terms)** You said that there was a failure to agree on the meaning of terms. Based on the talks that have been presented at this forum there is agreement on terms. Do you not agree with the consensus on terms provided at this forum?

Answer: Part of the reason I am here is to become part of the dialog that is taking place on this issue. I do think that working together is the solution. We have successfully worked with EPA and my purpose here is to meet the other people working in this area and be able to discuss the issues so that we can achieve a consensus.

Question: **(Effect of CCB placement on pre-existing toxicities)** Since many of the mining applications deal with pre-existing problems of toxicity due to past mining practices, how do you distinguish between potential toxicity issues from CCB placement in this environment in relation to pre-existing toxicity, and then how do you balance that with the benefit of the alkaline addition resulting from CCB placement that mitigates the pre-existing toxicities?

Answer: Concerning abandoned mine sites: I would agree that you have pre-existing sites with severe contamination. In some of these situations, water quality monitoring has been inadequate, and you may have application of power plant waste at the sites over a period of years that results in a situation where it is very difficult to interpret the data. This is the reason that I keep pursuing adequate water monitoring so that from this point forward we can obtain good pre-CCB placement background water monitoring and 30+ years of post-CCB placement water monitoring in order to know what is actually happening. This is based on the data from a CERCLA site that is an abandoned gravel quarry where the CCB waste was placed more than 50 years ago. The wells have only been in place for about two years, and we are finding arsenic leaching from the area at many times the standard for toxicity.

Comment: **(Environmental protection as good business)** As an economist in charge of ash management at several power plants, I have found that good environmental management is good for business and that most business have learned this lesson over the years.

Response: I would agree with you that the trend is in the direction of protection of the environment; however, just last year I was involved with a town in Massachusetts where the local power plant was going to fill a gravel quarry with power plant waste under the guise of structural fill. This is where there were public drinking water sources down gradient from the quarry. The town eventually had to pass a law to completely prohibit the use of power plant waste within the city limits. They also motivated the State to correct its rules that allowed the use of power plant waste as structural fill in these types of applications. Although the trend is better, you still need a law to prevent people from making this type of mistake.

Question: **(Federally enforceable standards)** You seemed to be advocating Federally enforceable national standards. Are you actually advocating that these materials be regulated as a solid waste under Subtitle D that is not Federally enforceable or as a hazardous waste under Subtitle C that is Federally enforceable?

Answer: I realize that we will not be able to obtain standards under Subtitle C and am pursuing regulation of CCB disposal under Subtitle D as the next best thing.

Comment: **(Protection of future land use)** In Pennsylvania, we have been requiring voluntary deed restrictions for years in order to ensure that we are protecting future land uses.

Response: I would agree that many of the protections provided in Pennsylvania should be adopted into national Federally mandated rules for all of the States so that this is not at the discretion of an individual regulator.

8. The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines. Kimery Vories, Office of Surface Mining, Alton, Illinois

SESSION 5: INTERACTIVE DISCUSSION

Question: **(Adequacy of water monitoring for damage case determination)** Concerning the amount of water quality monitoring that is done at active or abandoned mines, does EPA believe that there has been enough monitoring at these sites to determine if damage cases can accurately be determined according to the criteria laid out by EPA as to what defines damage?

Answer: I don't think I can answer this question in general, because it requires a very site-specific determination.

Comment: At the Navajo mine and at western mines in general, we have an overall water-monitoring plan for the mining operation. When a mine applies to permit CCB placement at the mine regulated by OSM, additional wells are required to specifically monitor groundwater that comes in contact with the CCB materials.

Question: **(Adequacy of water monitoring under SMCRA)** It is my understanding that only two lysimeters were installed at the BHP San Juan mine in New Mexico to determine that no groundwater was present at an area where 30 million tons of CCBs had been placed. Is it sufficient to make this type of determination with only two lysimeters?

Answer: SMCRA requires that the water monitoring be based on the Probable Hydrologic Consequences and Cumulative Hydrologic Impact Assessment studies required for permit approval. During this process the monitoring program must be determined to be suitable for the surface and groundwater conditions that exist at the site. Monitoring is determined on a site and permit specific basis. The State hydrologic specialists make these decisions during the approval of the permit based on all available hydrologic information.

Question: **(CCB placement at abandoned mine lands)** I think that OSM makes a decent case that SMCRA can handle permitting of CCB placement on SMCRA mine sites. At this conference, however, I have heard very little about disposal of CCBs in abandoned mines. Is this an area where further regulation may be needed?

Answer: CCB placement at abandoned mines is a completely different case than placement on a SMCRA mine site. Most States have some type of program where they have jurisdiction for regulation of non-SMCRA mining. Greg Conrad at IMCC is working with EPA and the States to come up with a separate program for handling placement at abandoned mines or non-SMCRA mines.

Question: **(Land use at CCB disposal areas in North Dakota)** In North Dakota, you showed the uses that could not be done after CCB placement. Based on your presentation, what can be done?

Answer: The depth of cover required at a State landfill where CCBs have been disposed is much thinner than that which would be placed over a SMCRA mine site. The CCB landfill is zoned as an industrial use area. In North Dakota, we do not want to disturb the final vegetative cover over a CCB landfill in order to ensure that the site will not erode. Basically the land uses that are allowed are wildlife food and cover, light grazing, or cutting for hay.

Question: **(National Federal rules relative to site specific design standards)** Given the site specific variability of climate, geology, types of CCBs, types of mining, and others, how can we achieve a unified national Federal standard?

Answer: Federal standards do not have to mandate that a certain disposal method is used. The RCRA regulations allow for some flexibility. For example, in the landfill regulations, you may have a specific design requirement but you also are allowed to make certain demonstrations that no groundwater exists or that existing groundwater is already contaminated that allows a facility to be exempted from a specific design requirement.

Question: **(Need for recording CCB placement on deeds)** In the Midwest, many of the areas used for CCB placement will be returned to agriculture. Shouldn't there be a requirement to record on the deed that CCB material

has been placed at that site to prevent someone from building a home in the future and trying to place a well in this material?

Answer: SMCRA doesn't address deed restrictions. The public is notified of specific CCB placement areas because all SMCRA permits are part of the public record. I think that it would be a good idea to require that it be recorded on the deed that CCB placement has taken place on the property, but it is not a requirement of SMCRA.

Question: **(Policy on CCB placement relative to coal as a fuel)** If we take the position that CCBs need to be treated like hazardous waste, are we also taking the position that coal should not be burned, and if so what are the alternatives?

Answer: I am not trying to imply that the problem is not correctable; I am trying to say that the current laws do not have enough safeguards that can result in problems when the material is mishandled. Concerning my position on the use of coal as a fuel, I just want to make sure that the cost of disposal is included in the cost of electric generation. I think that coal has gotten a free ride in terms of the disposal cost for CCBs. There have been a lot of cheap disposal options that have been harmful to human health and the environment. I believe that effective disposal options to dispose of these materials safely are available but it will be up to EPA, OSM, the States, and the environmental community to get together and come up with the regulatory framework that can guarantee safe disposal.

Question: **(Requirement for meeting EPA rules at AML sites in Illinois)** Under AML reclamation in Illinois, you look at the use of the material, are you required to meet EPA regulations at the site during reclamation and afterward?

Answer: In Illinois, we have a groundwater quality law that was based on the Federal Clean Water Act that establishes groundwater quality standards. Even though most of our AML sites far exceed the Class 4 water standards that is the most degraded standard, Illinois still uses these standards to evaluate reclamation at the site.

Question: **(Tracer tests for water monitoring)** Has anyone done any tracer tests in order to determine that the water that is being monitored at a mine site is actually coming from the CCB placement area?

Answer: Tracer and flow rate testing is being done in many, but not all cases.

APPENDIX II: POSTER SESSION

COAL COMBUSTION ASH (CCA) DISPOSAL IN A PENNSYLVANIA SURFACE MINE SITE AND ITS NONBENEFICIAL IMPACTS ON GROUNDWATER FLOW REGIME: A DEGRADATION EXPERIENCE

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Abstract

Between 1983 through July 2000, under the guidelines of PA Act 287 and Code: Ch 86-90, the Pennsylvania Department of Environmental Protection (DEP) permitted a total of 84 surface mine sites for coal removal in conjunction with coal combustion ash placement in four mine settings for "beneficial use." At the current level of post-operation assessment, it is the opinion of the author that these operations are of a mixed success. Almost 65 percent of these Pennsylvania operations are small, mostly around 100 acres, and are operated by small companies and are now trapped in water treatment liabilities. Emanated groundwater (springs, seeps, discharges, wells, etc.) and surface water quality in the receiving streams in many such operations did not improve to the level anticipated and has created adverse long-term hydrologic consequences beyond the base line level. This raises the question of perpetual 50-year treatment liabilities and the release of the posted reclamation bond. The current philosophy, followed by the regulatory agencies like an infectious disease, is "you touch it, you get it." The Federal and State environmental liability litigation proceedings, as a litmus test, have thrown the responsibilities upon the operator "owner and/or occupier" all of the treatment liability for water degradation at the site(s) resulting in performance bond forfeiture, insolvency, and bankruptcy of many small operators. The Federal Small Operator's Assistance Program is conspicuously silent on these complex issues.

Background

Of the 84 permits issued and/or operated by July 2000, 56 permits were spread over into four (4) PA-DEP district operations (Ebensburg, Greensburg, Hawk Run, and Knox) covering the bituminous coalfields and 28 were in the Pennsylvania anthracite region under the Pottsville District office. Coal ash (fly and bottom) placement in the surface mine site for its 'beneficial use' was expected to function as a high alkalinity reactive buffer material to leach through the medium of acidic water so as to produce alkaline water in the groundwater regime and surface water bodies in the watershed.

Standard laboratory method for the acid neutralization potential (NP) and the laboratory pH test are two of the most important criteria for acceptability of the coal ash placement in the surface mine site which qualify and quantify the ash's beneficial usage. The coal ash generators furnished and the laboratory controlled tests on the constituent concentrations of the toxic metals, both in mass-by-mass basis (mg/kg) and leachate concentration basis (mg/L). This data has become the guiding decision making tools of the Pennsylvania Department of Environmental Protection (DEP) to approve or deny a surface mine permit application without considering other contributory and compatibility factors. The leachate test performed on the coal ash (either on composite ash (fly and bottom or done separately) is customarily conducted for 17 metals, such as: Aluminum (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Selenium (Se), Silver (Ag), and Zinc (Zn). These tests are by "Acceptable Methods of Analysis (AMOA)," such as EPA SW-846 protocol or other methods in order to make a quantifiable determination against the EPA's groundwater parameters on potential leaching. The sulfate concentration, (mg/L), is a required EPA protocol for the coal ash placement at the surface site because most of the sulfur in coal burning processes is captured in the SO_2 scrubber plant by dry or wet scrubbing technologies. Numerous sulfur-scrubbing technologies are in practice in the USA's coal-fired boiler plants. One such technology is by dilute Na_2CO_3 wet

scrubbing developed by the Rockwell International Energy Systems Group, California, which does not produce pozzolanic cementitious ash.

Preliminary Studies

This independent investigator's preliminary studies indicate that the successes of the coal ash waste product, with unburnt Limestone ($CaCO_3$), and its placement in surface coal operations for the purpose of "beneficial use" is a misconception because the alkaline reactivity is far less than claimed. Many failures are attributable to, amongst many factors, the pozzolanic cementing effect of "glassy-phase" coal combustion ash with unreacted lime or limestone.

This material is mostly spheroidal in shape and of micron size (electron microscopy). They are negatively charged particles that are strongly bonded and adhere in the 'muddy' under clay floor, forming monolithic sheets of concrete by repetitive equipment movement.

The presence of Pre-SMCRA (Surface Mining Control and Reclamation Act) unreclaimed surface and reclaimed surface operations in contiguous properties without the benefit of:

- overburden analysis (OBA) and consequential 'special handling' techniques of the identified acidic-toxic host strata;
- presence of old abandoned deep mine within and contiguous of the newer planned operation;
- creation of permeability contrast between the coal ash placed newer operation in relation to the adjoining and/or contiguous old unreclaimed/reclaimed sites;
- effects of diffusive and advective transports of precipitation and oxygen through old reclaimed/unreclaimed adjoining spoils;
- storativity, transmissivity, and hydraulic conductivity of the adjoining/contiguous old mined spoils;
- thermo-dynamic (adiabatic) effects upon acidic-toxic host rocks in the old unreclaimed/reclaimed mined spoil due to seasonal temperature fluctuations;
- incompatibility of the placed ash material in light of geologic structural settings (fold, fault, fracture planes, and other anomalies);
- paleo-depositional environment contrast;
- presence of open-jointed massive sandstone;
- underlay/fire clay removal in the adjoining surface mine sites;
- presence of auger holes in the old unreclaimed or reclaimed adjoining surface sites.

Authorization to Investigate

Since October 1999, a reputable surety bond underwriter of Pennsylvania has authorized this independent consultant to investigate one such surface operation in Cambria County, west-central Pennsylvania.

Previously, this independent consultant was actively involved in another Pennsylvania Sub Chapter-F operation in the Pittsburgh coal of this same coal operator. In this case, a pre-mining Sub-F discharge site degraded beyond the base line level in the post-mining phase after 15 months of successful reclamation and revegetation. In this case, this consultant could affirmatively demonstrate to the Pennsylvania DEP regulatory authorities that the degradation was caused beyond the control of the operator that finally resulted in the release of the reclamation bond.

Numerous small surface coal operators from Pennsylvania, West Virginia, Eastern Kentucky, Ohio, Virginia, Illinois, Tennessee, and Oklahoma were permitted by the respective States' environmental regulatory agencies for coal ash placement have experienced and are experiencing similar problems.

Brief Review of Geologic, Hydro-geologic, and Mining Conditions of Pennsylvania Coal Operator

In January 1996, a Pennsylvania small operator was issued an 83.5 acre surface coal mine permit by the DEP to affect 71.9 acres for removal of two important coal seams, the Lower Kittanning (L.K. B-coal) and Middle Kittanning (M.K. C-coal) and partly from Upper Kittanning (U.K. C'-coal) with concurrent placement of high alkaline and a reactive coal combustion ash (CCA) product. Before issuance of the mining permit, the application

package to the DEP was thoroughly reviewed by a group of DEP hydrogeologists and engineers. According to the permit conditions, placement of CCA was required in three mine settings:

A. a uniform thickness in the L.K. (B-Coal) pit floor;
B. in top and bottom alkaline covers of the specially handled acidic-toxic overburden materials in the specially constructed "pods" at elevated ground; and
C. blended with the overburden spoil while backfilling and regrading.

Based on the OBA report, the initially assessed minimum coal ash placement was of 2,100 tons/acre in order to negate the possibility of acidic discharge from this operation. This was later increased to 3,200 tons/acre to offset the removal of host hard sandstone by the operator in order to market it as a road construction base material.

On standard practice of the overburden analysis (OBA) of the removed rock samples from overburden test holes, the bottom most L.K. coal (B-coal) overburden showed an alkaline deficiency varying between 20 to 600 tons/acre, averaging 650 tons/acre. The M.K. (C-coal) showed deficiency ranging between 100 to 500 tons/acre averaging about 65 tons/acre. The top U.K. (C'-coal), which crops at higher cover region, yielded a net excess alkalinity of 5,000 tons/acre. In an overall scenario, the overburden spoil materials of this permitted site showed a net alkaline deficiency of about 320 tons/acre.

The source of coal combustion waste (CCW) was initially identified from a local co-gen power project plant (Plant-A) utilizing circulating fluidized bed (CFB) technique to burn high sulfur local coals admixed with locally available limestone of 82 to 85 percent purity for SO_2 capture in the flue gas stream. The CCW product of Plant-A averaged a neutralization potential (NP) of 302.5 tons/1,000 tons of $CaCO_3$ equivalent with a pH ranging of 11.5 to 12.5.

The mine site is located on the western fringe of the Pittsburgh low plateau region in Cambria County, Pennsylvania. From the structural geologic settings, the site is within 0.5 miles of the axial plunge of a major fold, Laurel Land Anticline, with plunge running N-E to S-W. This fold directly influences the down gradient groundwater movement of the precipitation-infiltration cycle through the operation site over an extensive recharge area because all the seams mined dip toward the S-E direction. The proximity of this important anticline also has created multiple stress fractures in conjugate planes in the strata above and below the L.K coal. The overburden strata affected by mining is, from the surface—brown shale, brown sandstone, and brown siltstone (25 percent) and then gray shale and gray sandstone with some intervening gray siltstone (65 percent) and coal seams and bottom of gray clay (10 percent).

The bottommost coal seam, L.K. (B-coal), was previously deep mined within the permit boundary by three mine operators between 1948 through 1963 (DM-III, DM-IV and DM-V) and were abandoned since then leaving old mine voids and distressed strata conditions over and below the seam and bedding plane separations. For these old deep operations, it is quite evident that innumerable test holes were made in the general area without adequately plugging. This might have created hydrologic connections to the lower aquifer. These old test holes are unrecorded. These deep mines also have created identifiable and measurable acidic discharges, qualifying for the Sub Chapter–F protection.

One large old surface mine (SM-II) operated in the transitory phase of pre-to post-SMCRA, between 1976-1983, on approximately 212 acres. This site is contiguous and butting with the northern common boundary of this newer operation. This SM-II removed both L.K. (B-coal), and M.K. (C-coal) along with down-dip augering in the L.K. coal. Some of these auger holes have advertently or inadvertently penetrated the common northern property line. Evidence exists that this SM-II also was permitted by DEP to remove the bottom clay (fireclay) intermittently during the operational life. The required OBA was not conducted for this operation nor was the current state of the art of special handling of the identified acidic-toxic strata, other than coal cleanings.

Two other small and very old surface mines (SM-I and SM-VI) existed within the permit boundary where L.K. (B-coal) also was removed along the crop line to a maximum cover of 21 feet. The same operator who operated SM-II operated one of these small mines and, presumably, some fireclay removal also was done in small patches.

Between mid-March of 1996 and January 31, 2001 about 61.3 acres was mined and about 229-982 tons of high alkaline CFB ash (a mixture of coal ash and unburnt limestone) of co-gen plants A and B had been placed by this operator at Cambria mine site, averaging about 3,770 tons/acre of ash. However, the quality of water in three down-gradient monitoring sites, #MD-12, # MD-5, and #MD-3, continued to degrade. This situation clearly indicated the failure of the CFB ash to ameliorate the groundwater quality and the receiving streams. These waters were degraded

by many other Pre-SMCRA surface operations and old abandoned deep mines in the watershed area.

Three down-gradient groundwater monitoring wells, #MW-1, #MW-2 and # MW-3, were drilled below the L.K. (B-coal) crop line to a depth of 50 to 52 feet. Samples from these wells showed a consistent degradation of groundwater quality from the baseline levels. These monitoring wells are in massive open-jointed sandstone (95 percent), which constitutes the underburden of the L.K. and the overburden of the Clarion seam (A'-coal) and/or Brookville seam (A-coal). From a paleo-depositional environment standpoint, this sandstone formation of the lower Allegheny is of a "brackish" or "moderately brackish" marine environment deposition in the "Vanport Sea," that was chlorine-rich. The thick and massive sandstone of the Clarion/Brookville horizons was the coarse-grained sand channel flowing to the Vanport Sea.

Conclusions

In conclusion, this independent investigator observes the following:

1. There is a complete lack of coordination between the DEP technical professionals and the enforcement officials in determining the circumstances and causes of the groundwater degradation where the OSM officials play a silent role by not ascertaining the roots of those causes and circumstances. State primacy of the Federal SMCRA does not necessarily absolve the OSM of responsibility in reviewing the permit in the pre-issuance phase in order to determine what hydrologic conditions are ignored and overlooked by the DEP hydrogeologists.

2. The fact that, by the very presence of a previous old and large reclaimed surface coal operation, #SM-II, contiguous to and up gradient of this newer operation, could create dangerous adverse hydrologic consequences both to the groundwater and surface water emanations. This has been ignored by DEP. This old surface mine had affected the bottom clay impervious barrier (fireclay) below the L.K. floor. L.K. coal augering from the final highwall was allowed by the DEP, where cutting though the impervious clay floor at the farthest auger-head end could not be ruled out.

3. The SM-II operation also did not conduct the required OBA to identify the acidic-toxic overburden strata for special handling.

4. By review of the scanty and infrequent inspection reports of the Pennsylvania MCI available in the file records, it was evident that the SM-II operation was systematically and advertently drilling in the pit floor to avoid pumping of the accumulated pit water. The MCI report recorded that pit water accumulation in the down-dip coal block was a continuous ongoing problem to the SM-II operator.

5. The deleterious effects of the epigenetic Laurel Ridge anticline fold in close proximity of the old surface mine, # SM-II, in the L.K. (B-coal), which induced more vertical open joints in the underburden of massive sandstone of 50'-52' feet thick with low tensile strength, were failed to be recognized by the DEP hydrogeologists. These open joints are now the vertical paths to vast amounts (several million gallons) of stored acidic-toxic water in the reclaimed spoils of SM-II. By removing the fireclay from the pit floor intermittently, these depressions are acting as bowls of acidic water.

6. The precursor metals of the CCA, such as As, Cu, Cd, Hg, and Pb (Group-II metals of the qualitative wet chemistry) are not found to increase in the groundwater monitoring wells #MW-I, #MW-2 and # MW-3 to a leachable limit whereby I conclude that the alkaline CCA products are not sufficiently reacting to neutralize the acidity and, instead, the pit floor is sealed by the pozzolanic cement in this newer operation.

7. By sealing the pit floor with CCA products in this new operation in contrast to the enhanced vertical hydraulic permeability in the old reclaimed SM-II area, a permeability contrast has been created. For this situation, the acidic stored reservoir of the SM-II moves vertically downward through the disturbed pervious underclay of L.K. (B-coal) and enters into the massive sandstone layer of "brackish" marine paleo-depositional environment. Continued low pH, very high acidity, high Fe, high Mn, high Al, and high SO4 are all attributed to the customary acidic mine water; however, the concentrations of other leachable metals of the CCA, such as Sb, As, Ag, Cd, Cr, Cu, Se, Pb, Ni, Se, Ag, and Zn, have not changed as drastically as happened with mine drainage metals.

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