GEOMORPHIC RECLAMATION

NATURAL STREAM DESIGN & GEOMORPHIC RECLAMATION AT COAL MINES

A TECHNICAL INTERACTIVE FORUM

April 28-30, 2009 ◆ Bristol, VA

U.S. DEPARTMENT OF THE INTERIOR · OFFICE OF SURFACE MINING

PROGRAM

MONDAY, APRIL 27, 2009

4:00 - 8:00 PM	**Check in for Field Tour and Forum**
	at Holiday Inn, 3005 Linden Drive, Bristol, VA 24201; (276) 466-7725

TUESDAY, APRIL 28, 2009

7:00 AM	**Continental Breakfast at Hotel**
	Check in for Field Tour and Forum
7:45 AM	**Begin Loading the Vans for Field Tour**
8:00 AM	**Departure of Vans from Hotel for Field Tour**

Long pants are recommended; wear field clothes appropriate for weather.

The tour will include:

(1) Paramont Coal Co. Black Bear No. 1 Surface Mine stream channels restored using natural stream channel design;

(2) Lawson Hollow Surface Mine stream channel reconstruction & riparian vegetation; and

(3) Toms Creek Gob Pile Removal natural stream channel design & improved aquatic habitat.

Lunch

(Included in Field Trip Registration)

5:00 PM	**Return of Vans to Hotel from Field Tour**
6:00 PM	**Dinner at Hotel**
	(Included in Forum Registration)

WEDNESDAY, APRIL 29, 2009

7:00 AM	**Continental Breakfast**
	(Included in Forum Registration)
	Check in for Forum

WEDNESDAY, APRIL 29, 2009 (Cont.)

8:00 AM	**Welcome**
	Jackie Davis*, Director, Virginia Department of Mined Land Reclamation, Division of Mines, Minerals and Energy, Big Stone Gap, VA*
8:10 AM	**Introduction and Purpose of Forum**
	Kimery Vories*, Forum Chairperson, Office of Surface Mining, Alton, IL*
8:20 AM	1ST SESSION: ADVANCES IN GEOMORPHIC RECLAMATION
	Chairperson: ***Roger Calhoun****, Office of Surface Mining, Charleston, WV*
8:25 AM	**A Geomorphologist's Perspective on Stream Restoration in Mined Land**
	Dr. J. Steven Kite*, West Virginia University, Morgantown, WV*
8:55 AM	**Science Basis for Reclamation of Low-Order Streams**
	Dr. Peter R. Wilcock*, Geography and Environmental Engineering, Johns Hopkins University, Baltimore, MD*
9:25 AM	**Hydrological Functioning of Surface-Mined Watersheds in Western Maryland: Restoration or Reclamation?**
	Dr. Keith N. Eshleman *and Brian C. McCormick, M.Sc., P.E., Appalachian Laboratory, University of Maryland Center for Environmental Science, Frostburg, MD*
9:55 AM	**Refreshment Break**
10:25 AM	**Disturbed Land Reclamation Using Geomorphic Techniques: McKinley Coal Mine, New Mexico, Mining Area 12C**
	Richard Spotts, P.E., Water and Earth Technologies, Inc. (WET)
	Marie Shepherd, P.E., Chevron Mining Inc.
	Melissa Robson*, E.I., & Ryan Wade, E.I., (WET) Fort Collins, CO*
	Wayne Erickson, CPESC, Habitat Management, Inc.
10:55 AM	**Tools for Integrating Geomorphic Reclamation into Planning for Eastern Coal Surface Mines**
	Dr. Charles Yuill *and Michael Hasenmyer, Natural Resource Analysis Center, Environmental Design Visualization Group, West Virginia University, Morgantown, WV*

GEOMORPHIC RECLAMATION

WEDNESDAY, APRIL 29, 2009 (Cont.)

11:25 AM	Interactive Panel Discussion
11:55 AM	Adjourn to Lunch *(Included in Forum Registration)*
1:00 PM	2ND SESSION: GEOMORPHIC RECLAMATION IN APPALACHIA *Chairperson: **Craig Walker**, Office of Surface Mining, Knoxville, TN*
1:05 PM	**Challenges of Applying Geomorphic and Stream Reclamation Methodologies to Mountain-Top Mining and Excess Spoil Fill Construction in Steep Slope Topography (e.g. Central Appalachia)** *Peter Michael* and ***Lois Uranowski,*** Office of Surface Mining, Pittsburgh, PA ***Mike Superfesky**, Office of Surface Mining, Morgantown, VA*
1:35 PM	**Can Appalachian Mine Reclamation be called Sustainable using Current Practices?** ***Nicholas Bugosh**, Carlson Software, Ft. Collins, CO*
2:05 PM	**Geomorphic Restoration of Coldwater Fork Following Oct. 2000 Slurry Spill** ***George Athanasakes**, P.E., Stantec, Louisville, KY*
2:35 PM	**Modeling Sediment Loss on Geomorphic Regraded Forest Lands in Kentucky** ***Dr. Richard Warner,** Dr. Carmen T. Agouridis and Dr. Christopher D. Barton, University of Kentucky, Lexington, KY*
3:05 PM	Refreshment Break
3:35 PM	**Stream Restoration on the Cumberland Plateau, Tennessee** ***Dennis Clark,** Office of Surface Mining, Knoxville, TN* ***Tim Slone**, IRTEC, Caryville, TN*
4:05 PM	**Case Study - Kentucky: Recreating a Headwater Stream on a Head of Hollow Fill** ***Dr. Carmen T. Agouridis**, **Dr. Christopher D. Barton**, and *R.C. Warner, University of Kentucky, Lexington, KY**

WEDNESDAY, APRIL 29, 2009 (Cont.)

4:35 PM — **Use of Natural Stream Channel Design Techniques in the Coal Fields of Virginia**

__Lance DeBord__, D.R. Allen and Associates, Abingdon, VA

5:05 PM — Interactive Panel Discussion

5:35 PM — Adjourn to Social Reception

THURSDAY, APRIL 30, 2009

7:00 AM — Continental Breakfast

(Included in Registration)

8:00 AM — 3RD SESSION: GEOMORPHIC RECLAMATION IN THE WEST

Chairpersons: __Mychal Yellowman__, Office of Surface Mining, Denver, CO

8:05 AM — **Integrating Natural Processes with Drainage Reclamation Design in Montana**

__Tom Golnar__, Shannon Downey, and __Julian Calabrese__, Montana Department of Environmental Quality, Helena, MO

9:05 AM — **The Application of Geomorphic Reclamation Methods in Wyoming**

__Marcello Calle__ and __Jonathan Stauffer__, Wyoming Department of Environmental Quality, Cheyenne, WY

Scott Belden, Peabody Energy, North Antelope/Rochelle Mine, Gillette, WY

10:05 AM — Refreshment Break

10:35 AM — **Geomorphic Reclamation in New Mexico: A Regulator's Perspective**

__Dave Clark__, New Mexico Mining and Minerals Division, Santa Fe, NM

11:05 AM — **Geomorphic Reclamation at BHP Billiton New Mexico Coal – Successes, Challenges and Future**

__Daphne Place__, Collette Brown, and Cary Cooper, BHP-Billiton New Mexico Coal, Farmington, NM

11:35 AM — Interactive Panel Discussion

12:00 PM — Adjourn to Lunch

(Included in Forum Registration)

THURSDAY, APRIL 30, 2009 (Cont.)

1:00 PM	4TH SESSION: GEOMORPHIC RECLAMATION IN THE MID-WEST
	*Chairperson: **Bryce West**, Peabody Energy, Evansville, IN*
1:05 PM	**Anthropo-Geomorphology of Streams, Wetlands and Landscapes of the Illinois Basin, and Restoration Techniques** ***Tim Sandefur*** *, Wetland Services, Inc., Corydon, KY*
1:35 PM	**Current Stream Mitigation Requirements & Results** ***Mike Ricketts*** *and* ***Sam Werner****, US Army Corps of Engineers, Newburgh, IN*
2:05 PM	**From Rip Rap to Riffles: The Evolution of Stream Reclamation in the Indiana Coal Fields** ***Ramona Briggeman,*** *Indiana DNR, Division of Fish & Wildlife, Jasonville, IN*
2:35 PM	**Illinois Perspective – Past & Current Practices, Benefits and Challenges** ***David Lamb****, Associated Engineers, Inc., Madisonville, KY* ***Darrin Parrent****, T.H.E. Engineers Inc., Lexington, KY*
3:05 PM	**Refreshment Break**
3:35 PM	**Illinois Stream Restoration - Opportunities for Habitat Enhancement: Policy, Principles and Practices** *William G. O'Leary, Illinois DNR, Office of Mines and Minerals, Benton, IL* ***Jack Nawrot****, Cooperative Wildlife Research Lab, Southern Illinois University, Carbondale, IL*
4:05 PM	**Industry Perspective: Past and Current Practices, Benefits and Challenges** ***Scott McGarvie****, Peabody Energy, Evansville, IN*
4:35 PM	**Interactive Panel Discussion**
5:05 PM	**Where Do We Go From Here?** ***Kimery Vories****, Office of Surface Mining, Alton, IL*
5:15 PM	**Adjourn**

Proceedings of

Geomorphic Reclamation and Natural Stream Design at Coal Mines: A Technical Interactive Forum

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Proceedings of Geomorphic Reclamation and Natural Stream Design at Coal Mines:
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Edited by:
Kimery C. Vories
Anna H. Caswell

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FOREWORD

Geomorphology is the branch of Geology that studies landforms. It incorporates landform classification based on the shape of the earth's surface, the materials landforms are composed of, and the means by which they formed. The field also includes the study of the processes behind landform formation and the changes they go through during their development or evolution. Academic sub-disciplines to the field are distinguished by the geomorphic processes under investigation, regional locations in which those processes occur, or climatic conditions under which they operate. Examples include Fluvial, Glacial, Coastal, Tropical, and Aeolian Geomorphology. Beyond academic interest, the field has been applied to several subjects of practical interest, such as economic mineral exploration, geotechnical engineering, soil mapping, and land-use planning.

Environmental Geomorphology, which explores the interactions between humans and the earth's surface and surficial processes, is a relatively young field; although by now it has been around for several decades. Traditionally, the objective of the field has been minimization of human-induced land-surface degradation. More recently, the discipline has also included the application of geomorphic principles to restore streams that are already disturbed and to grade modified land surfaces into landforms compatible with natural processes. This approach to the reclamation of lands and waterways has already been applied to several coal mined lands in the U.S. The benefits of geomorphic reclamation of mined lands include: (1) the production, enhancement, or restoration of aesthetically pleasing landscapes and waterways; (2) restored stream reaches with steady state flow, that is with minimal amounts of erosion and an even in- and out-flux of transported sediment; (3) landforms that experience minimal erosion, and with virtually no or very little probability of large and rapid mass movements such as landslides; and (4) streams and landforms that support stable and flourishing ecological systems.

The Office of Surface Mining Reclamation and Enforcement (OSM) Technology Transfer Program first convened an interactive forum ("Putting a New Face on Mining Reclamation") on the geomorphic reclamation of coal mined lands in Farmington, New Mexico, from September 12 to 14, 2006. Presentations at the forum focused on 1) scientific and engineering concepts behind geomorphic reclamation, 1) geomorphic design tools (i.e. models and software), and 3) case examples of site-specific applications, most of which had taken place in the west. Since that time, the interest in geomorphic mine land reclamation has only increased and its use has expanded to--or intensified in--other parts of the country. Consequently, OSM decided to hold a second forum on the subject in the east. The event documented in these proceedings occurred from April 28 to 30, 2009 in Bristol, Virginia. Field visits to stream-restoration sites took place on the first day and the technical papers contained in this document were presented on the following two days. The order of papers in this document follows the schedule of the forum agenda. The 1st Session papers provide perspectives on the current state of geomorphic-reclamation science and technology. Papers of the subsequent sessions include reviews of mine-site-specific applications of stream restoration and landforming, and geomorphic reclamation efforts of state programs. The 2nd, 3rd, and 4th Sessions cover work in Appalachia, the West, and the Mid-West respectively. Following the session papers, these proceedings include: a list of forum participant recommendations for future work and technology events in mine-land geomorphic reclamation; and the results of the participants' evaluation of this interactive forum. The forum benefited from an excellent cross section of contributors. Among the principal authors, eight were associated with the coal-mining and engineering-consulting industries; six were connected with academic institutions; five represented state regulatory agencies; and three worked for federal departments. The talks also presented a rich assortment of issues and positions pertaining to geomorphic reclamation. Important themes include the following:

- The physiographic and climatic differences among mountainous and forested Appalachia, the nearly flat farm fields of the mid-west, and the dry, undulating landscapes of the western coal fields; and the unique challenges to geomorphic reclamation in those regions.
- The significant alterations and disruptions of the Appalachian landscape, watersheds, and eco-systems wrought by coal surface mining and the need to reclaim the land and water bodies in ways more in tune with local natural processes.
- Two alternative approaches to stream restoration: one alternatively called "natural stream design" or the Rosgen method utilizing stream classification and "reference reaches;" the other, termed "analytical," that utilizes numerical fluvial-process-based models.
- The availability of models and software for geomorphic reclamation design but also a lack of accounting for uncertainty, e.g. with respect to the relationship between stream hydrology/geomorphology and ecosystem structure.

- Current impediments to landforming and stream restoration from current mine-land reclamation regulations and practices, and the suggestion that surface-mine reclamation methodologies be rebuilt “from the ground up.”
- The keen interest in geomorphic reclamation and significant efforts made to apply the concept to mine sites but also the sense that the approach is in its infancy and would benefit greatly from additional interactive forums and workshops.

OSM will assess the outcomes of this interactive forum and other activities in the field of geomorphic reclamation and make recommendations for revisions to OSM policy or regulations, future technology transfer events, and possible support of experimental applications of the approach to mine sites. On behalf of the forum Chairperson and myself, I wish to express sincere gratitude to the members of the Steering Committee, invited speakers, and participants for their time and efforts in making this program a success.

Peter Michael

Geomorphic Forum Steering Committee

STEERING COMMITTEE MEMBERS

Kimery C. Vories (Forum Chairperson)
Mid-Continent Region
USDOI Office of Surface Mining

Brandon Wilson
Indiana Division of Reclamation

Bernie Rottman
Bryce West
Peabody Energy

Heather McDonald-Taylor
Jared Worley
Virginia Division of Mine Land Reclamation

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U.S. DOI, Office of Surface Mining
Coal Research Center
Southern Illinois University Carbondale

WELCOME

Jackie Davis, Director
Virginia Department of Mined Land Reclamation
Division of Mines, Minerals and Energy
Big Stone Gap, Virginia

Good morning and welcome to the second OSM-sponsored Technical Interactive Forum on the Geomorphic Reclamation and Natural Stream Design at Coal Mines. It is indeed a pleasure to be here today at the beginning of two days of discussion and information-sharing on this important environmental topic. I am glad that so many people from so many parts of the country are participating, from all levels of government, industry, universities, and especially our international guests from Spain. This is an excellent opportunity for communicating problems, solutions, and concerns related to new and developing technologies for improved reclamation design.

The goal of the current forum is to create an interactive environment that brings OSM, states, tribes, industry, and academia together to exchange technical innovations in the areas of geomorphic reclamation and natural stream design, share successes and failures, and discuss how to better implement geomorphic landscape and stream reconstruction into mined land reclamation.

We are already off to a very good start after the excellent field tour yesterday where most of you were able to visit these excellent examples of natural stream design here in Virginia. I would like to offer a special thank you to the State of Virginia who made Heather McDonald-Taylor and Jared Worley available to plan the tour and the Virginia and OSM staff who drove the vans for the tour.

I would like to commend the support and commitment of our cosponsors Peabody Energy, TECO Coal Co., and GOBCO whose sponsorship support has been essential in being able to ensure that we can provide all of the ingredients for a quality experience at this event.

I would like to thank the Steering Committee who have been working hard to organize this event since November of 2007. They include:

- Heather McDonald-Taylor and Jared Worley (Virginia)
- Kimery Vories (OSM Mid-Continent Region) Forum Chairperson
- Mychal Yellowman (OSM Western Region)
- Craig Walker, Peter Michael, Clairene Bailey, Tonya Blackburn, Jeff Trump, &Tom Gayla (OSM Appalachian Region)
- Steve Kite (WVU)
- Dennis Stottlemyer(West Virginia)
- Brandon Wilson (Indiana)
- Bernie Rottman & Bryce West (Peabody Energy)

Please feel free to contact any of the steering committee with questions or concerns about this or future events.

It is always true that the more we know, the more options we have. I am optimistic that constructive dialogues, such as those held here, will lead to a better understanding of the benefits and risks involved with these new technologies for creating more natural landscapes and streams after mining.

I commend all the forum participants for being part of this valuable information exchange. The public and the coalfield residents can only benefit from the information that is shared and the knowledge that is gained at this event. I thank you for applying your minds to the task and I wish you success in your efforts on behalf of the coalfield environment.

WHAT IS A TECHNICAL INTERACTIVE FORUM?

Kimery C. Vories
USDOI 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 second technical interactive forum cosponsored by OSM on Geomorphic Reclamation at coal mines. Papers from the 2006 forum are available on OSM's National Technology Transfer Website at www.techtransfer.osmre.gov.

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 Geomorphic Reclamation and Natural Stream Design 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 science.

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 Geomorphic Reclamation,
- outline our reasons for taking specific actions, and
- give a rational for our actions concerning permitting, material handling, reclamation, and protection of the environment.

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

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 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. OSM will mail all registrants a copy of the proceeding. This publication will be very similar to the proceedings of earlier forums conducted by OSM and 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
- 25 plus minutes of participant discussion is provided at the end of each topic session. The chairperson will recognize each participant that wishes 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, we will conduct an open discussion on where we should go from here
- A yellow 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 yellow

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 would also like to thank each of you the participants, for your willingness to participate and work with us on this important issue. Thank you.

Session 1

Advances in Geomorphic Reclamation

Session Chairperson:
Roger Calhoun
Office of Surface Mining
Charleston, West Virginia

A Geomorphologist's Perspective on Stream and Watershed Restoration in the Appalachian Coal Fields
Dr. J. Steven Kite, West Virginia University, Morgantown, West Virginia

Science Basis for Reclamation of Low-Order Streams
Dr. Peter R. Wilcock, *Geography and Environmental Engineering*, *Johns Hopkins University, Baltimore, Maryland*

Hydrological Functioning of Surface-Mined Watersheds in Western Maryland: Restoration or Reclamation?
Dr. Keith N. Eshleman and Brian C. McCormick, M.Sc., P.E., Appalachian Laboratory, University of Maryland Center for Environmental Science, Frostburg, Maryland

Disturbed Land Reclamation Using Geomorphic Techniques: McKinley Coal Mine, New Mexico, Mining Area 12C
Melissa Robson, E.I., Richard Spotts, P.E. and Ryan Wade, E.I., Water and Earth Technologies, Inc. (WET), Fort Collins, Colorado; Marie Shepherd, P.E., Chevron Mining Inc, Mentmore, New Mexico; and Wayne Erickson, CPESC, Habitat Management, Inc, Englewood, Colorado.

Tools for Integrating Geomorphic Reclamation into Planning for Eastern Coal Surface Mines
Dr. Charles Yuill and Michael Hasenmyer, Natural Resource Analysis Center, Environmental Design Visualization Group, West Virginia University, Morgantown, West Virginia

A GEOMORPHOLOGIST'S PERSPECTIVE ON STREAM AND WATERSHED RESTORATION IN THE APPALACHIAN COAL FIELDS

J. Steven Kite
Department of Geology & Geography
West Virginia University
Morgantown, West Virginia

Abstract

Mined lands present both challenges and opportunities to the science and practice of stream restoration. Although many geomorphologists working outside of mined lands argue against any aggressive intervention in stream channels, geomorphic impacts are so great and constraints so pervasive that "allowing nature to take its course" is not an environmentally viable approach for most streams in extensively mined watersheds.

The cumulative geomorphic impacts of surface coal mining are extraordinary. The annual volume of overburden and coal exhumed by surface mining in the Appalachian coal fields and Powder River Basin equals or exceeds the volume of sediments generated by the 1980 Mt. St. Helens volcanic eruption. Denudation from mining is five to seven orders of magnitude faster than prehistoric natural rates of erosion.

The greatest geomorphic disturbance occurs as a result of area mining, including the Appalachian practice of mountain-top mining and valley filling. Mountain-top relief can be reduced by up to 100 m, the equivalent of many million years of natural erosion removed in a geologic instant. Valley fill depths may exceed 200 m, and sediments in these fills are projected to remain on the landscape between a thousand and several million years. No matter how well constructed, reclaimed slopes composed of unconsolidated material are much more vulnerable to landslides and erosion than natural bedrock landforms. Results of "nature's experiments" on how valley fills hold up under >75 mm rainfall events have been disappointing, demonstrating the importance of durable reclamation and restoration.

Other mining techniques also greatly alter hydrology, sediment transport, and stream ecology. Post-SMCRA reclamation has not eliminated negative impacts; approximate original contour (AOC) reclamation does not yield natural streams. AOC mining in steep landscapes presents unacceptable landslide and flood risks to streams and downstream communities. Subsurface mining may lead to subsidence and subsidence-related stream dewatering.

In spite of the potential longevity of mining and reclamation landforms, current practices are driven by short-term cost efficiency and well-intentioned, short-sighted regulations, not by insights into long-term stability of a sediment legacy that will last long after all of the coal has been mined. The interests of streams, aquatic ecosystems, and water users would be better served if mining and reclamation practices were guided by long-term economics. Watershed-based approaches provide the most durable solutions to impaired streams, but reach-based solutions, including in-stream structures, may prove useful at the most negatively impacted sites. The development of GPS-guided geomorphic reclamation promises to allow the design and creation of mined-land topographies with better geomorphic and ecological function, while minimizing overburden hauling distances and costs of production.

Introduction

Undeniably essential in the early 21st Century world economy, mining, specifically coal mining, is the single most important agent of geomorphic change on the earth (Hooke, 1994; 1999; 2000) and promises to continue to be so for decades to come. The precise determination of the impacts of coal mining warrants additional research by the geomorphological community, but enough is known to allow general long-term predictions for the future of mined watersheds. Such predictions are at best order of magnitude approximations and are far from certain, but they can be used to promote discussion and stimulate new research into landforms, sediments and processes that may outlast human civilization. These rudimentary predictions are also sufficient to make the case that watershed restoration and reclamation in mined lands must be done competently because of the immense volumes of sediment created and stored on mined landscapes.

Coal mining practices have evolved over the centuries from dominance by underground mining to an ever-increasing reliance on surface mining. In recent decades, surface mining has seen a decrease in contour mining in favor of area mining, including mountain-top mining in the Appalachian coal fields. Underground, there has been a concurrent movement from traditional room and pillar mining to longwall mining. Each widely practiced coal mining method presents a set of challenges to the watersheds in which mining occurs. The focus of this paper is on watershed issues raised by 21st Century mining practices, with less attention on geomorphic issues inherited from coal mining in the past.

Although water chemistry is the most critical variable to stream ecology in coal-mined watersheds (Hartman et al., 2005), chemical issues such as acid mine drainage are more under the purview of geochemists than geomorphologists. Moreover, inclusion of geochemical issues also would require a much longer discussion than afforded here. In short, if water chemistry is badly impaired, geomorphic restoration may be ecologically unrewarding over decades or centuries, which are geologically short time intervals; however, geomorphic problems in many regions may long outlast chemical disequilibria in intensively mined watersheds.

The Scope and Scale of Geomorphic Issues in Surface Mined Lands

Surface mining yielded 69 percent of the coal tonnage produced in the United States during 2007 (National Mining Association, 2008), and in recent years has been responsible for about 40 percent of coal production worldwide (World Coal Institute, 2005). Trends suggest the proportion of coal extracted through surface mining will continue to increase in the future, with a requisite need for well-considered, resilient stream and watershed restoration.

The estimated volume of overburden and coal displaced through surface mining during 2007 in the Powder River basin exceeded 1 km^3, and the geomorphic impact of mining in the Appalachian basin was even greater, approaching 2 km^3 (Table 1). By comparison, the volume of volcanic ash erupted by Mt. St. Helens on 18 May 1980 was approximately 1.01 km^3, and collectively the impact of annual coal mining in the two coal basins (2.9 km^3) equates to the 2.6 to 2.9 km^3 of total volume of rock lost to lateral blast, debris avalanche, pyroclastic flow, mudflow, and ash fall in the spectacular St. Helens eruption (Tilling et al., 1990). The geomorphic impacts of the Mt. St. Helens eruption were so profound that this volcanic event determined the course of much geomorphic research for a decade or more, but it remains to be seen if the geomorphic impact of surface coal mining will receive similar research attention.

Table 1. Volume of coal and overburden displaced through surface mining in 2007. Coal production data from Energy Information Administration (2008); coal density from Wood et al. (1983); overburden ratios from a consensus of vocal participants attending National International Technical Forum in April 2009. Overburden includes interburden for multiple-seam mines. (N.B.1 km^3 = 1,000 x 10^6 m^3 or ~1.3 billion cubic yards).

	2007 Coal Production		Coal Volume	Overburden Ratio	Overburden Volume		Total Overburden+ Coal
Basin (coal type: density)	short tons x 10^6	metric tons x 10^6	m^3 x 10^6	yd^3 /short ton of coal	yd^3 x 10^6	m^3 x 10^6	m^3 x 10^6
Appalachian (bituminous: 1.32 metric tons/m^3)	150	136	103	15	2,250	1720	1,823
Powder River (sub-bituminous: 1.30 metric tons/m^3)	479	435	334	2	959	733	1,068

Comparison to natural rates of denudation (overall landscape erosion) in the Appalachians further attests to the geomorphic significance of the most voluminous mining method: mountain-top mining (Table 2). A large mountain-top mine may center on the removal of 30 to 100 m of overburden from sandstone-capped summits in time spans typically ranging from two to ten years. Geologically speaking, this time frame is virtually instantaneous. In the Appalachian coal fields where mountain-top mining is widely used, summits are capped by very resistant Pennsylvanian-aged sandstone. Hancock and Kirwan (2007) have used cosmogenic isotopes to determine natural erosion rates of ~ 5.7 m/1,000,000 yr on sandstone summits in West Virginia and Granger et al. (2001) determined rates of 2 to 7 m/1,000,000 yr for sandstone uplands in Kentucky. Hence, 30 to 100 m of mountain-top lowering represents the equivalent of ~ 4 to 50 million years of natural sandstone-summit erosion.

While active, the conversion of bedrock into unconsolidated material from mountain-top mining occurs at rates over five orders of magnitude faster than the weathering and erosion on summits through natural processes.

Table 2. Comparison of rates of natural geomorphic processes in the Appalachian Mountains to rates of mountain-top mining and valley-fill processes.

Natural Process	Natural Process Rate	Analogous Mining Activity	Mining Activity Rate	Mining Process Rate/ Natural Activity Rate (Range)
Denudation (erosion), sandstone summits, long-term	0.000002 to 0.000007 m/yr	Mountain-top mining, 30 to100 m deep on sandstone summits, in 2 to10 yr	3 to 50 m/yr	430,000 to 25,000,000
Outwash filling, Ohio River Valley, last glacial maximum	0.002 to 0.015 m/yr	Durable-rock valley filling, 30 to 100 m thick, in 2 to10 yr	3 to 50 m/yr	200 to 25,000
Colluvial filling, upland valleys, last glacial maximum	0.0002 to 0.005 m/yr	Durable-rock valley filling, 30 to 100 m thick, in 2 to10 yr	3 to 50 m/yr	600 to 250,000

Rates of valley filling also are orders of magnitudes greater than have been recorded by natural sedimentation in the Appalachian region. For the 10,000 years prior to large-scale human impact on streams, most Appalachian streams were relatively stable or in a slow incision mode. The last natural valley-filling event in the region occurred in response to increased sediment production caused by glaciation to the north and concurrent intense freeze-thaw in uplands. The Ohio River Valley and the mouths of its major tributary valleys filled when the Laurentide Ice Sheet advanced into the headwaters in Pennsylvania, New York, and Ohio about 20,000 years ago (Fullerton, 1986). During the glacial maximum, the Ohio River filled its valley with 10 to 30 m of sand and gravel glacial outwash within 2000 to 5000 years (Rogers, 1990). Hence, the rate of infilling was on the order of 2 to 15 m/1000 yr for a geologically brief episode (Table 2).

At roughly the same time as glaciers occupied northern areas in the Ohio River basin, small Appalachian upland streams, especially those above 750-900 m (2500-3000 ft) elevation, filled with 1 to 10 m of sediment produced by excessive freeze-thaw and colluvial activity under an extremely cold climate (Behling et al., 1993). During the geologically brief 2000 to 5000 year glacial maximum, the rate of colluvial filling in Appalachian valleys similar to those now experiencing mine-related valley filling reached 0.2 to 5 m/1000 yr (Table 2).

Valley fills associated with mountain-top mining typically take two to 10 years for completion, although the end dump method used in most durable rock fills leads to the full thickness at a site being accomplished in an even shorter period of time. Although some exceed 200 m thickness, valley fills more commonly range from 50 to 100 m thick; thus, a typical rate of valley filling ranges from 3 to 50 m/yr: 200 to 25,000 times faster than the fastest natural filling episodes known to have occurred in the region (Table 2). A 100 m deep natural colluvial valley fill would require 20,000 to 500,000 years to form under the most extremely harsh sediment-producing conditions known to have occurred in the uplands. The last glacial maximum lasted nowhere near that long, so no natural fills approach the thickness of mine-related fills in the steep upland valleys of the region.

Long-term rates of valley incision (Table 3) provide upper limits for how long valley fills may last, although these rates have been determined for the down-cutting of bedrock valleys that are not analogous to unconsolidated valley fill. Springer et al. (1997) and Granger et al. (1997) found that valleys in the central Appalachians have incised at rates of ~ 27 to 63 m/1,000,000 yr during the last few million years. If these rates were to hold true in the future, it would require 0.8 to 3.7 million years to erode a 50 to 100 m thick valley fill down to the underlying bedrock. Background sediment yields for unmined watersheds in portions of eastern Kentucky and southern West Virginia indicate even lower erosion rates of <16 m/1,000,000 yr (Hickman, 1990), which would require over 6 million years to incise 100 m.

Table 3. Extrapolations on how long valley-fill sediments might persist on the Appalachian landscape, based on natural incision rates, USGS suspended load measurements, and studies of pre-SMCRA mined-land erosion. Data are presented to demonstrate the range of possibilities, whereas actual erosion rates and persistence of valley fills will depend upon reclamation and restoration practices and sustained long-term maintenance.

Reference(s)	Geologic Scenario	Denudation or erosion rate	Extrapolated persistence of 50 to 100 m deep valley-fills
Long-term valley downcutting rates based on geologic dating methods			
Granger et al. (1997); Springer et al. (1997)	Valley incision, late Cenozoic	0.027 to 0.063 m $/10^3$ yr	800,000 to 3,700.000 yr
Historic denudation rates based on USGS suspended load measurements			
Hickman (1990), Collier et al. (1970)	Background sed. yield, eastern KY & WV	0.016 m $/10^3$ yr	3,100.000 to 6,200,000 yr
Hickman (1989), Osterkamp et al. (1984), Collier et al. (1970)	High-end sed. yields, partly mined watersheds, KY & WV	0.2 to 0.5 m $/10^3$ yr	100,000 to 500,000 yr
Historic denudation rates measured on pre-SMCRA mined lands			
Collier et al. (1970)	Denudation in mined areas w/in watershed	5.9 m $/10^3$ yr	8,500 to 17,000 yr
Curtis and Superfesky (1977)	Denudation of new head of hollow fill	10.9 m $/10^3$ yr	4,600 to 9,200 yr
McKenzie and Studlick (1978)	Denudation of steep mine spoil	26 to 54 m $/10^3$ yr	930 to 3,800 yr

However, in spite of advances in reclamation, long-term valley fill stability is not a given. Mining transforms Appalachian mountainsides from resistant, weathering-limited slopes to more vulnerable, transport-limited slopes, where erosion is limited by the energy to transport sediments. Abundant precipitation creates great sediment transport potential in Appalachian streams. Major hydrologic effects of coal mining in the region include an increase in stream sediment production through erosion of disturbed materials (Messinger and Chambers, 2001). U.S. Geological Survey suspended sediment load data in two Kentucky watersheds (Table 3) indicate these heavily mined watersheds are denuding at 300 to 400 m per million years (Hickman, 1989), which translates to erosion of a 50 to 100 m valley fill in 125,000 to 330,000 years, much faster than natural rates, but a very long time from human perspectives. Collier et al. (1970) and Osterkamp et al. (1984) determined similar erosion rates in Kentucky (Table 3),

It may be overly optimistic to expect steep-faced earthen structures to remain stable for hundreds of thousands of years; time spans many thousands of times longer than these structures' performance bond period. Valley fills certainly are designed to be more stable than abandoned mine spoil over short time spans, but when fills fail their slopes generate prodigious amounts of alluvial sediment over a geologically short time. Unstable slopes and sediment loss are likely to be exacerbated after reclamation maintenance ends, so worst-case scenarios need to be considered.

The geologically frequent occurrence of high intensity rainfall events provides abundant opportunities for slope failure and prodigious stream power to transport sediments downstream. During July 2001 in southern West Virginia, a 75 to 150 mm (3 to 6 inch), 6 hour rainfall that produced relatively benign 10 to 25 year floods in unmined watersheds (Wiley and Brogan, 2003) triggered major failures in several valley fills and numerous 2 to 6 m deep gullies in reclaimed slopes (Kite and Newell, 2001). Not all of the July 2001 failures were on properly completed valley fills, but enough were to call into question the geomorphic durability of valley fills and other steep reclamation landforms. Many similar historic floods have occurred in the region and tens of thousands of comparable or greater storms will occur in the next million years; these intense events will determine long-term rates of denudation in reclaimed watersheds. In the most extreme scenario, unmaintained valley fills locally could approach rates of denudation documented on pre-SMCRA mine sites: 5.9 m/1000 yr on unreclaimed contour mines in Kentucky (Collier et al. 1970), 10.9 m/100 yr for a head-of-hollow fill in Kentucky (Curtis and Superfesky, 1977), or 26 to 54 m/1000 yr on mine spoil in Ohio (McKenzie and Studlick, 1978). These rates are incredibly rapid compared to natural prehistoric erosion, and may greatly overestimate future conditions. However, even the most rapid of these worst-case rates extrapolates to moderately large valley fills surviving for a millennium (Table 3), a very long time in normal human perspectives.

The denudation of valley fills and other post-SMRCA reclaimed mined lands likely will fall somewhere between the extremes of the highly stable natural sandstone landscapes and rapidly disintegrating unreclaimed pre-SMCRA mine spoil. Where the denudation rates will lie between these end members will depend upon long-term practices in reclamation and watershed management. If erosion control and sediment containment are not sustained indefinitely, denudation rates may become unacceptably high and lead to downstream impacts similar to actively glaciated landscapes, where braided outwash streams carry prodigious sediment loads that choke channels and lead to deep floodplain aggradation. In the worst-case, rapid-erosion scenario, mobilized valley-fill materials will lead to unsustainably high sediment loads and severely impacted stream ecosystems. Realistically estimated rates of valley-fill erosion far exceed natural geologic rates of sediment production, so impacted coal field watersheds may challenge the mitigation skills and ingenuity of hundreds of generations to come.

Many have criticized mountain-top mining and valley fill, but alternatives are not risk free. Approximate original contour (AOC) mining and reclamation is not practicable in rugged landscapes such as the Appalachian coal fields where mountain-top mining and valley filling is practiced. The geomorphic impact of AOC reclamation would be more severe than mountain-top mining and durable-rock valley filling over conventional human time scales, and may be just as severe over geologic time. The ruggedness of the natural landscape stems from underlying sandstones' resistance to erosion. Mining greatly reduces these landscapes' inherent erosional resistance. Most natural slopes in the region are much steeper than the angle of repose of unconsolidated mined overburden; hence, in many cases reclamation back to stable AOC conditions is physically impossible. High-intensity storms would episodically turn steep AOC reclamation into a multitude of landslides and debris flows, with an unacceptable risk of great property damage and loss of life. Downstream impacts of slope failures on sediment loads and aquatic ecosystems would be devastating. Moreover, mining restricted to AOC conditions would recover less coal per square kilometer of surface area disturbed and would leave a larger footprint of disturbance for a given amount of resource extracted. In short, AOC reclamation is not realistic or sustainable in most locations where mountain-top mining and valley filling is practiced today.

Deep mining has been promoted as a mining alternative (Napoleon and Schlissel, 2009), but regional bedrock geology puts this method at an economic disadvantage. The coal stratigraphy in the mountain-top mining region is dominated by multiple seams, including some that are too thin, or have such bad roof properties that they cannot be deep mined economically using current technology at prevailing coal prices. Transformation from surface mining to deep mining would take some seams out of production, increase up-front costs to energy consumers significantly, and shift the geographic foci of coal production. These shifts have significant social implications that put caution in the hearts and minds of government and corporate decision makers, so mountain-top mining may persist for many years, in spite of geomorphic and ecological concerns.

Obviously, a geomorphologist's perspective favors long-term over short-term economic decision making. The stability of reclamation and mined lands, and the magnitude of legacy sediment liabilities are critical factors in determining what is truly cost effective in the long term. The economic discussion needs to include a time depth that is orders of magnitude beyond the active life of a mine, its reclamation, and the subsequent reclamation bond period. Economic arguments that currently prevail may not hold up if the costs of continued reclamation maintenance and mitigation are factored over centuries, long after most of the region's coal resources have been depleted.

Geomorphic Issues Related to Sub-Surface Mining

Most geomorphic issues over modern-day deep mining practices relate to subsidence or subsidence-related dewatering. The trend from room-and-pillar mining to longwall mining has transformed the nature of subsidence, but has not removed it as a concern.

Subsidence related to room-and-pillar mining is unpredictable and differentially distributed over the landscape, giving rise to sinkholes, small trough depressions, open cavities, building foundation failures, and wholesale stream-flow diversions into old mines, possibly into different drainage basins. Failures may occur many decades after the triggering mining activity (Fedorko, 1986; Fonner, 1987), and left untreated, most subsidence problems associated with room-and-pillar mines persist or worsen with time. Most of these subsidence problems require immediate aggressive intervention, such as sealing passages, filling void spaces and depressions, and structural repair. Impermeable, sub-streambed barriers may be required to prevent infiltration and loss of base flow; piping and opening of new connecting passages may also be a possibility. In the most egregious cases, subsidence is so extreme that restoration of the pre-mining flow path is fiscally impractical and dewatering is a *de facto* stream piracy event in which the flow diversion is "permanent" on a human time scale. The geomorphic responses to such subsidence-triggered stream piracy would include channel geometry adjustments to the new formative discharges on both gaining and losing streams. Stream restoration methods may allow creation of an appropriate hydraulic geometry for these misfit channels and prevent catastrophic erosion and deposition. Current stream restoration practices would focus on a bankfull channel designed to handle a 1-3 year recurrence formative flow, but also include a flood way for extreme events and a small “channel within a channel” to accommodate low flow.

In longwall mining, removal of roof supports leads to relatively predictable subsidence as the active mine face progresses. The largest longwall panels exceed 3 km in length and 300 m in width (Kern et al. 2002). Significant amounts of coal must be left in place adjacent to longwall panels in order to provide stable development tunnels (gate roads) for airways, manways, and coal conveyor routes. Overburden above gate roads will remain relatively intact, while, within a year or two of each panel completion, unsupported overburden above the panel may form large subsidence troughs; depth of subsidence is related to the ratio between panel width and depth below the surface, with typical subsidence being ~ 1 m (Hunt, 2007). The trough’s lateral dimensions will reflect the shape and dimensions of the panel, widening upward by the overburden’s angle of draw, and complicated by topography, bedrock structure, and inherent forces of tension, compression, and shear.

Longwall mining occasionally leads to catastrophic stream flow losses where mining occurs too close to stream beds or old mine workings that are hydraulically connected to active channels. A much more common problem is the loss of base flows into stress-release fractures that develop in response to the removal of longwall roof supports far below the surface (Booth, 2006). Longwall dewatering may last only as long as required to fill stress-release fractures with water or plug the fractures with sediment, or subsidence may transform perennial channels into intermittent or ephemeral regimes. Base-flow losses may ruin aquatic habitat or greatly exacerbate chemical problems in mined watersheds, particularly during seasonal low flows or prolonged drought.

Longwall panel subsidence also may alter stream longitudinal profiles and require stream restoration. Larger streams in the Appalachian region typically have longitudinal gradients of only 2 to 4 m/km (Hickman, 1990), and trough subsidence may locally reverse stream gradients and pond stream water on to nearby floodplains and low stream terraces. Unsubsided areas between longwall panels may dam hundreds of meters of channel and floodplain in subsided reaches. Remediation of ponding is affected by excavating channels above the gate roads, lowering the unsubsided stream beds to restore the longitudinal profile and allow unimpeded flow. Until recently, straight channelization excavation techniques were used, but modern practices include channel restoration toward hydraulic geometry and meander patterns that are more likely to be stable and ecologically intact through time.

Although problems presented by subsurface mining may be less evident than those in surface-mined lands, the hydrologic and geomorphic disequilibria are substantial and critical to many aquatic ecosystems. Both surface and subsurface mining have occurred over many decades in watersheds throughout the Appalachian Coalfields, providing complex scenarios that require creative solutions and substantial restoration and reclamation effort.

The Potential for Stream and Watershed Restoration in Mined Lands

The term “restoration” denotes assisting the recovery of a system that has been degraded, damaged, or destroyed, and in the strictest sense, the term implies a return to historic conditions (Society for Ecological Restoration International [SERI] Science & Policy Working Group, 2004). Within the discipline, the term “restoration” is applied to a wide range of activities that include reclamation, rehabilitation, mitigation, engineering, resource management, and “pure” restoration back to a preexisting condition (SERI Science & Policy Working Group, 2004). Furthermore, most practitioners use either “stream restoration” or “river restoration” to refer to restorative activities throughout a watershed. Terminology notwithstanding, professionals in the discipline recognize “restoration” must address processes and conditions throughout the whole watershed to be effective and is not limited to returning a channel reach to a state that existed prior to human impact.

A spirited debate over stream restoration has resounded for over a decade (Lave, 2008). The debate is wide-ranging, and includes controversy ranging from the efficacy of specific practices to the appropriateness of any human intervention in the natural recovery of fluvial systems. Several efforts have shown the potential of negative outcomes in specific projects (Kondolf et al. 2001) or disappointing results for stream restoration in general (Bernhardt et al., 2005; Miller et al., 2006), but stream restoration’s harshest criticism has come from academics outside the practice of restoration, whose analysis may inappropriately lump out-dated, ill-designed, or poorly constructed projects with those that meet current industry practices. Although vulnerable to counter attacks that their viewpoints are isolated from the realities, limitations, and conditions in the practitioners’ world, these critics play an invaluable role in prompting the stream restoration community to focus on weak areas in the practice, such as clear definition of restoration goals, cost-effective decision making, fitting appropriate techniques to geomorphic and ecological problems, and peer-reviewed publication of techniques, practices, and results.

By and large, the stream restoration debate has taken place outside of coal-mined watersheds and, as a result, much of the debate to date is virtually irrelevant in mined lands. As in the case of the most heavily impacted urban watersheds, "allowing nature to take its course" is not an environmentally viable option for most mined-land streams. Watershed impacts are so great and constraints so pervasive as to demand aggressive intervention, including in-stream structures. There is ample room for debate over which practices are most effective, and mined lands can serve as laboratories in which to test different design techniques and restoration approaches. The scale of landscape modification may allow results from different techniques to be evaluated much more quickly and thoroughly than would be possible in less impacted landscapes.

Although frequently criticized, Dave Rosgen's Natural Channel Design techniques have guided many restoration efforts in the last two decades. This approach relies heavily on hydraulic geometry data collected on reference reaches. Reference reaches must be in a "geomorphic potential state" that is "stable" but may or may not be "natural" (Rosgen, 1996, Rosgen, 2007). If a reference reach approach is applied to mined watersheds where hydrologic regime and sediment loads have changed significantly, the attributes of "natural" streams may be irrelevant to the design of sustainable streams in the mined watershed. Any attempt to force the stream back to its original state will be doomed to failure if new conditions in the watershed are incompatible. Rosgen recognizes and emphasizes watershed conditions that are almost guaranteed to cause channel failures in his Natural Channel Design training workshops (where most practitioners have been informed about fluvial geomorphology), but he needs to stress this aspect of his approach more explicitly and more frequently in his publications (where most academics have been informed of the Rosgen approach).

Rosgen critics have attacked Natural Channel Design as a short-sighted, "band-aid" approach that only addresses symptoms in a small part of a sick watershed. Rosgen recognizes the limits of channel-reach solutions in his workshops, but correctly notes that experience shows that heavy equipment is already in streams across the country and most problem reaches will undergo dramatic human intervention whether or not overriding watershed issues are resolved. The political, social, and short-term environmental consequences of ignoring reach-scale solutions and doing nothing unless the watershed is "fixed" negate a passive approach in the view of most stakeholders. Although they may not resonate among geomorphologists to whom long-term solutions are the only solutions worth pursuing, there is a need for reach-scale channel "restoration" or enhancement projects to address the worst stream sites in mined lands, especially those with unstable banks. However, it is important for all to recognize reach-scale mitigation must be properly maintained through time and may do little to attain long-term geomorphic equilibrium or optimize ecological function.

Critics have rightly pointed out that process is more important than form in understanding fluvial systems, but process and form are linked in watersheds that have reached geomorphic equilibrium. Most heavily mined watersheds have not yet reached equilibrium; therefore, a practitioner must look for stable channels in reclaimed landscapes or abandoned mined lands if a reference reach approach to channel design is to be followed. However, analogous streams and watersheds may be difficult to verify, and inherent instabilities may be overlooked, so other approaches to optimizing geomorphic and ecological function may prove more effective.

Throughout the Appalachian coal fields, undisturbed watersheds and stable streams are rare because of previous generations of mining, much of which occurred before passage of the Surface Mining Control and Reclamation Act of 1977. So-called "pre-law" mined lands may have significant forest vegetation cover, but under the canopy a legacy of mining induced sediments lurks along stream banks and on hillslopes. Most coalfield stream channels are in a transitional response to altered hydraulic regimes and increased sediment supply from their watersheds. The hydrologic geometries, channel patterns, and longitudinal profiles of such streams in transition may reflect neither original conditions nor eventual channel configuration. Channel evolution models (Simon, 1989; Rosgen, 1994; 1996) may provide insights into the ultimate channel attributes, but a thorough understanding of fluvial process is essential to successful design of a functioning fluvial system on a mined landscape.

The materials, dimensions, and configuration of the numerous valley fills in the Appalachian region have no natural analogs, a sure-fire geomorphic indicator that these anthropogenic landforms are not likely to be stable over geologic time. If one assumes mountain-top mining is an economic "necessity" to satisfy the American cheap energy habit, the industry and oversight agencies might do well to divorce the mining method from valley fill disposal of the overburden. The long-term cost-benefit ratio of mountain-top mining may be less daunting if geomorphic reclamation (Michael et al, this volume; Bugosh, this volume) is applied in lieu of valley filling. The geomorphic reclamation approach attempts to create a sustainable landscape that functions as much like the pre-mine fluvial system as economically feasible. Overall gross morphology, such as AOC, is less important than small-scale landscape features where geomorphic processes operate and most organisms live. With high-resolution GPS-guided equipment and computer directed mining, the creation of reclaimed landscapes with stable slopes, convex stream profiles, and landforms analogous to those that have persisted for hundreds of thousands of years can be accomplished without greatly increasing materials handling or haulage distances.

The most important aspect of a geomorphologist's perspective as applied to mined lands is the true meaning of geological time, not just viewed backwards, but also looking forward over the enormous time spans in which valley fills and other extensive landforms will last into the future. Strategies for mine reclamation and watershed restoration in mined lands need to start at a millennial time scale and expand from there. Valley fills and other mine-related landforms and legacy sediments will outlast the corporations that pay to mine the coal and reclaim the landscape. The geomorphic problems are societal. The long-term costs of stable streams, good water, and viable ecosystems inevitably will pass on to "government" and Appalachian coal field citizens.

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SCIENCE BASIS FOR RECLAMATION OF LOW-ORDER STREAMS

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Abstract

Most stream channel design is based on analogy. A template is sought in a nearby or idealized channel that the designer judges to be suitable. The science basis for such an approach is weak. There is little definitive guidance for the choice of template, nor does it provide a basis for linking cause and effect in a logically complete and testable framework. In the uncommon event that a stream has experienced only a local disturbance (typically livestock grazing or forest road construction), a template argument may be plausible, but cannot be shown to be correct. A scientific approach to stream design must explicitly incorporate the essential drivers including: the supply of water; sediment; nutrients; and organisms in a predictive, testable framework linking: drivers; objectives; design; and predicted outcomes. The tools available for an explicit, predictive design process have advanced in recent years, particularly in linking water and sediment supply to the physical performance of the channel. Yet, particular challenges remain. Forecasts of sediment supply remain difficult, time consuming, and highly uncertain. Improved guidance for selecting a design discharge awaits explicit connections between the physical and ecological components of the project. Uncertainty is rarely accounted for in channel design. The largest unmet challenge in stream restoration design is predicting ecosystem structure and function from stream hydrology and geomorphology. Trends and constraints are emerging, but predictions of ecosystem response to design choices are generally not possible. Stream design in mine reclamation has some parallels to restoration following a local disturbance such as grazing: in either case, putting the stream back the way it was is a plausible if unsubstantiated hypothesis. However, *de novo* construction of a reclaimed stream faces extra challenges: which elements must be replicated and how does one know if the list is sufficiently complete? If a pre-disturbance or undisturbed template is used to replicate the gross appearance of the stream, what assurance is there that the biogeochemical and ecological functions and populations will be restored? Of particular concern in a reconstructed valley bottom would be the interaction between surface and subsurface flow in the maintenance of stream temperature and water quality. Development of a science-based restoration practice will require close collaboration through which research results find their way into practice and practice helps define the most pressing research priorities.

No paper was provided by the author.

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HYDROLOGICAL FUNCTIONING OF SURFACE-MINED WATERSHEDS IN WESTERN MARYLAND: RESTORATION OR RECLAMATION?

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Abstract

The Surface Mining Control and Reclamation Act requires mine operators to minimize disturbance to the prevailing hydrologic balance at a mine site and associated offsite areas. A significant portion of the engineering design and hydrologic evaluation to support this requirement is performed using the Natural Resource Conservation Service Curve Number Method (SCS-CN). The SCS-CN method is widely used due to its simplicity, relation to readily grasped watershed properties, and requirement by ordinance. Accurate application of the method is limited by a scarcity of tabulated CN values for reclaimed minelands, however. Assumptions regarding the hydrologic behavior of reclaimed minelands may be inaccurate leading to an underestimation of runoff volume and peak runoff rate with predictable consequences downstream. Four watersheds (three reclaimed mines and one forested reference site) in the Georges Creek basin of western Allegany County were instrumented for rainfall and runoff. CNs calculated for the reclaimed mineland watersheds using rainfall and runoff data (range = 64-92) were generally higher than CNs estimated by prevailing engineering methods (range = 65-79). Though these results can only be explicitly applied to the watersheds studied, their general agreement with other CN values in the literature indicates that a more conservative approach may be warranted in engineering design and hydrologic analysis of surface-mined lands.

Introduction

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 (Public Law 95-87) requires the reclamation of lands surface-mined for coal including: backfilling and regrading to approximate original contour, revegetating, and minimizing disturbance of the prevailing hydrologic balance at the mine site and in associated offsite areas. To meet this requirement, conveyances, erosion and sediment control measures, and stormwater management structures are utilized. A significant portion of the design of these engineering methods and hydrologic evaluation of the mine site and surroundings is accomplished using simple hydrologic models such as the Natural Resources Conservation Service (formerly Soil Conservation Service) curve number (SCS-CN) method.

The SCS-CN method is a hydrologic event model that computes total storm runoff volume from total storm precipitation depth. It is essentially a one-parameter model, in which the Curve Number (CN) describes the hydrologic response of the landscape based on *a priori* knowledge of soil type and land cover treatment. The SCS-CN method was developed by the USDA Soil Conservation Service in 1954 (Rallison, 1980) and is described in the National Engineering Handbook, Section 4: Hydrology (NEH-4; SCS, 1972). The method was developed from data obtained from experimental watersheds and infiltrometer plots, and is broadly applied due to its simplicity and wide acceptance (Rallison, 1980). Ponce and Hawkins (1996) state that the method's popularity is rooted in its convenience, its simplicity, its authoritative origins, and its responsiveness to four readily grasped catchment properties: soil type, land use treatment, surface condition, and antecedent condition. They criticize the SCS-CN method due to its lack of a physical basis, lack of accounting for time, origin as agency methodology, and isolation from the peer review process. Additionally, the inability of the method to differentiate between streamflow generation processes specifically assuming that excess precipitation is spatially uniform across a watershed, has led to misapplication in water quality modeling applications (Garen and Moore, 2005; Lyon et al., 2004).

The SCS-CN method was primarily developed empirically and justified largely on the grounds that it produces rainfall runoff curves of a type found on natural watersheds (Rallison, 1980). The SCS rainfall-runoff relation was designed for use with precipitation amounts measured by non-recording rain gages; more specifically precipitation totals for one or more storms occurring in a calendar day. The relation contains no explicit provision for time and therefore ignores rainfall intensity (SCS, 1972). In an attempt to capture temporal variability, the SCS rainfall-runoff relation is often applied in an incremental manner. This method of estimating increments of runoff for incremental periods within a storm is questionable unless the incremental periods are long enough to include infiltration recovery (Rallison, 1980).

Amidst these criticisms however, the SCS runoff equation has provided a uniform basis for estimating the effects of land treatment and land use changes on volumes of runoff under a wide range of climatic conditions, and is an effective index of runoff potential over a 24-hour period (Rallison, 1980). The CN procedure is the most frequently used method within SCS to estimate direct runoff from ungaged areas (Rallison and Miller, 1982). The CN method is well established in hydrologic engineering and environmental impact analyses (Ponce and Hawkins, 1996), urban hydrology and stormwater management (SCS, 1986; MDE, 2000), and in the emerging field of low impact development design (Landers, 2004; Prince Georges County, Maryland, 2000). The SCS-CN method is utilized for hydrologic calculation by common non-point source water quality models such as SWAT (Nietsch et al., 2001) and AGNPS (USDA-ARS, 2006). The use of the method in engineering design or analysis is often required by ordinance.

The SCS method is best utilized to represent average conditions and does not always reproduce measured runoff from specific storm rainfall (Rallison and Miller, 1982). Optimal curve numbers for a watershed vary between storm events and even within storm events. Between-storm variation may be accounted for by varying the Antecedent Moisture Condition (AMC) (SCS, 1972). The AMC II or median condition represents the average conditions in a watershed and is most often used in design. The AMC I and AMC III conditions represent lowest runoff potential and highest runoff potential, respectively, and represent the most likely range of conditions that will be encountered at a site. The AMC acts as a surrogate for other sources of variability (Ponce and Hawkins, 1996). Unless otherwise noted, CNs reported in this article are AMC II values.

SCS CN Method Equations

The SCS rainfall runoff relationship (SCS, 1972) is:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (1)$$

where: Q = direct runoff (mm), P = precipitation (mm), I_a = initial abstraction (mm), and S = potential maximum retention (mm). S is related to watershed physical characteristics (soil, land cover, and condition) by the dimensionless Curve Number:

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

The SCS method is parameterized by selection of a CN that is representative of the runoff potential of a landscape. CNs theoretically can be between 0-100, but are most commonly between 40-99. Higher CNs represent greater runoff potential. CNs are typically selected from published values (SCS, 1986) tabulated based on soil Hydrologic Soil Group (HSG) and land cover treatment and hydrologic condition. HSG is a parameter that defines the propensity of drainage for a soil type and is tabulated for over 4000 soil series in the United States alone. Hydrologic Soil Group (A, B, C, or D) is assigned to soil series by the Natural Resources Conservation Service (NRCS) according to infiltration rate, which is obtained for bare soil after prolonged wetting (Rawls et al., 1993). HSG D soils have the lowest infiltration rate and consequently the highest runoff potential. Conversely, HSG A soils have the highest infiltration rates and lowest runoff potential.

Initial abstraction is expressed as a proportion of S as:

$$I_a = \lambda S \qquad (3)$$

To remove the necessity for estimating I_a, the SCS evaluated data from experimental small watersheds and recommended that λ=0.2 be generally used (SCS, 1972). For λ=0.2, the familiar form of Eq. (1) is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (4)$$

Solving for *S* in Eq. (4):

$$S = 5\left[P + 2Q - \sqrt{(4Q^2 + 5PQ)}\right] \quad (5)$$

Eq. (5) and (2) can be used to calculate CNs for observed storm events.

Application to Reclaimed Minelands

The application of the SCS-CN method to reclaimed minelands is limited by a scarcity of tabulated CN values for these lands. Ritter and Gardner (1991) describe the following CN selection methods for reclaimed minelands: (1) the use of agricultural CN values with pre-mine soil classification and post-mine land use, (2) calibrated CN values based on rainfall and runoff data from watersheds disturbed by surface mining and reclamation, and (3) simulated CN values from rainfall infiltrometer tests on reclaimed mine soils.

Experimental watershed studies have been undertaken to determine representative CN values for surface minelands both during active mining operations after reclamation practices (regrading to approximate original contour and revegetation). Bonta et al. (1997) calculated CNs for three small (9.9–19.8ha) experimental watersheds in Ohio during three phases. The pre-mining phase (phase 1) resulted in CNs ranging from 71-81. The active mining and reclamation phase (phase 2) resulted in CNs 83-91, and the post reclamation phase (phase 3) produced CNs 87-91. Curve numbers for these watersheds increased significantly (+7 to +20 CNs) between phase 1 and 2, and generally remained constant (-1 to +5 CNs) from phase 2 to phase 3. Although the three sites were lithologically dissimilar (differing coal seams, geological and soil characteristics), the resulting phase 3 CNs were quite similar, suggesting that the CN for a newly mined and reclaimed watershed is not sensitive to widely varying, lithological and hydrological differences of undisturbed watersheds (Bonta et al., 1997).

Ritter and Gardner (1991) calibrated CNs for three small (3.1–32.2ha) watersheds in central Pennsylvania. All watersheds were surface-mined and reclaimed according to SMCRA standards. Resulting CNs post reclamation ranged from 83 to 88. Ritter and Gardner (1991) concluded that pre-mine HSG cannot be assumed for the post-mine soil classification due to reduced infiltration rates and recommended that, at minimum, HSG D should be used for reclaimed, sandy loam and silty loam mine soils in central Pennsylvania. The Office of Surface Mining (OSM, 1982) recommends a wide range of values for reclaimed minelands, specifically: 39-72 (HSG A), 61-81 (HSG B), 74-88 (HSG C), 80-91 (HSG D). The maxima of these ranges correspond to recommended values for disturbed areas or active mining.

The SCS-CN method is deeply entrenched in engineering practice and it is expected that the method will continue to be widely used. The purpose of this paper is to suggest techniques and parameters such that the method may be more accurately applied to reclaimed minelands.

Methods

Four watersheds located in the Georges Creek basin in western Allegany County, Maryland were selected for study (Figure 1). Georges Creek is a 188 km^2 basin; as of 2006, 17.3% of the land area in this basin was being actively mined or has been previously mined and/or reclaimed (McCormick et al., 2009). Two watersheds (TNEF, TMAT) were instrumented in 1999 (Negley and Eshleman, 2006) and two others (TSNR, TSSR) in 2004. The watersheds and their instrumentation are described fully by Negley and Eshleman (2006) and Eshleman (2005). Basically, stream stage and discharge were measured at the sites using prefabricated 'Montana' (truncated Parshall) flumes. Hourly precipitation is measured at these watersheds with a universal weighing type precipitation gage located in the TMAT watershed. Watershed physical characteristics and reclamation histories are summarized in Table 1.

Curve Numbers for the three mined/reclaimed watersheds and the forested reference watershed were *estimated* using the procedures described in Technical Report 55 (TR-55), Urban Hydrology for Small Watersheds (SCS, 1986). CNs were estimated based on the pre-mine soil classification and the post-reclamation land use condition through the lookup tables in TR-55 (SCS, 1986). CNs for AMC I and III were determined from NEH 4 (SCS, 1972). These values represent values by method 1 of Ritter and Gardner (1991).

Curve Numbers for the study watersheds were *calculated* from observed precipitation and runoff data. Processing included event selection, baseflow separation, event S and CN calculation, and calculation of a representative CN for varying antecedent conditions. Rain events only were used (snowfall or snowmelt were not included) and events between December and March were excluded to minimize the effect of frozen ground. A total of 67 precipitation events with total precipitation at least 18mm between June 2000 and September 2008 were evaluated. Baseflow separation was performed using a technique recommended by Dunne and Leopold (1978; method B, p288).

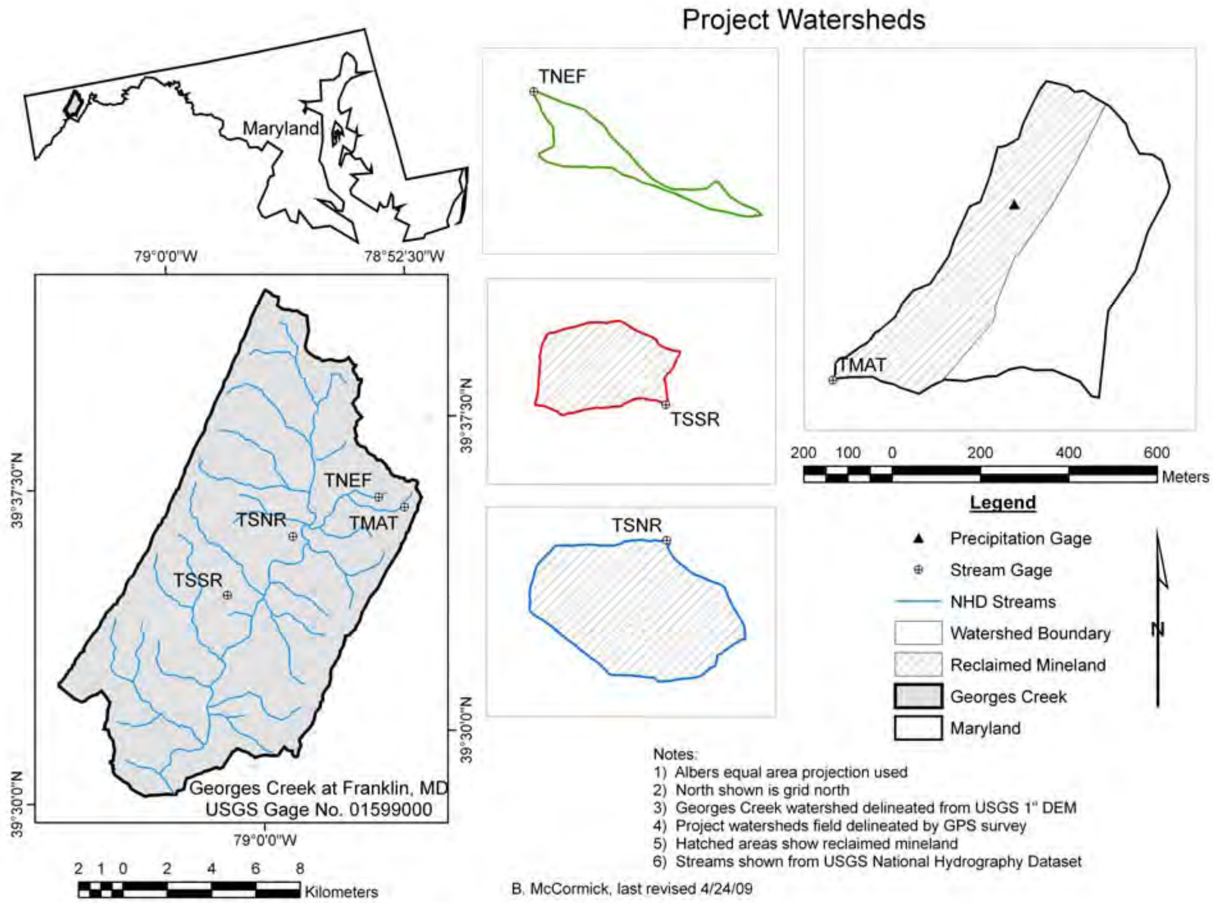

Figure 1. Locations of study watersheds in Georges Creek basin and Maryland.

Table 1. Physical Characteristics of the Study Watersheds.

Watershed	Area (ha)	Mapped HSG	Mined Area	Year Reclaimed[1]	Elevation (m MSL)	Flume Installed	Flume Removed
Tributary East Branch Neff Run (TNEF)	3.0	C	0%	N/A	720	10/1999	Active
Tributary Matthew Run (TMAT)	27.1	C	47%	~1982	830	10/1999	10/2008
Tributary Squirrel Neck Run (TSNR)	11.1	B/C	100%	~1982	580	1/2005	Active
Tributary Seldom Seen Run (TSSR)	5.1	C	100%	~2002[2]	630	9/2004	Active

[1]All mined areas reclaimed by regrading to approximate original contour and replanting with grasses per PL95-87.
[2]Reclamation in this watershed continued after 2002 with planting of some woody vegetation, regrading including filling of rills and gullies, and liming and reseeding.

CNs were calculated for each storm event using $I_a = 0.2S$ and Equations (5) and (2); the logarithms of S were assumed to be normally distributed (Hjelmfelt and Kramer, 1982). The median value of CN calculated from this distribution was taken as the CN for AMC II, with CNs for AMC I and AMC III calculated as 10% and 90% exceedence probabilities, respectively.

The CN for the reclaimed mine land portion of TMAT was back-calculated from the results of TMAT and TNEF using an area-weighted average CN technique. The calculated CN for TNEF was considered representative of the forested portion of TMAT based on similar soils and type of vegetation.

Results

Due to different periods of instrumentation and occasional equipment difficulties, the number of storm events used in the CN calculations varied among the four watersheds. Rainfall ranged from 18-170mm and runoff ranged from 0-93mm (Table 2). Storm events with zero runoff were included in analysis. Rainfall and runoff were plotted for each watershed along with curves for calculated CNs corresponding to the AMC I, II, and III conditions, or the 10% exceedence, 50% exceedence, and 90% exceedence values, respectively (Figure 2). Calculated CNs were higher than estimated values for both the TMAT (+7CN) and TSSR (+8CN) watersheds. The calculated CN for the reclaimed mine portion of TMAT was significantly higher (+13CN) than the estimated CN. The calculated and estimated CNs for the TNEF and TSNR watersheds were very similar, however (Table 3).

Table 2. Summary of Storm Events Used in the CN Analysis.

Watershed	Events	Dates	Rainfall (mm)	Runoff (mm)
TNEF	65	6/2000-9/2008	18-170	0-35
TMAT	64	6/2000-9/2008	18-170	0-93
TSNR	29	1/2005-9/2008	18-90	0-11
TSSR	30	9/2004-9/2008	18-107	0-50

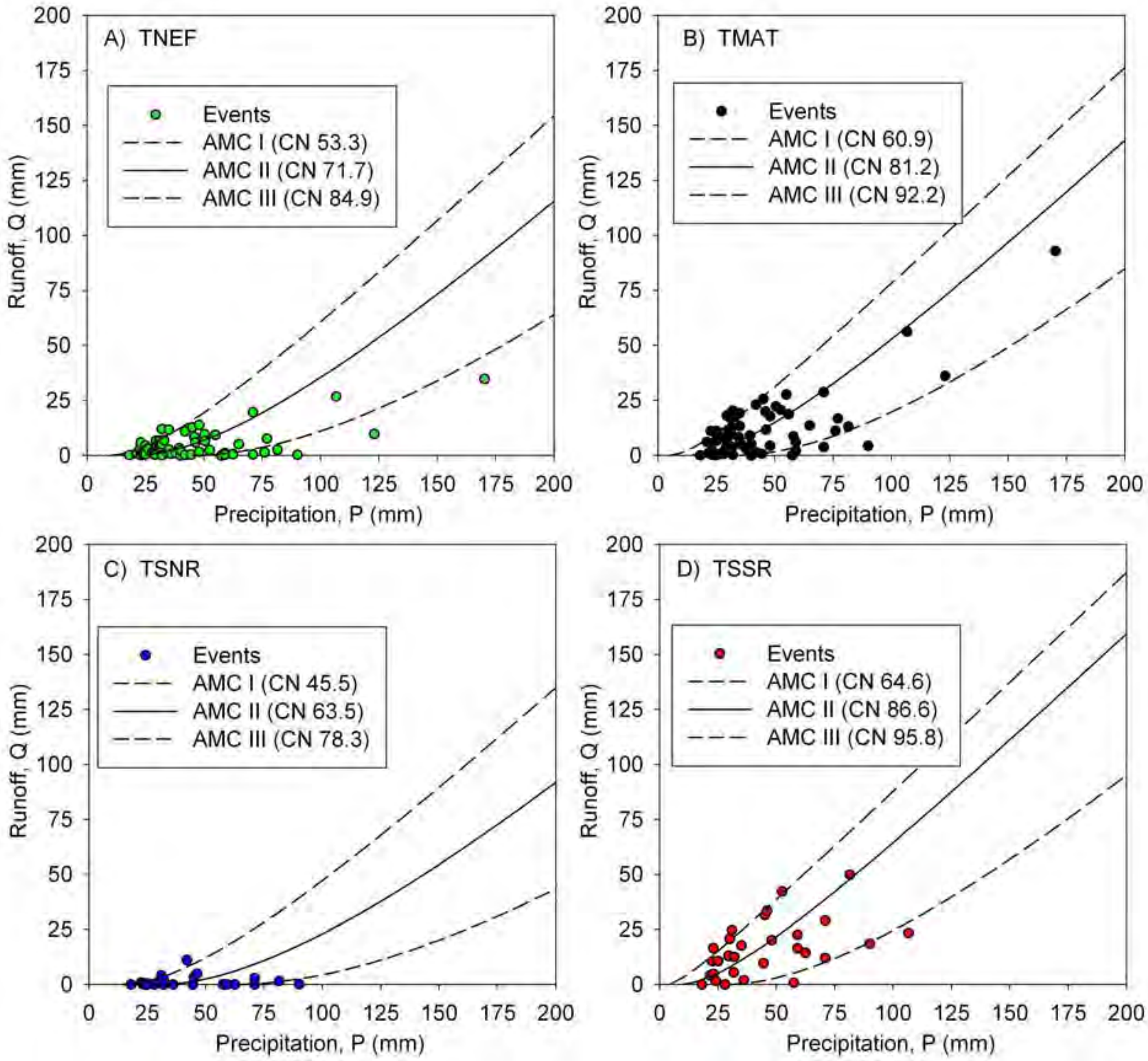

Figure 2. Rainfall and runoff for storms used in the study (with enveloping curves and medians).

Discussion

Calculated CNs were generally higher than those estimated using pre-mine soil classification and post-mine agricultural land use, even when accounting for hydrologic condition. Calculated CNs were in general agreement with those published for reclaimed minelands (Table 4). The calculated CN for the forested reference watershed (TNEF; 72) was essentially equal to the estimated value of 70 (based on woods, good hydrologic condition, and HSG C). The calculated CN for one reclaimed watershed (TSNR; 64) was essentially identical to the estimated value (65) from TR-55 (based on meadow, between 50% HSG B and 50% HSG C).

Table 3. Comparison of Calculated and Estimated CNs

Watershed	Calculated CN Values			Estimated CN Values[1]		
	AMC I	AMC II	AMC III	AMC I	AMC II	AMC III
TNEF	53	72	85	51	70[3]	85
TMAT	61	81	92	55	74[2]	88
TMAT (reclaimed area)	70	92	100	62	79[4]	91
TSNR	46	64	78	45	65[5]	82
TSSR	65	87	96	62	79[4]	91

[1]TR-55 Appendix D for AMC II (SCS, 1986); NEH-4 Table 10.1 for AMC I, III (SCS, 1972)
[2]Area-weighted average CN using woods, good condition, HSG C and pasture fair condition, HSG C
[3]Woods, good condition, HSG C
[4]Pasture, fair condition, HSG C
[5]Meadow; 50% HSG B and 50% HSG C

Calculated CNs for the other two watersheds, TMAT and TSSR, were in poor agreement with TR-55 estimated values. Using an area-weighted average of woods in good condition and pasture in fair condition (HSG=C), the TR-55 value for TMAT was 74, a value that is 7 CNs less than the calculated CN of 81. If the forested portion of TMAT can be characterized by a CN equal to TNEF, the mined portion would require a median CN of 92 to produce the observed response. The calculated CN of 87 at TSSR was significantly larger (8 CNs) than the TR-55 estimated value of 79.

Regulatory requirements for the selection of CNs to model reclaimed mine areas for use in permitting or hydrologic impact assessment vary by region and some regions may impose more conservative requirements than the pre-mine soil, post-mine agricultural land use scenario presented in this paper. Note that this method would become less conservative with the use of "good" hydrologic condition; a value often chosen in design. The fair hydrologic condition used for reclaimed areas at TMAT and TSSR was chosen based on observed vegetation density. These tabulated values are presented to show a potential misapplication of the SCS-CN method to reclaimed minelands.

The enhanced runoff responses of TMAT and TSSR (relative to TNEF and TSNR) are likely a function of reclaimed soil properties in these watersheds, particularly high soil bulk density, low organic matter content, and extremely low soil infiltration capacity due to soil compaction resulting from the reclamation process. Regrading of surface mine soils typically results in significant compaction of surface soils and generally lower infiltration rates (Negley and Eshleman, 2006). Based on these results, soil compaction seems to be the primary driver behind the enhanced response of reclaimed mine areas. The use of HSG D to describe post-mine soils, as suggested by Ritter and Gardner (1991), would significantly improve the fit between TR-55 CN estimates and observed CN values in this study.

Table 4. Estimated and Calculated CNs for Reclaimed Minelands From Published Reports.
All values are for AMC II (Average Antecedent Moisture Condition).

Source	Location	Watershed	Estimated CN[1]	Calculated CN
Ritter and Gardner (1991)	Central PA	Browncrest	74	88
		Moshannon	75	83
		Snow Shoe	77	88
Bonta et al. (1997)	East Central OH	C06	-	87
		M09	-	92
		J11	-	88
Eshleman and McCormick (this study)	Western MD	TMAT	74	81
		TMAT (Reclaimed Area)	79	91
		TSNR	65	64
		TSSR	79	87

[1]Based on pre-mine mapped soil and post-mine land use; TR-55 Appendix D for AMC II (SCS, 1986); NEH-4 Table 10.1 for AMC I, III (SCS, 1972).

Interestingly, a comparison of the reclaimed area of TMAT (almost 20-30 years after reclamation) and TSSR (5-10 years after reclamation) shows little difference in observed CNs (Table 4). Furthermore, no time trend in CNs was seen during the 9 years of data for the TMAT watershed. Clearly, the mining and reclamation activities employed at the TMAT and TSSR watersheds have resulted in a net change to hydrologic response at these sites based on the comparison of observed CNs with those observed at TNEF, and these changes should probably be considered permanent.

Data from the TSNR watershed indicate that the reclamation process, as measured by calculated CNs, can result in hydrologic behavior comparable to those of un-mined areas, however. Unlike the TMAT and TSSR watersheds, the TSNR watershed was in agricultural use prior to surface mining and based on its location in the Georges Creek valley and pre-mine mapped soils, it could be expected to have had significantly better developed surface soils to stockpile for use in the reclamation process. This watershed was returned to agricultural use following mining and is currently in a meadow condition. Thus, the availability of better soil materials and a higher degree of care involved in the reclamation process to restore an agricultural use have likely improved the hydrologic outcome for TSNR.

As with any study involving field data, uncertainties exist. In mountainous terrain, precipitation generally increases with elevation (SCS, 1972; Dunne and Leopold, 1978). The precipitation data used in this study was from a gage located in the highest elevation watershed, TMAT. It is therefore likely that precipitation was overestimated for the TSSR and TSNR watersheds as they are 200-250m below the elevation of TMAT. This would actually lead to an underestimation of CN for the TSSR and TSNR watersheds. Indeed, preliminary comparisons of precipitation data between a weighing bucket precipitation gage installed in the TSSR watershed in July 2006 (removed February 2007) and the gage used in this study indicate approximately 20% less total precipitation at the lower elevation sites (TSSR and TSNR). Calculated CNs show significant sensitivity to precipitation depth. A 10% decrease in precipitation depths for the TSSR and TSNR watersheds for example results in an increase of +2 to +3 CN.

The results seen in TMAT and TSSR are believed to be representative of hydrologic change associated with surface mining in the Georges Creek watershed. McCormick et al. (2009) examined stormflow response of the Georges Creek watershed and found that it experiences higher peak flows and shorter centroid lag times than an adjacent, unmined river basin, consistent with the plot-scale results produced by the current analysis.

Conclusions

The observed CNs for TMAT and TSSR support Ritter and Gardner's (1991) recommendation that, at minimum, reclaimed mine soils should be treated as a HSG D in post-development hydrologic calculations. Moreover, the observed CNs from TMAT and TSSR are in general agreement with those of Bonta et al. (1997) and Rittter and Gardner (1991), implying that these collective results could be extended to minelands reclaimed using traditional practices throughout the Central Appalachian Mountains. Our results and those from the published literature clearly indicate a need for greater care in selection of CNs for engineering design and hydrologic analysis for reclaimed surface-mined lands. Our research also suggests that surface soil compaction resulting from traditional reclamation practices can enhance the hydrologic response of small watersheds to rainfall and supports the need for development of reclamation practices that minimize compaction of surface soils.

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DISTURBED LAND RECLAMATION USING GEOMORPHIC TECHNIQUES: MCKINLEY COAL MINE, NEW MEXICO, MINING AREA 12C

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Abstract

The disturbance footprint typical of a surface coal mine consists of large piles of overburden spoiled in the process of coal removal. These spoil piles can be over 100 feet high and are typically comprised of uncompacted materials that can be easily moved and reshaped with heavy earthmoving equipment. Fluvial geomorphic post-mining topography (PMT) designs must: 1) aesthetically blend reclaimed surfaces into adjacent undisturbed lands; 2) account for runon from upgradient watersheds; 3) control reclamation costs by using available soil materials (optimize cut/fill balance); 4) establish reconstructed soil depths adequate to support growth of desired vegetation communities; 5) produce a stable landform; and 6) reconstruct adequate drainage features.

Chevron Mining Inc.'s McKinley Mine is located about 27 miles west northwest of Gallup, New Mexico. Mining Area 12C presents unique PMT stability challenges that require the application of a geomorphic PMT design approach. This area is comprised of 20 acres of steeply sloping material with a southwest facing aspect. At McKinley Mine, steep southwest facing slopes pose unique challenges in reclamation, because vegetation density is typically low and root mass establishes slowly, conditions that hinder slope stability. Other challenges specifically encountered in this area include the presence of an undisturbed rock outcrop at the lower end of the slope, the operational need to limit bulldozer push distances under 200 feet, the goal to obtain a cut-fill balance over the entire acreage and within individual subwatersheds, and the need to provide interim stability immediately after construction and prior to vegetation cover establishment.

A state-of-the-art fluvial geomorphic PMT design method to reclaim steep slopes is presented and contrasted with traditional draining terracing methods previously used at the mine. Potential construction and maintenance cost savings associated with this fluvial geomorphic PMT design method are identified.

Introduction

Water & Earth Technologies, Inc. (WET), Habitat Management, Inc. (HMI) and Chevron Mining, Inc. (CMI) together developed a solution for reclaiming steep southwest facing slopes in mining Area 12C that have historically been prone to excessive erosion, low vegetation establishment and continuing maintenance. Area 12C is located in the east wing of the Chevron McKinley Coal Mine, 27 miles northwest of Gallup, New Mexico, on Navajo Nation land administered by the Office of Surface Mining (OSM). Mining in this area was completed in May of 2007. Challenges encountered for this reclamation project included the need to reclaim graded material on a slope of 18-35% with southwest facing aspect, the presence of undisturbed rock outcropping that needed to be avoided during reclamation, the operational need to limit bulldozer pushes and the inability to import or export additional materials for construction.

Two different reclamation alternatives were considered for Area 12C. The first alternative would use a traditional reclamation approach including three levels of draining terraces designed to convey water on a 3% slope to a single riprapped down drain. Terracing and down drains have been used to reclaim areas with similar terrain conditions elsewhere at the

McKinely Mine and have failed to adequately control erosion (Williamson 2006). Terrace overtopping and down drain blowouts have been issues in maintenance and functionality for the mine. Maintenance routines consist of cleaning out terraces where they have filled in with sediment and repairing damaged or blown out terraces and down drains.

As a second alternative preferred by the regulatory agencies, the McKinley Mine committed to a geomorphic approach for the development of a sustainable post-mining topography (PMT) design at Area 12C. The geomorphic approach taken can be categorized in four steps: 1) the evaluation of undisturbed stable land forms where the characteristics of landforms that develop naturally under the influence of rainfall and runoff processes are applied to the design of a reclaimed landform, 2) the determination of appropriate modeling tools, 3) the watershed network design, and 4) the need to address other permit stipulations. Like natural landforms, a PMT designed using a fluvial geomorphic approach would be characterized by many small drainage subwatersheds to reduce the concentration of runoff and the associated flow velocities. Concave, meandering channel profiles similarly reduce the gradient and therefore the velocity of concentrated flows. The lower slope and channel gradients increase the reclaimed landform's resistance to erosion and the greater topographic diversity promotes the establishment of vegetation and produces a landform that looks more natural.

The specific goals for the reclamation design were to: 1) develop a PMT configuration that will ensure long term stability, 2) balance spoil cut and fill volumes, 3) design hydrologic features capable of passing storm water runoff through and from reclaimed lands and 4) promote the establishment of vegetation.

Modeling Tools

A comprehensive PMT design was developed using a combination of software recommended by the OSM's Technical Innovative Professional Services (TIPS) toolbox (USDOI 2009). Selected software includes Carlson's *Natural Regrade with GeoFluv*™, Sediment Erosion Discharge by Computer Aided Design (SEDCAD 4.0) and the Revised Universal Soil Loss Equation (RUSLE) Version 1.06c.

The Natural Regrade with GeoFluv™ modeling applies fluvial geomorphic principles to landforms using computer software linked to an AUTOCAD platform. GeoFluv™ simulates the features of natural landforms that would evolve over time as a result of natural processes controlled by weather and climate. This geomorphic modeling approach was used to design stable landforms that possess a hydrologic equilibrium between water conveyance and sediment transport (Carlson Software 2007 Users Manual 2006).

SEDCAD 4.0 is a hydrology and sedimentology routing model used to simulate peak flows, drainage volumes, and sediment yields from undisturbed and disturbed/reclaimed watersheds. Hydrograph development and peak flow determination are based on a user-input design storm (i.e., rainfall amount and duration and selection of a rainfall distribution). Hydrographs are developed for each subwatershed based on the area, time of concentration and Natural Resources Conservation Service (NRCS) curve number for that subwatershed. One of three dimensionless double triangle unit hydrograph shapes is selected. Routing of hydrographs is accomplished by Muskingum's method (Warner, Schwab & Marshall 1998). Hydrologic analysis using SEDCAD was used to quantify the rainfall and runoff characteristics for watersheds to determine appropriate input parameters for input into the Natural Regrade with Geofluv™ model.

The RUSLE software was used to calculate weighted annual average soil detachment rates for the pre-mining and reclaimed conditions at Area 12C. RUSLE estimates soil loss from a hill slope caused by raindrop impact and overland flow (collectively referred to as "inter-rill erosion"), plus rill erosion. Gulley and stream erosion are not estimated (Toy et al. 1998). The software allows soil detachment rates from the reclaimed land area to be compared to those that would exist for that area under undisturbed conditions.

Model Input Parameters

Natural Regrade with GeoFluv™ utilizes inputs that have been correlated with the development of stable landforms as defined by the scientific field of geomorphology. A brief description of the critical inputs follows:

- Bankfull and Floodprone Rainfall Amounts: The rainfall associated with the 2-yr, 1-hr and the 50-yr, 6-hr storm events,
- Drainage Density: The ratio of Valley Length to Reach Area,
- Ridge to Head of Channel: The shortest distance from the ridgeline to the head of a stable channel,

- A-Channel Reach Length: One-half a meander length for a Rosgen-classified A channel, and
- Sinuosity: The meander characteristics of a channel based on the valley slope.

These input parameters were determined by characterizing an undisturbed landform in the project vicinity with similar hydrologic and climatic attributes to Area 12C. Most of these parameters could be measured from an aerial photograph overlain with topographic data. Some of these characteristics were determined by performing a field survey. Site specific parameters for Area 12C are shown in Table 1.

Table 1: Input Parameters for the Natural Regrade with GeoFluv™ Model

Bankfull 2yr, 1hr Rainfall	0.7 in
Floodprone 50yr, 6hr Rainfall	2.12 in
Drainage Density	>125 ft/acre
Ridge to Head of Channel	80 ft
A Channel Reach Length	50 ft
Sinuosity	1.2

SEDCAD 4.0 requires inputs for peak flow modeling including a rainfall distribution and infiltration characteristics indicated by curve numbers that describe the permeability of the area based upon soil and vegetation conditions. The NOAA Atlas 14 for New Mexico was used to establish precipitation frequencies and their corresponding rainfall amounts, and associated rainfall distributions. New rainfall distributions have been developed by the NRCS for New Mexico (Type II-60, -65, -70, and -75). The rainfall distribution recommended for the mine area and used in modeling for Area 12C is the Type II-70, in which 70% of the rain from a 6-hour storm falls in a 30-minute period. Use of the Type II-70 distribution consistently produces higher peak discharges than the standard Type II distribution.

The curve number (CN) used to model the reclaimed condition is 82. The CN 82 for reclaimed conditions assumes that revegetation has been completed. Although vegetation will not be present immediately following re-seeding, surface roughening and loosening for seedbed preparation and the application of mulch will temporarily provide soil-cover conditions similar to re-established 5+ year old reclaimed land vegetation. Previous modeling for other locations on the mine site used a CN of 74 to model reclaimed conditions. The increase from a CN of 74 to 82 was chosen to reflect the lower average vegetation and total cover typically found on steep, southwest aspect conditions. It assumes that there will be only 30 percent total vegetative cover after 7 years. Total cover is defined as the sum of vegetation cover, surface litter, and rock fragments.

Design Approach

Seven subwatersheds ranging in size from 2-5 acres were configured in Area 12C. The design incorporated a series of ridges and valleys. The distance between the valleys and main ridges was kept below 200 feet to economize construction by minimizing bulldozer push distances. Watershed boundaries and channel locations were optimized to achieve a cut-fill balance in each individual subwatershed. Slope lengths were shortened an order of magnitude from 1,000 feet to 100 feet to minimize sediment particle detachment. Runon from upgradient watersheds was determined using peak flow modeling in SEDCAD and then applied to the Natural Regrade with GeoFluv™ model to be accounted for in channel sizing. The watershed configuration in the final PMT design produced a mutli-aspect surface better suited for vegetation establishment than the previously existing uniform southwest facing slope.

Additional Design Requirements

The watershed hydrology was modeled using both Natural Regrade with GeoFluv™ and SEDCAD to demonstrate that proper design flows were used to size channel cross-section geometry designed in the Natural Regrade with GeoFluv™ model and provide adequate freeboard. Concentrated flow characteristics were compared for each watershed based on the two models. Natural Regrade with GeoFluv™ predicted slightly higher peak flow estimates than SEDCAD as seen in Table 2.

Table 2: Flow Comparison and Model Sensitivity Analysis

Subwatershed	Peak Flow (cubic feet per second) Natural Regrade (50-yr, 6-hr = 2.12")	Peak Flow (cubic feet per second) SEDCAD (50-yr, 6-hr = 2.12")
12C-1	2.52	2.46
12C-2	2.33	2.28
12C-3	4.95	4.87
12C-4	6.1	5.99
12C-5	5.02	4.95
12C-6	6.11	6.03
12C-7	9.32	9.16

Although geomorphic approaches to reclamation can sometimes avoid the use of channel protection by increasing drainage density and lowering channel slopes, for this project channel protection was necessary. Channels with slopes ranging from 18 to 20 percent will be constructed on a spoil material that had previously been mechanically disturbed and recompacted, limiting its ability to withstand shear stress from runoff. To determine the riprap sizing, flows calculated from Natural Regrade with GeoFluv™ at the outlet of each subwatershed were modeled using the PADER method (PADER 1986) in the SEDCAD Channel Utility. The limiting velocity in SEDCAD was set at 5 ft/s, which would typically correlate to a Natural Regrade with GeoFluv™ shear stress of 1.7 lb/ft^2. Where these velocities and shear stresses were exceeded, riprap was needed through the channel length to the junction with a larger receiving channel.

Existing reclamation specifications require a 2 ton/acre mulch cover over reclaimed areas. A RUSLE analysis was conducted on the final design PMT to evaluate its erosion potential and determine if any additional treatment would be necessary. The C factor in the RUSLE calculation equation, which quantifies the vegetation establishment, ground cover and root mass expected to be established within seven years post-construction, was selected to reflect the difficult climatic and aspect conditions present at Area 12C. Soil detachment rates were analyzed assuming that the mulch cover will be replaced by a 30% total vegetation cover 7 or more years after the reclamation has been completed. Because established vegetation cover on this south aspect slope may be expected to vary over time in response to precipitation patterns, a variable-density rock mulch was incorporated into the design to promote soil stability during periods of drought and other adverse scenarios. The rock mulch cover was modeled to address the worst-case conditions on these slopes, assuming that 0% vegetation cover leaves only the rock cover to protect against erosion. Different percentages of rock cover were specified for different slopes, depending upon local conditions.
A pre-mining analysis was conducted to determine background soil detachment rates expected for Area 12C. The natural soil detachment rate determined was 7.3 tons/acre/year. However, the soil detachment rate associated with the reclaimed landform limited to 5.0 tons/acre/year.

Construction

Prior to construction, a digital Triangulation Irregular Network (TIN), created from the data output from Natural Regrade with GeoFluv™, was developed using Carlson Software's civil design module. An iterative approach to the design was taken to ensure a cut-fill balance for each of the seven subwatersheds. To maximize construction efficiency, push distances were limited to under 200 feet. To visually depict the cuts and fills for construction, mapping was produced showing all cuts with a red negative number and all fills with a blue positive number. All tie-in locations were indicated by a green zero. A digital staking file was created from the TIN to indicate strategic locations to place stakes for construction. All of these points were uploaded into a survey grade Trimble GPS to be accurately located in the field. Field stakes were placed along ridge tops, in channel bottoms and at tie-in locations and were marked with red, blue and green flagging to correspond to the mapping.

Construction of the design surface commenced in February of 2009 and is expected to be completed in June of 2009. Rough grading was completed using a CAT D11 by pushing material along the contour from the channel bottoms to the ridge tops. During construction, GPS elevation spot checking was continuously monitored as a means of quality control and an indicator of construction progress. Upon completion of the rough grading, all channels were fine tuned using an excavator to achieve exact channel geometry and proper sinuosity. In various locations, coal stringers were exposed on the surface and were removed and covered with mitigation material using an excavator. A dozer and truck operation was used to move and place mitigation materials and topsoil to a depth of 4 feet over the graded surface prior to revegetation, as specified by the McKinley Mine permit application.

Compliance and Conclusion

Because this type of reclamation has never been completed at the McKinley Mine, sideboards were developed to give acceptable deviation limits for watershed construction. For regulatory oversight, it was agreed that the as-built graded-spoil surface would be within plus or minus 10 vertical feet of the planned post-mining elevation. However, channel gradients and tie-in locations had to remain the same and the boundaries of the watershed could change as long as the watershed area did not exceed the designed watershed size by more than 10%. Drainage locations were permitted to shift provided they remained evenly distributed and consistent with the design. Constructed channels were designed with freeboard to exceed the required minimum freeboard. An as-built survey will be conducted and the as-built TIN will be compared to the TIN of the design surface so that deviations can be evaluated.

When construction in completed in June 2009, the final PMT will be a visual pleasing, functional watershed system that improves vegetative habitat diversity, enhances post-mining land use and requires little to no maintenance. All permit requirements for reclamation will have been met.

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TOOLS FOR INTEGRATING GEOMORPHIC RECLAMATION INTO PLANNING FOR EASTERN COAL SURFACE MINES

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Abstract

Geomorphic reclamation concepts and methods have not had wide application to active coal surface mines in the eastern United States. However, such methods are now widely applied in the region for applications such as stream restoration, highway impacts reduction and mitigation, and abandoned mine reclamation. A variety of conditions account for this lack of application in active mining including: the steep slope topographic conditions of the Appalachians; typically utilized mining methods and equipment; post-mining reclamation land use objectives; and compliance with regulations that do not strongly encourage alternative reclamation methods. However, with carefully integrated mining methods, reclamation, and post-reclamation land use planning, geomorphic reclamation methods can be effectively applied in eastern mining, particularly for mountaintop mining areas.

This paper addresses the integration of a variety of tools that are under development that were introduced two years ago at the previous Geomorphic Reclamation Meeting held in New Mexico. These tools and methods are being integrated into a potential framework for improved mining/reclamation/post-mining land use planning for mines in the Appalachian region. The tools include software for high-fidelity environmental visualization, landform shaping and evaluation that are integrated in a comprehensive GIS environment. The tools also include an involving framework for pre-mining and potential post-mining landform classification and analysis. The tools are being refined as a toolset for conducting applied mining/reclamation research and not necessarily as an off-the-shelf set of software and methods. Application to a couple of case study sites in the Central Appalachians will also be presented.

No paper was provided by the author.

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Session 2

GEOMORPHIC RECLAMATION IN APPALACHIA

Session Chairperson:
Craig Walker
Office of Surface Mining
Knoxville, Tennessee

Challenges of Applying Geomorphic and Stream Reclamation Methodologies to Mountaintop Mining and Excess Spoil Fill Construction in Steep-Slope Topography, e.g. Central Appalachia
Peter Michael and Lois Uranowski, Office of Surface Mining, Pittsburgh, Pennsylvania and Mike Superfesky, Office of Surface Mining, Morgantown, West Virginia

Can Appalachian Mine Reclamation be Called Sustainable Using Current Practices?
Nicholas Bugosh, GeoFluv, Ft. Collins, Colorado

Geomorphic Restoration of Coldwater Fork Following October, 2000 Slurry Spill
George Athanasakes P.E., Stantec, Louisville, Kentucky

Modeling Hydrology and Sediment Loss on Head-of-Hollow Fills: Geomorphic Versus Traditional Approach
Dr. Richard Warner, Dr. Carmen T. Agouridis and Dr. Christopher D. Barton, University of Kentucky, Lexington, Kentucky

Stream Restoration on the Cumberland Plateau, Tennessee
Tim Slone, IRTEC, Caryville, Tennessee and Dennis Clark, Office of Surface Mining, Knoxville, Tennessee

Recreating a Headwater Stream System on a Head-Of-Hollow Fill: A Kentucky Case Study
Dr. Carmen T. Agouridis, Dr. Christopher D. Barton, and R.C. Warner, University of Kentucky, Lexington, Kentucky

Use of Natural Stream Channel Design Techniques in the Coal Fields of Virginia
Lance DeBord and Jonathan Stamper, D.R. Allen and Associates, Abingdon, Virginia

CHALLENGES TO APPLYING GEOMORPHIC AND STREAM RECLAMATION METHODOLOGIES TO MOUNTAINTOP MINING AND EXCESS SPOIL FILL CONSTRUCTION IN STEEP-SLOPE TOPOGRAPHY, e.g. CENTRAL APPALACHIA

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Abstract

Proponents of geomorphic mine land reclamation have criticized current reclamation practices in the coal fields of steep-sloped Central Appalachia as too narrowly focused on civil engineering principles and neglectful of the functional and aesthetic benefits of reclaiming mine sites in ways that mimic natural landforms and drainage patterns. They observe that current mining and reclamation practices are radically transforming the mountain-and-valley terrain into gigantic flat plateaus and, in doing so, disrupting the beauty and ecology of the natural landscape. Instead of designing and constructing linear or planar surfaces and unvarying slope gradients during the reclamation process, they recommend "landforming," i.e. the adoption of curvilinear, compound slope forms that blend well with the surrounding physiography and represent the result of naturally stabilizing geomomorphic processes. The authors feel that the concept of geomorphic mine land reclamation is sound, however, its application to the Central Appalachian coal fields faces significant--albeit not insurmountable--challenges. They include: 1) existing reclamation-enforcement regulations that are focused on civil engineering principles and not explicitly supportive of geomorphic methodologies; 2) regulatory agencies' current intent to limit the down-gradient reach of excess spoil fills in order to allay disruption or burial of natural streams; 3) actual or perceived increases in reclamation costs; and 4) the challenge of designing and constructing "natural" landforms that are mature and stable in an otherwise youthful, erosional landscape.

Introduction

Some of the most contentious issues related to coal surface mine reclamation surround the practice of mountaintop coal mining in the steep-slope topographic settings of Central Appalachia and the construction of excess spoil fills in valleys below the mine sites. Chief among them include: the flattening of the ridge and valley landscape that often results; the burial and pollution of headwater streams and riparian zones during and after the construction of fills; and extensive disruption to the wide variety of biota unique to Appalachia. Proposed solutions vary from increasing environmental restrictions on surface mining in the region to the application of alternative approaches and methodologies to surface mining and reclamation.

One approach to mine-land reclamation that has received keen interest in other parts of the U.S. over the last decade is the application of "landform grading" and stream restorative techniques. Broadly speaking, the objective of this approach is to copy nature, i.e. reclaim the land and water in a way that reflects what geomorphic processes have already engendered in the surrounding environment. By doing so, the hope is that the product of reclamation will approximate what natural processes would do to the land over geologic time anyway, thus restoring the land and ecology to its natural beauty, diversity, and stability in a relatively short period of time.

Relative to other parts of the country, interest in geomorphic reclamation, or "landforming" and stream restoration[1], has been slow to develop in Central Appalachia.[2] One likely reason for this pertains to the nature of the region's landscape. Unlike

[1] Henceforth, the meaning of "geomorphic reclamation" will include both stream restoration and "landforming." The term, landforming, which is borrowed from Schor and Gray (2007), will signify "natural" reclamation of upland terrain (land upslope and beyond the direct influence of, stream channels).

coal mining sites in the west, where landforms are nearly flat or gently undulating and excess spoil is not generated, the mountainous terrain in Central Appalachia presents significant challenges to earth-moving operations as mine sites are backfilled to achieve the approximate original contour (AOC) of the land and excess spoil fills (or "valley fills") are built on steep foundations. The perception in the mining industry has been that the practices of landforming and stream restoration would be uneconomical because of the extra time and skill required, especially in steep terrain, and the potential loss of storage volume in valley fills. Since the Federal regulations under the Surface Mining Reclamation and Enforcement Act (SMCRA) do not explicitly reference geomorphic reclamation, there has been little impetus to utilize or encourage use of its methodologies.

Until recently, the authors and other members of the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) engaged with mountaintop mining and excess spoil disposal have focused on ensuring the exercise of prudent civil engineering practices in the design and construction of backfill structures and excess spoil fills. Important issues they have addressed include the long-term mass stability of fills and drainage, erosion, and sedimentation control. Most of the attention has been focused on valley fills. In contrast to spoil backfills, valley fills are artificial landforms that are added to the natural landscape and that rest on inclined foundations. Several of them have been the sites of mass instability and dramatic occurrences of floods or mudflows. To date, nearly all site-specific problems took place on active mining and reclamation sites and were subsequently remediated by the mine operator.

However, engineers and geologists of the OSM Appalachian Region offices remain concerned about the long-term stability of the fills and their drainage diversion channels. There is no provision in SMCRA for the maintenance or remediation of the structures once the mined land has been reclaimed to the satisfaction of the governing regulatory agency, and final bond moneys have been returned to the mine operator. The authors' concerns pertaining to long-term stability of the artificial structures are in large part behind their interest in landforming and stream restoration as alternative approaches to valley fill design and construction.

This paper provides a brief summary of mountaintop mining and reclamation with emphasis on valley fills and identifies aspects of SMCRA related regulations and policies, mining and reclamation practices, and regional geomorphic conditions that may affect landforming and stream-restoration applications on mined lands in Central Appalachia. This paper relies heavily on the pioneering work of Horst Schor and Donald Gray, which has recently been assembled in a reference guidebook (Schor and Gray, 2007). Other important references in this work include a study of valley fill long-term stability (U.S. OSM, 2002b) and a paper on the potential effects of recently promulgated regulations on fill stability by Michael and Superfesky (2007).

Generation of Excess Spoil and Valley Fill Construction

Mountaintop mining in the Appalachian coal fields removes overburden and interburden material to facilitate the extraction of coal seams. When coal is mined by surface mining methods, rock and soil that overlie the coal must be first temporarily removed and stored outside of the immediate mining area. The rock is blasted as it is removed. When sufficient storage space is available, the operator begins to transport the blasted rock, or spoil, back to the mine area for permanent storage. The operator grades the spoil so that it closely resembles the pre-mining topography or AOC and eliminates the highwall.

Mountaintop mining normally produces more spoil than can be stored in the mined out area. Because the angular blast rock comprising the spoil includes voids the volume of spoil removed during mining increases or "bulks" relative to the volume of rock that was in place prior to mining. Additional excess spoil can result from slope stability considerations in the mountaintop backfill if stable spoil slopes (i.e. with the slope-stability safety factor of 1.3) are not as steep as those of the natural, premined ridge top. Finally, relatively large volumes of excess spoil may be generated in steep-slope terrain when the operator proposes to reclaim the mining area to a flatter or more gently rolling topography in lieu of AOC so that a more economical viable land use may result. In these situations, the regulatory authority must approve the mountaintop removal AOC variance. Inadequate storage within the mine site requires placement of excess spoil into the adjacent narrow valleys, or hollows, of the Appalachian landscape.

Excess spoil generation and fill construction are almost exclusively limited to states in the Central Appalachian coal fields (Figure 1). During the period October 1, 2001 to June 30, 2005, 1589 of the 1612 fills (98.6 %) approved to be constructed

[2] One important exception is the important work of Agouridis et al. (2008), involving the restoration of a headwater stream system on a small hollow fill in eastern Kentucky.

nationwide were located in Kentucky (1079), Tennessee (13), Virginia (125), and West Virginia (372), and only 23 fills outside of Central Appalachia. The valley fills vary greatly in size. For example, a sample of 128 valley fills were analyzed in a valley fill long-term stability study in support of the Mountaintop Mining/Valley Fill Programmatic Environmental Impact Statement. The sampled fills ranged in volume from 0.2 to more than 200 million cubic yards; and they varied in length from 300 to nearly 10,000 feet (USOSM, 2002b).

The Federal SMCRA regulations recognize several excess spoil fill construction methods. In most of the recognized construction methods, excess spoil is deposited in uniform and compacted horizontal lifts or layers (four feet or less in thickness). Prior to placement of the spoil, the foundation (i.e. valley floor and sides where the spoil will be placed) must be prepared and rock underdrains installed to accommodate groundwater seepage and surface-water infiltrations. The regulations require that the rock underdrain be durable (rock that will not slake in water nor degrade to soil material) non-acid or toxic forming and free of coal, clay or other non-durable material.

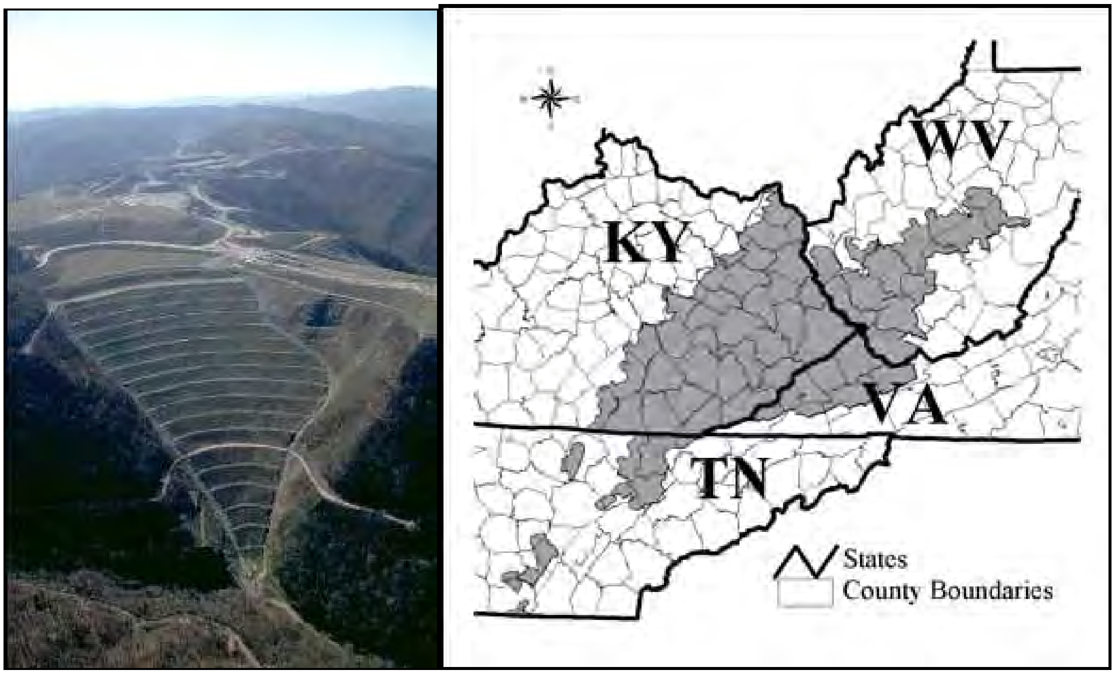

Figure 1. Valley Fills in Central Appalachia; (left) example of a valley fill at a mountaintop mining site; (right) counties with watersheds affected by mountaintop mining and valley fill construction.

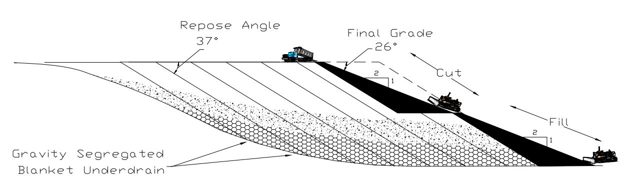

Figure 2. Schematic of durable rock fill construction.

The predominant valley fill construction technique employed in steep-sloped Appalachia is the *durable rock fill* method (Figure 2). Unlike other fill construction techniques, this method does not require underdrain construction prior to spoil placement or spoil placement in thin lifts. Instead spoil is end-dumped into valleys in a single lift or multiple lifts (30 CFR 816 / 817.73). The fill construction begins at an elevation where the crown or top of the completed fill will occur. Dump trucks haul spoil to the center of the hollow and dump the material down slope. This continues to take place, allowing a platform of spoil to lengthen down the hollow, and ends when the toe or bottom of the fill approaches its as-designed final location. Lifts of existing fills are known to range between 30 to over 400 feet in thickness. At the completion of spoil placement, the face of the fill is graded from its dumped angle of repose into a less steep, terraced configuration. The durable rock fill method can only be used if durable rock overburden is present and will comprise at least 80 percent (by volume) of the fill. The installation of a designed rock drain prior to spoil placement is not required for this type of fill, since it is assumed that the gravity segregation during dumping forms a highly permeable core and/or blanket drain at the interface between the natural ground and fill material.

The objective of most federal regulatory requirements pertaining to excess spoil fills is to ensure long-term stability. Required steps to achieve stability include:

- A site investigation for each proposed excess spoil fill, specifically an investigation of the terrain and materials that will form the foundation of the fill. Important concerns include soil depth, the engineering strength of the soil or rock foundation materials, and the occurrence of seeps or springs.

- A stability analysis of the designed fill mass based on 1) accurate values representing the engineering strengths (i.e. internal friction angle and cohesion) of the placed spoil and foundation material and 2) anticipated pore-water pressures in the fill mass. The analysis must demonstrate a static safety factor (SF) of 1.5 and dynamic SF of 1.1.

- Following certain specific requirements in the design or construction of the fill body and appurtenant drainage structures, such as: removal of all vegetative and organic materials from the disposal area (the fill foundation) prior to spoil placement; grading the final outslope of the valley fill to an inclination not steeper than 2h:1v (50 percent); the construction of keyway cuts or rock toe buttresses where the slope of the disposal area is in excess of 2.8h:1v (36 percent); construction of diversion ditches to keep uncontrolled drainage from flowing over the face of the fill; incorporation of flood control measures, e.g. designing and constructing drainage diversions adequate to safely pass runoff from a 100-year, 6-hour event for durable rock fills; and the protecting the fill slope from surface erosion.

- Professional engineer's certifications during the construction of the fills, quarterly and during critical phases of construction, to document that the fill is being constructed according to the permit plan. Critical construction phases include: foundation preparation; underdrain construction; surface drain construction; grading; and revegetation.

Valley Fill Design, Construction, and Inspection Issues

Several past and current issues pertaining to the long-term stability of valley fills, particularly durable rock fills, may also influence the application of geomorphic reclamation to those structures. The issues, in the original context of stability concerns, are briefly summarized below. More detailed discussions are available in USOSM (2002a&b) and Michael and Superfesky (2007).

<u>Excess Spoil Minimization and Valley Fill Stability</u>

OSM promulgated changes to the Code of Federal Regulations in the interest of minimizing the adverse effects of excess-spoil-fill construction on the "prevailing hydrologic balance, fish, wildlife and other environmental values" (73 *FR* 75814). Among other provisions, the proposed changes require: 1) minimizing the amount of excess spoil generated at a mine site; 2) restricting the volume of excess spoil fills constructed; and 3) avoiding placement of the fills within intermittent as well as perennial streams. Achieving those objectives can result in valley fills that toe out at higher elevations in the hollows (i.e. to prevent or limit burial of streams). Consequently, the slopes of fill foundations may generally be steeper than in the past. While OSM staff engineers and geologists have supported those measures to protect the hydrologic balance and general environment, they have also warned that placement of fills on steeper foundations can negatively impact the stability of the fills if proper care is not taken during their construction. An example of a failed durable rock fill on a steep foundation slope in eastern Kentucky is shown in Figure 3.

<u>Shear Strength of Foundation Materials</u>

Several studies have emphasized that the identification of soil-like material in the foundation of a proposed excess spoil fill—and the use of accurate foundation shear strength properties—is essential for a realistic valley fill stability analysis (USOSM, 2002; KYDNR and USOSM, 2006). They identified needed improvements to foundation investigations in support of the permit application process.

Figure 3. HNR durable rock fill in eastern Kentucky; (left) general view of landslide looking upslope from toe; (right) aerial view of fill during the post-landslide remediation.

Subsurface Drainage Control in a Durable Rock Fill

The effectiveness of gravity-segregated underdrain depends on whether the end-dumped material is sufficiently permeable to convey subsurface water out from the durable rock fill. An inadequate underdrain results in pore-water pressure build-up in the spoil, which diminishes the stabilizing effects of internal friction and cohesion. In the case of non durable rock fills, underdrains can easily be designed and constructed to meet site-specific subsurface drainage conditions. In durable rock fills, however, the quality of the end-dumped underdrain completely depends on: the supply of durable rock; the selective use of durable rock during end-dumping (if necessary); and the effectiveness of the gravity segregation process. In most cases, as long as a permit application successfully demonstrates the on-site availability of 80 percent durable material in the coal overburden and interburden (through the use of Slake Durability Index or some other accepted lab testing protocol), construction of a durable rock fill is permitted. However, the experience of federal and state reclamationists over the years has indicated that the correlation between lab-tested rock durability and the formation of an effective underdrain is not strong (Welsh et al., 1991 and USOSM, 2002; see Figure 4). Unfortunately, there is no consensus among geotechnical experts working for the industry, environmental groups, and government as to what constitutes a realistic rock durability testing protocol. In response to this problem, OSM has established a Federal inspection protocol that emphasizes the importance of visible evidence of durable rock fill underdrain formation, i.e. that gravity segregation during end dumping visibly results in a graded fill face, with the largest particle size at the bottom and gradually decreasing particle sizes up the fill outslope (USOSM, 2008).

Figure 4: Gravity segregation of durable rock fill underdrains; (left) effective underdrain formation with durable sandstone boulders; (right) ineffective underdrain formation with “durable” shale fragments.

Another issue related to the durable rock fill underdrain is related to the required regrading of the fill outslope after the end dumping is completed. The outslope has to be regraded from the angle of repose to a more stable, 2:1 slope. This is commonly accomplished by grading spoil from upper sections of the fill outslope towards the toe, thus extending the toe downstream (Figure 2). This reworked spoil is finer-grained than the gravity-segregated underdrain material. The placement of the fines downstream of the terminus of the blanket underdrain can retard free drainage from within the fill, and consequently increase pore pressures in the spoil, reducing fill stability. For this reason, several state regulatory authorities require machine placement of underdrains that are contiguous with the blanket drain and that extend beyond the final toe position of the outslope.

Surface Drainage Control Durable Rock Fills

Excess spoil fills other than durable rock fills are constructed from the bottom of the fill, or toe, upwards. As such, the final appurtenant surface drains are installed with each lift during fill construction. For durable rock fills constructed via end dumping of the excess spoil, final surface drains are not installed until the fill placement is complete and ready for final regrading. However, the mine operator, certifying engineer, and regulatory inspector are still charged with ensuring effective drainage control *throughout the construction of the fill*. Uncontrolled surface drainage over a barren outslope results in severe erosion and transport of fines towards the fill toe. Clogging or burying of the underdrain can result. Further, outwash deposits beyond the advancing toe can become weak foundation materials below the finished fill if not removed. In a worst case, severe, life-threatening floods or mud flows can occur during a storm event as in the Lyburn incident in West Virginia in 2002 (Figure 5; USOSM, 2002a).

Contemporaneous Reclamation

Sometimes durable rock fills are abandoned for long periods of time following partial construction. Long exposure of spoil to the elements without the benefit of revegetation and surface drains could accelerate rapid spoil degradation and erosion. This can lead to rapid in-filling of sedimentation ponds near the toe of the fill and significant downstream sedimentation; and can also result in instability in the completed fill from internal weak zones parallel to the face of the completed fill. In the case of the 2002 Lyburn event, absence of contemporaneous reclamation and consequent spoil deterioration may have contributed to the heavily sediment-laden flood or mud flow.

Figure 5. Lyburn flood; (left) erosion and sloughing on the outslope of the durable rock fill following storm event; (right) property damages downstream of the fill.

Wing Dumping

A common problem in mountaintop mining has been the dumping of spoil across the valley from the mining bench at points down-valley of the toe of a developing fill. Ideally, all spoil is first transported up the valley and then dumped from the top of the fill in the down-valley direction. In this way, the end-dumped face of an advancing fill progresses uniformly down the valley and parallel to the fill face. This preferred procedure maximizes gravity segregation of competent (unweathered) rock for underdrain development; minimizes spoil exposure, and consequent breakdown and stream sedimentation; and ensures minimization of land disturbance. Several states authorities now have rules or policies that limit wing dumping.

The combination of wing dumping and unanticipated reductions in excess spoil volume has frequently resulted in a concave outslope on the completed fill (Figure 6). A concave face typically includes over-steepened slopes at the side abutments with natural ground. It is also characterized by longer and less-inclined terrace drainage channels. Increased water transport distances and diminished channel gradients can cause ponding on the terraces. Ponding, in turn, may promote water infiltration into the fill material, fluvial erosion, and consequent fill instability.


Figure 6. Comparison of concave (left) and flat (right) valley fill outslopes.

Applying Geomorphic Reclamation to Mountaintop Mining: *The Concept*

Geomorphic reclamation involves the application of principles and insights gained from the study of geomorphology to land and stream modification and reclamation. Schor and Gray (2007) identify two primary benefits of landforming, namely: 1) the production, enhancement, or restoration of an aesthetically pleasing landscape; and 2) artificial landforms that are stable i.e. that experience minimal amounts of erosion and with virtually no or very little probability of large and rapid mass movements such as landslides. Objectives of the approach include: 1) constructing artificial landforms that blend in with the surrounding landscape; and 2) constructing landforms that nature itself would form or at least will accept without significant further modification through erosion and mass wastage. For reclaimed coal mined lands, we can rephrase the objectives as follows: to construct or modify landforms that look like they "belong" and that are stable in the long-term, thus maintenance free in the post-final-bond-release environment.

Schor and Gray contrast traditional methods of grading, drainage control, and landscaping with landforming as follows:

- Conventional grading results in slopes that generally have "…rectilinear- and planar-slope surfaces with unvarying gradients and angular slope intersections." The crests of the slopes are "…devoid of topographic relief…" and the "…bottom of the slope exhibits a linear and angular intersection with the base." Drainage diversion structures are usually "…constructed in a rectilinear configuration (parallel for surface drains, perpendicular for down-drains) in prominent and highly exposed positions, maximizing the negative visual impact on the slope face." Landscaping is "…applied in rigid, uniform patterns, and plant material such as trees and shrubs are placed at equal spacing to achieve the stated conventional objective of 'uniform coverage.'" This results in surfaces that are not aesthetic and are "devoid of creative opportunities for either the placement of drainage devices or plantings that would mimic the characteristic natural landscape of the area."

- Landforming, on the other hand, results in graded slopes "…characterized…by a continuous series of distinctive concave and convex forms interspersed with mounds that blend into the profiles—by nonlinearity in plan view and by varying slope gradients. The profile of slopes "…exhibits a concave form with steeper gradients near the top and with gradually decreasing, flatter inclinations near the bottom." Schor and Gray emphasize that a "…concave-slope profile is more stable than a linear profile, and it more closely resembles the equilibrium profile of natural slopes." The man-made slopes are smoothly transitioned with natural slopes to "…create a minimally perceptible blending of the two…." Surface runoff is directed into swales formed from the varying gradients across the slope face. This way, the channels are concealed. Also, their lengths are increased, "…resulting in the reduction of gradient and flow velocity in the drain." The revegetation plan also mimics nature by concentrating trees and shrubs in the concave slope areas and swales (where moisture is concentrated), while planting grasses and other ground covers on the convex or interfluves areas.

The contrasts between conventional and landform grading and drainage control are illustrated in Figure 7. In the case of coal-mine lands in steep-sloped Appalachia, Schor and Gray observe that reclamation is being carried out by conventional grading, drainage control, and revegetation methods, thus all too often producing landscapes characterized by broad, flat plateaus and adjoining or proximate fills in the hollows shaped like dam embankments. For both the backfill and excess spoil fill areas they recommend the construction of more complex, curvilinear forms (both in plan and cross section) that more closely achieve AOC and blend in with the natural topography. To exemplify their recommendations with respect to valley fills they offer the comparative photographs (shown in Figure 7) of a valley fill built by current methods versus a preferred, natural topographic form in an adjacent natural slope. They also recommend that reclamation planners adapt designs and construction methods to natural watershed drainage and vegetation patterns.

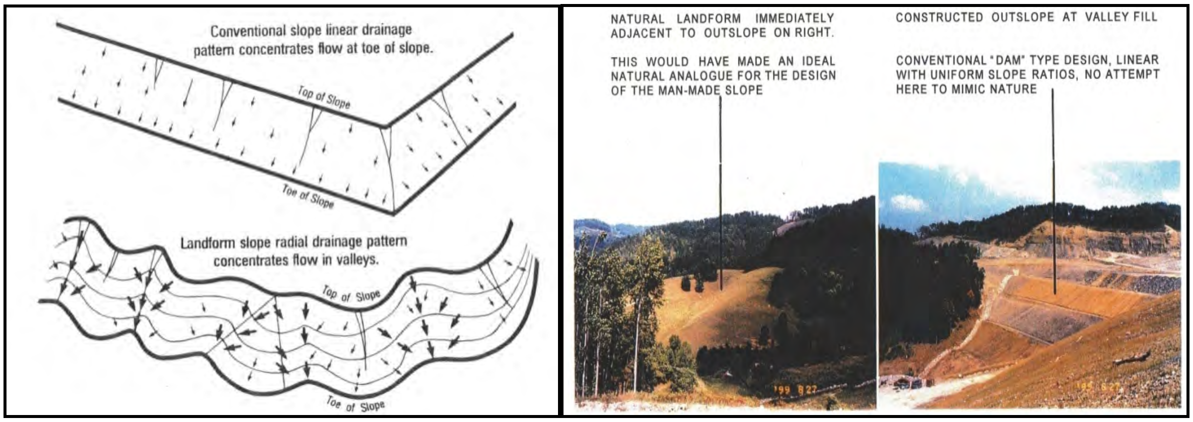

Figure 7: Comparisons between conventional and landform grading of fill slopes; (left) schematic illustration; (right) in-field comparison between a typical valley fill outslope and alternative "design" provided by natural geomorphic processes. (Left illustration from Schor and Gray, ©2007 John Wiley and Sons, Inc., reprinted with permission of John Wiley and Sons, Inc; right photograph from Schor, 1999)

Applying Geomorphic Reclamation to Mountaintop Mining: *The Challenges*

The authors find the concept of geomorphic reclamation to be sound and they generally support its application to coal mine land reclamation. However, they also recognize several potential challenges to its application to site conditions unique to the rugged topography of Central Appalachia. Those potential challenges are described below.

Lack of Support for Geomorphic Reclamation in the SMCRA Regulations

The terms, geomorphic reclamation, landforming, or stream restoration are not used in the federal regulations. However, there are some important rules requiring the mine operator to take into account natural conditions that 1) existed on the mine site prior to mining and 2) surround the site. Most significant among them is the requirement that the mined and reclaimed land be returned to AOC. Specifically 30 CFR 701.5 defines AOC, in relevant part, as "…surface configuration achieved by backfilling and grading of the mined areas so that the reclaimed area, including any terracing or access roads, *closely resembles the general surface configuration of the land prior to mining and blends into and compliments the drainage pattern of the surrounding terrain*, with all highwalls, spoil piles and coal refuse piles eliminated." [Italics added]. Other rules referencing premining site conditions and the conditions of surrounding mine sites include:

- § 816.43 (a) (3), which requires designing and constructing permanent drainage diversion channels "…so as to restore or approximate the premining characteristics of the original stream channel including the natural riparian vegetation to promote the recovery and enhancement of the aquatic habitat."
- § 816.71 (a) (3), requiring that excess spoil fills are "…suitable for reclamation and revegetation compatible with the natural surroundings and approved postmining land use."
- §§ 816.111 (b) (2) and (4), respectively stipulating that reestablished plant species have "…the same seasonal characteristics of growth as the original vegetation," and be "…compatible with the plant and animal species of the area."

Finally, the practice of landforming is suggested in §§ 816.71 (e) (4) and 816.102 (h), which permit the construction of small depressions on excess spoil fills and spoil backfills, respectively. The depressions are allowed if needed to "…retain moisture, minimize erosion, create and enhance wildlife habitat, or assist revegetation."

Most other regulations neither imply support for nor potentially impede geomorphic reclamation. However, there are several rules that are potential impediments. Those regulations pertain to alternative postmining land uses and to the application of certain civil engineering principles and practices to fill design. These rules are described below:

- AOC variances: With respect to surface mining sites as a whole, the regulations do allow, under certain circumstances, backfilling of spoil to achieve surface configurations other than AOC. 30 CFR 785.14 (c) permits an AOC variance for "mountaintop removal" mining if the proposed postmining land use will be "…industrial, commercial, agricultural, residential, or public facility…" and if other, non-AOC, requirements in the regulations are met. Some of the same contingent allowances are available for "steep slope mining" (see § 785.16). Horst and Gray acknowledge that there is some justification behind these variances: "There are certainly good reasons for a limited amount of level ground in mountainous terrain for such developments as housing, schools, shopping centers, golf courses, prisons, sports fields, and so forth." However, they warn that "…this level ground and associated land uses should not come…at the expense of damage to the beauty and environmental integrity of vast tracts of the original landscape that have attracted generations of residents and tourists alike."

  The authors of this paper share Horst's and Gray's position. However, they also note that there is no programmatic mechanism for controlling how often AOC variances are approved or how much land area they effect. The frequency of variances only depends on how often a variance is requested by a mining company and granted by a regulatory authority (based on the merits of the specific request). Variances for "equal or better economic or public use of the affected land" invariably result in the permanent removal of original ridge tops and creation of plateaus. However, it is also noteworthy that, with sufficient amounts of backfill, the plateau surfaces themselves can be graded into landforms that are stable, and more supportive of healthy local environments and aesthetic than simple flattops. Figure 8 shows an example of alternative grading on a reclaimed ridgetop, in this case to construct a cattle watering hole. In like manner, grading can be designed to establish a "natural" landscape compatible with "equal or better" uses of the land.

Figure 8. Backfill grading to construct a cattle watering hole on a mountaintop mining site being reclaimed.

- References to engineering principles and practices**:** Rules in the SMCRA regulations based on engineering principles or practices include those that actually apply the words "engineer" or "engineering" to requirements relating to the design and construction of excess spoil fills. 30 CFR 816.71 (b) requires that "…current, prudent, engineering practices…" be applied to the design of fills and appurtenant structures and that a "…qualified registered professional engineer experienced in the design of earth and rock fills…" certify the design. Section 816.71 (h) stipulates that a "…qualified registered professional engineer, or other qualified professional specialist under the direction of the professional engineer…" periodically inspect the fill during its construction. Further, inspection reports must be certified by the "…qualified registered professional engineer…." These rules are necessary to ensure proper fill design and construction and none of them negate the practice of geomorphic reclamation. Nevertheless, mining and civil engineers are not normally educated in geomorphology. They are trained to design structures that are not only stable and functional, but also cost effective *to build*. For this reason, valley fills with simple, linear geometries are preferred. Future emphasis on the geomorphic reclamation of fills would require the reorienting of most engineers and/or the added input of landforming and stream-restoration specialists. Further, if regular application of geomorphic reclamation to steep-slope surface mining is desired enforcement of the practice may require additional regulations.

Other "engineering" regulations pertinent to excess spoil fills include the requirement for a valley fill outslope inclination of 2 horizontal to 1 vertical (2:1) or less, the allowance for terraces on the outslope, and stipulations relating to durable rock fill diversion channels. 30 CFR 816.71 (e) (3) states in part that the "grade of the outslope between terrace benches shall not be steeper than 2h:1v (50 percent)." The intent of the rule is to promote mass stability and minimize erosion. The rule does not address the *shape* of the outslope in cross section or in plan. However, the crest-to-toe profile of outslopes is typically straight. As stated above, straight slopes are simpler, less time consuming, and less costly to construct.

In contrast to outslope profiles, valley fill outslopes are often concave *in plan.* Concave outslopes commonly result from wing dumping and the placement of less excess spoil than anticipated for the designed fill. Although geomorphic reclamationists may favor concavity in plan as well as in profile, OSM engineers have historically promoted straight surfaces across the face slope in order to ensure: 1) 2:1 or gentler slopes where the fill face abuts the natural side slopes; 2) efficient transport of rainwater and snow melt along the outslope terraces to the side drains; and 3) minimization of land disturbance.

Another engineering practice that appears to contradict the geomorphic reclamation approach is related to the objective of minimizing water flow on the valley fill. The purpose of the objective is to: 1) control erosion; and 2) minimize seepage into the fill material and concomitant pore water pressure build-up and potential mass instability. Ideally, the top or "crown" of the fill is graded and the outslope is terraced to divert water off the fill into drainage diversion ditches located off the fill. 30 CFR 816.71 (e) (3) states in part that terraces "…may be constructed on the outslope of a fill if required for stability, control of erosion, to conserve soil moisture, or to facilitate the approved postmining land use." Although terraces are optional in the federal regulations, they are constructed on valley fill outslopes on a regular basis.

The requirements of diversion ditches appurtenant to excess spoil fills are included in 30 CFR 816.71 (f), § 816.72 (a) (2), and § 816.73 (f). The first section contains, in part, the general requirements that "…the fill design shall include diversions and underdrains as necessary to control erosion, prevent water infiltration into the fill and ensure stability," and that the diversions comply with the requirements of § 816.43."[3] Section 816.72 (a) (2) applies to valley fills and "head-of-hollow" fills constructed in lifts and stipulates that runoff "…from areas above the fill and runoff from the surface of the fill shall be diverted into stabilized diversion channels designed to meet the requirements of § 816.43 and, in addition, to safely pass the runoff from a 100-year, 6-hour precipitation event."[4] Section 816.73 (f), applicable to durable rock fills, is similar to the other sections, but is also unique in that it specifically states that surface water runoff "…from areas adjacent to and above the fill is not allowed to flow onto the fill…." Over the years OSM has advocated the use of grading and diversions to keep runoff from areas above and around the durable rock fill from flowing onto the fill, and terraces that direct precipitation off the outslope as efficiently as possible. This position reflects, in part, the intention to ensure that seepage into the fill mass is sufficiently limited so that gravity-fed underdrains can prevent the destabilizing build-up of a phreatic surface.

The stipulated means for minimizing erosion and preventing a phreatic surface in the fill clearly result in fill geometries that do not resemble natural landforms and streams. A geomorphically reclaimed valley fill would be characterized by complex curvilinear forms blending in with the surrounding terrain. The precise form of the fill would have to be carefully considered. For instance, simply converting a conventional, linear geometric shape to one that is concave in profile and/or plan could force a choice between reducing the volume of excess spoil storage and increasing the area of disturbance. Further, forming a concave outslope in profile in a durable rock fill would probably require more spoil regrading than what is currently done to achieve a straight, 2:1 slope. Extensive machine placement of durable material beyond the end-dumped toe may be necessary to maintain a continuous underdrain system.

Another potential outcome of geomomorphic reclamation is that one or several ephemeral-to-intermittent streams would flow on top of the fill's surface. The design and construction of the fill would have to ensure that seepage from the channels would not recharge a phreatic surface within the structure and consequently jeopardize its stability.

[3] Section 816.43 contains specific requirements for the design and construction of all diversion channels on surface mines.

[4] Section 816.72 allows for the use of rock core chimney drains in the center of the fill for surface and subsurface drainage for head-of-hollow fills and valley fills less than 250,000 cubic yards in volume.

Priority of Excess Spoil Fill Minimization
The relationship between the interests of excess spoil fill minimization and geomorphic reclamation has at least two aspects. One aspect questions the placement of significant volumes of spoil in the most elevated positions within hollows. The natural analogue to spoil is colluvium. Natural geomorphic processes do not normally result in deep deposits of colluvium in the upper reaches of the Central Appalachian landscape. Exceptions occur where colluvial deposits rest on natural or man-made topographic benches. Fully replicating the work of nature would usually entail placing excess spoil where nature tends to concentrate colluvium, i.e. within the lower topographic reaches where the underlying slopes are gentler. Natural landslides and earth or debris flows typically occur in the middle to upper reaches of hill sides; and they result in colluvial deposits in lower positions where a safety factor of at least one occurs and additional erosion is predominantly fluvial and, with sufficient vegetation, more gradual. Locating and building valley fills that replicate nature in this manner would clearly violate the current regulatory emphasis of minimization.
The other aspect allows the disposal of excess spoil at high elevations (in the interest of minimizing land and stream disturbance) but also entails grading an elevated fill into a complex, curvilinear configuration that blends in with the surrounding terrain. It may be possible to build such fills that not only look natural but are also more stable than fills as currently constructed. But, as stated previously, the landformed fills would probably store excess spoil less efficiently, forcing a choice between less volume in a particular hollow and greater terrain disturbance.
One potential advantage of geomorphic reclamation is that it would not necessarily result in stream burial no matter where a valley fill is constructed. More ephemeral or intermittent stream length may be disturbed during the construction of a landformed valley fill (relative to current construction methods), but only in the sense of being *modified*. Streams affected by excess spoil placement could be *restored*. One could argue that disturbance and subsequent (successful) restoration of longer stream lengths is a more environmentally efficacious practice than complete burial of shorter ones. Nevertheless, this viewpoint does not comport with current regulations and policies.

Cost concerns
Horst and Gray acknowledge that the practice of landforming, relative to more conventional methods of earth movement, is more costly. Some of the cost increase is restricted to initial applications of landforming where design engineers and surveyors are inexperienced in the methodology. Temporary cost increases for each of those services typically range between 10 and 15 percent, but reduce to 1 to 3 or 5 percent with training and greater familiarity. Cost increases related to earth movement involving 1 million cubic yards or more have historically been limited to 0.5 percent. This is because an average of approximately 90 percent of the total earth volume is placed by conventional methods. The actual landforming work is applied to only the outer slope layers which are 20 to 50 feet thick in thickness (Figure 9).

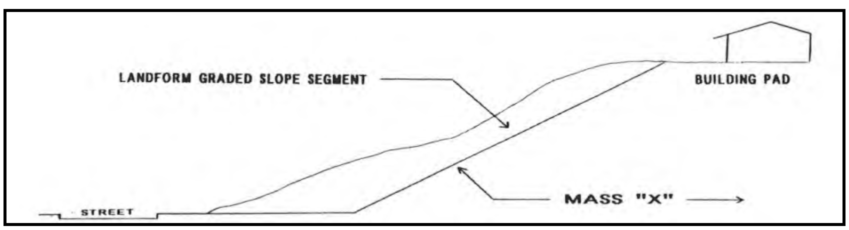

Figure 9. Relative amounts of earth moved by conventional vs. landform granding. (From Schor and Gray, ©2007 John Wiley and Sons, Inc., reprinted with permission of John Wiley and Sons, Inc.)

The temporary and permanent cost differentials with respect to engineering design and field survey control described by Horst and Gray may turn out to be true for mining reclamation in Central Appalachia. Minimal cost increases pertaining to earth movement may also apply to mine backfilling in accordance with AOC and the construction of relatively large valley fills. The cost differential between landforming and more conventional earth movement could be significantly greater where mountaintop or steep-slope mining AOC variances apply and the thickness of spoil backfill is limited. The difference could also be marked in the case of small valley fills. Small fills can result from excess spoil minimization to avoid stream disturbance or from economic considerations, such as long transport distances between the points of excess spoil generation and disposal. Since these fills typically occur within the upper elevations of the hollow where slopes are relatively steep, they are thin. An example is the failed HNR durable rock fill in eastern Kentucky (Figures 3 and 10). The maximum thickness of the structure, in its remediated condition, is 70 feet.

Contemporary Reclamation

The additional time and cost associated with a requirement for landform grading of durable rock fills may induce greater delays in their reclamation. Any additional reworking of the spoil to achieve a more complex, curvilinear surficial configuration could also increase the surface area relative to conventional practices and consequently increase the severity of erosion and flooding if a significant storm event occurred during the regrading process. Inspectors would need to be extra vigilant to ensure timely reclamation of the fills.

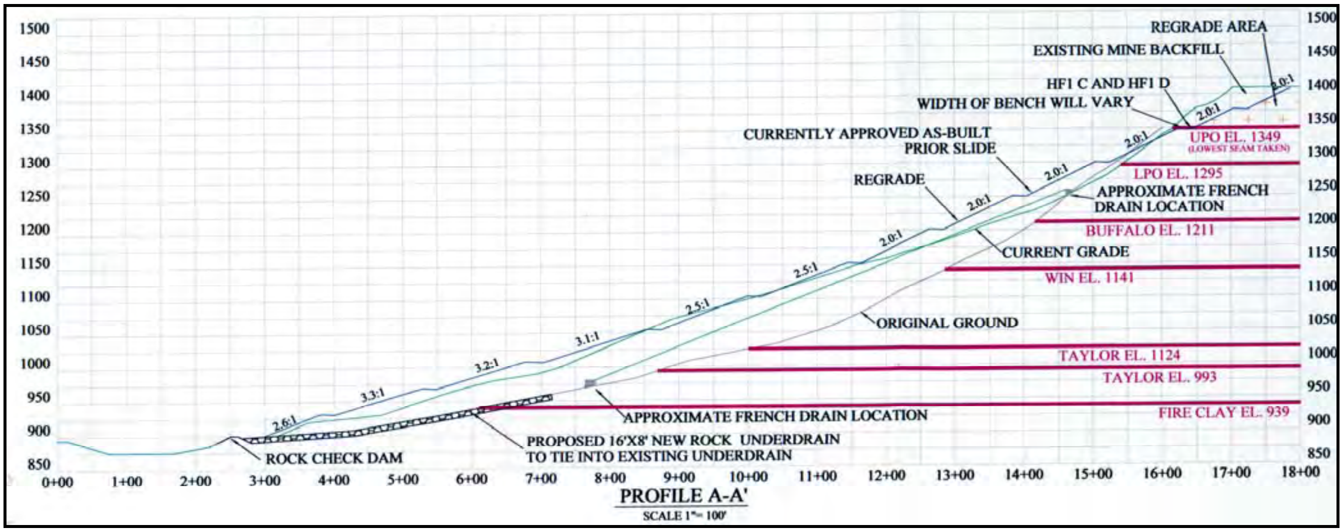

Figure 10. Profile of remediation plan for the HNR durable rock fill. (From CBC, 2005)

Building Stable Landforms in an Erosional Topography

Horst and Gray report that the available field, laboratory, and modeling evidence suggests that, all else being equal, concave slopes have greater fluvial and mass stability than uniform, planar slopes. They emphasize that greater stability is one of the benefits of landforming fill structures. Their description of successful applications of landform grading in housing and community development projects on steep and geologically unstable slopes in California suggests that the application of landforming to backfills and valley fills in the rugged, erosional terrain of Central Appalachia may be feasible. The authors of this paper wish to underline that naturally looking and well blending artificial landforms would not necessarily be stable. The unstable character of the natural Central Appalachian mountains and hills is very well documented on soil maps of the U.S. Natural Resources Conservation Service; in regional slope-instability mapping by Lessing et al. (1976) and Outerbridge (e.g. 1979, 1982); and numerous geotechnical investigations of natural landslides and other types of major mass movements (Figure 11).

OSM provides annual training on spoil handling and disposal to state and federal surface mine permit reviewers and inspectors under its National Technical Training Program and much emphasis is placed on the identification of "landslide topography" to avoid fill construction on unstable foundation slopes. The overwhelming evidence demonstrates that nature is not patient with deep sequences of unconsolidated material on steep slopes, especially where subsurface drainage is at high discharge. The intention of SMCRA-related regulations is to ensure backfills and valley fills are stable indefinitely. The implication is that they should be at least *more* stable than the wide-spread, *natural* landslide-prone slopes in Central Appalachia. One means by which geomorphic reclamation can promote greater stability on valley fills is to anticipate or model the shape and position of a naturally-formed and stable distribution of unconsolidated material (i.e. one limited to gradual, equilibrated erosion and free of rapid mass movements). The result could be a series of gentle, concave slopes bounding a restored stream in the lower reach of a hollow. An alternative approach that would be more in line with current attention to excess spoil fill minimization would be to grade elevated valley fills into curvilinear slope forms while ensuring that measures to stabilize the fills are also performed. Most imperative are the preparation of a stable foundation and construction of adequate underdrains.

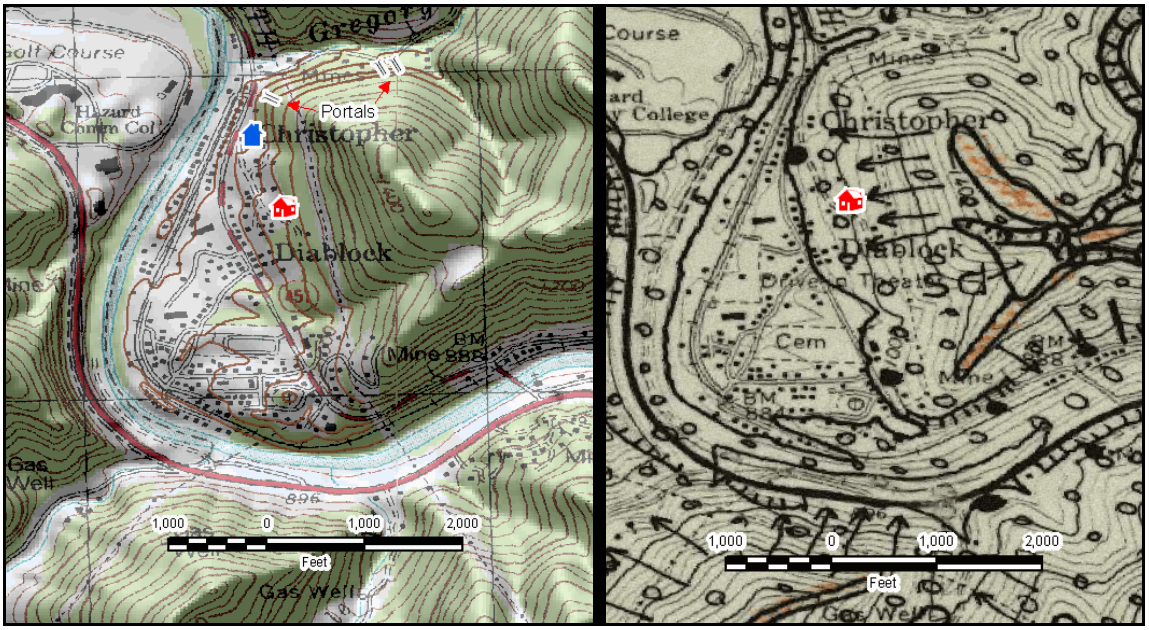

Figure 11. Site of OSM landslide investigation in Perry County, Kentucky; (left) site topography; (right) 1979 USGS survey of landslides and related features surrounding the site. Area covered with small circles represents colluvial slopes with landslides. Arrows delineate zones of debris flows and debris avalanches. Orange shading represents rock and soil susceptible to landslides. (modified from USOSM, 2005).

Conclusions and Recommendations

The authors find the concept of geomorphic reclamation to be sound and propose that the techniques of landform grading and stream restoration may have potential for coal mined lands in steep-sloped Appalachia as well as in other regions of the U.S. However, before the concept is applied to the coal fields of Central Appalachia, certain regulatory and practical bottlenecks will need to be addressed: Those bottlenecks are summarized as follows:

- The federal SMCRA regulations as they currently stand include provisions that appear to be contrary to some of the objectives of geomorphic reclamation. These include: (1) AOC variances which turn natural ridges into broad plateaus; (2) references limited to expertise in rock- and earth-fill engineering (i.e., which do not include expertise in geomorphic reclamation); (3) lack of references to complex, curvilinear shapes (typical of natural landforms) for reclaimed surfaces; (4) and the requirements for or practices of constructing unnatural drainage control systems such as fill outslope terraces and steep diversion ditches on the sides of the fill.

- Recently promulgated regulations require, among other provisions, restrictions on the volume of excess spoil fills to avoid disturbance of natural streams. Placing excess spoil in naturally optimal locations (i.e. in lower topographic reaches) in the interest of stability as well as aesthetics could contravene these requirements. On the other hand, landform grading of a valley fill that is placed closer to a ridge top could either reduce spoil volume storage capacity or necessitate more land and stream disturbance relative to a conventional fill.

- Although cost increases connected with landforming have been shown to be minor after an adjustment period, they might still be enough to discourage its voluntary application to Central Appalachian mine sites on the part of the industry. The observation that earth-movement cost increases are minimized since only the surficial layers of a fill are landform graded probably would not apply to AOC variance sites and small valley fills.

- Requirements for more sophisticated and time-consuming regrading associated with landforming could motivate more delays in final reclamation relative to conventional earth-moving procedures. Inspectors would need to be especially vigilant to ensure contemporaneous reclamation of the valley fills.

- The terrain of Central Appalachia is erosional in nature and many of its steep slopes are prone to rapid mass movements. For this reason, constructing artificial landforms that look natural and blend well with the surrounding landscape will not necessarily satisfy all environmental objectives connected with coal mine land reclamation. One significant challenge will be to build valley fills that are stable as well as aesthetic.

Serious pursuance of landforming and stream restoration on valley fills in rugged topographic settings will require both workshops and in-field experimentation. The compatibility (or lack of which) between the objectives and procedures of geomorphic reclamation on the one hand and current regulations and enforcement policies on the other should be further assessed. However, rule changes to accommodate geomorphic reclamation should not be proposed without first determining the geotechnical feasibility of the approach to a variety of site conditions existing in Central Appalachia. This cannot be accomplished without experimental construction projects on mine sites.[5]

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CAN APPALACHIAN MINE RECLAMATION BE CALLED SUSTAINABLE USING CURRENT PRACTICES?

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Abstract

Modern mining methods can drastically change landforms in the project area. Mine reclamation goals have advanced from merely smoothing the disturbed area and establishing a vegetative cover to the concept of "land use sustainability.' The land use sustainability concept recognizes the need to maintain *environmental* functions related to landforms when conducting *economic* development activities for the benefit of *future users* of the land.

Traditional reclamation grading methods, e.g., valley fills with terraces and down-drains, uniform, constant-gradient slopes, and linear 'stream channels,' often do not address all the criteria that must be met for the environmental functions for the future users. Water quality standards, in-stream uses, vegetation diversity and other reclamation criteria may not be satisfied by traditional reclamation grading methods. For example, the Appalachian Regional Reforestation Initiative (ARRI) has identified that coal mine reclamation in the region '. . . *has not been accompanied by widespread replacement of forests disturbed by mining"* that may reduce the economic use of the land for future users (Angel et al., 2005).

The deficiencies in meeting these environmental functions for future users can also have immediate and longer-term negative economic effects on the mine operations. Inability to mitigate for these land use changes caused by the proposed reclamation landform can stop mining activity from proceeding, or expanding, at the permitting stage. The traditional grading methods produce erosive landforms that can add costs for 'erosion control measures.' Additional traditional reclamation landforms often fail to resist erosion and require maintenanc, and may postpone bond release. The limitations of existing landform grading practices for meeting environmental and economic goals for future land users prohibit them from achieving sustainability.

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A new, natural approach to landform grading called GeoFluv™ is the heart of the Natural Regrade three-dimensional computer software. The GeoFluv design approach offers a cost-effective alternative for sustainable mineral development that can satisfy the reclamation criteria, including reforestation, while maintaining natural landform water runoff and soil erosion functions and thereby achieve true land use sustainability.

Introduction

Modern mining methods can drastically change landforms in the project area. Traditional reclamation grading methods often do not address all the criteria that must be met for the desired post-mining land use. Often traditional reclamation design criteria consist only of smoothing the land surface to approximate pre-mine shape, routing the water away, and minimizing the disturbance footprint. Water quality standards, in-stream uses, vegetation diversity and other reclamation criteria may not be satisfied by traditional reclamation grading methods. Inability to meet or mitigate for these changes caused by the proposed reclamation landform can even stop mining activity from proceeding successfully beyond the permitting stage because the landforms would not satisfy the evolving sustainable development goals.

What Does "Sustainable" Landform Mean For Mine Closure?

What is this evolving concept of 'sustainability?' Variability exists in the definition of the concept, but an internet review of several definitions in use provides some clarification. Underlining has been added in the quotations to draw emphasis to key terms in the definitions. "Sustainability is synonymous with integrating ecology, economics and social justice for long-term global stability and prosperity," according to Portland City Commissioner Dan Saltzman's website. This definition gives equal consideration to environmental, capital, and moral concerns.

A view that emphasizes the capital aspect is presented by Dave Lister, 'The Eastside Guy' in BrainstormNW magazine:

> "I've managed or owned small businesses in Portland for twenty-five years, and one thing I can tell you unequivocally is that, to be 'sustainable,' a business must make profit. Without profit, no amount of storm water management, green building practices, or energy efficiency can ensure 'sustainability.' Without profit, business fails, cannot endure and therefore, by definition, is 'unsustainable.'"

The following definition (Ewoldt, 2007) seems to focus on a balance of two considerations, the social and economic:

> "Sustainability means to integrate our social and economic lives into the environment in ways that tend to enhance or maintain rather than degrade or destroy the environment; . . . not necessarily unchanged, but . . . staying within, the balance point . . . so that watersheds and bioregions can maintain their ability to recharge and regenerate . . . distilled to four core principles: 1) mutual support and reciprocity, 2) no waste, 3) no greed, and 4) increasing diversity."

The UN Commission on Sustainable Development (CSD) defines land as follows:

> "Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)."

Finally, a textbook relating these concepts to the mining industry reiterates the three-part view, "Mining is sustainable when it is practiced in a manner that economic, environmental, and social considerations, often referred to as the 'triple bottom line' . . ." (Rajaram et al., 2005).

The above definitions pertaining to 'land use sustainability' share recognition of the need to maintain *environmental* functions related to landforms when conducting *economic* development activities for the benefit of *future users* of the land.

Why Do Traditional Grading Practices Not Satisfy Sustainability Goals?

The traditional mine closure grading practices that are still widely used today either do not meet these sustainability goals or only minimally satisfy them. But if one part is satisfied, and another is not, the *balance* among the criteria is upset, which also fails to satisfy the emerging definitions of sustainability. If the term is to have meaning, we must agree that something is either sustainable or it is not. These traditional grading practices include long, constant-gradient slopes, terracing, rock-lined down-drains with associated linear drainage channels, and an effort to minimize the disturbance footprint.

Figure 1 below shows an example of a traditionally-graded closure slope at an abandoned Western uranium surface mine. The grading was completed in 1969 and the vegetation did not re-establish, slope sediment polluted stream channels and washed out public roads, and the slopes were difficult to traverse for any land use purpose (Chancellor et al., 2008). The striations on the slope include gullies deep enough to hide a standing man. Similar practices are used in the Appalachian region and the Appalachian Regional Reforestation Initiative (ARRI) has identified that coal mine reclamation in the region *"has not been accompanied by widespread replacement of forests disturbed by mining"* that may reduce the economic use of the land for future users (Angel et al., 2005). Reclamation grading practices in the Appalachian region where the Forestry Reclamation Approach (FRA) was developed are often limited to traditional valley fill designs that do not satisfy all reclamation criteria and thus do not provide for sustainability.

Figure 1. Mine slope reclaimed in 1969 using traditional grading practices in Wyoming.

Economic competition demands most efficient use of resources. Mine operators can add efficiency by integrating and coordinating mine development, operational, and closure plans as an on-going process throughout the mine life. This integration of all phases of mine activity through mine life leads to *land use sustainability* after mine closure.

What is the Geofluv Alternative to Satisfying Sustainability Goals at Mine Closures?

A new, natural approach to landform grading called GeoFluv offers a cost-effective alternative for sustainable mineral development than can satisfy the reclamation criteria. It offers environmental function for hydrologic, and plant and animal uses, lower costs for economic benefit, and can provide desired land use function for the long-term to meet social obligations. Figure 2 shows the same slope as Figure 1 above when freshly re-graded after completion of construction of a GeoFluv-design in 2007. Even without any vegetation or artificial erosion controls, this landform did not have erosion problems from flash storm events that occurred during the construction process because the natural *function* of the landform was restored (Chancellor et al., 2008).

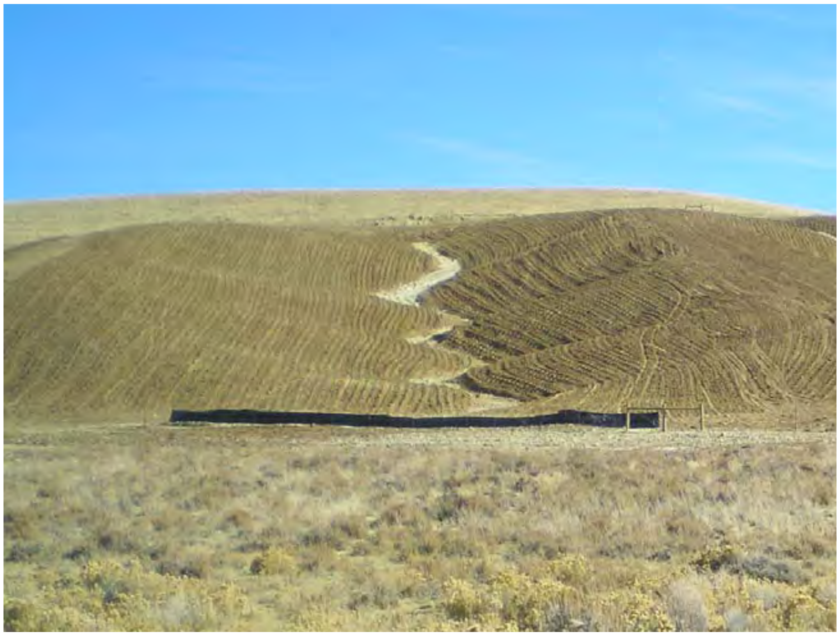

Figure 2. The GeoFluv-design that re-shaped the Wyoming slope shown in Figure 1 is shown here immediately after grading.

The reader can compare the image below of a natural, undisturbed slope with the landform in Figure 2 these landforms have similar relief. It is clear from comparison of Figures 1, 2, and 3 that the essential landform elements that support diversity in sunlight, cover, and vegetation on the natural slope in Figure 3 are present in Figure 2, but not in Figure 1. This is part of the reason why the GeoFluv-designed landform provides sustainability to post-mine closure landforms.

Figure 3. A natural, undisturbed slope in Arizona with greater diversity and stability against erosion that is related to the landform.

The GeoFluv Concept

The GeoFluv design approach can offer: greater stability against erosion, maintenance of hydrologic function of the landform, greater opportunities for plant and animal diversity, lower construction and maintenance costs, and promotion of successful bond release, as compared to traditional reclamation landform design methods.

What Does Geofluv Mean?

The term GeoFluv is not a generic term describing landform designs that incorporate fluvial geomorphic characteristics, but rather GeoFluv is a trademark for a very specific fluvial geomorphic landform design algorithm. Fluvial geomorphic literally means "landforms made by the processes of flowing water." The GeoFluv landform design method forms the heart of the Natural Regrade computer software module that simplifies and speeds the making of these complex landform designs.

How 'Stable' Landforms Develop Naturally

The fundamental concepts of the GeoFluv approach to stable landform design are taken from the study of the development of landforms over time, from youthful, actively eroding landforms to mature, 'stable' landforms. The 'youthful' slope shown in a 3D computer surface model in Figure 4, has longer, constant-gradient slopes that allow water to collect into discharges capable of eroding the surface.

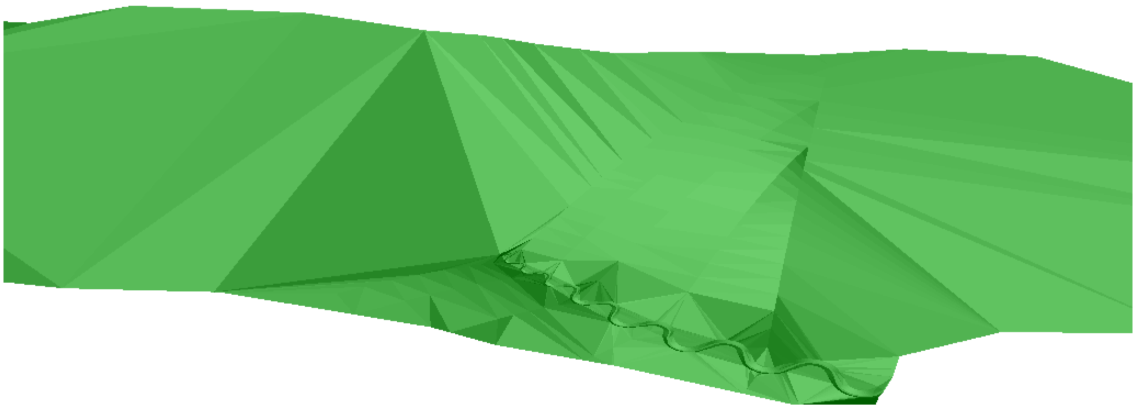

Figure 4. A computer 3D model of landform in the early 'youthful' stages of development.

The intermediate landform in Figure 5 is forming more drainage valley length, and simultaneously shorter slopes and smaller drainage areas, to minimize the erosion potential of the landform. Finally, the 'mature' landform in Figure 6 has maximized channel lengths and minimized slope lengths to bring the erosive force of the runoff discharge into balance with the stabilizing forces of the local earth materials and vegetation.

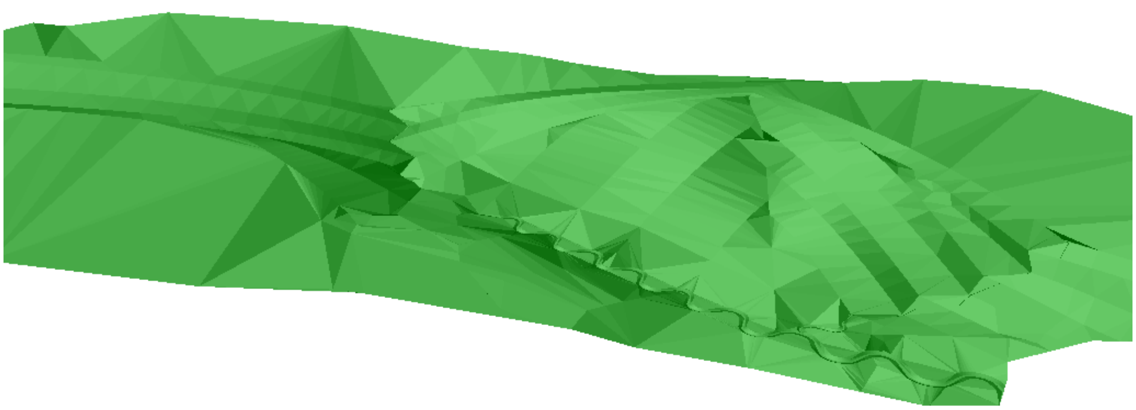

Figure 5. A computer 3D model of landform in intermediate development showing long convex slopes eroding at a high rate.

The mature landform is considered 'stable' against erosion because it is eroding at a very slow rate that does not interfere with land uses. Appreciation of this *process* is important because the *form* that we see is the integration of the climate, earth materials, and vegetation in the area producing the landform that best balances these erosive and stabilizing forces to make a *'sustainable'* landform. In contrast, the traditional grading approach used in Figure 1 produces a highly erosive 'youthful' form, with long, constant-gradient slopes, minimal valley length, minimal channel development, and large watershed areas, similar to that in Figure 4. The landform produced by traditional grading practices is predictably erosive for these reasons; powerful erosive energy is out of balance and will persistently seek to move to a 'mature' landform that does balance these forces.

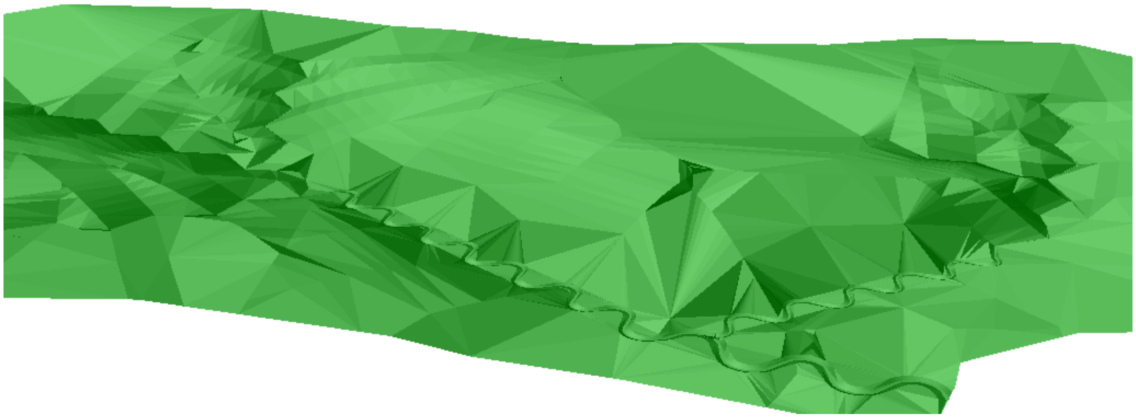

Figure 6. A computer 3D model of a 'mature' landform with minimal on-going erosion.

<u>Geofluv Design According to Natural Principles Yields Natural, Sustainable Function</u>

The GeoFluv approach has critical input factors that include empirical measurements of certain stable landform dimensions taken in the design area. These empirical measurements integrate the effects of local variation in climate, earth materials, and vegetation that define local landform stability against erosion. Importantly, the mature landform has developed over thousands of years and can be expected to include the response to extreme storms, i.e., 1,000-yr, 10,000-yr, etc. recurrence interval events. By collecting empirical measurements from stable landforms in the area of interest and using these as inputs to the design, the designer can have a high degree of certainty that the GeoFluv landform design will perform similarly to the stable, natural landform in that area.

Figure 7. A GeoFluv landform constructed from mine waste materials at the New Mexico/Colorado border.

The GeoFluv landform design method has proven to provide landform designs that are stable against erosion in what is arguably the most erosive area in North America, near the Grand Canyon. Figures 7 and 8 show one of these sites; ten weeks before the image in Figure 8 was taken, a greater-than 100-year, 3-hour storm hit the site and caused no erosion problems. It has proven to compress design time, allow more cost-effective construction, and better address land use criteria than traditional methods. Case histories of several GeoFluv landform designs will be presented to illustrate various applications.

Figure 8. The same mine waste pile graded to a GeoFluv design shown in Figure 7 above is shown here the following year with early vegetation growing after successfully passing a greater-than 100–year storm event.

Landform Diversity Relates to Vegetation and Animal Life Use

The slope diversity of the GeoFluv landform provides benefits beyond resistance to erosion. It results in different amounts of water being harvested on different parts of the landform because the slopes are not uniform grade, but rather are complex with steeper and flatter areas. It also results in different sunlight exposures during different parts of the day on different parts of the landform because of the variations in aspect (slope direction). The Appalachian Regional Reforestation Initiative (ARRI) has identified that coal mine reclamation in the region '. . . *has not been accompanied by widespread replacement of forests disturbed by mining* (Angel et al., 2005)." The traditional criteria to minimize disturbance footprint has often resulted in steep constant-gradient slopes that must have the earth materials highly compacted in an effort to minimize slope failures, but ARRI has found that this compaction frustrates tree growth. Additionally, the traditional constant-gradient grading practices produce much less diversity in slope steepness and aspect, which reduces diversity in water harvesting and aspect; this in turn reduces diversity in vegetation types and coverage, and opportunities for animal life. Having fewer ecological niches in a landform tends to produce a vegetation monoculture or worse, a landform that is unsuitable for the desired species while inviting invasive species.

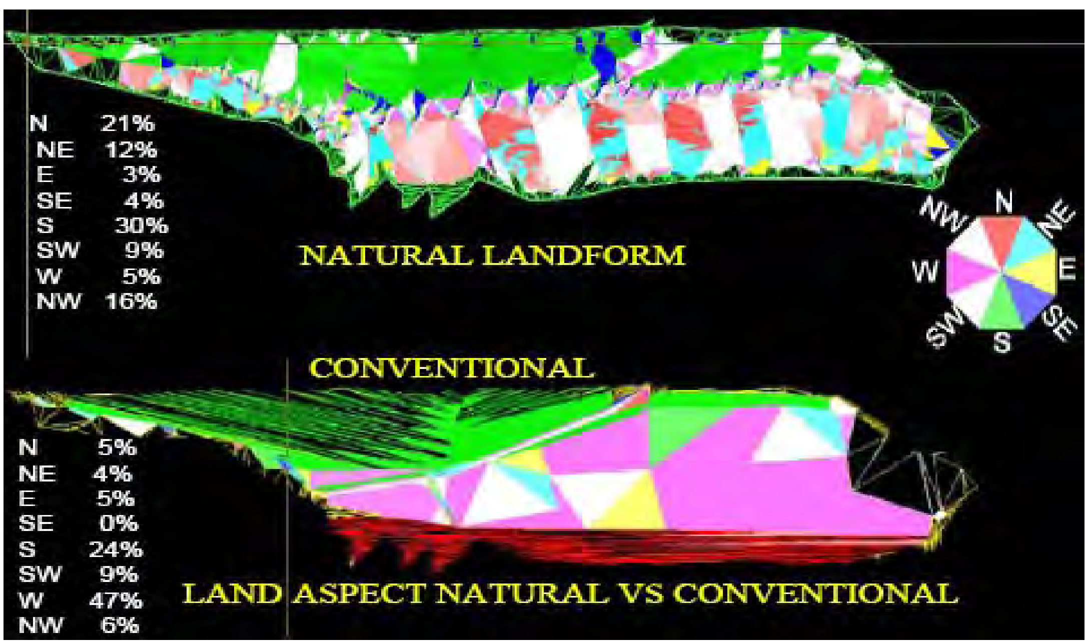

Figure 9. Comparison of slope aspect diversity between a natural (GeoFluv) design and conventional design for the same project area.

As an example of the variation in slope diversity, consider the computer slope analysis of a GeoFluv design versus a traditional design for an abandoned mine closure project in Indiana (Hause, 2006). The mosaic patterns on the 3D images are rendered in various colors and the percentages of the landform designs at various aspects are presented on the left. The traditional (conventional) design has 71 percent of the slope facing south and west, and none of the slope facing southeast, whereas the GeoFluv design has portions of the slope facing all directions and the aspects are much more evenly distributed. In contrast, the GeoFluv landform has diversity similar to the native, undisturbed land that provides the optimal niches for native species productivity, while simultaneously providing natural invasive species control and promoting suitable water quality.

Figure 10. A perspective view of a freshly graded GeoFluv landform (left) with an adjacent undisturbed natural landform (right) for comparison.

When describing the completion of a GeoFluv reconstruction (Figures 2 and 10) of a traditionally graded mine waste pile (Figure 1) in Wyoming the authors referred to both the benefits to vegetation and wildlife and related those to sustainability as follows: "Due to the varied landscape created by the project, vegetative diversity will be promoted. . . and undulating topography will create improved habitat for Wyoming's abundant wildlife and restore quality grazing lands where once barren spoils and highwalls existed. In addition, a small surface water impoundment was created to provide water for stock and wildlife. . . The benefits of this project will be enjoyed by generations to come (Chancellor et al., 2008)."

Water Quality Benefits from the GeoFluv Method

During 2007, the La Plata Mine staff sampled runoff from different areas of the hundreds of hectares of GeoFluv-designed reclamation on the Colorado border north of Farmington, New Mexico. In the relatively narrow and shallow ephemeral channels of smaller upland watersheds, the usual sampling method is a grab samples taken with a wide-mouth bottle with the inlet restricted by the sampler's fingers. If the stream is wadeable, the sample may be both depth- and width-integrated, but if the stream is not wadeable they will be sampled from one bank. These samples included areas of graded spoil, final graded surfaces with topsoil applied, and older fluvial geomorphic reclamation with vegetation establishing. These water quality analyses results provide some quantification of the GeoFluv reclamation discharge water quality as compared to the native stream water quality.

Table 1 lists total suspended solids (TSS) values for storm water samples collected within the reclamation area and for undisturbed areas outside of the reclamation. The total suspended solids values taken on various sites within the GeoFluv reclamation during the 5 October 2007 event can give a 'snapshot' of erosion control by comparing concentration results among the various samples: from native (660 mg/L), graded spoil (2,140 mg/L), topsoiled (47 mg/L), and re-vegetated (39 mg/L) sites (NMED, 2007). These results are averaged for the different types of sites and presented graphically in Figure 11 below.

Typical sample areas can be seen in Figures 7 and 8. Figure 7 above shows a fluvial geomorphic reclamation area that has been topsoiled; all the landform without tree cover is graded and topsoiled reclamation, while the area with tree cover is native land. The image in Figure 8 shows a fluvial geomorphic reclamation area that has vegetation starting.

Table 1. Total suspended solids (TSS) values from storm water samples inside the La Plata reclamation area taken during a 5 October 2007 storm (NMED, 2007).

5 OCT 2007	TSS mg/L
NM James – Native	660
Pond 27 – suitable spoil	2,140
Pond 40 – topsoil	47
Pond 3 – revegetated	39
S. Little Cinder – Regrade spoil	33
Little Cinder – topsoil	1,880
Lynch's Pond – spoil	182

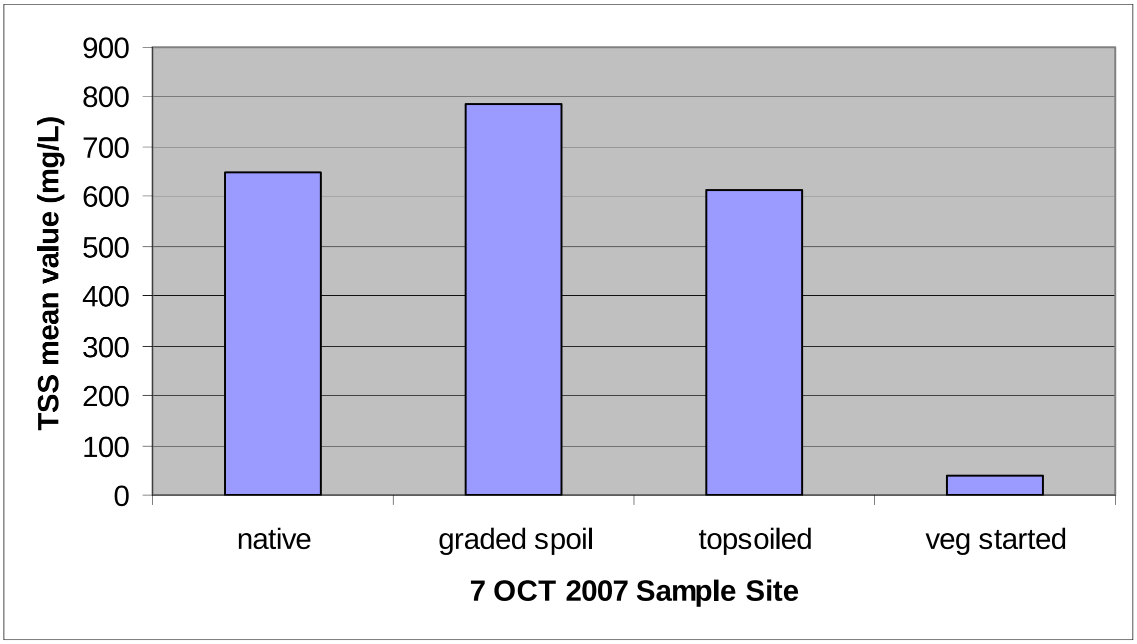

Figure 11. Graphic presentation of results of 7 October 2007 storm water sampling at La Plata Mine

These results strongly suggest that the geomorphic-designed landform with merely a topsoil cover can satisfy erosion control needs sufficient to meet water quality goals, but they do not tell the soil volume or mass that was involved. The concentration values, without discharge and duration data, and supplemental concentration values taken throughout the event, cannot quantify the actual amount of erosion associated with the storm event. Nonetheless, the 'topsoiled' and 're-vegetated' samples total suspended solids concentrations were an order of magnitude lower than the 'native' sample. Further research has been proposed to quantify the actual erosion rate associated with the GeoFluv landform to provide valuable data to future reclamation designers and regulatory oversight staff.

<u>Economic Comparison of Geofluv Approach versus Traditional Grading</u>

At first glance, the more complex grading associated with a natural GeoFluv landform design might suggest that costs would be greater to construct a natural design as compared to a traditional design. This has not been shown to be the case, largely because of three reasons. The more significant of these is that the GeoFluv designer has flexibility to minimize material movement by placing topographic lows and highs to correspond with material location at the cessation of mining. The next significant factor in material movement reduction can be seen in Figure 9 in traditional grading, material along the entire slope face is pushed to the toe, whereas in a natural landform ends of the ridges mark the toe line and material to grade the adjacent valleys is not moved out as far. Finally, because the GeoFluv design inputs come from stable, natural slopes that are effective by themselves in conveying runoff without erosion, the rock armor and other 'slope treatment' costs associated with traditional grading practices are not needed. In Table 2, examples from various mine closure projects provide economic comparisons:

Table 2. Economic comparison of a conventional design to a GeoFluv design for a 15.4 hectare (38-acre) limestone quarry reclamation project (Spotts, 2007).

Conventional Design (Berms, Terraces, Down-drains)	
Engineering design & permitting	$20,000
Regrading and placement of growth medium	$25,000
Rock mulch	$20,000
Construction of berms, terraces, downdrains	$150,000
Future maintenance and repair	???????
Total	$430,000+
Natural Regrade fluvial geomorphic design (GeoFluv)	
Engineering design & permitting	$20,000
Regrading and placement of growth medium	$250,000
Total	$270,000

Spotts (2007) reported (Table 2) that the overall initial cost for design and construction of a 15.4 hectare (38-acre) reclamation project at a limestone quarry was 37 percent less than traditional methods. Additionally, savings in repeated maintenance repairs are anticipated.

Figure 12. Cost to reclaim a 15.4 hectare (38-acre) reclamation project at a limestone quarry was 37 percent less than traditional methods. This New Mexico project is technically similar to an Appalachian mountain top removal site.

The project used the GeoFluv design method because the repeated blow-outs of berms, erosion of terraces, washout of rock and geotextile-lined down-drains, and off-site discharge of sediment was unacceptable to the facility operators and regulators. The completed project has performed as expected and has not required maintenance or caused water quality discharge problems.

Figure 13. The same quarry site as in Figure 12 is shown here after final grading with first-year vegetation starting. The area in the background that has not yet been graded will have a GeoFluv design that drains to the opposite site of the mountain.

Hause (2006) reported (Table 3) that two of three construction bidders required to bid on both a traditional and a GeoFluv design for an Indiana abandoned coal mine reclamation project submitted lower bids for the GeoFluv design and, though the bids varied considerably, they averaged 10 percent lower for the GeoFluv design.

Table 3. Economic comparison of a conventional design to a GeoFluv design for an abandoned coal mine reclamation project [4]

Bid	Conventional	Natural	% Difference
#1	$245,021.70	$237,822.20	-3
#2	$269,014.00	$294,668.00	+9
#3	$537,000.00	$417,000.00	-23

Figure 14. An Indiana abandoned coal mine project is shown here before construction of a GeoFluv design made using the Natural Regrade computer design software.

After construction, this project was recognized with the Mid-Continent Regional Award for reclamation by OSM in 2008. The award description noted that in addition to having natural slopes replace 4,000 feet of highwall, the Log Creek Church AML sequestered more than 70 acres of acid producing waste, established forested wetlands, and provided sustainable geomorphic stream channels and upland areas.

Figure 15. This is a view of the abandoned mine site shown above in Figure 12 the first year after construction to a GeoFluv design. The bids for the GeoFluv design averaged 10 percent lower than traditional designs.

Chancellor, Locke, and Shelley (2008) reported the following about the change to a GeoFluv design (shown in Figures 2 and 10) to repair a traditionally-designed, and un-sustainable, uranium mine waste dump; "Overall, the project cost came in below the engineer's pre-bid estimate, despite the increases due to the change in plans."

Measles and Bugosh (2007) reported greater cost efficiency at an active Wyoming coal mine. The mine was committed to reclaiming 32.4 hectares (80 acres) of mine waste per year, which in 2005 worked out to 1,308,365 million cubic meters (1.7 million cubic yards) of material movement to construct a traditional design. In 2005 the construction of the traditional design took 14 days longer than was scheduled and required movement of an additional 12,782 cubic meters (16,718 cubic yards) of material.

Table 4. Economic comparison of a conventional design to a GeoFluv design for an active coal mine reclamation project (Measles and Bugosh, 2007)

Method Used	Traditional		GeoFluv	
Year	2005		2006	
Area	R57-3-4		R58-3-3	
Target Volume	1,308,365 m^3	(1,711,278 yd^3)	1,299,743 m^3*	(1,700,000 yd^3)
Actual Volume	1,321,148 m^3	(1,727,996 yd^3)	1,175,458 m^3	(1,537,441 yd^3)
Difference	12,782 m^3	(16,718 yd^3)	124,285 m^3	(162,559 yd^3)
Days Scheduled	28		31	
Actual Days	42		31	
Difference	14		0	

* Designed using approved Post Mining Topography and traditional reclamation.

The similar traditional design for 2006 was revised using a GeoFluv design and the GeoFluv design required 9.5 percent (124,285 cubic meters or 162,559 cubic yards) *less* material movement. Because the GeoFluv design for the 32.4 hectares was completed ahead of schedule and under budget the decision was made to continue reclaiming until the budgeted funds were used. The result was that 40.5 hectares (100 acres) were completed for the cost that had been budgeted for 32.5 hectares (80 acres).

The examples above discuss the economics of applying the GeoFluv design method to sites where mining was planned without integration of reclamation design into the initial overburden removal and material placement. In other words, the mine plan did not consider placement of waste material during mineral extraction to minimize later material movement during reclamation. Even greater cost and time savings are feasible if the mine plan is coordinated with the GeoFluv design so that the mine waste material is placed as near to final reclamation grade as possible when it is first handled during the mining operation.

<u>Using Natural Regrade to Evaluate Designs</u>

The Natural Regrade computer design module can also be used to evaluate a landform design for stability against erosion. Any existing design can be evaluated by drawing a boundary polyline around the area, sketching polylines over the existing valleys, entering the site-specific fluvial geomorphic input data (valley slope at the project's channel tie-in, precipitation, etc.), and running the design command. The resulting GeoFluv design can be quickly compared to the design under evaluation and any differences in channel slopes, channel bottom elevations, etc., can indicate potential areas of concern. Additionally, the GeoFluv inspector tool, shown in Figure 16, can be used by moving the cursor across the design to read user-specified design information directly from the drawing at any vertex that the cursor crosses.

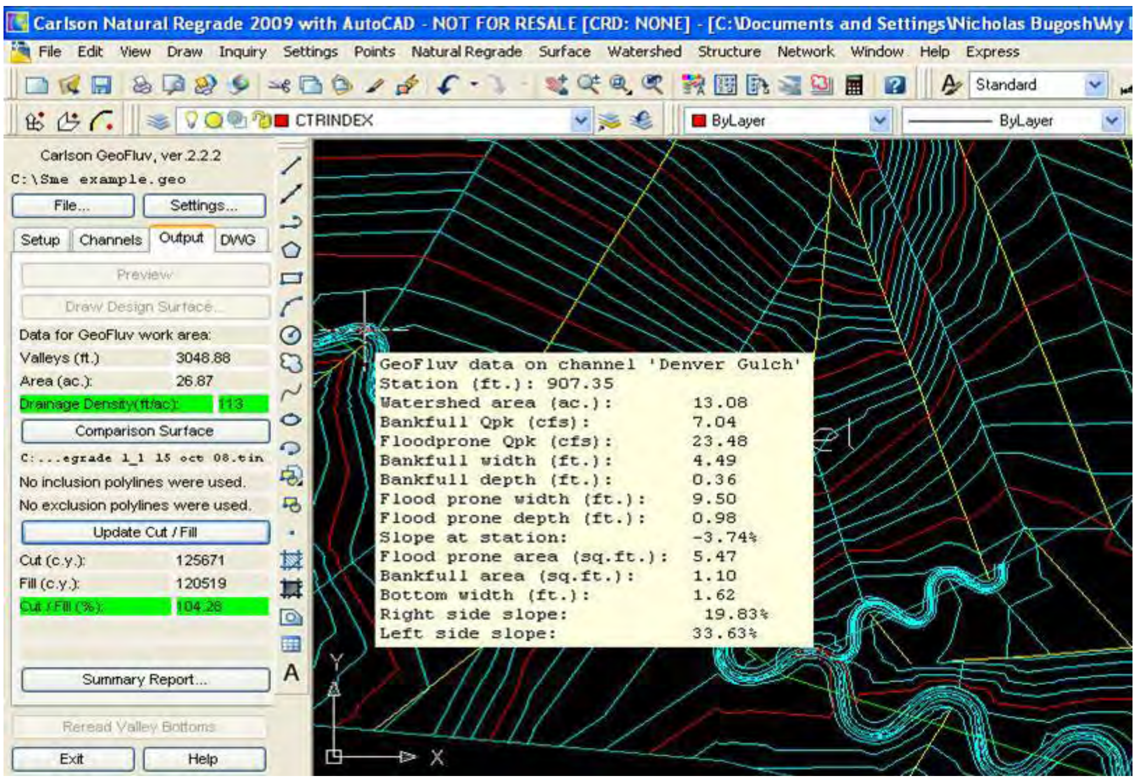

Figure 16. Screen capture of Natural Regrade GeoFluv design software showing channel information read directly from the drawing at point at which cursor rests.

The same GeoFluv inspector tool can be used on a draft GeoFluv design to edit the draft landform to optimize its characteristics to meet a desired goal, e.g., steeper or flatter slopes, greater or less channel shear (tractive) stress, etc. The Cut/Fill balance can be calculated with a mouse click to compare a GeoFluv design to an existing surface to verify material quantities, balance cut and fill volumes, or determine import and export volumes needed to make the design. Similarly, the Mass Haul (material centroid) command can, with a mouse click, find the centroids of mass that need to be moved and the voids to which the material must be hauled to build the design. The Haul Optimization routine can determine optimum straight-line material hauls and distances to help the user find the most efficient construction solution (this information is also needed for standard reclamation bond calculations).

Application of Geofluv Approach to Steep Mountain Terrain and Valley Fills

The Appalachian regional mining industry faces intense pressure on all three aspects of sustainability: economic, environmental, and social. Public interest groups are expressing discontent with the affect of current regional mining practices on environmental values and this in turn can slow mine permitting for start-up or expansion, or even threaten to deny mining which has severe economic consequences. The environmental issues include the change in appearance of the mountain tops, the loss of stream length and associated values that results from traditional mine waste valley fills, the potentially problematic discharge water quality from traditional reclamation landforms, and the reclamation vegetation species and diversity falling short of desired goals for sustainable land use.

A conceptual 3D Appalachian landform surface model is shown below in Figure 17 as it might appear before mining by mountain-top removal methods. In this example, the top of the ridge at the upper left will be removed to access the target mineral and the overlying waste rock will be placed in the adjacent valley.

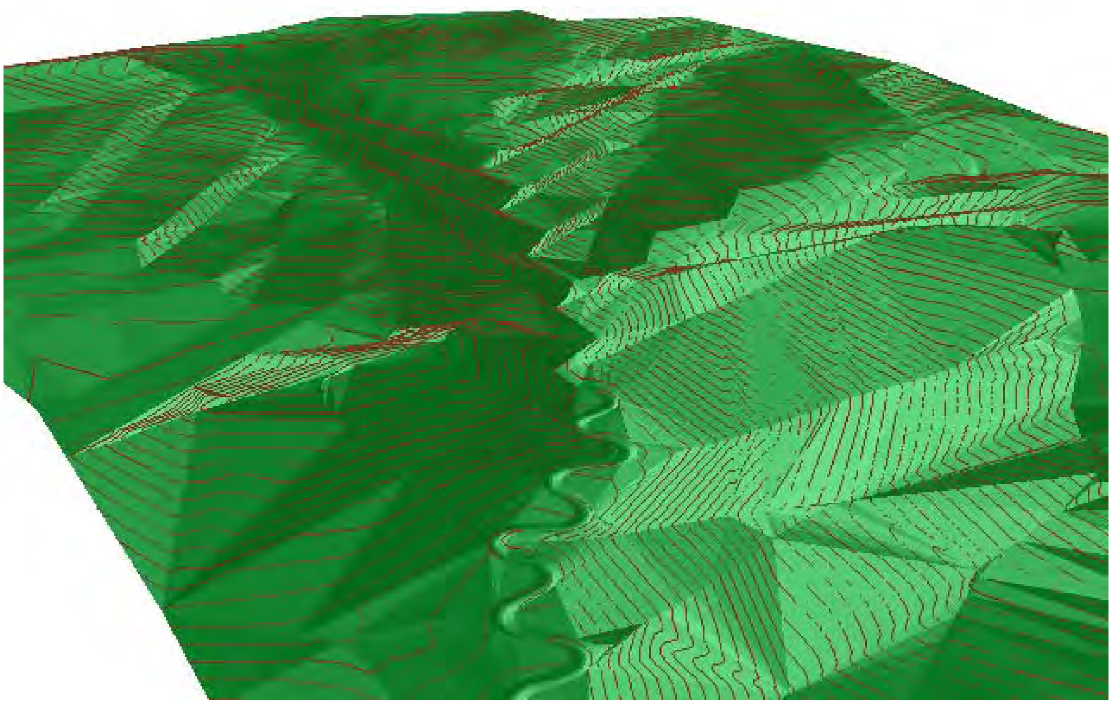

Figure 17. A pre-mine 3D conceptual model of steep mountain terrain with potential for mountain-top removal mining and valley fill.

The conceptual image in Figure 18 shows the same area after mountain-top removal and construction of a traditional valley fill waste dump. The fill volume in the 3D image approximates the mountain top removal volume. The mountain top removal area is mostly flat, with some highwall areas remaining, and the valley fill has buried considerable stream length and replaced that with a steep rip-rapped downdrain to convey the valley flows. This image presents some of the post-mining landform elements that compromise the landform's ability to meet reclamation goals that provide sustainability.

In this conceptual project, the flattened mountain top does not blend with surrounding terrain, and can disrupt drainage patterns to the valleys surrounding the mountain. The valley fill has a very steep, constant-gradient face to minimize the disturbance footprint, and that steep face is crossed by gradient terraces connecting to a downdrain. When constructed and observed, these valley fill landforms are obviously not natural land features. Unconsolidated material is inherently unstable against erosive forces in this configuration and those natural forces will rapidly work to wear the fill down to a more stable configuration. The valley fill is difficult and expensive to construct, buries a reach of stream channel that provides various environmental functions, replaces the stream channel with a down-drain that does little more than convey water, and the fill may require expensive maintenance and repair in perpetuity.

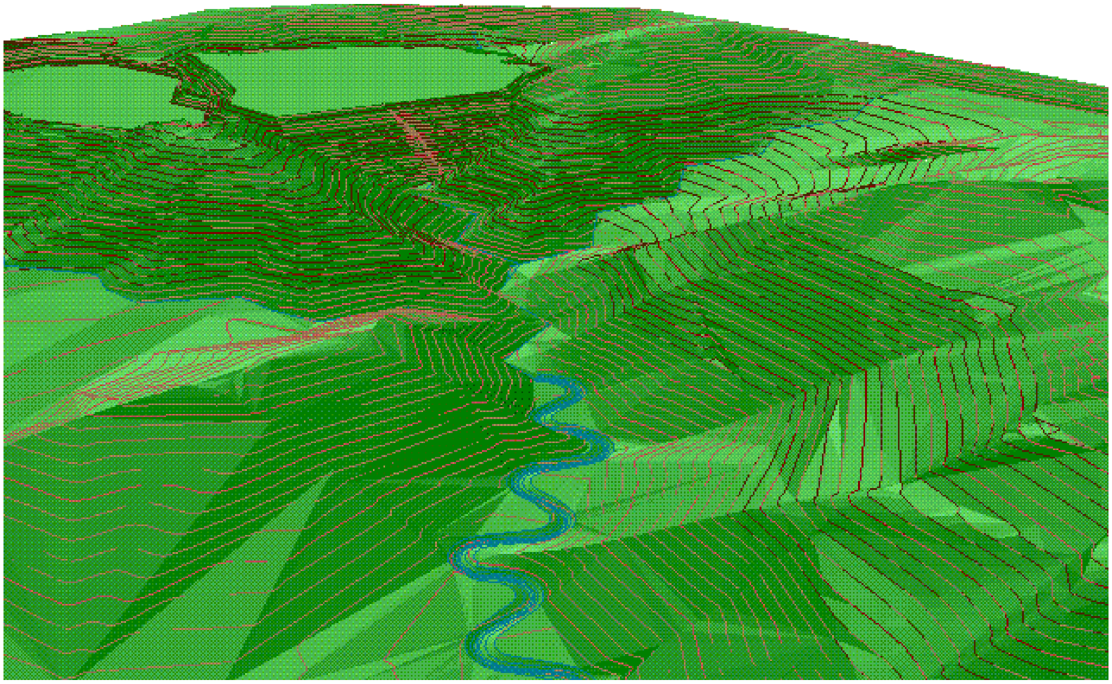

Figure 18. Mountain top removal with traditional valley fill.

A starting point for a GeoFluv design can be finding a natural analogy for the land disturbance that will be reclaimed to provide guidance to how natural erosional forces will stabilize disturbed land over time. A landslide can be considered a natural analogy for removing the top of a mountain and filling the adjacent valley with debris. The photograph in Figure 19 is of the Quake Lake landslide outside of Yellowstone Park which blocked the Madison River in 1959. Notice that the river did not stop flowing as a result of the slide debris filling the valley, but instead it re-routed its course through the slide debris.

Figure 19. The Quake Lake landslide can provide a natural analogy for a valley fill.

Using the landslide as an analog to an Appalachian valley fill, a GeoFluv waste dump landform can fill the valley bottom, but allow the pre-existing stream or storm water runoff to route to either side of the fill and establish natural stream functions. A valley fill composed of unconsolidated material will not tolerate long, constant-gradient slopes without erosion for long, so the GeoFluv fill has complex slopes with drainage subwatersheds in accordance with fluvial geomorphic principles.

The example alternative fill footprint must extend farther down the valley to accommodate the same volume as the over-steepened traditional fill. This larger disturbance footprint may be a 'paradigm shift' in that some long-held perceptions are that any disturbance equates to environmental damage and a consequent lessening of environmental quality. The extended disturbance area of the GeoFluv fill does not equate to more environmental harm and loss of sustainability, but instead provides establishment of stream values on-site, promotes improved water quality, provides niches for vegetation species diversity and composition, and minimizes maintenance, and has been shown to do so at lower initial cost.

This example shows an alternative way that mountain top highwall areas can be reclaimed using fluvial geomorphic principles to landforms that may not duplicate the pre-mining forms, but are fully functional for natural drainage characteristics, and have appropriate natural shapes that do not create disharmony in the viewshed. This alternative design offers one way to bring true sustainability to the reclamation.

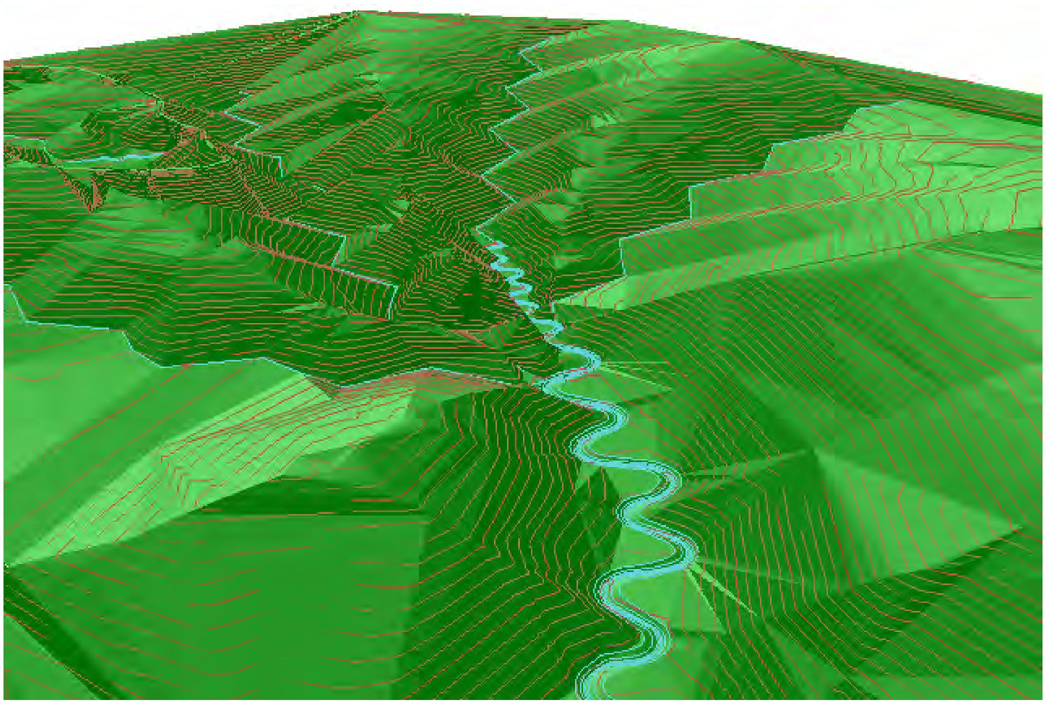

Figure 20. A possible GeoFluv alternative to the traditional approach is shown above. The GeoFluv solution includes fluvial geomorphic reclamation of the mountain top and the waste dump.

The image below is a mine waste dump constructed to a GeoFluv design. The image was taken in September 2008 during the first year following spoil grading, application of topdressing, and seeding. The slopes in the image are steep, long, and still bare of vegetation, but have endured a greater-than-100-year (near 200-year) recurrence interval storm and display no evidence of rill or gully erosion, without artificial sediment controls. They are in one of the most highly erosive environments in North America, near the Grand Canyon.

Figure 21. A constructed GeoFluv design is shown in the highly-erosive Four Corners region near the Grand Canyon. This image is from the largest GeoFluv designed project constructed to date. The project has approximately 2,066 acres of GeoFluv reclamation landforms including waste dumps, highwalls, valley bottoms, stream channels, and ponds. Construction of the reclamation landforms began in 2001. The site provided the 2007 water quality data presented in Figure 11. Figure 8 shows some of the earlier work at the site that has vegetation sprouting.

Can this approach based on natural fluvial geomorphic principles provide sustainability to Appalachian mine reclamation? Part of the answer is if natural landforms can be found in the area that are stable against erosion and can be used as reference areas for GeoFluv design inputs, but another part of the answer is if those making mine reclamation plans there are willing to make some fundamental changes in the way they design and build mine reclamation.

Conclusion

Current Appalachian reclamation practices may not satisfy all three sustainability criteria: economic, environmental, and social. Even missing one of these can keep the project from truly being considered sustainable. Although the current regional reclamation practices may not provide for sustainability, improvement is possible.

All of the constructed GeoFluv examples discussed above are providing the desired *environmental* functions, have shown to do so while providing economic benefits, and indications are that they will continue to do so for *future users* of the land.

Mining operations in the contemporary environment must satisfy many criteria in addition to those needed to meet the primary function of mineral extraction. These include those related to the safety and health of the employees, stewardship of the environment on and around the mine site (which includes maintenance of hydrologic functions, and plant and animal uses), and interaction with the local community (which includes long-term stability against erosion, minimizing maintenance costs, and satisfying post-mining land uses). The concept of sustainability is now applied to mining operations and the GeoFluv design method for reclamation grading design can significantly affect the mine's ability to satisfy the criteria of sustainability, "the economic, environmental, and social considerations . . . often referred to as the "triple bottom line . . ."

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Nicholas Bugosh is presently the Principal of his firm, GeoFluv, and the GeoFluv Technical Director for Carlson Software. He resides in Fort Collins, Colorado and is responsible for the development and promotion of the Natural Regrade fluvial geomorphic landform design module and Hydrology module worldwide. Natural Regrade is used across the United States, in Canada, Australia, and Romania. His training in geology and hydrology includes Bachelor of Science in Geology and Master of Science in Earth Sciences. Mr. Bugosh has conducted field research on bedload transportation in mountain streams, worked for state agencies in South Dakota, Montana, and Idaho with mining and water quality regulation, worked as a hydrologic consultant on projects across the United States, and worked as Senior Hydrologist for the New Mexico operations of the largest mining company in the world. Mr. Bugosh has developed a new approach to land grading that returns disturbed lands to natural function and appearance that he calls GeoFluv™. This approach forms the heart of the new Carlson Software Natural Regrade module.

GEOMORPHIC RESTORATION OF COLDWATER FORK FOLLOWING OCTOBER, 2000 SLURRY SPILL

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Abstract

A coal slurry release from the Big Branch Slurry Impoundment on October 11, 2000 resulted in the flow of millions of gallons of slurry into the Coldwater Fork and Wolf Creek watersheds. Clean up efforts along both streams included removal of slurry using excavators and the use of temporary dams and pumps. Efforts were made during excavation of the spill to maintain Coldwater Fork's pre-spill channel configuration, however, portions of the creek were realigned.

Since the slurry release, significant portions of Coldwater Fork have exhibited recovery on it's own including the reestablishment of pools and riffles, and gravel substrate. However, a series of head-cuts formed which threaten to destabilize the recovering portions of the creek and the excavation process resulted in a stream that was highly entrenched. In late 2003, a design was initiated to restore the damaged sections of Coldwater Fork.

In this presentation, an overview of the restoration of Coldwater Fork will be given, and the use of a reference reach to design the restored sections of Coldwater Fork will be discussed.

No paper was provided by the author.

George Athanasakes, **PE** has a broad range of experience in Ecological Restoration including the use of natural channel design, stream and wetland restoration, watershed master planning and dam removal. Over the past 15 years, George has served as Project Manager on numerous stream restoration projects throughout the United States. George also led the development of the RIVERMorph Stream Restoration Software and is responsible for software content, new releases and training. His career began with FMSM Engineers, where he led FMSM's Ecosystem Restoration Group. In 2007, FMSM Engineers was acquired by Stantec Consulting Services. George now serves as the Ecosystem Restoration Practice Leader for Stantec and is responsible for leading these services throughout North America. He holds a Bachelor's of Science and Master's of Engineering Degrees from the University of Louisville. He is also a Registered Professional Engineer in several states.

MODELING HYDROLOGY AND SEDIMENT LOSS ON HEAD-OF-HOLLOW FILLS: GEOMORPHIC VERSUS TRADITIONAL APPROACH

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Abstract

Head-of-hollow fills (valley fills) are required for placement of excess spoil generated during surface mining operations. Head-of-hollow fills have traditionally been constructed with an emphasis on the structural stability of the fill. The traditional approach includes compaction of the crown and face coupled with the establishment of a grass cover to reduce erosion resulting in a structurally sound fill that increases the peak flow and erosion rates above the pre-mining forested watershed condition. An alternative head-of-hollow fill technique has been constructed by researchers at the University of Kentucky that incorporates the geomorphic watershed design using the Forest Reclamation Approach (FRA) integrated with natural channel design. The geomorphic watershed design results in a topography and natural stream system that mimics pre-development forested characteristics. The FRA provides a non-compacted spoil medium and establishment of a diverse hardwood forest. Hydrologic and sedimentologic modeling was conducted to compare responses from the traditional and geomorphic approaches of head-of-hollow fill designs compared to a pre-mining Appalachian forested watershed. The goal of reclamation should be that of sustainability; addressing the hydrologic response, sediment generation, water quality (organic material and nutrients), and Appalachian geomorphic landforms, natural streams and forest. Key hydrologic parameters are curve number, time of concentration, and unit hydrograph response. Erosion parameters are erosivity, eroded particle size distribution, cover factor and slope length, and gradient. Data from previous and on-going research on undisturbed forests, compacted, and loose-dumped spoil were used to quantify key input parameter values. The timeframe for model comparisons is 1) after earthwork completion with well established grasses on the traditionally constructed head-of-hollow fill and 2) after tree planting, but prior to tree establishment, for the geomorphic design approach. Based on modeling the 2-year 24-hour design storm, the hydrologic response of the geomorphic head-of-hollow approach shows substantially lower peak flows and lower runoff volumes than the undisturbed forested watershed whereas there is a large increase in peak flows and an increase in sediment loads generated by the traditional head-of-hollow fill technique compared to the undisturbed forest.

Introduction

Successful tree establishment has been well documented using the Forest Reclamation Approach (FRA) (Graves et al., 2000; Burger et al., 2005; KDSMRE, 1997). Yet, there continues to be controversy regarding the potential hydrologic and sedimentologic impact of head-of-hollow fills. Since there is limited data from traditionally constructed head-of-hollow fills, modeling has predominantly been utilized to assess the probable hydrologic impact of such fills compared to undisturbed Appalachian forests (U.S. EPA, 2000). Unfortunately, selection of values for hydrologic parameters were based on historical literature and/or published tables that may or may not be representative of hydrologic processes found in undisturbed Appalachian forest or traditionally compacted head-of-hollow spoil. This is especially true during head-of-hollow fill construction where very limited data exists. Modeling results were further complicated when expanded to erosion predictions that were based on even more limited data such as eroded particle size distribution, K-factors, and C-factors that were extrapolated from 'similar' soil and land use conditions.

The Approach

The objective of this report is to contrast two alternative approaches to head-of-hollow fill construction and compare predictive modeling results to an undisturbed Appalachian forest. The program SEDCAD was used for modeling all scenarios (Warner et al., 1998). Both the hydrologic response and predicted sediment generation rates are addressed. Modeling focused on the crown portion of the head-of-hollow fill since it was most affected by the alternative head-of-hollow fill design approaches. Additionally, selection of model input parameters was predominantly based on measured values from undisturbed, compacted, and loose-dumped research watersheds in close proximity to the geomorphically-designed head-of-hollow fill. The traditional head-of-hollow fill is constructed such that it is structurally stable through use of durable rock and compacting the crown and face. Erosion rates are controlled by planting vegetation consisting of a mixture of grasses and forbs. The geomorphic head-of-hollow fill design incorporates contouring to establish ephemeral and intermittent streams, the FRA of spoil placement and forest establishment, and natural channel design (Agouridis et al., 2009). The geomorphic head-of-hollow fill approach has the structural stability attributes of traditional fill construction techniques with the addition of a more highly compacted upper crown layer prior to placement of the final loose spoil layer. Additionally, enhanced compaction occurs during stream and vernal pond construction.

Undisturbed Appalachian Forest - Input Parameters

Hydrologic data were acquired from the University of Kentucky's Robinson Forest located in southeastern Kentucky about 5 km from the geomorphic head-of hollow fill research site, Guy Cove. The Robinson Forest watershed is considered highly representative of Guy Cove prior to mining with respect to established forest, soils, geology and geomorphology. Shallow soil overlaying a sandstone cap is typical of most sites in this region and is representative of both the Robinson Forest and Guy Cove sites. The hydrologic input parameters of interest are: 1) Natural Resources Conservation Service (NRCS) curve number, 2) time of concentration and 3) hydrologic response function (dimensionless unit hydrograph shape). The curve number determines runoff volume whereas all three parameters affect peak flow and the shape of the hydrograph at the watershed outlet.

The NRCS curve number is often selected from the NRCS table which is based on hydrologic soil group and land use condition. A range of seemingly acceptable values in state mining guidance documents is quite narrow: 72 +/- 2 for all Appalachian forested sites in Kentucky and West Virginia. Such a value is representative of deep soils with a well established forest litter in hydrologic soil group 'C' with woods in fair or good condition (SCS, 1969).

For this analysis, rainfall-runoff data from natural forest in eastern Kentucky were used to determine curve numbers. Curve numbers ranged from 86 to 88 (Springer et al., 1980), 85 to 93 (Hawkins, 1993) and most recently a mean of 83, based on 12 storm event ranging from 28.4 to 67.6 mm (Taylor et al., 2009). A curve number of 83 was input to the model. It is important to note that the curve number analyses conducted by Hawkins (1993) and Taylor et al. (2009) were for watersheds located in Robinson Forest ranging in size from 82 to 116 ha. The Guy Cove site is 40 ha (100 ac). The time of concentration was calculated using the NRCS upland curve method for overland flow and channel flow based on Manning's equation. A dimensionless unit hydrograph shape of 'slow' was assigned to represent the undisturbed forested watershed condition (Warner et al., 1998).

Sedimentologic inputs for the pre-mining watershed condition were: 1) erosivity (K-factor), 2) eroded particle size distribution (EPSD), 3) slope length and gradient (LS-factor cover) and 4) cover (C-factor). K-factors for undisturbed forest in eastern Kentucky range from 0.170 to 0.256 based on analysis of eight composite samples acquired between northeastern and southeastern Kentucky. For the Starfire Mine forested area (closest proximity to Guy Cove) K-factors ranged from 0.206 to 0.256 (Warner, 1999). A value of 0.23 was assigned for the SEDCAD model analysis. An eroded particle size distribution for the undisturbed forest, located adjacent to Guy Cove, was also input to the model. The representative watershed length (25 ft) and gradient (45%), based on pre-mining topography, were input to determine the LS-factor. The C-factor for undisturbed forested conditions ranges from 0.0001 to 0.009. A value of 0.003 was input accounting for an effective canopy of 35% and forest litter coverage of 70%.

Traditional Head-of-Hollow Fill - Input Parameters

The hydrologic characteristics of run-of-mine (ROM) spoil are needed to assign model input parameters for tradition head-of-hollow fills. Such fills have compacted crowns and a 2:1 (H:V) face with inverse benches every 50 ft, spaced vertically. Curve numbers for compacted Appalachian mine spoil range from 83 to 88 in Pennsylvania (Ritter and Gardner, 1991) and 87 to 97 in Southern Ohio (Bonta et al., 1997). Model input of curve numbers was based on analysis of rainfall-runoff data from a nearby mine site. Analysis based on 42 runoff producing events over a 28 month monitoring period resulted in a compacted spoil mean value of 85 (Taylor, 1995). Time of concentration again was based on applying the NRCS curve number with channel flow along rock riprap diversions. A dimensionless unit hydrograph shape of 'fast' was assigned to represent the compacted fill condition. The best fit unit hydrograph shape for compacted spoil was evenly divided between 'medium' and 'fast' (Taylor, 1995). The crown area is 18.0 ac. This area input was used for all scenarios.

Sedimentologic inputs for the traditional head-of-hollow fill are: 1) erosivity (K-factor), 2) eroded particle size distribution (EPSD), 3) slope length and gradient (LS-factor cover) and 4) (C-factor). K-factors for slightly weathered (approximately 6 months) ROM spoil in Kentucky range from 0.159 to 0.232 based on analysis of eight composite samples acquired between northeastern and southeastern Kentucky. For the Starfire Mine, spoil K-factors ranged from 0.191 to 0.200 (Warner, 1999). A value of 0.19 was assigned for the SEDCAD model analysis. An eroded particle size distribution for spoil at the Starfire Mine was also input to the model. The representative watershed length (150 ft) and gradient (3%), based on crown topography, were input to determine the LS-factor. The C-factor for compacted spoil has a wide range from 0.7 to 0.9 based on the literature for disturbed areas. Once grass is well established, the C-factor decreases to 0.042 to 0.013 for a grass canopy of 60% to 80%, respectively (SCS, 1977). Grass C-factors are based on USLE literature that is not specific to reclaimed mined lands. A value of 0.0275 was input accounting for an approximate effective canopy of 70%.

Geomorphic Head-of-Hollow Fill - Input Parameters

There are limited data on the hydrologic characteristics of loose-dumped spoil as utilized in the FRA. A study, specifically conducted to acquire curve number data from an end-dumped head-of-hollow fill resulted in a curve number of 35 for a simulated rainfall event of 2.5 in/hr following an antecedent rainfall of 2.1 inches (Highland Coal, 1984). Hence, no significant runoff occurred due to the high infiltration rate. An applied research program was conducted at Starfire Mine to determine the rainfall-runoff relationship of loose-dumped spoil placed using the FRA. Three monitoring locations were used that acquired runoff from the loose-dumped site and an adjacent earthen diversion (Bryd, 2001). Surface runoff was not observed in the loose-dumped areas but only existed on the outermost side-slopes and from the diversion. An adjacent research site was used to characterize the infiltration rate of loose-dumped spoil using 38 lysimeters (5 m x 5 m) installed prior to end-dumping 2-3 m of loose ROM spoil. The average annual infiltration rate was 32.2%. An Appalachian forest has an annual average infiltration rate of 30 to 35%. Thus, loose-dumped spoil, employing the FRA, even before the establishment of a mature forest, resulted in an annual infiltration rate similar to a forested watershed.

A comprehensive hydrologic assessment of loose-dumped spoil was conducted at the Bent Mountain research site on six plots consisting of two replications of brown weather sandstone, gray unweathered sandstone, and ROM spoil (a combination of brown weathered sandstone, gray unweathered sandstone, and shale). No surface runoff was observed and a mean curve number, based on interflow, of 77 was determined (Taylor et al., 2009). To be conservative, a high value of 77 was input to model for the curve number of loose-dumped spoil placed using the FRA. Since the curve number represents the runoff volume, such a selection would be similar to the long hydrograph response measured in forested areas (Figure 1a-b).

It should be noted that a curve number of 77 is based on measuring interflow that occurred through infiltrating the loose-dumped spoil and migrating along the loose-dumped - compacted spoil interface. Based on the highest rainfall received to date, 77.1 mm, and no observed surface runoff the calculated curve number would be approximately 50 for loose-dumped spoil at the Bent Mountain site. It should be noted that the overall slope of loose-dumped spoil plots was approximately 2% longitudinally and 3-10% laterally. The time of concentration was approximated based on the hydrologic response of the loose-dumped spoil plots, and a slow dimensionless hydrograph response was assigned to model inputs.

Sedimentologic inputs for the geomorphic head-of-hollow fill design are similar to the traditional head-of-hollow fill with respect to erosivity (K-factor) and eroded particle size distribution (EPSD) since the same spoil is used. A representative slope length of 15 ft and a 40% gradient were input to determine the LS-factor. The length and slope gradient are representative of loose-dumped spoil piles constructed using the FRA. The distribution of surface and in-situ rock fragments affects many spoil physical properties: infiltration rate, permeability, pore space, water holding capacity, bulk density, and erodibility. Erodibility is especially affected by surface roughness and surface rock content, which consists of gravel through boulders.

The C-factor for loose-dumped spoil is difficult to assess due to observations of no surface runoff and deposition of eroded sediment in the depressions among spoil piles on the Starfire and Bent Mountain research sites. Both of these factors indicate a very low C-factor that approaches zero for the overall slope of the Bent Mountain experimental site. The geomorphic head-of-hollow design is based on 3:1 side-slopes. There are no measured hydrologic or sedimentologic data from a loose-dumped site with such a slope. Based on the high degree of surface roughness and surface rock content, a very low C-factor would be justified for a 3:1 slope. The infiltration rate will certainly be a factor in determining the C-factor. Although outside of the surface roughness database of the Revise Universal Soil Loss Equation (RUSLE), this program was used to estimate an approximate C-factor of 0.02 based on extrapolated surface roughness and a surface rock content of 60% (Renard et al., 1997; Warner and Foster, 1998).

Model Results

Predicted peak flow, runoff volume, sediment load, and peak sediment concentration for the crown of the two alternative head-of-hollow fill designs compared to the pre-mining forested watershed, Table 1, shows an increase in peak flow for the traditional head-of-hollow fill compared to the forested watershed. The geomorphic head-of-hollow fill has a predicted decrease in peak flow of an order of magnitude compared to the forested watershed. Peak sediment concentration is 25% higher for the traditional head-of-hollow fill design and approximately equal for the geomorphic design compared to the forested watershed.

Table 1. Peak Flow, Runoff Volume, Sediment Load and Peak Sediment Concentration of Traditional and Geomorphic Head-of-Hollow Fills Compared to a Forested Watershed

Watershed	Peak Flow (cfs)	Runoff Volume (acre-ft)	Sediment Load (tons)	Peak Sediment Conc. (mg/L)
Forest	13.4	2.1	1.5	1,430
Head-of-Hollow - Traditional	23.6	2.3	2.9	1,810
Head-of-Hollow - Geomorphic	1.4	1.6	1.2	1,200

Research Needs

Based on model input parameter considerations, it is evident that there is limited hydrologic and sedimentology data that can be used to quantity these input terms. This is especially true for loose-dumped spoil placed in accordance with the FRA. No watershed-based verification data exists for the FRA as described in the geomorphic head-of-hollow fill design option.

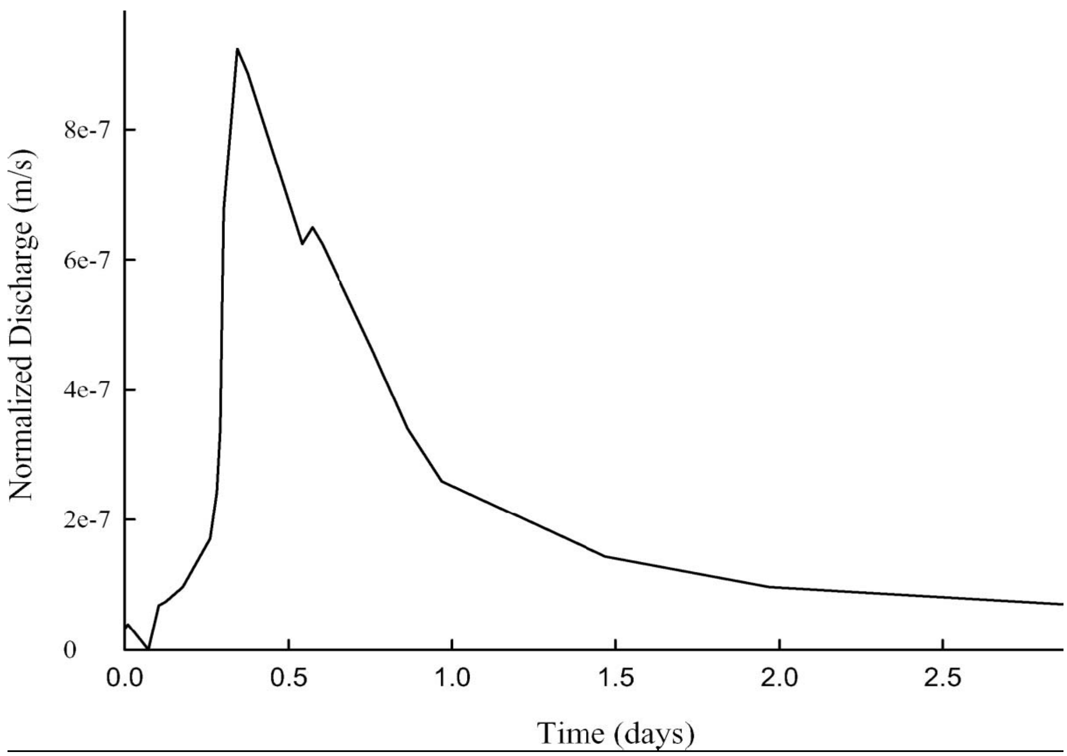

Figure 1a. Representative hydrologic response at Little Millseat. Storm event: Precipitation, 42.9 mm; Duration, 18.h.

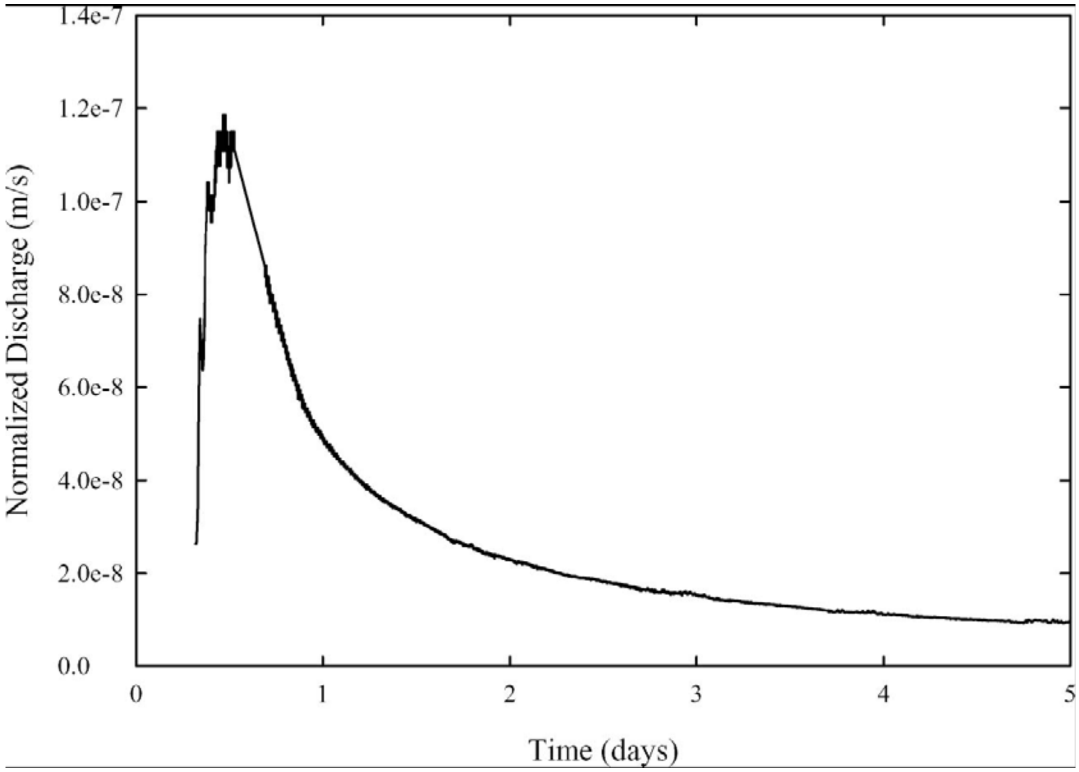

Figure 1b. Representative hydrologic response at Bent Mountain surface mine test cell 5. Treatment: mixture of both brown, weathered sandstone and grey unweathered sandstone and shale; Storm event: Precipitation, 38.1 mm; Duration, 17.7 h.

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STREAM RESTORATION ON THE CUMBERLAND PLATEAU, TENNESSEE

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Abstract

This presentation discusses the ongoing project that involves the final reclamation of a surface coal mining and reclamation operation involving a dragline operation in Sequatchie County, Tennessee. The final pit was reclaimed by blasting the final highwall and utilizing the final dragline bench and spoil ridge to rough backfill and grade the site. A previously approved Aquatic Resource Alteration Permit (ARAP) was modified to make use of the final pit reclamation area as a stream restoration area. The original ARAP was for the restoration of a small intermittent and perennial stream that bisected the surface coal mine.

This presentation will address the history of the site leading up to the modified ARAP that improves aquatic habitat along with addition of riparian vegetation and the current progress of construction, including plans, problems and construction phases.

Introduction

This presentation involves a stream restoration project at a reclaimed surface coal mining and reclamation project in southeast Tennessee. The project site lies near the community of Dunlap in Sequatchie County. Dunlap is an old coal mining area and home to the Dunlap coke ovens park and museum.

The detailed plans of the stream restoration project were designed by STANTEC, formerly Fuller, Mossbarger, Scott & May.

The mine site, originally investigated by AMAX, was started by Skyline Coal Company, a general partnership. Ownership of the mine complex went through several changes before ending up with Lexington Coal Company. This is the company now charged with completion of the reclamation work at the mine.

The big brush creek mine no. 2 is the site of the stream restoration. Initial production was started at the very southern end of the mine in 1986. The mine was a dragline operation consisting of BE 1300 42 Cubic Yard (CY) machine and a Marion 7400 12 CY machine. The operation mined approximately 550,000 tons per year, moving about 1,400,000 CY of overburden per month.
A lot of people get involved in stream investigations when an apparent problem is identified. This usually involves several regulators, as you can imagine.

Stream Restoration

Iron seeps were identified in the early 1990s associated with the mining operations ongoing along Glady Fork Creek and Big Brush Creek. Inspector Dave Turner was much involved in the subsequent stream investigations.

After much debate, studying and plan implementations, the creeks are much improved. The reclamation plan map indicates cut limits, water flow directions and creeks. The final pit reclamation plan map (Figure 1) indicates the unnamed tributary, pond #007, low areas within the reclaimed pit, the original aquatic resource alteration permit (ARAP) location and the proposed cut through.

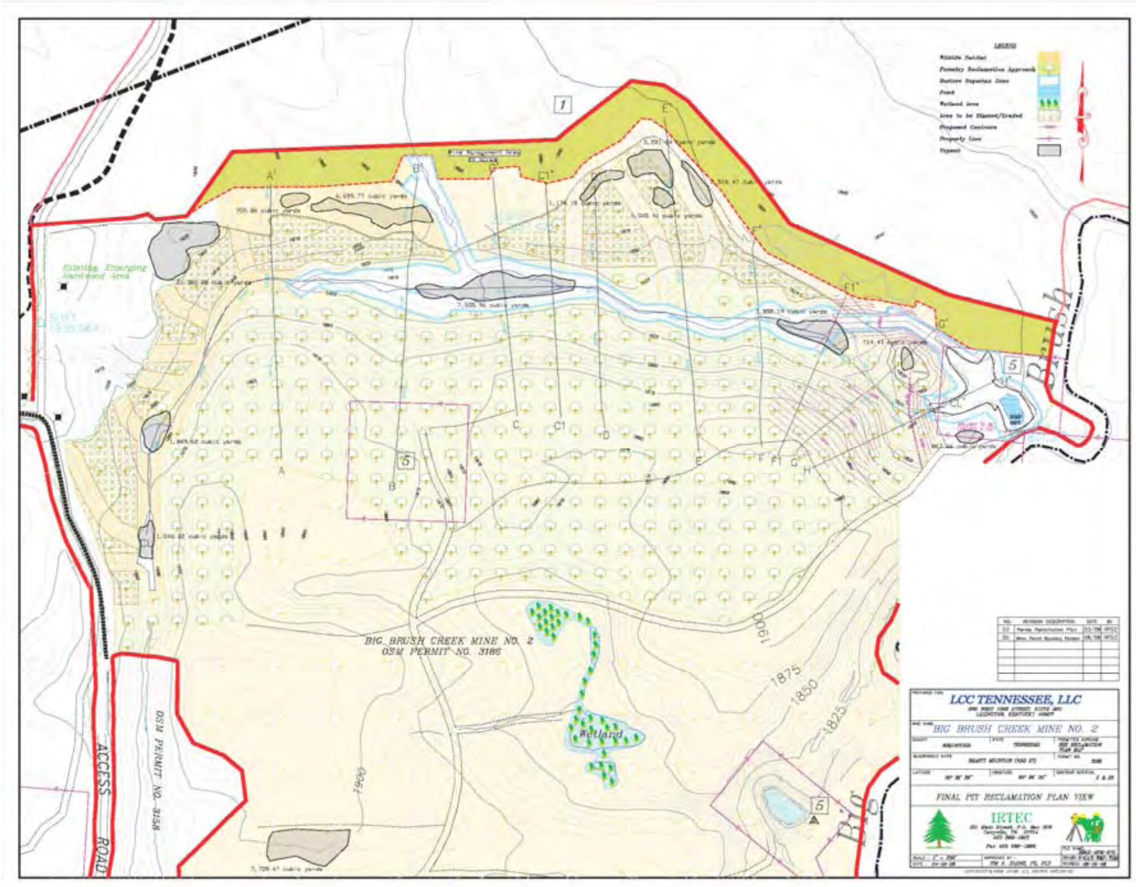

Figure 1. Final Pit Reclamation Plan

The aerial photograph (Figure 2) depicts the features again, including the draglines still on the site. Skyline Coal company stopped mining in September 1999 and finished grading of the site in February 2000.

Figure 2. Aerial photo of mine site.

Reclamation consisted of merely shooting down the highwall side of the pit and grading such that a steeper slope than desired was achieved, leaving mostly rock with little to no growth medium. After several years of settling, the pit developed low areas and sinks. Some areas settled about 8 ft in all. The east end of the pit developed into a large sink. Not quite as bad as our mega-sink in Washington, DC.

The final discharge of the mine area groundwater is through a constructed wetland area. A weir (Figure 3) was constructed at the outlet to keep up with discharge rates.

Figure 3. Weir constructed at final discharge.

Final reclamation began in 2008 after around 100 soil samples were collected to 4 foot depths to determine suitability for the forestry reclamation approach and necessary soil amendments. Topsoil material was mixed with darker shale areas prior to ripping. The spoil side of the final pit was ripped on 8 foot centers for tree planting under the forestry reclamation approach. The area was hydro-seeded and trees were planted at the earliest opportunity. Vegetation is looking good.

To tackle the highwall side, we knew we were going to need some heavy duty equipment. This one picture was sent to TDEC to let them know we were beginning the work on the highwall side of the final pit. Lexington Coal Company sent some heavy iron down to complement the equipment owned by Walker Construction.

Areas had to be drilled and shot to generate the desired slopes and growth medium. TNT was the blasting company involved from Dunlap. Pre-blast surveys had to be performed on the draglines as they were owned by another entity. The first shot was greatly anticipated and drew an audience.

Topsoil material was mixed in with the graded shot material generating a desired mix of sandstone/shale/organics for the growth medium.

Grading began in the stream channel location to achieve rough grading for bowls and bulkheads and to remove large boulders and/or root wads. After final grading, fine gravel was placed down and graded smooth for a liner base. Bowls and bulkheads were all lined to maintain a moist environment for aquatic life during dry times. A Bentomat Claymax liner was utilized to line the stream channel and flood plain. Each roll weighed about 1 – 1 ½ tons and required some ingenuity to handle. You don't have to be a rocket scientist to figure it out, just some creative thinking. The liner had to be trenched in at the outer edges. It had to be overlapped and Bentonite seal utilized at each overlap. Once the liner was in place, it had to be covered with a layer of topsoil material with light equipment to protect the liner. Final grade was achieved with spoil material placed over the topsoil layer.

Weather was a constant concern, especially heavy precipitation events, which required pumping. Once the lower wetland area was completed things really got going.

The small unnamed tributary is dry most of the time, but can really flow during a heavy rain event (Figure 4). Construction plans were modified to accommodate the witnessed flows.

Figure 4. Runoff during heavy rain event.

Construction plans were modified to accommodate the witnessed flows. Construction is ongoing and it is desired to achieve pool and riffle zones along the stream reaches similar to those indicated.

We don’t expect to quite achieve the results as shown (Figure 5), but we are well aware of the watchful eyes of the regulators and want to achieve something worthwhile for the beautiful mountains of East Tennessee.

Figure 5. Final Stream restoration.

Tim K. Slone is a Professional Engineer, Professional Surveyor and Professional Geologist who has been working in the mining industry since 1972. He is currently President and CEO of Innovative Reclamation Technologies and Engineering Company, Inc., (IRTEC). IRTEC employs 15 people consulting to the mining industry, construction industry and municipalities. IRTEC has extensive experience in coal mining, reclamation and remediation. He initially worked in engineering after graduation but soon returned to underground mining, becoming a Mine Foreman. By 1983, engineering work was beginning to dominate more of his time. After working in both Eastern Kentucky and Western Kentucky, Virginia and Tennessee, Tim and his family settled in Tennessee in 1985. He has worked out of the Caryville-Jacksboro area since that time. He graduated from Harlan High School and attended the University of Kentucky, graduating in the Spring of 1979 with a BS in Mining Engineering.

RECREATING A HEADWATER STREAM SYSTEM ON A HEAD-OF-HOLLOW FILL: A KENTUCKY CASE STUDY

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Abstract

Head-of-hollow fills or valley fills have gained national attention due to increasing environmental concerns, particularly with regards to headwater stream loss. Researchers at the University of Kentucky in conjunction with outside scientists and consultants in the fields of stream restoration, wetland restoration, and mined land reclamation have developed new design methodologies for creating a headwater stream system for a head-of-hollow fill in eastern Kentucky. The design was largely built on the Forestry Reclamation Approach (FRA), which encourages a non-compacted spoil medium to promote tree growth, in an effort to address concerns related to water quantity and quality as well as habitat development. The major components of the design included 1) modifications to the crown geometry, 2) compaction of the crown to control infiltration, 3) utilization of natural channel design techniques, 4) use of the FRA to promote tree growth, 5) creation of ephemeral channels and vernal ponds, and 6) implementation of a novel bioreactor-wetland treatment system to improve water quality. A total of approximately one-mile of streams and nearly an acre of vernal ponds were created in the fall and winter of 2008. Intensive on-going monitoring efforts are focused on assessing long-term hydrologic, water quality, and habitat changes.

Introduction

Research indicates that between 60 to 80% of the cumulative channel length in mountainous areas, such as eastern Kentucky, is comprised of headwater streams (Shreve, 1966). Many researchers view headwater streams as vital components of these ecosystems for they serve as the primary pathways for water, sediment, and organic matter transport to higher-order systems (May and Gresswell, 2003). Gomi et al. (2002) indicated that headwater regions receive and mediate the majority of surface runoff in watershed, thereby serving as regulators of flow intensity (i.e. flooding) for lower gradient regions. Additionally, headwater streams support large populations of macroinvertebrates and exhibit high biodiversity. Headwater stream systems that have been impacted by surface mining, particularly valley fills, are unlikely to perform these vital watershed functions, provided such channels still exist. Recognizing the importance of headwater systems, it is imperative that practical stream restoration techniques be developed for post-mined lands so that lost headwater system values can be regained.

Additional Key Words: Natural channel design, water quality, habitat, Forestry Reclamation Approach (FRA)

Natural channel design (NCD) employs a technique in which the dimension, pattern and profile of reference reaches are utilized to create the new channel. The crux of this design approach rests with the ability of the designer to locate one or more suitable reference streams – ones with similar hydrogeological characteristics (e.g., watershed area, valley type, geology) as the impacted reach. However, mined lands, particularly head-of-hollow fills, present a unique challenge in that the valley configuration has been notably altered to a non-natural state, plus the geologic age of the material in the structure itself is relatively young as the weathering process from the spoil has recently begun. Adding to the challenge of the design is the incorporation of habitat enhancement aspects, particularly with respect to water quality.

Building on prior successful research and demonstration efforts pertaining to hardwood forest reestablishment (Graves et al., 2000), an endeavor was undertaken to develop and implement a novel head-of-hollow fill re-design at the University of Kentucky's Robinson Forest. The objectives of the design were to:

- Recreate headwater stream functions through utilization of natural channel design techniques and implementation of the Forestry Reclamation Approach (FRA).
- Attenuate runoff events to reduce peak discharges and increase base flows.
- Promote surface expression of water and enhance wetland treatment efficiency to improve water quality.

- Improve habitat through the development of vernal ponds and reestablishment of a hardwood forest.
- Establish an outdoor classroom for demonstrating design principles, construction techniques, and measurement of system performance.
- Educate a myriad of stakeholders including consulting and mining engineers, land reclamation design professionals, regulatory community, environmental advocacy groups, and students.

Project Site

The project site is located in the University of Kentucky's Robinson Forest, which is an approximately 6,100 ha experimental forest located in southeastern Kentucky. The forest sits in the rugged eastern section of the Cumberland Plateau. Vegetation is typical of the mixed mesophytic forest region and ranges from xeric oak-pine dominated stands to rich mesic cove hardwoods. During the mid-1990s, a portion of Robinson Forest was mined for coal, resulting in the creation of head-of-hollow fills. In the valley known as Guy Cove, a head-of-hollow fill was constructed over ephemeral, intermittent, and perennial channels. A portion of the ridge-top was harvested but unmined. A spring fed water from this area to the underdrain, which had begun to clog. Water emanating from Guy Cove discharged into Laurel Fork before entering Buckhorn Creek, which is a 303(d) listed stream.

Utilizing the Forestry Reclamation Approach

A key component of this restoration project is the incorporation of the FRA into the restoration design. The FRA is a method designed to promote the reforestation of mined lands and consists of five steps: 1) selecting best available growth medium, 2) minimizing compaction during placement of the rooting medium, 3) selecting appropriate tree species based on approved post-mining land use and site specific characteristics, 4) use of tree compatible ground cover, and 5) use of proper tree planting techniques (Burger et al., 2005). While information regarding the ability of loose-dumped spoil to grow a hardwood forest is available (Torbert and Burger, 1994; Graves et al., 2000), information regarding the hydrologic and water quality response of loose-dumped spoil is lacking. To answer questions pertaining to the hydrologic and water quality response of loose-dumped spoil in the Cumberland Plateau of eastern Kentucky, a research effort was undertaken at the Bent Mountain surface mine near Pikeville, Kentucky. Results from this research endeavor indicate that 1) the hydrographs from loose-dumped spoil are similar to those of a forested watershed, and 2) notable improvements in water quality with regards to electrical conductivity have occurred throughout the study period. Important to note was that 1) the probable hydrologic consequences requirement that the hydrologic response of pre-mining land be similar to reclaimed mined land can be successfully achieved through the use of loose-dumped spoil and 2) that in only a two-year period, electrical conductivity levels were approaching the 500 $\mu S\ cm^{-1}$ threshold identified for healthy Appalachian streams, by Pond (2004) and Green et al. (2000), with projections indicating that this threshold will be met within an additional year

Major Design Components

Movement of water through the unconsolidated fill has resulted in significant water quality problems for the watershed and downstream environment. As such, the design placed a heavy focus on techniques to improve water quality and create habitat. The project consisted of the following major design components:

- Identification of reference reaches of similar valley types, flow regimes, and sediment regimes for each proposed stream type.
- Reconfiguration of the crown to allow for multiple valley slopes (>1% to 8%), which required the movement of approximately 150,000 yd^3 of material.
- Compaction of the subgrade of the crown to control infiltration.
- Use of the FRA outside of the riparian areas to promote tree growth.
- Use of NCD techniques to determine the appropriate dimension, pattern, and profile for the main (intermittent) channel along the crown.
- Development and/or enhancement of a variety of ephemeral channels utilizing different materials such as rocks, logs, and woody debris.
- Creation of vernal ponds for habitat enhancement.
- Implementation of a novel bioreactor-wetland treatment system to improve water quality.

With regards to the main channel, it transitions from a Rosgen stream type C4 to a B4 to a B3 and finally back to a C4 before flowing down the face of the fill. Table 1 contains typical bankfull dimensions for a riffle section. In-stream structures predominately comprised of wood, such as log cross vanes and log steps were used to provide habitat as well as stability until the vegetation is established.

Table 1. Typical Design Riffle Bankfull Dimensions.

Parameter	Value
Width	8 - 9 ft
Area	4.5 - 5 ft^2
Width/Depth Ratio	13 - 18
Maximum Depth	0.7 - 1 ft
Entrenchment Ratio	1.4 - 3.5
Water Surface Slope	0.7 - 8%
Discharge	12.5 $ft^3\ s^{-1}$

Bioreactor-Wetland Treatment System

The exposure and oxidation of iron sulfide materials from coal mining activities has resulted in the formation of acid drainage, which adversely impacts approximately 20,000 km of stream and rivers in the U.S. (Kleinmann, 1989). Pyrite oxidation and subsequence acid drainage formation is a complex process involving hydrolysis, redox, and microbial reactions (Nordstrom, 1982). The general stoichiometry can be described by the reaction:

$$FeS_{2(s)} + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_{3(s)} + 2H_2SO4$$

where iron sulfide, and other mixed-metal sulfides, decompose upon exposure to water and air producing sulfuric acid and insoluble ferric iron hydroxide from hydrolysis (Bigham et al., 1992). This ferric iron precipitate, typically referred to as "yellow boy," and the associated acidity are considered the principle causes for the degradation of water bodies receiving acid drainage and for the endangerment of aquatic habitat that resides within. The extent of sulfuric acid production and the acidity of waters emanating from the oxidation of pyrite are ultimately regulated by the purity and size fraction of the mineral, the degree of disturbance to the geologic environment in which it resides, the degree of oxygen saturation, and the content and chemical nature of other materials within the surrounding environment. Even though negative pH values have been recorded, most acid mine drainage sites exhibit pH ranges from 2 to 4. The reason for this is that the sulfuric acid quickly dissolves minerals in its vicinity, which often times buffers the acidity. Neutral mine drainage is common in areas that contain appreciable amounts of carbonate materials, such as in the case of Guy Cove. The primary difference between the acid and neutral drainages lies in the content of metals, trace elements and sulfate that it exhibits. The mobility of many elements of concern within these environments are generally greater at lower pH levels; thus, concentrations tend to also be elevated in those waters over that observed in neutral pH conditions.

In recent years, several low-cost passive treatment technologies have been developed that utilize natural chemical and biological processes to clean contaminated mine waters without the expense or potential hazards associated with chemical additions. Constructed wetlands, anoxic limestone drains, and successive alkalinity producing systems are examples of such technologies (Barton and Karathanasis, 1999). To address the water quality problem at Guy Cove, a passive treatment system was designed that incorporates the use of bioreactors, similar to the successive alkalinity producing systems, and an artificial wetland (Edwards et al., 2009). Water quality improvements will be the result of several processes including: 1) reduction of drainage flowing through the fill material and 2) reduction of redox conditions in the seepage to promote the precipitation of metal sulfides and hydroxides, complexation of organo-metal compounds, and surface exchange of cations in the wetland substrates. There is a strong level of confidence in the ability of a wetland to treat Fe in these waters, as evident in the current water quality analyses; however, Mn treatment via sulfate reduction in the bioreactors is experimental and several approaches (substrate types, biological inoculation) will be evaluated to enhance its removal.

Newly Constructed Habitat

Construction of the project began in July 2008 and concluded in December 2008, and tree planting occurring in early March 2009. Approximately one-mile of ephemeral and intermittent streams were created along with about one acre of vernal ponds and a wetland (Figures 1-3). Over 30,000 trees were planted on 40 acres to re-establish the hardwood forest.


Figure 1. Intermittent Channel One Month Following Construction.


Figure 2. Ephemeral Channel One Month Following Construction.

Figure 3. Bioreactor-Wetland Treatment System.

Conclusion

At present, intensive monitoring efforts are underway to assess the long-term hydrologic, water quality and habitat changes at the project site. Preliminary data indicated that a 75% reduction in EC from pre-restoration levels has been achieved on the crown of the fill. In the wetland-bioreactor treatment system, Eh levels have been maintained at <-300 mV, pH is neutral, and reductions in Mn, Fe, and SO_4 have been observed.

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Richard C. Warner, Ph.D. is an Extension Professor in the Biosystems and Agricultural Engineering Department at the University of Kentucky. He is co-author of SEDCAD as well as numerous books, chapters and publications. His research focuses on the design and implementation of stormwater, erosion and sediment control systems for mining and construction sites with large scale land disturbance. Additionally, Dr. Warner serves as a consultant/advisor to major mining corporations with mines in South America, Africa, Indonesia, South Pacific and throughout North America.

THE USE OF NATURAL STREAM CHANNEL DESIGN TECHNIQUES IN THE COAL FIELDS OF VIRGINIA

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Abstract

Prompted by changes in U.S. Army Corps of Engineers regulatory policy concerning the restoration of streams impacted by coal surface mining, D.R. Allen & Associates began using natural stream channel design techniques in Virginia's coalfields in 2002. Since that time, over 10,000 linear feet of natural stream channel restorations have been implemented by our clients. Natural stream channel design criteria are based upon measured morphological relations associated with the bankfull stage for a specific stable stream type (Rosgen 1998). Stream restoration sites are not only designed to pass bankfull flows but also the sediment delivered to them from the upstream watershed. Constructing stream restorations based on a range of morphological variables from stable reference streams, and considering both bankfull flow and sediment transport, allows the practitioner to achieve a stable stream condition. Natural stream restorations reduce bank erosion and enhance habitat for aquatic organisms. Stream restorations designed and implemented in the coalfields of Virginia include headwater streams in drainages of 0.5 - 3.0 square miles. Typical restoration sites include: streams impacted by pre-SMCRA surface mining; streams previously mined and restored using traditional engineering methods; and recently removed sediment ponds located downstream of reclaimed surface mined areas. Restoration activities include: construction of a proper dimension, pattern, and profile; active floodplains (bankfull benches); in-stream grade control and habitat structures; and bioengineering. Restoring streams impacted by surface and underground coal mining present unique challenges that must be addressed during the design process. Nevertheless, following the guiding principles of natural stream channel design appears to be a successful restoration technique for Virginia's coalfields.

Introduction

Restoration activities to offset impacts from coal surface mining have been conducted in Virginia's coalfields since the inception of the Surface Mining Control and Reclamation Act (SMCRA). Since then a diverse mix of restoration projects were used to offset stream impacts. Both in-kind and out-of-kind projects were implemented primarily consisting of traditional engineered channels in combination with wetland creation. In 2002, the U.S. Army Corps of Engineers, Norfolk District recognized the need to place a greater emphasis on in-kind mitigation to offset stream impacts. With this new directive came the requirement to use natural stream channel methodologies.

Stream Mitigation

Today, natural stream channel methodologies used in Virginia's coalfields primarily follow Rosgen 1998. This method is based upon measured morphological relations associated with the bankfull stage for a specific stable stream type. Stream restoration sites are designed to accommodate both bankfull flows and the sediment delivered to them from the upstream watershed.

The majority of stream restoration sites conducted by D.R. Allen are located within the footprint of reclaimed surface mined areas. On-site stream restoration focuses on areas located downstream of valley fills. These stream segments are typically impacted by untreated drainage from the mine area as well as the construction of sediment control basins used to treat mine runoff. Off-site stream restoration generally includes streams impacted by pre-SMCRA coal mining, or previously mined areas where earlier methods of stream restoration were employed. These earlier restoration methods typically resulted in oversized rip-rap ditches designed to pass a 100-year, 6-hour duration storm event, a SMCRA requirement (Figure 1).


Figure 1. Typical restoration prior to use of Natural Stream Design.

The Chaney Creek restoration site was also chosen because of previous impacts from mining. In the late 1990's, surface mining in the watershed was initiated and a sediment pond was required to control runoff from upstream in the watershed. The pond was constructed in Chaney Creek. Upon reclamation, the pond was removed and a riprap lined ditch was constructed in order to pass the flows from Chaney Creek. The old pond site was an excellent candidate for restoration.


Figure 2. Chaney Creek before restoration.

The restoration of each stream reach was conducted using natural stream channel design methods. Additionally, a riparian zone with trees, shrubs and herbaceous vegetation was established on both sides of the stream, where practicable. Both are located in similar landscape settings and were designed as Rosgen type B3 stream channels. Cross-vane structures were used to provide grade control and habitat enhancement. Design criteria were based on a least disturbed reference reach.

Figure 3. Chaney Creek after restoration

Monitoring

The U.S. Army Corps of Engineers requires at least five years of monitoring for all mitigation projects associated with coal surface mining. Mitigation typically occurs each of the five years and includes photographic documentation, geomorphic survey, benthic macro-invertebrates, fish and riparian zone success. Because natural stream channel design is relatively new to Virginia's coalfields, most project sites are less than five years old. However, the results of the two examples discussed above are presented in Table 1.

Table 1. Monitoring Results

Laurel Branch						
Year	MBI	Conductivity	RBP Habitat	Fish (#species)	Trees/acre	EKSAP
2006	0.48	729	166	231(3)	-	0.50
2007	0.52	768	166	547(3)	750	0.51
2008	0.58	725	167	95(3)	710	0.54
2009	0.66	452	173	94(3)	1140	0.62
Chaney Creek						
2007	0.54	622	169	156(5)	700	0.52
2008	0.59	500	181	89(6)	-	0.56
2009	0.66	455	183	171(6)	-	0.62

MBI - Macroinvertebrate Index, EKSAP – Eastern Kentucky Stream Assessment Protocol score

Discussion

Monitoring results indicate incremental improvements to the macro-invertebrate assemblages and the overall EKSAP scores since the restorations were completed. EKSAP baseline conditions scored 0.1 at each site prior to restoration activities. Conductivity as used in EKSAP indicates slight improvements in water quality during the monitoring periods. However, this improvement may likely be correlated with improvements in overall watershed condition as upstream reclaimed mined lands mature. Fish populations have fluctuated in both streams likely due to drought conditions during the summer of 2007 through 2008. RBP habitat scores have remained steady indicating structural stability of the stream reaches. Riparian zones have met the minimum regulatory requirements of 400 trees/acre.

Conclusion

Although limited information exists on the success of natural stream channel design methods in the coalfields of southwest Virginia, monitoring results indicate that it may be a viable method to improve instream habitat and stream biota. Continued monitoring of existing and future restoration sites should continue, as well as additional research into the affects of natural channel restoration on stream structure and function and overall improvements to water quality, wildlife, and watersheds.

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Session 3

GEOMORPHIC RECLAMATION IN THE WEST

Session Chairperson:
Mychal Yellowman
Office of Surface Mining
Denver, Colorado

Integrating Natural Processes with Drainage Reclamation Design in Montana
Tom Golnar, Julian Calabrese, Montana Department of Environmental Quality, and Coal Program, Helena, Montana, and Shannon Downey, US Fish & Wildlife Service Helena, MT

The Application of Geomorphic Reclamation Methods in Montana
Marcello Calle and Jonathan Stauffer, Wyoming Department of Environmental Quality, Cheyenne, Wyoming

Geomorphic Reclamation in New Mexico: A Regulator's Perspective
Dave Clark, Mining and Minerals Division (MMD), Energy, Minerals and Natural Resources Department, Santa Fe, New Mexico

Geomorphic Reclamation at BHP Billiton New Mexico Coal - Successes, Challenges and Future
Daphne Place, Collette Brown and Cary Cooper, BHP-Billiton New Mexico Coal, Farmington, New Mexico

INTEGRATING NATURAL FORM AND PROCESS WITH DRAINAGE RECLAMATION IN MONTANA

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and

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Abstract

Reclamation of drainages at Montana coal mines has gone through changes in design and field reclamation approaches since the introduction of Montana's Surface and Underground Mining Reclamation Act (MSUMRA) in 1973. Montana regulations outline reclamation requirements for drainage basins, including valleys, channels, and floodplains. Drainage reclamation is further explained through a set of guidelines outlining practices and approaches for drainage basin and channel reclamation, approximate original contour and postmine topography.

Native creeks, coulees, and draws in the mine areas often form entrenched, erosionally dissected ephemeral drainage networks, with steep upland slopes and tributary basins below sandstone or clinker capped hills and ridges. While losses of premine topographic, geologic, and vegetation character are unavoidable with strip mining, building a postmine landscape with similar drainage basins and channel morphology allows for better approximation of premine hydrologic processes.

As a channel develops, soil particles redistribute in relation to floodplain hydraulic characteristics, creating channel and floodplain features such as alternating point bars which host microenvironments where mesic vegetation will dominate. Stream sections experiencing increased erosion or exposing less fertile subsoil or spoil, create microenvironments where shrubs and warm-season grasses will dominate. Thus, the combination of topographic diversity and geomorphic processes results in vegetative diversity with patterns similar to native landscapes.

Integrating Natural Form and Process with Drainage Reclamation in Montana

Requirements

Reclamation of drainages at Montana coal mines has gone through changes in design and field approaches since the introduction of Montana's Surface and Underground Mining Reclamation Act (MSUMRA) in 1973, and the federal Surface Mine Control and Reclamation Act of 1977 (SMCRA). One of the fundamental requirements of SMCRA is to regrade postmining topography (PMT) to approximate original contour (AOC) which closely resembles the general surface configuration of the land prior to disturbance, and blends into and complements the drainage pattern of the surrounding terrain.

In addition, Montana regulations outline more specific requirements for reclaimed drainage basins, valleys, channels and floodplains including that they would be designed and constructed to:

- approximate original contour,
- an appropriate geomorphic habit or characteristic pattern,
- provide for long-term relative stability of the landscape,
- an overall concave longitudinal channel profile,
- exhibit dimensions and characteristics blending with the undisturbed drainage system above and below,
- safely pass runoff from a 100-year, 6-hour precipitation event, and

- remain in dynamic equilibrium with the drainage basin system without artificial structural controls (unless approved).

Note: see, for example, Administrative Rules of Montana (ARM) 17.24.313(1)(e) and (f), and 634 at http://deq.mt.gov/dir/legal/Chapters/Ch24-toc.asp). We've also developed reclamation guidelines in Drainage Basin and Channel Reclamation, Approximate Original Contour (AOC), and Postmine Topography (PMT) to further explain reclamation goals and requirements, and methods or practices to address them (see http://deq.mt.gov/CoalUranium/guidelines.asp).

Our requirements to approximate premine drainage basin, valley, channel and floodplain morphology (unless otherwise approved) support other fundamental requirements of SMCRA and Montana regulations, including requiring the operator to:

- minimize disturbance to the hydrologic balance on and off the mine plan area,
- prevent material damage to the hydrologic balance outside the permit area, and
- establish a diversity of habitats consistent with the approved postmining land use, and restore, enhance or maintain natural riparian vegetation.

Setting

The large strip mines of southeast Montana are in a semiarid climate, typically with wet green spring months, followed by hot summers and mild autumns with periodic thunderstorms, and dryer winters. Annual precipitation in Colstrip, one of the larger mining areas, averages about 15 inches (1948-2007), ranging from under 6 inches in 1979 to over 23 inches in 2005. Mean annual snowfall total in Colstrip averages about 36 inches, with 12 inches recorded in 1961, and 86 inches in 2003.

Native creeks, coulees and draws in the mine areas often form entrenched, erosionally dissected ephemeral drainage networks, with steep upland slopes and tributary basins below sandstone or clinker capped hills and ridges. Local streams are generally ephemeral above the coal outcrop, with some intermittent or perennial ponded and flowing reaches below, though often only for short distances.

Background and Trends

Early reclamation at the mines was often limited to a patchwork of broad reclaimed upland slopes and divides between pit ramps. Often, old pit ramps were resoiled and revegetated with little additional shaping as broad, homogeneous grassland drainage valley swales. These relatively featureless drainages only poorly approximated the more diverse topographic and ecological character common to the native ponderosa pine-grassland landscapes of Southeast Montana.

More recently, with some pits completed, and with larger contiguous reclamation areas available, there have been more opportunities for reclamation of complete drainage basins. Some of these are rejoined and blended with native tributaries and drainages above and below mining and have more obvious drainage network pattern, long profile, and cross section requirements. Others may have fewer native tie-points or other guides where drainage basin and tributary divides are built entirely within mine spoils, or where there are fewer or less obvious stable, natural premine profile or cross section examples.

Working with larger reclamation areas has also allowed additional flexibility in making adjustments to initial, approximate PMT designs, improving on them to better mimic relevant premine characteristics. Balancing initial PMT planning with adjustments in spoil placement, final grading, and long-term erosional development in reclamation requires consideration of individual channels and tributaries in relation to overall drainage basin geomorphology and hydrologic response, following premine characteristics where appropriate, including:

- drainage basin area, dimensions and shape,
- drainage density, profiles,
- slope profiles, aspect, relief, and
- valley bottom and floodplain morphology, channel shape.

Some of the more effective drainage reclamation efforts in Montana were designed with more focus on ensuring an appropriate morphological network of larger components with tributaries leading from upland swales to valley bottom floodplains designed and constructed to allow for natural development of smaller meandering channel features. Close attention to appropriate characteristics in larger landscape features, such as complex slopes, adequate drainage density and tributary development, concave longitudinal drainage profiles, and appropriate valley bottom cross sections help to prevent long-term drainage profile aggradation or degradation issues.

Native bankfull channel features in most local ephemeral drainages are relatively small, fully or partially vegetated, and often discontinuous in upland reaches. These smaller features are often impractical to construct with the mine equipment, and develop with more natural characteristics in an appropriately designed and constructed floodplain. A network of variable width floodplains similar to premine can more easily be built to meander around valley bottom features, and to connect with upland slopes through variable sideslopes. Short-term, localized erosion and deposition is used as a final reclamation development tool in these drainages, while also contributing to long-term relative stability of the channel network.

Channel and floodplain widths can be estimated from premine features or can be derived indirectly from regional drainage area - channel width relationships. Rosgen's relationship of meander width ratio (meander belt width / bankfull width) provides one example of a method to approximate floodplain width from channel width for different channel gradients and types.

Soils

Mineral soil is a mix of three particles with the following diameters: sand 2mm to .05mm, silt .05mm to .002mm, and clay less than .002mm. The percentage of each particle present designates the soil type. For example, sandy clay could consist of 45% - 65% sand, 0% - 25% silt, and 35% - 55 % clay. If the particles are evenly mixed the resulting soil type is loam. Loam Soil types are the only ones considered suitable for salvage in the Montana program, thus leaving all redistributed soil substrates as some variation of a loam (e.g., sandy loam, clayey loam, loam, etc.). Loam could be considered the most desirable growth medium in a garden or cropping system. However, uniformly distributed loams are not present in a native landscapes, and are not conducive to vegetative diversity in the rangeland setting. Drainage reclamation can be utilized to alleviate some of this uniformity.

When transported by water the soil particles will tend to disperse and sort by size and weight, leaving settling zones that create soil substrates not generally found in reclamation due to the suitability criteria. These soil types fall into the sand, silt and clay categories. The sorted soils create microsites for vegetation. Sandy microsites are well drained, droughty, and well aerated and would support species adapted to such conditions. Conversely, clayey sites are poorly drained, poorly aerated, and may be droughty, as water is held tightly in the soil pores and often not available to plants, creating microsites for drought tolerant species. Silt falls in the middle ground between these two. These zones are opportunities to create vegetative diversity in drainage channel reclamation.

In the same manner, scoured areas exposing subsoil and spoil are useful opportunities, as well. All these sites may be small in scale compared to an entire mine area; however, in the context of the whole landscape and vegetation diversity, these sites are critical.

Mining law does not allow for soil loss and generally discourages erosion at the extent where channel formation would occur. Allowing for channel development in re-soiled areas requires some management of soil transport to minimize soil loss. Soil loss through transport within a site should be expected and is acceptable; however, allowing soil loss through runoff into haul roads, down drainage ditches, into pits, across areas that are not at PMT or out of a mine's boundary are not. Geomorphic design principals reduce flow energy and when applied with appropriate sediment controls will adequately control soil loss. For example a properly designed trap below reclaimed drainages would adequately capture transported soils. Following a large storm event the captured soils could be re-spread in drainage repair, or simply used to reclaim the trap.

Vegetation

The development of this variety of substrates presents a challenge as to how best to establish appropriate and diverse vegetation suited to each site. Targeting a given substrate with a suite of adapted species is neither practical nor effective. Rather than individually planting each site with the appropriate seed mix, ensuring the mix includes a range of species that will utilize specialized microsites is often a more sensible approach that maximizes diversity across the landscape. These sites allow plants to gain the competitive advantage needed for establishment. Such sites are useful for establishing both mesic and xeric species that do not compete well with the cool season grasses that dominate a uniform deep, loamy soil substrate.

Species will self sort from a seed mix via their ability to utilize a site whether it is sandy, silty, clayey, and sunny, wet, or any combination found in the field. Most importantly a diverse mix of microsites must be available. Adjusting seed mixes to accommodate species best suited for the diversity of microsites found in drainages as opposed to an upland setting will promote the use of microsites created during channel formation.

In the case of larger woody species, targeting microsites following channel formation will allow for better survival of the plantings. Planting riparian or mesic shrubs such as rose or snowberry before herbaceous species are seeded provides an opportunity for establishment and vigorous root development with reduced competition. After establishment of shrubs, the herbaceous species may be broadcast seeded among the shrub plantings.

Once the desired species are established, management through grazing, interseeding, mowing, or other husbandry practices can be used to promote expansion of target species or community types. There are many factors involved in the development of plant communities. As practitioners we have the opportunity to attempt establishing a vegetative base point, hopefully setting a trajectory toward our vegetative goal. While we set up what we can with substrates, seed mixes, and woody plantings all in favorable locations, there will always be climatic fluctuations complicating our efforts.

Conclusion

Changes in reclamation approach at Montana coal mines have reflected regulatory changes and application of relevant reclamation science, principals, and practices. While losses of some premine topographic, geologic and vegetation character are unavoidable with strip mining, building a postmine landscape with similar drainage basin and channel form allows for better approximation of premine hydrologic processes, which will improve with long-term vegetative development. Montana will continue monitoring and evaluating reclaimed drainage development to understand appropriate design and field practices, and for eventual bond release decisions. This should also help us improve our design and field practices to better accommodate geomorphic, hydrologic, and related processes in shaping reclaimed landscapes.

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THE APPLICATION OF GEOMORPHIC RECLAMATION METHODS IN WYOMING

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Abstract

Disturbances associated with surface mining drastically alter the form and function of a landscape. The design and construction of a suitable post-mine topography is essential to satisfying reclamation responsibilities including the maintenance of acceptable erosion and sediment control, establishment of appropriate fluvial hydrology and successful revegetation. Landforms develop in what researchers describe as dynamic equilibrium, constantly adjusting to acting forces such as concentrated precipitation runoff. Wyoming coal producing regions demonstrate an arid to semi-arid climate. Near-surface geology is tertiary coal with overlying sedimentary strata. Reclamation design challenges include: Creating new landforms that; 1) are regionally in context yet recognize alterations in pre-existing controls such as geology; 2) are economically realistic; and 3) observe regulatory policy.

Since its initiation, the Wyoming coal regulatory program has required the application of fundamental fluvial and geomorphic principles to reclaim surface coal mines. Historically, an inventory and comparison of pre-mine and post-mine basin morphometry has served as the dominant tool in evaluating proposed reclamation landforms. Published regional studies have also provided significant guidance regarding observed geomorphic and fluvial relationships in Wyoming and their application to reclaimed mine surfaces.

Wyoming continues to encourage progressive reclamation strategies that integrate geomorphology into the design of post-mining landscapes. Developing software has recently provided calculating power to create terrain models that incorporate geomorphic and fluvial design principles. Recently, the Wyoming Abandoned Mine Land Program has been applying this developing technology to abandoned surface coal and uranium mine reclamation projects in Wyoming. Predicted benefits include less follow up maintenance and enhanced topographic variability that effectively controls run off, captures moisture, and promotes vegetation and habitat diversity.

Introduction

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 established a regulatory and compliance structure (SMCRA Title V) to ensure coal mining is conducted in an environmentally and socially responsible manner and that lands affected by coal mining are suitably reclaimed. Additionally, it established a funding mechanism (SMCRA Title IV) to mitigate mining hazards and environmental degradation associated with historic mining that occurred prior to the enactment of SMCRA.

Chapter 25 of Title 30 of the Code of Federal Regulations details regulatory requirements of SMCRA and §1265 specifically addresses reclamation performance standards. These performance standards include:

- returning the disturbed land to “approximate original contour,”
- post-mining landscape compatibility with natural drainage and intended use,
- establishment of diverse and self regenerating plant succession,
- minimizing disturbances and adverse impacts on fish, wildlife, and related environmental values, and achieve enhancement of such resources where practicable,
- control of erosion/sediment and the maintenance of hydrologic balance in quantity & quality, and
- use of best technology currently available (BTCA) including equipment, devices, systems, methods, or techniques which are currently available anywhere, even if they are not in routine use.

The application of geomorphic and fluvial concepts during reclamation design and construction is consistent with the reclamation performance standards presented above.

General Setting

Wyoming coal mines are located in the northeast Powder River and Gillette coal fields (Powder River Basin), the south central Hanna and Rock Springs fields and to a lesser extent the southwest Kemmerer coal field. Early (1890-1950) large scale underground coal mining occurred in the Hanna and Rock Springs coal fields to supply the Union Pacific railroad with a reliable fuel source. Currently, the Powder River Basin (PRB) is the most productive region, supporting approximately 38% of the nation's coal demands. The PRB contains 58% of the nation's federal coal reserves, approximately 550,000 million short tons. With increasing demand for clean burning coal, low sulfur PRB coal is expected to be in demand for the foreseeable future (U.S. Department of Energy, 2007).

Climate

The mean elevation of Wyoming is about 6,700 feet, making the state the second highest in the United States (only Colorado has a higher mean elevation). Wyoming climate is generally semi-arid, receiving between 10-20 inches of precipitation annually, but also demonstrates areas that can be classified as desertic, exhibiting high evapotranspiration rates ranging from 20-25 inches of mean annual evapotranspiration and receiving less than10 inches of precipitation annually. The Gillette climate station can be used as representative for the PRB and demonstrates mean annual precipitation of around 15 inches. Conversely, the Bitter Creek climate station is representative of the Rock Springs area and demonstrates mean annual precipitation of around 5 inches. In the PRB, about 60 to 80 percent of the mean annual precipitation falls during spring and summer months in the form of high intensity thunderstorms, with remaining precipitation (20-40 percent) occurring as snow during fall and winter months (Anderson, 1995). Mean annual temperature for the state ranges from 40-45 degrees F with large seasonal and daily temperature variability.

Drainage and Streamflow Regime

Wyoming is a headwaters state with 72% of the state's area, including the PRB and Hanna coal fields, contributing to the Missouri River Basin and 21%, including the Kemmerer and Rock Springs coal fields, contributing to the Upper Colorado River Basin. The remaining 7% is distributed among the Great Basin and Pacific Northwest River Basins. Wyoming is dominated by ephemeral streams that flow in direct response to rainstorms and snow melt. Perennial streams exist where sufficient contributing area, climatic, orographic and/or geologic conditions support sustained flows throughout the year. A significant portion of annual stream flows is made up of snowmelt runoff occurring during the months of April, May, June, and July. Annual and seasonal variations in precipitation are highly variable and are reflected in streamflow data (WWC Engineering, 2007).

Geology, Soils and Vegetation

Near surface geology can be characterized as Upper Cretaceous and Lower Tertiary sedimentary formations with dominant formations being the Paleocene Fort Union and the more recent Eocene Wasatch and Hanna formations consisting of alternating beds of sandstone, shale, siltstone and coal (Rathburn, 1995). Subterranean burning of coal in some areas has resulted in the baking of overlying shales and clays into "clinker" or "scoria." These clinker beds are resistant to erosion and commonly form highly permeable upland areas that serve as significant sources of groundwater recharge (Bartos, 2002).

Coal regions demonstrate mineral soils such as Entisols and Aridisols that are characterized by minimal horizon development and water deficiencies for long periods (> 6 months annually) of time. These soils demonstrate limited subsurface weathering and downward translocation of clays, developed horizons of lime or gypsum accumulations and/or salty layers (Miller, 1998). Typical soil textural classes are sandy loams and clayey loams.

Native vegetation can be classified into dominant vegetation classes whose species composition reflects moisture availability. Upland sagebrush/grassland communities occur on terraces and gently rolling hillsides. Upland communities include big sagebrush (*Artemisia tridentata*), blue gramma (*Bouteloua gracilis*), needle and thread grass (*Stripa comate*) and prairie june grass (*Kohleria micrantha*). Bottom land communities receive augmented moisture via surface and subsurface hydrologic convergence, and thus demonstrate species with higher water requirements. Ephemeral drainage dominant species include western wheatgrass (*Agropyron smithii*), Kentucky bluegrass (*Poa pratensis*) and silver sagebrush (*Artemisia cana*). Immediately adjacent to stream courses, narrow primarily sub-irrigated mesic communities may demonstrate prairie cordgrass (*Spartina pectinata*), chair maker's rush (*Scirpus americanus*) and common spikerush (*Eleocharis macrostachya*).

Process Geomorphology

Process geomorphology is the study of landforms and the processes that are responsible for their evolution. These processes include driving forces (application of energy) and resisting forces (lithology and structure). A landform is the product of many interrelated processes, or systems, that have existed in periods of balance and disequilibrium (dynamic equilibrium) over time (Hack, 1960; Chorley, 1962).

It is important to note that equilibrium is dependent upon the time frame or scale the phenomenon is considered. Schumm and Lichty (1965) introduced the concept of “steady”, “graded” and “cyclic” time frames. An understanding of geomorphic time is critical when discussing the perception of equilibrium or ‘stability.’ For example, as reclamation specialists we are concerned with graded time (10-100 years) when considering the stability of a landform. Toy (1982) describes geomorphic stability as “a state where driving and resisting forces are in flux within a range and do not exceed thresholds, seeking a new equilibrium state.” Major climatic shifts or other disruptions including anthropogenic activities can push equilibrium systems beyond their threshold. This concept of geomorphic threshold and stability is detailed by Schumm (1973) and Coates and Vitek (1980). The act of reclamation itself has the potential to establish new conditions that may cause an exceedance of the equilibrium threshold.

As reclamation specialists responsible for recreating stable landforms, it is important to understand how geomorphic processes are expressed in a landform. Through an understanding of geomorphic systems, we can better predict the probable or logical landform for the specific environment. Within the scope of this paper, we will focus on exogenic (near surface) processes such as, weathering, mass movement, erosion, and deposition or denudation; the rendering of the earth’s surface to a common elevation.

<u>Climate, lithology and denudation</u>

Climate is one of the most important factors responsible for spatial and temporal variability in landforms (Peltier, 1950). Wilson (1968) developed six possible climate-process systems presented in Figure 1 where mean annual temperature and mean annual precipitation values tend to drive dominant geomorphic processes that function most effectively under those climatic conditions resulting in distinct landscape characteristics. Intimately associated with climate are lithology, soil, and vegetation, which work in concert to create complex systems of driving and resisting forces.

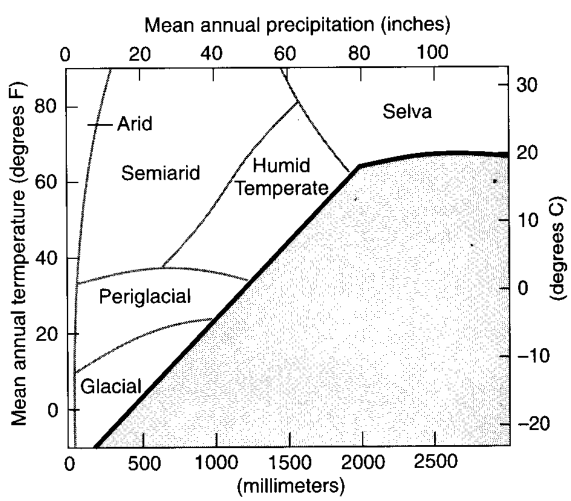

Figure 1. Wilson’s six possible climate-process systems.

An example of a climate-process system that is particularly significant with respect to geomorphic land reclamation in the arid to semi-arid west is one that is clearly demonstrated in the Langbein-Schumm (1958) curves presented in Figure 2. Maximum sediment yield is observed in semiarid environments where there is enough precipitation to promote runoff and sediment transport, yet there is insufficient precipitation to support good vegetative cover that will inhibit erosion.

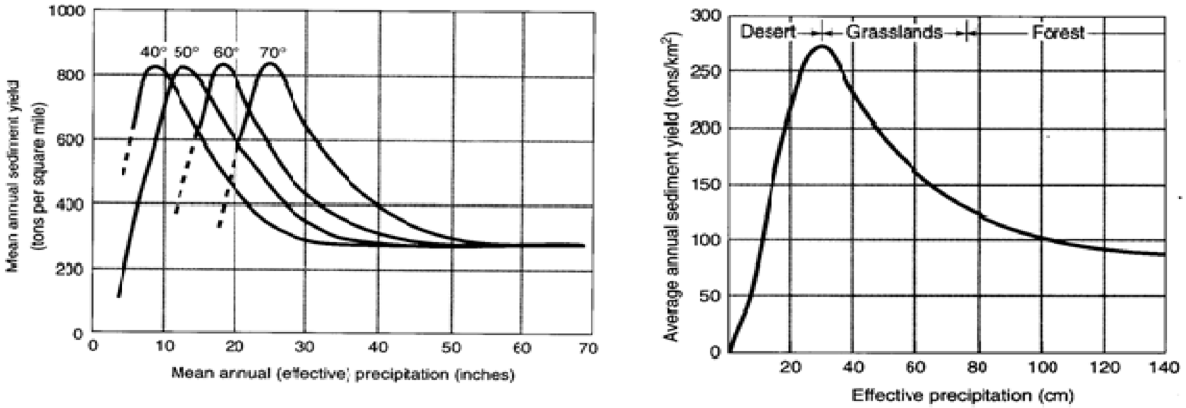

Figure 2. Langbien and Schumm curves, average annual sediment yield as it varies with effective precipitation and temperature.

In arid or desertic environments, the average annual sediment yield is reduced due to a lack of sufficient precipitation to initiate runoff. Additionally, the Langbien-Schumm curves demonstrate how mean annual temperature can also have an effect on this relationship.

Drainage basins consist of hillslopes and channels in an "orderly spatial arrangement" bounded by divides (Toy, 2000). This spatial arrangement will reflect how acting and resisting forces are managed by a landform to achieve an equilibrium state. Drainage density (the ratio of total channel length to drainage area) is a fundamental geomorphic measurement that describes the spatial arrangement of a drainage basin. Research has demonstrated that in the semi-arid west drainage density and basin slope or relief ratio (ratio of basin relief to basin length) are important parameters that reflect how precipitation, runoff, and sediment transport are handled in a drainage basin.

Like the relationship expressed by the Langbien-Schumm curve, drainage density also appears to be strongly correlated to climate. Melton (1957) demonstrated that in the semi-arid west, drainage density is inversely related to effective precipitation. This is because as discussed previously the semi-arid environment is limited in its ability to support good vegetative cover capable providing surface roughness and resistance to the erosive forces associated with surface runoff. Therefore a basin demonstrating a higher drainage density is required to manage concentrated overland flow and the associated suspended sediment. Similarly, drainage density has also been shown to have an inverse relationship with infiltration rates. Hadley and Schumm (1961) demonstrated this in Wyoming by utilizing drainage basin data from five distinct areas with differing near-surface geology. For example, the Wasatch formation demonstrated a significantly higher infiltration rate than the White River Group formation and, subsequently, drainage basins formed in the Wasatch formation lithology demonstrated a lower drainage density. The relief ratio of a drainage basin is an index of the potential energy that is available for erosion. Relief ratio has been shown both in field and experimental studies to have a positive correlation with drainage density (Gregory, 1985). Hadley and Schumm (1961) demonstrated that in the Cheyenne River Basin, where climate and lithology is generally unvarying, relief ratio is positively correlated to annual sediment yield. Zimpfer's (1982) rainfall-erosion experiments, where climate and lithology were held constant, also support this relationship.

Geomorphic Reclamation Approaches

The application of geomorphology in reclamation design has been approached in two dominant forms: (1) detailed measurement and inventory of pre-mine landscape is used to 'recreate' the post-mine landform as closely as possible; and (2) regional landform relationships are used to design a post-mining landform that may not be exact in form to the pre-mine landform but is regionally representative and functional. The two forms are not mutually exclusive and can be integrated during reclamation design. In some cases, circumstance may preclude the application of one form over another. For example, if the proposed reclamation design will dramatically alter pre-mine landform parameters like drainage area and relief, then a 'carbon copy' recreation may not be appropriate and regional geomorphic relationships would be investigated. There are also instances where the pre-mine landform may include geologic control that cannot be recreated or the pre-mine landform is not desirable as a post-mine landform, such as with erosional 'badlands.'

Watershed Measurement and Reconstruction

Since its initiation, Wyoming mine reclamation administered by the Wyoming Department of Environmental Quality (DEQ) Land Quality Division (LQD) and Abandoned Mine Land (AML) programs, has required that reclamation design engineers develop a pre-mining geomorphic baseline investigation consisting of geomorphic data intended to provide a representation of the landform that developed under the climatic and geologic regimes present in the area. The requirement to construct a post-mining topography that strongly resembles pre-mine condition was well-supported by the scientific literature of the time. In order to develop the geomorphic baseline, reclamation design engineers have consistently been required to provide the following measurements during the reclamation design process.

Linear Measurements

Average and total stream length (mainstem, tributary, and basin-wide), stream valley length (mainstem and tributary), basin length, number of streams in each order, total stream number in each basin, and bifurcation ratio (Horton, 1945) have all been provided historically and are currently required by DEQ. In order to provide consistency, regardless of scale, DEQ established the 50-acre parcel as the smallest contributing area for stream measurement and stream order determination. Stream length measurement, stream order determinations, and channel design requirements are generally initiated at this scale and drainage areas under 50-acres are considered overland flow situations, not requiring hydraulic design. This determination was made based on anecdotal observations in the field, and the professional judgment of DEQ staff. Linear measurements are used in conjunction with other measurements to develop a variety of analytical relationships such as basin relief ratio, drainage density, and ranges of stream channel sinuosity present in the pre-mining environment. Because the reclaimed drainage basins are often configured quite differently than the pre-mining configuration, these relationships, as well as the absolute measurements, are used to ensure that the overall post-mining landform provides similar geomorphic functionality. As an example, DEQ commonly compares total stream length within sub-basins and the number of streams in each order (in basins of similar area) to ensure that individual post-mining sub-basins are providing similar basin texture to the pre-mining landform.

Areal Measurements and Characterization

Areal measurements and relationships such as drainage area and drainage basin delineation of the basins and sub-basins, drainage area by stream order, drainage density, drainage basin shape, drainage pattern, and constant of channel maintenance (Schumm, 1956) have been historically provided, and are often currently required by DEQ. Due most significantly to the geology and landscape orientation of coal seams, surface coal mining methods are generally disruptive of complete drainage basins. This fact has made the areal measurements and relationships, particularly drainage density, some of the more significant measurements considered when determining the appropriateness of a proposed post-mining topography. Drainage basin shape is also often significantly altered after mining has occurred with operators proposing long, narrow drainage basins in the post-mining topography where relatively circular basin shapes were noted in the pre-mining landform. These long, narrow basins are often proposed based on the development of linear, relatively narrow mining cuts and adjacent spoil ridges. In addition to basin shape, proposed drainage patterns are often distinctly modified from the pre-mining patterns. For example, operators often propose trellised patterns to replace dendritic patterns. In reviewing the appropriateness of these modifications to basin shape and pattern, DEQ uses the information provided for the pre-mining landform to ensure that basin number and size, drainage area by stream order, and drainage density are meeting the geomorphic functionality exhibited by the pre-mining landform. The constant of channel maintenance, a relationship that is the inverse of drainage density and describes the drainage area necessary to maintain a linear length of stream channel, has been provided and evaluated on some permits within the coal program. This relationship provides relatively fine-scale, comparative insight into the inclusion of the appropriate length of stream per unit drainage area and implications on the initiation of erosional processes for basins within the post-mining topographic design. For example, if the constant was determined to trend around 300 square feet per foot of stream in the pre-mining landform, and the constant of channel maintenance calculated from the proposed post-mining topography is 500 square feet per foot of stream, DEQ would note that the erosion was likely to occur if all other factors remain equal.

Relief Measurement and Relationships

The primary tool used in characterizing relief relationships is hypsometric analysis (Strahler, 1957). This tool provides significant information for quickly understanding the relative maturity of the landform. By comparing the ratio of the relative height of each contour interval to the maximum height of the basin to the ratio of the area contained between each contour interval to the total area of the basin, hypsometric analysis presents the relative distribution of mass within the basin.

Simply put, the analysis indicates whether more of the mass is located in the upper or lower portion of the watershed. DEQ has generally required proposed post-mining hypsometry that demonstrates the operator will be constructing a landform that is more mature than the pre-mining basins. This decision was made due to the fact that the mature evolutionary stage was considered more likely to be stable in the reclaimed mine environment because of the loss of geologic control, soil structure, and vegetative stabilization. While the primary tool used for relief comparisons is hypsometric analysis, measurements of absolute basin relief and the development of basin relief ratios (for sub-basins and larger drainage basins) are also often required. To encourage a more stable landform, DEQ generally requires a proposed post-mining topography that includes lower values of absolute basin relief and lower basin relief ratios. These guidelines, along with hypsometric analysis detailing more mature basins, provide for a post-mining landform that is more subdued than the pre-mining landform.

Hillslope Measurements and Form

Hillslope length, profile, slope, and aspect distribution are generally required to characterize the pre-mining landform. Aspect distribution is generally the only pre-mining hillslope parameter that provides a direct target for the development of the proposed post-mining topography. This pre-mining parameter is maintained to ensure a post-mining landform that provides appropriate landform diversity and texture, and positively influences the reclaimed vegetative diversity, wildlife habitat diversity, and water storage and delivery. Significant research has identified relationships between hillslope form and soil loss (Wischmeier, 1978; Renard, 1997). DEQ requires, or strongly encourages, a proposed post-mining topography that includes hillslope lengths that are shorter than pre-mining, profile shapes that include a shift toward a concave or complex slope shape (fewer uniform or convex shaped hillslopes), and slope distribution analysis supporting a shift towards reduced slope ranges.

Channel Measurement and Characterization

In order to characterize channel form that has developed in the pre-mining landform, DEQ requires the measurement of a variety of linear, areal, and cross-sectional channel morphometry parameters. These include measurements of longitudinal profile shape and slope, channel pattern, channel feature measurement and spacing, and hydraulic geometry. The pre-mining longitudinal profile slope and shape are used to provide a comparison demonstrating that the post-mining landform incorporates longitudinal profiles indicative of a more mature landform, i.e. concave longitudinal profile shape and lower longitudinal profile slope. Channel pattern measurements, including wavelength, belt width, amplitude, and radius of curvature are used more directly during design of the post-mining fluvial pattern. This reference reach concept is applied most commonly to the mainstem intermittent and perennial reaches, with less emphasis on replication of the longitudinal profile measurements, because these reaches are reclaimed within the regional valley system, and grade-match to these regional systems is required by DEQ. For both upland, ephemeral channels, and mainstem fluvial features, DEQ requires the collection of hydraulic geometry data including, cross-sectional area, bankfull discharge depth, bankfull and floodplain width, hydraulic radius, and wetted perimeter. The data may then be used to compare the proposed post-mining hydraulic design to the pre-mining data to ensure that the proposed channels and floodplains are sized appropriately. Due to equipment limitations, ephemeral channels are often designed as non-erosive, vegetated channels that will pass a 100-year event. This generally leads to the design and construction of the floodplain with an active channel proposed within the floodplain. The active channel is generally designed and constructed to pass the 2-year event, but operators also often propose no active channel within the floodplain with the expectation that the active channel will gradually form in a dynamically stable manner within the constructed floodplain.

Empirical Geomorphic and Fluvial Relationships

The use of regression analysis to characterize empirical geomorphic and fluvial relationships is common in geomorphic research. Early researchers attempted to realize predictive or causal relationships between geomorphic variables. As the reclamation science evolved in Wyoming, significant research was performed in coal mining regions in an effort to establish regional geomorphic and fluvial relationships that could be used to design and evaluate post-mining reclamation topography and hydrology. The following examples are not exhaustive and only representative of some of the geomorphic research performed in Wyoming.

Basin relationships

One of the well noted comprehensive studies of characteristics of natural drainages in Wyoming was performed by Lowham (1993). In this study, Lowham expanded upon data collected by Martin (1988) and Craig and Rankl (1978), collecting 27 drainage basin measurements for 124 drainage basins located throughout Wyoming. Using these, data correlation analysis was performed to determine which measurements were significantly related and could potentially be used to guide reclamation drainage basin design. Figure 3 and Figure 4 present two graphs developed from these data that are used to: 1) determine the recommended basin order based upon a delineated drainage area (In the graph, a drainage area of 1.9 square miles is determined to require a 2.8 or 3 basin order); and 2) determine the corresponding number of streams per basin order, respectively.

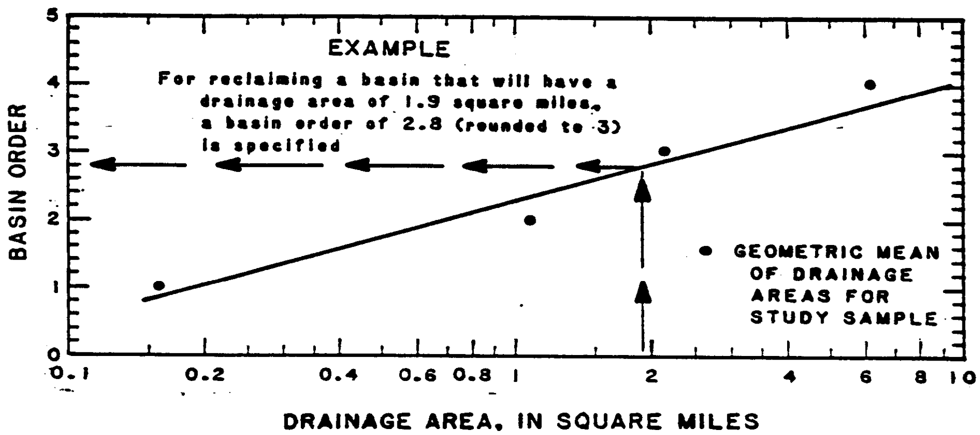

Figure 3. Graph developed by Lowham (1993) to determine basin order as function of drainage area.

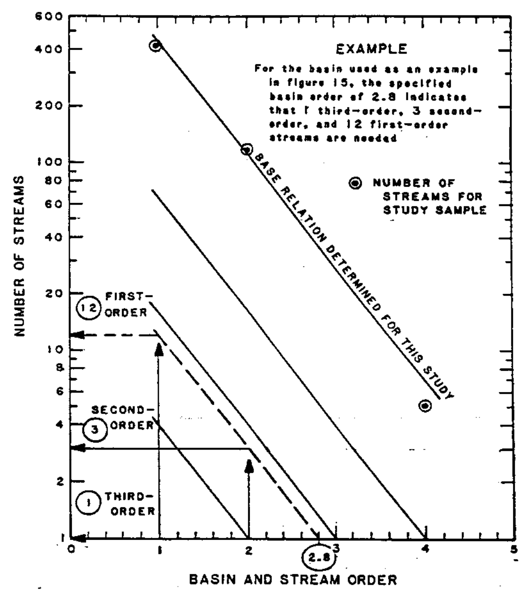

Figure 4. Graph developed by Lowham (1993) to determine number of streams per basin order.

Once again, a basin order of 2.8 is used for example in Figure 4 and thus would require 12 first order streams and 3 second order streams. Lowham also developed regression equations (1-5) as presented in Figure 5 to be used when designing a reclaimed drainage basin in Wyoming. Equations 1 and 2 predict basin length (BL) and basin relief (R) as a function of contributing area (A), equation 3 predicts basin relief from basin length, and equations 4 and 5 predict channel length (CHAN-L) and channel slope (CHAN-S) from the corresponding basin length and used relief (UR). Used relief is a parameter unique to Lowham's research and is defined as the difference in elevation between two points on the channel in question.

$$BL = 1.81\ A^{0.49} \quad (1)$$

$$R = 224\ A^{0.27} \quad (2)$$

$$R = 162\ BL^{0.54} \quad (3)$$

$$CHAN\text{-}L = 0.92\ BL^{1.15} \quad (4)$$

$$CHAN\text{-}S = 0.00033\ BL^{-0.94}\ UR^{0.92} \quad (5)$$

Figure 5. Regression equations developed by Lowham (1993) for multiple basin parameters.

Lidstone & Associates (2008) performed a comprehensive geomorphic and hydraulic analysis in the Gas Hills Uranium Mining District (Gas Hills) in Fremont County, Wyoming. The effort expanded on previous geomorphic studies for the Gas Hills (Lidstone and Anderson, 1988) and developed geomorphic reclamation design criteria through the application of step wise regressions. The results were included in the Report of Investigation for the proposed Day Loma Area AML reclamation project.

Twenty eight undisturbed basins ranging from 7 to 236 acres in the vicinity of Day Loma were measured for morphometric variables as discussed earlier. During regressions, drainage area was used as the dependent variable and all remaining variables were investigated to determine their relationship to drainage area. Drainage density, length, and number of first order and second order streams variables were most correlated to area (R^2 >90%). All developed models were plotted versus observed values and demonstrated good predictive results. Drainage density, number of first order streams, and length of first order stream were more highly correlated with south to southwest facing streams where channel development is more important in managing the stable delivery of water due to less vegetation and associated surface stabilizing properties. Results from this analysis were used to develop the design template presented in Figure 6 for small basins (30-150 acres). Drainage area (A) is used to first calculate the total length of first order streams (L_1). L_1 is then used to calculate the drainage density (D) for the contributing area. Drainage density and area are then used to calculate total number (N) of first and second steam orders. Area and stream order number are used to calculate recommended stream frequency (F) for first and second order streams.

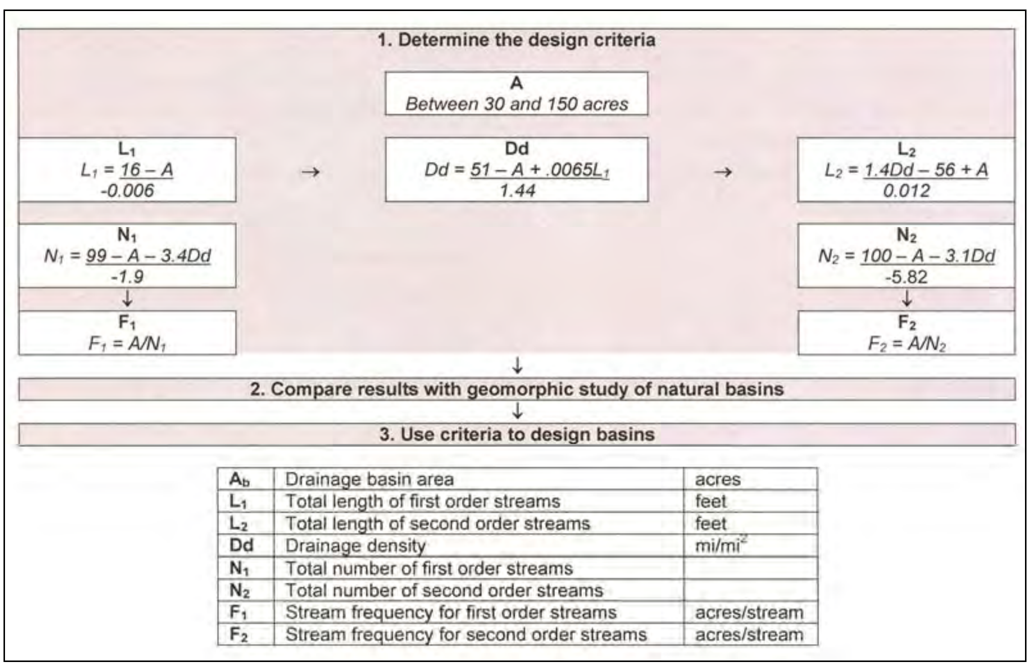

Figure 6. Recommended design criteria for small basins in the Day Loma area (Lidstone, 2008).

Channel relationships

Early studies in channel morphology determined that mean values of channel width, depth and area could be expressed as function of discharge (Leopold, 1953). Using 12 Wyoming streamflow gaging stations, Lowham (1988) developed the equations (7-10) presented in Figure 7 that: (1) predicted bankfull discharge (P_2) as a function of drainage area (A), average annual precipitation (PR) and a dimensionless geographic factor (G_f) for the plains and high desert regions of Wyoming; and (2) used bankfull discharge to determine bankfull channel width (W) and cross sectional area (A_C). The relationships assume that the formative discharge or bankfull discharge is determined by the 1 to 2 year recurrence interval (Wolman, 1957; Lowham, 1982).

$P_2 = 41.3\ A^{0.60\ A\wedge -0.05}\ G_f$	*Plains*	(7)
$P_2 = 6.66\ A^{0.59\ A\wedge -0.03}\ PR^{0.60}\ G_f$	*High Desert*	(8)
$W = 0.98\ P_2^{\ 0.54}$		(9)
$A_C = 0.173\ P_2^{\ 1.02}$		(10)

Figure 7. Lowham's equations for estimating channel hydraulic characteristics in Wyoming plains and high desert.

Natural Channel characteristics were also later studied in the Hanna and Rock Springs mining areas (Rathburn, 1993). This study included cross section surveys of 27 channels in small (< 10 acres) unmined drainage basins. A strong correlation between stream power quantified as the Area Gradient Index (AGI), where AGI is the product of drainage area and basin slope, and channel characteristics flow depth, flow area, hydraulic depth and hydraulic radius were observed. AGI was chosen as the independent variable due to the fact that drainage basin area and mean basin slope are seen as more inflexible design parameters.

Using channel form characteristics of ephemeral and intermittent streams in northeastern Wyoming Rechard (1980) and Divis and Tarquin (1981) developed the regression equations (11-13) presented in Figure 8 that predicted fundamental channel form parameters radius of curvature (R_C), meander length (L_M) and linear wavelength (λ) as a function of drainage area (A), relief (H) and channel slope (S_C).

$R_C = 65.5\ A^{0.35}$	*Rechard, 1980*	(11)
$L_M = 317\ A^{0.28}$		(12)
$\lambda = 30.6\ A^{0.52}\ H^{0.09}\ S_C^{\ 0.41}$	*Divis and Tarquin, 1981*	(13)

Figure 8. Regression equations used to predict fundamental channel form characteristics for ephemeral streams in northeastern Wyoming.

Wyoming Geomorphic Reclamation Examples

Rosebud Coal Sales Company (Rosebud)

The Rosebud Mine is located in the Hanna Basin coal field in south-central Wyoming. The Hanna Basin is a relatively high elevation (7000' above MSL) coal field, and provides numerous reclamation challenges due to cold winter temperatures, high winds, short growing season, poor soil development and faulted geology. Mining of the Rosebud permit area began prior to the implementation of federal or state regulatory programs, and continued through the implementation of each stage of regulatory authority with mining ceasing in the early 1990's. Rosebud provides an interesting example of changes in reclamation practice through time in Wyoming. Early reclamation (pre-law) is noticeable as specific pits exhibit the grading of pit highwalls into uniform hillslopes with 3:1 sideslopes. The pit reclamation created a uniform, often rectangular drainage basin with almost no texture designed into the landscape. These reclaimed pits replaced a dissected native landform characterized by a steep, incised, gully system. In later pit reclamation, the use of contour ditches on uniformly graded slopes shortened runoff travel distance and resulted in higher erosional stability. The contour ditches acted as tributaries to interceptor ditches. The interceptor ditches were not typical downdrains, but vegetated swales that increased the drainage density of the reclaimed areas when compared to earlier reclamation methods. As reclamation sophistication progressed, the pit reclamation at Rosebud showed evidence of the use of geomorphic principals. More hillslopes were graded with concave profiles, drainage density and hillslope dissection were increased, interceptor ditches, while still designed using non-erosive, engineering principals, became more sinuous, and looked more like a natural, ephemeral grass swales. As one would expect, the reclamation landforms created with uniform hillslopes and minimal drainage density have presented erosional stability problems throughout the permit term, and many continue to require regular maintenance to address the tendency towards an increase in drainage density. Pits where reclamation methods included a more subdued landform, mature hillslope profiles (concave), and higher drainage densities are generally characterized by a relatively stable landform with lower erosion rates, higher vegetative success and diversity, and, in some cases, difficulty in visually distinguishing reclaimed areas from native areas.

Dave Johnston Mine (DJM) – Ephemeral Channels

DJM is located in plains of central Wyoming, in the southern Powder River Basin at a relatively moderate elevation (4500' above MSL). When compared to the Hanna Basin, DJM has higher precipitation, somewhat warmer winter temperatures, a longer growing season, and more uniform lithology. DJM provides a good example of the use of a more sophisticated geomorphic approach to landform design. Mining at DJM ceased in 2000, and much of the reclamation design and construction was conducted between 2001 and 2005. DJM is located in the headwaters of the Cheyenne River Basin, and all pre-mining channels (and constructed post-mining channels) are ephemeral in nature. The post-mining landform designed for DJM included drainage density similar, or slightly higher, than was measured in the pre-mining landform, and stream sinuosity values similar to those measured in the baseline study. The design also included hillslopes and longitudinal stream profiles graded with a complex or concave shape and lower slope values than were measured in the baseline study. Most of the ephemeral channel designs for DJM consisted of wide channels designed to pass the 100-year event in a non-erosive manner. Effectively, the 100-year floodplain was graded with the expectation that the bankfull, or low-flow, channel would gradually develop in a dynamically stable manner. Due to the lower hillslope values, higher drainage density, appropriate sinuosity, concave longitudinal profiles, and lower slope values of the stream profiles, this expectation has generally been borne out. Most of the reconstructed ephemeral channels at DJM exhibit very little channel erosion. Channel erosion is most pronounced, but still reasonable, on lower, second-order reaches with relatively low slope values. These lower channels collect runoff from multiple tributaries so it is not unexpected that a low-flow channel is developing within the larger floodplain graded during reclamation. This minor channel erosion has not created undue regulatory concern from DEQ because it appears to be driven by the increased flow in the lower reaches, and not by inherent geomorphic instability as the minor erosion is not rejuvenating into the adjacent, steeper tributaries.

Cordero-Rojo Mine (CRM) – Mainstem Intermittent Channel, Belle Fourche River

CRM is located in the plains of northeastern Wyoming, in the Powder River Basin at a relatively moderate elevation (4500' above MSL). In general, the setting is similar to that described for the Dave Johnston Mine. In 1996, CRM diverted 22,700 feet of a large, intermittent stream, the Belle Fourche River, in order to access underlying coal reserves, and committed to fluvial reconstruction of the river as mining was completed. The Belle Fourche River is a significant plains river draining much of the northeastern portion of Wyoming before flowing into South Dakota. The section of river flowing through the CRM permit area is dominated by long shallow runs, terminating in wide pools with downstream control provided by bedrock outcrops. The river exhibits relatively low sinuosity, especially considering slope values range from 0.1%-0.2%. These slope values are characteristic of many of the regional valley mainstem channels in the Powder River Basin. In order to replicate the hydrologic function of the river, CRM undertook a relatively extensive measurement and modeling protocol prior to disturbance of the river corridor. CRM measured cross-sectional area, width, depth, and length of all runs and pools, spacing of pools, slopes of runs and pools, slopes across bedrock outcrop steps, and width of the 100-year floodplain. CRM also conducted a study to characterize floodplain alluvial sediment deposits and water storage in the alluvium, and developed a HEC-2 model to characterize the hydraulic properties of the native channel. Between 2000 and 2004, CRM reconstructed 8250 feet of the mined through Belle Fourche River. Based on the pre-mining studies, modeling, and measurements, CRM constructed a 50’ wide, 2’-3.5’ deep, low-flow channel designed to pass the 2-year event, and a two-stage floodplain designed for the 10-year and 100-year events. The reconstruction included the establishment of runs similar in length to the pre-mining measurements. Nine pools were constructed within the range of dimensions collected during pre-mining assessment, and nine vortex rock weirs were installed to simulate the pre-mining bedrock control and provide downstream grade control for the reconstructed pool features. As is common practice in Wyoming at this time, the fluvial reconstruction design of this section of the Belle Fourche River incorporated the collection of geomorphic analog and hydraulic geometry data to guide the development of the design while incorporating standard engineering practice to ensure erosional stability of the channel. To date, this blend of geomorphic and engineering practices is generally considered to be successful, yields stable channels, and meets regulatory requirements.

Natural Regrade Software

Recently, Wyoming AML has used Carlson’s Natural Regrade (NR) software to design reclamation topographies on two projects. NR is a landform design module that uses Autodesk drafting software to generate digital terrain models that integrate basic geomorphic design elements to create a landform that is ‘stable’ relative to the regional environment and consequently more ‘natural’ in appearance. Use of the software requires significant expertise in AutoCAD drafting ability as well as a good understanding of hydrology, hydraulics and geomorphology. The fundamental idea behind NR is creating a landform that reflects the acting and resisting forces that are dominant in the regional context. In this way a landform is created that would evolve over time naturally. By creating a mature landform form, the period of mass denudation and sediment transport is reduced and a landform in quasi-equilibrium is created.

The drainage basin network is controlled by assigning the appropriate tolerance range for the drainage density of the area. These values are derived by morphometric analysis of the region, using representative values for the area, with the understanding that unconsolidated fill material will develop a drainage density distinctly different than a surface exhibiting consolidated geologic control. The program uses the 2-year, 1-hour precipitation recurrence event to design channel dimensions of the bankfull channel and the 50-year, 6-hour event to calculate the flood prone dimensions. Channel stability can be evaluated using the calculated channel shear stress relative to Shield’s critical shear stress values for uniform non-cohesive sediments. A maximum permissible channel velocity can also be assigned if desired. The program maintains a concave upward longitudinal profile for all channels. Slopes are steeper (>4%) in headwaters where there is less contributing area and associated runoff, tapering to less than 4% in valley bottoms. Channel cross sections and planar form are constructed using associated channel parameters as defined in Rosgens’s classification of natural rivers (e.g., entrenchment ratio, width to depth ratio and sinuosity) (Rosgen, 1994). Upstream and downstream elevation and slope match points are maintained supporting a stable transition, avoiding elevation discontinuities that may initiate erosion through the formation of head cutting.

Figure 9. AML Project 16N site overview and the Central Spoils pile demonstrating rilling of uniform slopes.

By dissecting the drainage basin into subdrainages runoff and erosion is more effectively managed, by limiting distances of overland flow and distributing runoff. This dissection also increases the topographic variability providing a distribution of varying aspects and microclimate conditions that enhances moisture retention and subsequently assists in vegetation establishment and variability. The slope and aspect of a vegetated surface strongly affects the amount of solar radiation intercepted by that surface. Solar radiation is the dominant component of the surface energy balance and influences ecologically critical factors of microclimate, including near-surface temperatures, evaporative demand, and soil moisture content. Spatial variation in slope and aspect is therefore a key determinant of vegetation pattern, species distribution and ecosystem processes (Bennie, 2008). Additionally, the dissected terrain provides beneficial topographic diversity in the form of security cover and calving habitat for large ungulates such as elk, deer and antelope (Triton Environmental Consultants, 2005).

Project 16N was the first AML project to utilize NR. The project site is located in an intensely disturbed area of the West Gas Hills Uranium Mining District in Fremont County, Wyoming. The overall design calls for the placement of approximately 7 million cubic yards of backfill materials in the D9 and K Pits, imported from adjacent mine spoils including the Central Spoils, and from local highwall excavation. Figure 9 shows the location of the Central Spoils excavation area, as well as the D9 and K Pits fill area. The entire project is located on public lands administered by the Bureau of Land Management. The purpose of AML Project 16N is to mitigate hazardous conditions and risk to the public associated with open pit highwalls and toxic, acid forming, and radioactive mine waste materials. Prior to reclamation, the Central Spoils waste pile consisted of a long, continuous 3:1 pre-law reclamation slope with failed vegetation and erosional problems. Engineering design and construction management were provided by BRS Engineering of Riverton, Wyoming. The NR reclamation design presented in Figure 10 for the Central Spoils area consisted of the removal of material from the spoils area to construct stable drainage, open up the view shed to include a natural tree covered ridge previously blocked by spoils, and provide aspect diversity to the slopes rather than the long, continuous 3:1 slopes that were present.

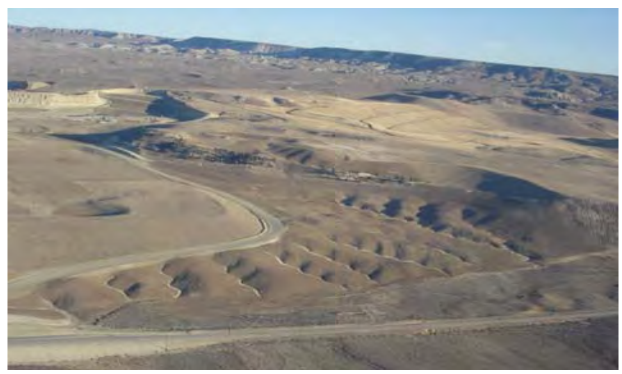

Figure 10. AML Project 16N Natural Regrade design and completed topography

Summary

Wyoming DEQ continues to encourage the integration of geomorphic principles in the preparation of post-mining topographic designs for surface coal mine and AML reclamation projects. The use of these principles has been demonstrated through time to provide reclaimed landforms that conform to the climatic and geologic conditions present in the mining regions, meet federal and state regulatory requirements, meet public expectations with regard to aesthetics, and meet the goals for the approved post-mining land use. DEQ strives to develop an atmosphere that encourages the application of emerging geomorphic reclamation methods so that regulators and operators alike come to a more complete understanding of the limits and possibilities presented by the complex science of mine reclamation.

As a basis for continuing the discussion among scientists, researchers, regulators, and operators on the further incorporation of geomorphic principles and emerging technologies into the reclamation design process we offer the following questions:

- Based on our current understanding of the reclamation design process and the broad knowledge developed during the last 30 years of mine reclamation implementation, should the use of pre-mine analogs still be considered the most appropriate comparative tool, or target, for the development of the post-mining topography? Or, should stronger consideration be placed upon fluvial and watershed process-based methodologies? Simply put, should we reconstruct the pre-mine landform, or develop a new landform based on changes in the system?
- Are regulatory expectations that “any erosion is too much erosion” unrealistic, especially in the arid and semi-arid western region?
- If the erosion issue is reconsidered, and erosion flexibility policies are considered, will permitting and inspection personnel be retrained, and will guidelines be developed to assist in the understanding of “how much erosion is too much erosion”?

- As new guidance, methodologies, and technologies emerge, how will they be reviewed for technical adequacy, and incorporated into the current regulatory framework? Should operators be included in the development of these emerging techniques to ensure their feasibility?
- How will operators be provided assurance that flexibility in the allowance of progressive geomorphic designs and inspection criteria will be consistently applied? How can regulators be assured that the pursuit of these emerging reclamation approaches will not penalize the operators?
- Will these types of changes, if determined to be desirable, require extensive rule changes, or are can they be fit into the existing regulatory framework?

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Geomorphic Reclamation in New Mexico: a Regulator's Perspective

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Abstract

Each of New Mexico's active coal mines has reclamation challenges that are being successfully resolved through the application of geomorphic grading methods. At the San Juan Mine, the soils and overburden material are of poor quality, and it is not uncommon for the mine to receive less than 6 inches of precipitation per year. Without irrigation, the San Juan Mine can expect successful revegetation establishment in only 1 of 5 years. Revegetation on uniformly flat or gently sloping regraded areas sometimes failed to persist after it had been established with irrigation. MMD had therefore been encouraging topographic diversity on reclamation to improve water harvesting and reduce the percentage of south aspect slopes. At La Plata Mine, steeply dipping, multiple coal seams were mined by open pit methods. It was recognized that the structurally-controlled trellis drainage pattern that existed premine would have to be replaced with a dendritic drainage pattern on reclamation where the overburden had been pulverized. At the McKinley Mine, sodic spoil material is prone to differential settling and the creation of piping features in areas where runoff ponds, which may lead to downslope instability. In each of these scenarios, the approximation of natural drainage patterns on the reclamation has reduced erosion and sedimentation by creating shorter slopes with correct profiles, and by improving conditions for revegetation establishment.

Introduction

The Mining and Minerals Division (MMD) is the coal regulatory authority in New Mexico. MMD also regulates hard rock mining, reclaims and safeguards abandoned mines, and maintains a database and registry of all mining activity within the state. MMD has been promoting the creation of topographic diversity on reclaimed lands for many years, in response to a number of different problems and limitations on our mines. Most New Mexico reclamation is conducted in arid or semi-arid climates. Revegetation typically takes at least three years to become fully established, and once established the density of plants is often low. We are seldom able to rely on dense vegetation cover to shield soils, or high root mass to bind soils. These same limitations exist in our undisturbed desert plant communities.

In New Mexico, erosion control on reclaimed lands must be achieved by careful: (1) management and use of materials excavated during the course of mining, and (2) consideration of geomorphic principles to build stable post mine landscapes. Most native slopes in our region are armored by rock, in consequence of the erosion of soil particles by rain impact and runoff, or deflation of the soil by wind action. Valley soils, while they may be relatively deep, often are high in clay and salt content. The best root zone material is often found near the toes of slopes, on the downwind side of ridges and mesas, and similar "jackpot" scenarios. In our experience, relatively high coarse fragment content in salvaged materials is a plus, so long as there are enough soil fines to hold moisture and support plant growth.

The bottom-line geomorphic principle is that watersheds on disturbed lands need to be constructed to simulate the relatively stable, equilibrium topography that the erosive forces of nature would eventually form over a very long time. Any other strategy amounts to the old- fashioned engineering maxim, "strive to conquer nature." MMD believes that emulating nature is a much better policy, and is arguably required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

Problems with the traditional contour terrace and down drain method of slope construction include:

- continuing maintenance of terrace gradients and berms in consequence of differential settling, localized soil movement, extreme precipitation events, or burrowing activity;
- designs based solely on large storm events are subject to sediment deposition from smaller, more frequent events, resulting in flow blockage, diversion, and washouts;
- vegetation diversity is discouraged by uniformly graded, single aspect slopes, due to unvarying moisture harvest, wind exposure, and a lack of transition zones; and
- vegetation is particularly difficult to establish on south and west facing slopes in an arid climate due to high evaporation rates.

Geomorphic reclamation methods were developed to address the concerns outlined above, and promote the following goals:

- provide long-term drainage stabilization;
- meet runoff water quality criteria;
- reduce long-term maintenance costs;
- provide topographic diversity to enhance vegetation community development and wildlife habitat; and
- promote timely liability bond release.

Early in MMD's incitement of geomorphic reclamation methods, we heard a question from some of our mine operators: "When did the rules change to require this?" Our answer was that no change in the rules was required. We reminded these operators that: "BEST TECHNOLOGY CURRENTLY AVAILABLE [BTCA] means equipment, devices, systems, methods, or techniques which will (a) prevent, to the extent possible, additional contributions of suspended solids to stream flow or runoff outside the permit area, but in no event result in contributions of suspended solids in excess of requirements set by applicable state or federal laws; and (b) minimize, to the extent possible, disturbances and adverse impacts on fish, wildlife and related environmental values, and achieve enhancement of those resources where practicable. The term includes equipment, devices, systems, methods, or techniques which are currently available anywhere as determined by the Director, even if they are not in routine use. The term includes, but is not limited to, construction practices, siting requirements, vegetative selection and planting requirements, animal stocking requirements, scheduling of activities and design of sedimentation ponds in accordance with 30 CFR parts 816 and 817. Within the constraints of the permanent program, the regulatory authority shall have the discretion to determine the best technology currently available on a case-by-case basis, as authorized by the Act and this chapter"(30 CFR 701.5, in part).

It is unfortunate, and we believe in error, when the requirement to use the BTCA is interpreted as synonymous with requiring best management practices (BMPs) or similar sediment control measures. The term BTCA is clearly much broader in scope, and it conveys much more authority and responsibility to the SMCRA regulatory authority than do standard sediment control practices.

Challenges

Thirty years ago, many experts thought that reclaiming mines to meet SMCRA standards would be impossible in the San Juan Basin. They had good reason to be concerned. Large scale erosional processes have created the most sublime and characteristic aspects of New Mexico's landscape. The dry climate requires careful management strategies for harvesting moisture. Shallow and poor quality soil, or no soil development at all, is a common challenge. Seed production in perennial desert vegetation may be low, episodic and difficult to harvest. Very real problems needed to be solved, but the coal industry and its consultants and suppliers responded with innovation, and today coal operators in the Southwest are winning national reclamation awards.

A number of specific challenges needed to be addressed with respect to geomorphic reclamation. Acceptance of the concept by mine management was among the first issues. Mine managers tend to be engineers, and engineers tend to be cautious and conservative by nature, much more comfortable with standardized and proven construction methods than with untried solutions. That is exactly how we want and expect engineers to think, because they design and build the infrastructure that the rest of us unthinkingly depend upon. Generally, regulators are not much different than engineers in their affinity for standard and proven practices. Clear performance standards are much easier to enforce than conceptual goals and visions.

As we began to discuss implementing geomorphic designs with San Juan Coal Company, a means to address these conservative construction inclinations happened to be at hand. La Plata Mine had an out of pit spoil dump that was approved to be reclaimed in place. In fact, the east aspect of the McDermott Dump had already been reclaimed with a gradient terrace and riprapped down drain. About 52 acres were available as a test case on which to build meandering channels, "scalloped" watersheds, a talus slope, rim rock features of varying design, slopes armored with suitable spoil, and an artificial aquifer to feed a wildlife watering hole. The idea was to learn how difficult such features were to build and how well they functioned. Features that proved to be undesirable would not be used in future reclamation, and if any features were considered outright failures, they could be removed without too much trouble. A considerable degree of confidence and buy-in from management and regulators was generated as McDermott Dump was reclaimed, and as it weathered storms. In contrast to having to re-construct any of the reclamation, the operator received an excellence in reclamation award for the project from MMD's parent organization, the Energy, Minerals and Natural Resources Department.

Mitigation of unsuitable spoil, generally on account of high clay or salt content, is often an issue on New Mexico coal mines. The more complex the post mine topography, the more difficult it is to apply uniform mitigation treatments to ensure that a quality root zone has been built. This is one concern that arose during the McDermott reclamation project. We negotiated a solution to address the potentially acid or toxic forming material rule by a commitment to monitor revegetation establishment, ascertain the most likely cause of failure, and apply mitigation material if unsuitable root zone material was the most likely cause of failure. Thus far, a cyclic peak in the rabbit population has had the most significant impact on revegetation establishment at La Plata Mine.

Both topsoil lay down and seeding are more difficult on undulating terrain. Tie-in with undisturbed drainages requires an extremely good survey of the disturbance edge. Sometimes it is necessary to extend drainage channels into previous reclamation, in order to ensure capture of runoff from older areas by the new stream channels.

Geomorphic grading is dozer intensive and mining equipment is typically larger than optimal for constructing drainage channels. The work requires enhanced equipment operator skills and better communication and feedback from the designers, especially during the first few months of construction. Operators incorporating GPS machine control on their dozers report improved efficiencies, once proficiency with the guidance tools is attained.

If the errors were not fatal, MMD accepted some features that we didn't think were ideal in the early stages of development, so that operators and managers wouldn't get discouraged or frustrated. We offered constructive criticism for the next opportunity, rather than demand a redo. MMD also learned that moving less spoil is not inherently bad, if it results in a better final product. If properly shaped, steeper slopes may be built in the heads of watersheds, which means that less material has to be moved. Moving less material is often the most attractive short-term result of geomorphic grading from the operator's perspective.

Case Study: San Juan Mine

MMD has long been concerned with a lack of revegetation success at the San Juan Mine. The soils and overburden material are uniformly of poor quality, and it's not uncommon for the mine to receive less than 6 inches of precipitation per year. Los Lunas Plant Material Center has estimated that without irrigation, the San Juan Mine could expect successful revegetation in only 1 of 5 years. True to predictions, establishing revegetation without irrigation has rarely been successful. Water pumped from the San Juan River has therefore been used to irrigate revegetation during the first year after seeding and sometimes early in the spring of the second year.

Revegetation on uniformly flat or gently sloping regraded areas sometimes failed to persist for long after it had been established with irrigation. When the revegetation did survive, it was predominantly made up of 2 native grass species and one shrub species. That limited array of species is not likely to provide very much resilience in a harsh environment and represented only a small fraction of the species being seeded. MMD had therefore been encouraging topographic diversity on reclamation to improve water harvesting, reduce the percent of south aspect slopes, and achieve a better expression of the seeded species.

> The Cottonwood Pit reclamation, for which San Juan Coal Company won the 2004 Best of the Best National Reclamation Award, has demonstrated that adding topographic diversity through geomorphic grading does indeed increase revegetation diversity. Cottonwood is supporting the highest species richness of any San Juan Mine reclamation. It is hard to imagine that this would be true if conventional grading methods had been used to construct the predominantly south-aspect slopes in this area (Figure 1).

Figure 1. Cottonwood Pit reclamation at the San Juan Mine in 2004, three years after seeding.

Case Study: La Plata Mine

At La Plata Mine, steeply dipping, multiple coal seams had to be mined by open pit methods. The structurally controlled trellis drainage pattern that existed premine would have to be replaced with a dendritic drainage pattern on reclamation where the overburden had been pulverized. When the operator (again, San Juan Coal Company) committed to a minimum drainage density (feet of drainage bottom per acre of watershed) and the replacement of premine watersheds, MMD considered those to be acceptable sideboards for a workable hydrologic reclamation plan. The operator proposed a drainage density standard that exceeded the premine drainage density because of the loss of bedrock control in stream channels on reclaimed land. This helped MMD to recognize that we were negotiating with people who “get it.”

We accepted a narrative, conceptual permit commitment to construct drainages, rather than requiring up-front certified designs for each feature. The operator was moving toward a new approach and needed to know that there was an allowable margin of error. RUSLE and SedCAD runs that were conducted on earlier-permitted post mine topography designs demonstrated that post mine erosion rates and sediment yields wouldn’t exceed the premine condition. The extra drainage density produced when the geofluvial designs were draped over those basic watershed designs was clearly more conservative, because slopes were shortened (Figure 2). The proof was provided when large storms (including a 200 year – 2 hour event) on freshly soiled reclamation did not result in more erosion than would be expected on undisturbed land.

Figure 2. Reclamation that has been seeded and mulched at La Plata Mine.

Case Study: McKinley Mine

The use of terraces and riprapped down drains had become a standard reclamation practice at McKinley Mine, operated by Chevron Mining, Inc. Continuing maintenance on the terraces and repair of down drains throughout the minimum 10-year liability period was causing concern within MMD. We considered whether we could, in good conscience, release the operator from liability on reclaimed areas that were not proving capable of withstanding routine summer storms. Sodic spoil material at McKinley Mine also had the potential to form large subsidence piping holes that represented a hazard to post mine land users. The operator agreed to remove a number of terraces that were causing chronic problems. Although terrace removal was very successful on older reclamation, both MMD and the operator wanted to adopt grading methods that would reduce the need for future repairs. Geomorphic grading is being used to complete the reclamation of the final pits and address these issues (Figure 3).

It is unlikely that geomorphic reclamation can completely remove the risk of differential settling or piping in sodic spoils. However, the number and size of these types of problems has been drastically reduced on areas where geomorphic grading has been completed. The need for riprap is far less than in prior years. This is likely to result in considerable savings to the operator as mining ends and riprap would need to be purchased from off-site sources.

Figure 3. Southwest end of Area 11 pit reclamation at the McKinley Mine.

Conclusion

MMD has no regrets concerning the implementation of geomorphic reclamation on New Mexico's coal mines. We believe that the stability and productivity of our reclaimed areas has been greatly improved by creating more natural landscapes. Our concerns regarding release of liability have been alleviated by observing reclaimed lands stand up to large precipitation events without damage. Continuing improvements in geomorphic grading software allow the operators to produce complex post mine topography designs more efficiently, and submit those designs for review and approval by MMD. GPS machine control is also becoming a common tool on our mines and provides assurance that complex geomorphic designs can actually be constructed.

Perhaps the most surprising and gratifying result of giving our operators a little more flexibility, though, has been the ownership that they are showing in their reclamation product. After a bit of skepticism in the beginning, the operators soon realized that they had been empowered to create something special. The sense of inventiveness in the reclamation process has become evident across all of our mines, from the managers to the equipment operators. Dozer operators don't want any other operators mucking around in "their" watersheds. Artificial rock outcrops are built in near perfect replication of natural features. At our mines that are in full closure after decades of operation, with layoffs coming soon, employees can take pride in their final efforts. At La Plata Mine, the operator contracted with a professional filmmaker to depict the history of the mine from start to finish, as a thank-you gift to everyone who contributed.

Monthly inspections have become an opportunity to look at what's been done since the last visit, to discuss creative opportunities in specific areas, and to give and get feedback on how different approaches and types of equipment are working out. It is hard to imagine a better environment in which to practice the science and art of mined land reclamation.

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GEOMORPHIC RECLAMATION AT BHP BILLITON NEW MEXICO COAL – SUCCESS, CHALLENGES AND FUTURE

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Abstract

BHP Billiton operates three coal mines in northwest New Mexico: La Plata Mine, a truck shovel operation that completed reclamation at the end of 2008; San Juan Mine, a surface dragline operation that transitioned to an underground operation in 2002; and Navajo Mine, a multiple dragline operation located on the Navajo Reservation. BHP Billiton first applied fluvial geomorphology principles to part of an out of pit spoil pile at La Plata Mine in 2002. Successful application of these principles led the way for the remainder of La Plata Mine to be reclaimed using the GeoFluv™ approach. We also found opportunities to construct geomorphic based land forms as San Juan Mine was transitioning from traditional engineered reclamation (i.e., gradient terraces) to fluvial geomorphic based reclamation. As a result, San Juan Mine earned the Office of Surface Mining's 2004 National Reclamation Award and 2004 Best of the Best award for reclamation of a final dragline pit area in the South Lease Extension, know as Cottonwood. This reclamation demonstrated the successful implementation of both steep and flat slope geomorphic reclamation. Navajo Mine has begun evaluating opportunities to integrate fluvial geomorphology into its reclamation and recently completed construction of a GeoFluv™ based design. Our transition from traditional to geomorphic reclamation, although successful, includes many challenges. Expanding the skills set of our professional staff to include fluvial geomorphology and our operators and foremen to understand the construction of such land forms has been and continues to be an area of continual development. The future of geomorphic reclamation at BHP Billiton's New Mexico coal operations is bright. We continue to improve our design and construction skills to achieve successful, sustainable reclamation and to identify opportunities to implement our geomorphic reclamation strategies. We also look forward to monitoring the performance of our geomorphic reclamation areas to quantify its success through maintenance cost reductions, improved bond release timing, and revegetation success.

Introduction

BHP Billiton operates three coal mines in northwest New Mexico: La Plata Mine (LPM), San Juan Mine (SJM), and Navajo Mine. San Juan Coal Company (SJCC) operates LPM and SJM. BHP Navajo Coal Company (BNCC) operates Navajo Mine. BNCC is also in the process of permitting a fourth coal mine, referred to as the Navajo Mine Extension Project (NMEP). The SJCC operations are located on State regulated lands and have SMCRA permits issued from the New Mexico Mining and Minerals Division (MMD). BHP Billiton first applied fluvial geomorphology principles in New Mexico to part of an out of pit spoil pile at La Plata Mine in 2002. Successful application of these principles led the way for the remainder of La Plata Mine to be reclaimed using the GeoFluv™ approach. We also found opportunities to construct geomorphic based landforms as San Juan Mine was transitioning from traditional engineered reclamation (i.e., gradient terraces) to fluvial geomorphic based reclamation. BNCC operations are located entirely on the Navajo Reservation and have SMCRA permits issued from the Office of Surface Mining Reclamation and Enforcement (OSM). Navajo Mine is evaluating opportunities to integrate fluvial geomorphology into its reclamation and recently completed construction of a fluvial geomorphology based design. We have developed a geomorphic reclamation plan for the Navajo Mine Extension Project to be implemented over the life of the operation.

Our transition from traditional to geomorphic reclamation, although successful, includes many challenges and development opportunities. Among these opportunities is expanding the skill set of our professional staff to include fluvial geomorphology and our operators and foremen to understand the construction of such landforms. We have support and encouragement from our regulators, MMD and OSM. SJCC and BNCC continue to develop meaningful metrics for inspection and enforcement of reclamation practices on the fluvial geomorphic landforms.

Fluvial geomorphic reclamation is influenced by numerous inputs including the regional setting of the operations (topographic and climatic conditions) and post-mining design criteria. Each of BHP Billiton's New Mexico coal operations have tailored their geomorphic reclamation approach their site specific inputs. The following discussion will present information on the design emphasis applied at each operation and summarize the successes, challenges, and future of geomorphic reclamation at BHP Billiton's New Mexico coal operations.

Regional Setting

Location

BHP Billiton's New Mexico coal operations are located in northwest New Mexico within San Juan County, near Farmington (Figure 1). The operational areas are located on the west flank of the San Juan Structural Basin, within the Navajo Section of the Colorado Plateau in northwest New Mexico. The Colorado Plateau, or Colorado Plateaus Province, is a physiographic region of the Intermontane Plateaus, roughly centered on the Four Corners region of the southwestern United States. The Colorado Plateau covers an area of approximately 130,000 square miles within western Colorado, northwestern New Mexico, southeastern Utah, and northern Arizona (Leighty 2001). This basin is an asymmetric, structural basin with a northeast trending axis parallel to the Hogback monocline in northwest New Mexico. The Hogback monocline causes the beds to dip steeply into the basin from the northern, northwestern and eastern flanks, whereas the beds dip gently and evenly in the southern and southwestern parts (SJCC 2004).

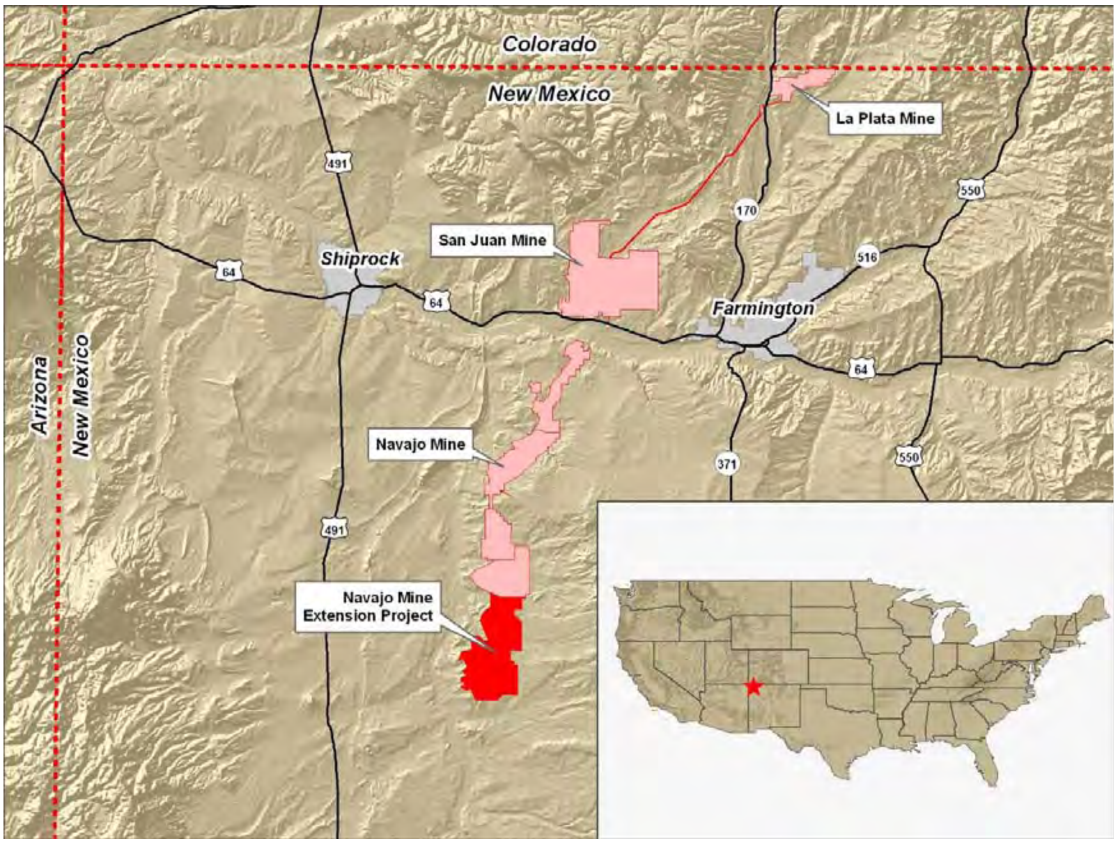

Figure 1. General location of BHP Billiton's New Mexico coal operations in San Juan County New Mexico.

Geology

The San Juan Basin is bounded to the north by the San Juan Uplift and to the south by the Zuni Uplift and the Chaco Slope (Laubach and Tremain 1994). The western rim is formed by the Defiance Uplift and Four Corners Platform and the eastern rim is formed by the Brazos Uplift and the Nacimiento Uplift (Laubach and Tremain 1994). The Continental Divide trends north to south along the east side of the San Juan Basin (Laubach and Tremain 1994). The age of the San Juan structural basin is Late Cretaceous to early Tertiary (SJCC 2004). The stratigraphic section in the permit areas reflects the Late Cretaceous transition of shallow marine depositional environment to a terrestrial fluvial depositional environment (SJCC 2004). The operations are developing the coal seams of the Fruitland Formation. The land surface elevations within the basin range from 5,100 feet on the western side to over 8,000 feet in the northern side.

Climate

San Juan County has an arid climate, characterized by low humidity, infrequent precipitation, intense solar radiation, and wide variations in diurnal and annual temperature. The area receives precipitation during the summer months, July through October, when afternoon showers form as a result of moist air from the Gulf of Mexico moving over the area, and in the fall and winter, when cold fronts moving to the east and southeast from the Pacific Ocean create steady, usually light rain and snow showers across the area (SJCC 2004). The total amount of precipitation received at specific locations may be related to topographic features and changes in altitude, ranging from 5 to 14 inches per year. Most snowfall is light and evaporates within a few days. Most precipitation occurs during the seasonal monsoon periods, when the prevailing winds shift to the southwest and carry sub-tropical moisture into the area. These generally occur in March and August of each year and are characterized by short, sudden cloudbursts, and often associated with thunderstorms. Due to its moderately high elevation, ranging from 5,000 to 6,600 feet above mean sea level, San Juan County experiences mild summer and cold winter temperatures. Average annual temperatures are in the low to mid-50 degrees Fahrenheit (ºF). Summer temperatures generally range from the mid-60ºF to the low 90ºF. Temperatures in excess of 100ºF are rare. In winter, early morning temperatures normally drop to the high teens or low 20ºF; however, the air usually warms rapidly and reaches the upper 30ºF or low 40ºF by mid afternoon (WRCC 2009).

<u>Rivers</u>

Tributaries of the San Juan River associated with the mining operations are the La Plata River, a perennial stream, and the Chaco River, an ephemeral stream (Figure 2). The mine areas are traversed by several major and minor ephemeral arroyos that ultimately drain into the San Juan River. The LPM watersheds drain into McDermott Wash and into the La Plata River. SJM watersheds drain into the Shumway Arroyo or Stevenson's Arroyo and into the San Juan River. The Navajo Mine and NMEP watersheds drain into several major and minor arroyos that flow into the Chaco River. Streams and washes in the operational areas are ephemeral, which means that they only carry surface water during infrequent periods resulting from heavy precipitation events within their discharge basin. Localized flash flooding occurs during high intensity precipitation events which are often associated with the late summer monsoonal thunderstorms. Discharges of several hundred to several thousand cubic feet per second (cfs) from drainages of only a few square miles in size are not uncommon. Winter storms, in contrast, are usually of low intensity and short duration and produce little or no runoff. Ephemeral channels tend to be deeply incised and carry very high concentrations of suspended solids and bed loads during storm events. Overall, these channels are typically dry during long periods between storm events.

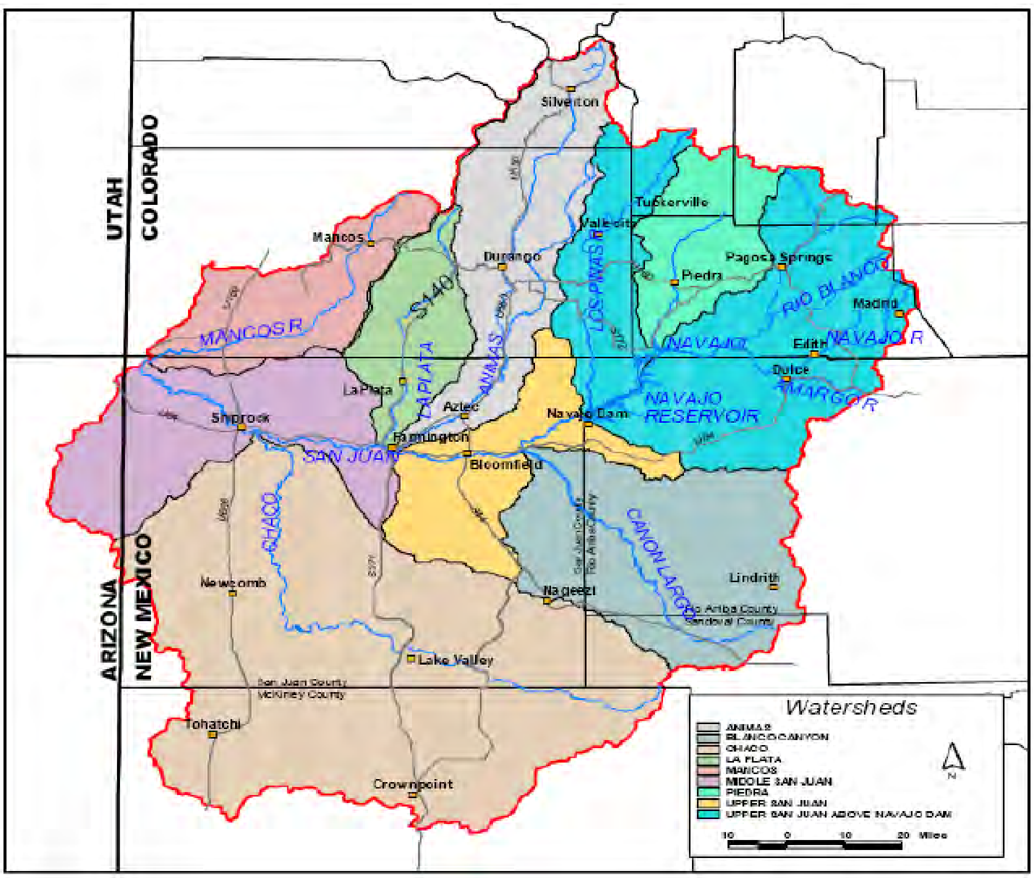

Figure 2. San Juan Basin watershed Map 1.

Vegetation

The native vegetation communities within the mine areas are characteristic of the Colorado Plateau flora. This ecosystem contains a large number of salt tolerant species and a significant shrub component. Common shrubs include numerous species of saltbush (*Atriplex* ssp.), greasewood (*Sarcobatus vermiculatus*), Mormon tea (*Ephedra* spp.), winterfat (*Krascheninnikovia lanata*), and rubber rabbitbrush (*Ericameria nauseosa*). The grass community is generally dominated by the warm season species of galleta (*Pleuraphis jamesii*), and alkali sacaton (*Sporobolus airoides*). The only cool-season grass of any consequence is Indian ricegrass (*Achnatherum hymenoisdes*). Common forb and half shrub species include globemallow (*Sphaeralcea* spp.) buckwheat (*Eriogonum* spp.), and broom snakeweed (*Gutierrezia sarothrae*). At the higher elevations around the La Plata Mine, the vegetation is characterized by stands of pinyon pine (*Pinus edulis*), juniper (*Juniperus osteosperma*), and big sagebrush (*Artemisia tridentata*).

Geomorphic Reclamation Approach

Both SJCC and BNCC use the GeoFluv™ approach to geomorphic design, coupled with SEDCAD™ analysis to predict sediment transport. The design process includes the collection of site specific geofluvial inputs. Specifically, the GeoFluv™ approach identifies five essential elements: local base level elevation, slope downstream of the local base level elevation, drainage density, ridge to head of channel distance, and A-channel reach length (Bugosh 2007). These inputs are collected from the specific project area and undisturbed representative (reference) watersheds. These undisturbed watersheds may be located within or adjacent to the operating area to ensure data is collected from landforms that were influenced by the same climatic and erosive forces over geologic time. In many cases, the mining areas originally contained durable surface strata, such as the sandstone outcrops, and unstable surface features, such as incised channels and cut banks. In such cases, we adjust the input parameters to correlate with material replaced during reclamation or identify watershed that contain materials similar to those used for reclamation.

The different topographic, geologic, and climatic conditions at each of the three mining areas results in different sets of key concept inputs. For example, LPM has higher drainage density and shorter ridge to head of channel distances because the terrain at LPM is steeper and it receives more precipitation. Enough design and construction work has been completed at SJCC that the reference watershed for the uplands is well characterized. Additional fluvial geomorphic design and construction at Navajo Mine and NMEP will enable BNCC to develop a well characterized uplands reference watershed(s). Table 1 provides information on some of the essential GeoFluv™ input elements for LPM and BNCC.

Table 1 Select essential GeoFluv™ elements for LPM and BNCC.

Operation	Drainage Density (ft/acre)	A-channel Reach (ft.)	Ridge to Head of Channel (ft.)
LPM	150	50	60
BNCC	110	80	100

After the general or global geomorphic parameters have been identified, specific project area information is collected. Upstream watersheds are identified and sized. Upstream channels are surveyed to determine tie-in elevation, slope, channel type, and channel dimensions. The GeoFluv™ approach requires information about the bankfull width and depth, and the flood prone width and depth. According to the approach, the bankfull area is formed by the frequent, 2-year 1-hour storms, while the flood prone area is formed by the less frequent, 50-year 6-hour storms. Also, inputs about the upstream and downstream watershed are collected. Specifically, base elevation and channel dimensions for the bankfull and flood prone areas are determined. Figure 3 shows an area where channel dimensions were being collected.


Figure 3. Photograph of channel measurements in the Pinabete Arroyo inside the BNCC lease area.

Once we identify factors that may affect transitioning the fluvial geomorphic design into the surrounding, undisturbed topography, the goals and scope are established for the design. These vary depending on whether the design is part of an adjacent area with geomorphic reclamation or traditional reclamation. Natural Regrade software is then used to develop drainage networks and generate a surface. This surface is tested against the goals and scope of the design and modified as needed. Successful designs are evaluated for constructability and analyzed for sediment transport using SEDCAD™, as needed. This step in the process is typically done for the SMCRA permit for sediment control review and to comply with NPDES requirements.

When the design goes to the field for construction, it is communicated to the operators using stakes or machine control, depending on the operation. SJCC and BNCC have also used a sandbox to train operators or explain strategies for constructing channels. Recent LPM geomorphic reclamation was completed using machine control. SJM and Navajo Mine geomorphic reclamation were completed using staking. NMEP geomorphic reclamation will likely be completed using machine control. Figure 4 shows channel construction by a dozer using stakes at SJM. Figure 5 shows channel construction using machine control at LPM. Figure 6 shows the machine control display in the foreman's truck.

Figure 4 Photograph of a dozer constructing a channel using stakes as guides at SJM.


Figure 5 Photograph of a dozer constructing a channel using machine control at LPM.

Figure 6 Photograph of machine control display in a foreman's truck at LPM.

SJCC has adapted topdressing (topsoiling) and revegetation practices to the geomorphic surfaces. Topdressing is placed at varying depths and different seed mixes are planted depending on slope and aspect, as described in each SMCRA permit. BNCC is in the early stages of developing an approach to geomorphic reclamation and is evaluating whether similar adaptations in topdressing and revegetation practices are appropriate. SJM and BNCC operations augment the low precipitation with supplemental irrigation. Operation specific revegetation and irrigation practices are discussed below.

The goal of revegetation activities at SJCC and BNCC, regardless of reclamation approach, is to establish a diverse, stable, and self-sustaining vegetation community. Both SJCC and BNCC have conducted extensive research to determine which native species are most suited to our reclamation areas. Combined, the operations have conducted numerous studies evaluating the effects of revegetation procedures and the establishment of vegetation communities on native and reclaimed soils (Buchanan et al. 1990, Buchanan et al. 2005, Buchanan et al. 2006, Ramsey et al. 2006, Samson et al. 1990, Stutz et al. 1990, Wood et al. 1991, Wood et al. 1995). From this research we have developed site specific revegetation plans for each operation that meet the above stated revegetation goals. Although each operation has developed site specific revegetation plans with multiple seed mixes to meet their individual topographic, climatic and reclamation conditions, the seed mixes prescribed for the four operations contain many of the same native species. The main key species for these seed mixes include: galleta grass, alkali sacaton, indian ricegrass, bottlebrush squirrel tail (*Elymus elymoides*), globemallow, fourwing saltbush (*Atriplex canescens*), winterfat, Wyoming big sagebrush (*Atremisia tridentate ssp wyommingensis)*, and New Mexico saltbush (*Atriplex obovata*). Figure 7 presents an example of how La Plata Mine is using its revegetation plan with four seed mixes, north shrub, south shrub, grassland, and drainage, to meet the goals of creating a diverse, stable, self sustaining vegetation community (LPM Permit 2006).

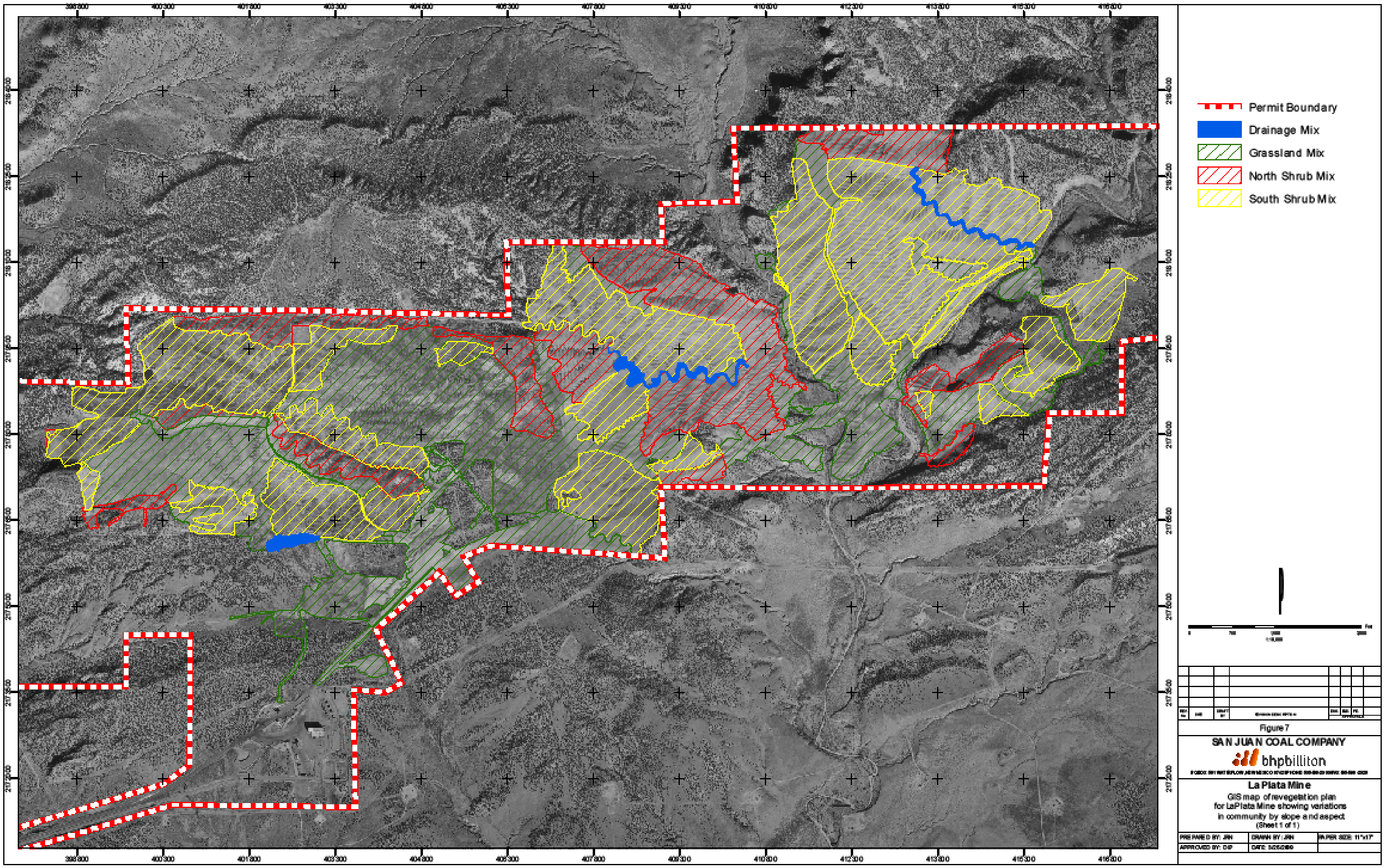

Figure 7. GIS map of revegetation plan for LPM showing variations in community by slope and aspect.

The revegetation plan developed for LPM takes advantage of the geomorphic approach and establishes four revegetation communities that have varying species composition: north community, south community, grassland community, and drainage community. These communities were developed to be seeded on the different aspects and slopes of the reclamation areas. The north and south plant communities are aspect driven, while the grassland community and drainage community are slope and topdressing thickness driven. The drainage community occurs on the channel side slopes in the bottom of larger and flatter drainage channels. The SJM revegetation plan takes advantage of the slope component geomorphic approach rather than the aspect component for vegetation community establishment. SJM has developed two seed mixes, grassland mix and shrubland mix, for seeding on different slope intervals. The grassland community is seeded on slopes up to 8% and shrubland mix seeded on slopes greater than 8%. The revegetation plan developed for BNCC emphasizes the influence of seeding timing rather topography. The reclamation areas at BNCC are less diverse and the climatic conditions tend to be dryer than either SJM or LPM. This emphasis on seeding timing allows BNCC to take advantage of a longer seeding window through the targeted selection of cool versus warm season grass species. BNCC has developed three seeding mixes: cool season mix, warm season mix, and high shrub mix. The cool season mix is applied during early spring and late fall, while the warm season mix is applied during late spring and throughout the summer. The high shrub mix is targeted for low lying areas and small areas depressions where water may accumulate.

To aid the establishment of the revegetation plan seed mixes, SJCC and BNCC irrigate the revegetation areas for two growing seasons after the initial seeding. As stated earlier, SJM and Navajo Mine receive less than 8 inches of precipitation a year. The irrigation plan attempts to compensate for these arid conditions. Irrigation is applied at different rates, a germination and support cycle, during the first growing season. The germination cycle is applied directly after mulch has been applied and occurs for about two weeks. The purpose of this initial cycle is to develop sufficient subsurface moisture to overcome seed inhibition and initiate germination. Irrigation applications are reduced during the support cycle, which continues through the remainder of the growing season to facilitate plant establishment and encourage root development. SJCC and BNCC may irrigate reclamation areas once or twice during second growing season depending upon winter and spring moisture and the presence of drought conditions. Figure 8 shows irrigation at SJM on a geomorphic reclamation area.

Figure 8. Photograph of irrigation on geomorphic reclamation at SJM.

Geomorphic Reclamation Activities by Operation

Although the fluvial geomorphic reclamation design approach used at each of the operations is the same, the results and implementation are different based on climate, topography, equipment, and reclamation goals. BHP Billiton first applied fluvial geomorphology principles to part of an out of pit spoil pile at La Plata Mine in 2002. Successful application of these principles led the way for the remainder of La Plata Mine to be reclaimed using the fluvial geomorphic reclamation approach. We also found opportunities to construct geomorphic based land forms as San Juan Mine was transitioning from traditional engineered reclamation (i.e., gradient terraces) to fluvial geomorphic based reclamation.

San Juan Coal Company

The LPM is situated on the north-western flank of the San Juan Basin in higher and steeper topography. The eastern one-third of the mine property has numerous parallel faults with up to 80 feet of vertical displacement. The mine area ranges in elevation from 5,900 to 6,200 feet. Annual precipitation at LPM ranges from 12 to 13 inches. Based on nearby meteorologic data, average annual potential evaporation is about 38 inches (pan evaporation). The average number of frost free days per year is 139 (SJCC 2006).

The SJM is situated on the lower and more gently sloping western flank of the San Juan Basin. Average annual precipitation is 9.7 inches. However, annual rainfall amounts can vary considerably from year to year. Average annual potential evaporation is about 49 inches at a nearby meteorologic station but may be as much as 25 percent higher on the higher plateau locations where wind speed is greater. The average number of frost-free days per year is 158 at the New Mexico State University, San Juan Branch Station, located about 15 miles east south-east of the mine site. (SJCC 2004).

In 2002, SJCC began to use the fluvial geomorphic approach for reclamation design and construction at the LPM operations. SJCC wanted to do more to meet their goals for reclamation including creation of stable landforms, enhancement of topographic diversity, compliance with water quality standards, promote bond release, and reduce long term maintenance costs. Use of traditional reclamation practices would not accomplish these goals, thus the integration of fluvial geomorphic principles in our reclamation plans.

In order to construct fluvial geomorphic reclamation, SJCC had to develop a plan to address the potentially acid or toxic forming materials (PATFM) in its root-zone material because traditional mitigation of PATFM in fluvial geomorphic reclamation could cause unstable and erosive topography. LPM does not have PATFM conditions, but the issue needed to be addressed to keep the permit commitments in line with the reclamation strategy. LPM coordinated with MMD to address PATFM mitigation by making a commitment to first monitor revegetation to identify areas of denuded vegetation. Monitoring would be followed by sampling and analysis to determine if limiting conditions were associated with root-zone material quality. An additional foot of suitable material would be added to areas with limiting conditions then reseeded.

The first attempt was to apply the fluvial geomorphic principles, as described above, was on an out of pit spoil dump. A channel was built by a backhoe using stakes and a geomorphologist, Nicholas Bugosh, to guide the operator during the channel construction. Once the channel and the associated slopes connected to the channel were constructed the channel was observed over a period of time to understand the effects of different precipitation events on its stability and function. Through observation and field measurements it was found that the use of fluvial geomorphic principles in reclamation provided a very stable and more natural approach to reclamation. This newly developed technology was then further refined at SJM. In 2002, the author (C. Brown) joined SJCC as a summer student and was assigned to assist N. Bugosh in implementing fluvial geomorphic reclamation.

In the beginning, the reclamation surface was designed using surveying for elevation control, using spreadsheets to calculate longitudinal profiles, drafting designs on paper, calculating the channel dimensions on paper, and ultimately staking the desired elevations and two dimensional features of the desired topography in the field. At the SJM operations, we were given the opportunity to work with a great dozer operator, Larry Yazzie, who helped us significantly in refining the construction and implementation of the fluvial geomorphic principles into our reclamation. In order to construct the desired channels and slopes, L. Yazzie would have to rely on stakes in the field and through consultation with N. Bugosh and the author (C. Brown).

The initial implementation of the fluvial geomorphic reclamation was very labor intensive. It would require those who had completed the reclamation designs to be out in the field with the dozer operators constantly to oversee the placement of material and to explain the desired landscape, staking and re-staking designs, and checking elevations. As we would construct the topography, we would do field checks to ensure proper function and to continuously improve the process. In addition to the time we spent fine tuning the fluvial geomorphic process, we also had to continuously re-train our operators. The approach to building the new topography was almost contrary to what they had traditionally been trained to do. The new diverse and more complicated topographic design required the operators to understand basic fluvial geomorphic principles in order to build properly functioning channels and slopes. Our operators have traditionally been trained to construct landforms which were very uniform in topography (i.e., flat and smooth). Tim Ramsey, reclamation supervisor, suggested we train operators using a model to show and explain the desired topography in the fluvial geomorphic reclamation. The model was a box of sand that was treated with mineral oil to maintain some cohesion and the use of small model dozers. The operators used the sand box model to figure out possible maneuvers for their dozers to construct the channels and slopes.

Another challenge at SJM operations was the transition zones from traditional reclamation to the fluvial geomorphic process. Areas within the mine site that were previously reclaimed using the traditional approach had to be transitioned into geomorphic landforms. There were many areas where we were able to use the fluvial geomorphic principles to tie into the existing reclamation features with some innovative approaches. For an example, the author (C. Brown) designed reclamation in an area in which 40% of the watershed was reclaimed using traditional methods. In order to tie into the existing reclamation to achieve the appropriate longitudinal profile and head to channel lengths we had to disturb minor sections of the traditionally reclaimed areas. In order to avoid re-disturbing thousands of yards of material, we had to use the fluvial geomorphic principles in innovative ways. We designed and constructed a small section of the area to capture runoff from the previously reclaimed channel running along the slope. This portion of the reclamation has been in place since 2002 and has withstood the test of precipitation events over the years.

At SJM in the summer of 2002, the author (C. Brown) suggested that much of the design work could be facilitated with the use of computer aided drafting (CAD) technology. Once we began using CAD technology, the efficiency of designing geomorphic technology spring boarded. With the use of CAD and calculation through spreadsheets, much of the design work became automated. In 2003, LPM began to use machine control technology so that the required staking of channel designs in the field was nearly eliminated. N. Bugosh implemented these new tools at SJCC and worked with personnel involved in reclamation to further develop spreadsheets and to automation. It was at this point that N. Bugosh realized that this newly developed technology could be further refined and simplified. That is when he decided to join Carlson Software and began development of GeoFluv™. SJCC participated in beta testing the Natural Regrade module during the development period through its release in May 2005.

In 2004, SJM completed construction of the Cottonwood mining area. The author (C. Brown) assisted N. Bugosh with the fluvial geomorphic design for this final dragline pit in the South Lease Extension area of the mine. The reclamation area was approximately 122 acres and demonstrated the successful implementation of both steep and flat slope geomorphic reclamation. SJM earned the Office of Surface Mining's 2004 National Reclamation Award and 2004 Best of the Best award for reclamation of Cottonwood. Figure 9 is an orthophotograph of the Cottonwood mining area taken in 2008.

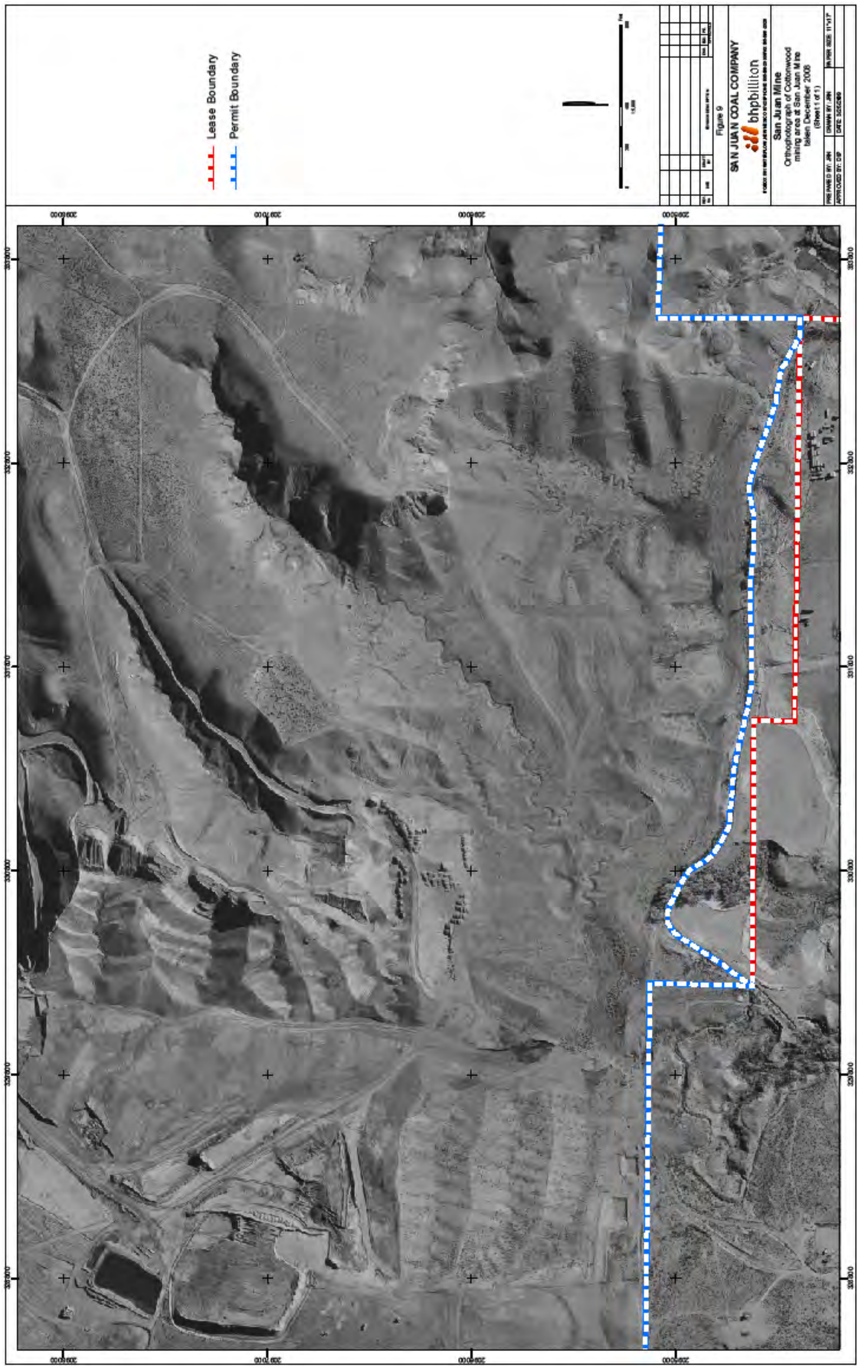

Figure 9. Orthophotograph of Cottonwood mining area at SJM taken 2008.

The geomorphic reclamation at LPM was tested in July 2006 when it was subjected to consecutive days of significant rainfall followed by a monsoon storm event. The mine site meteorological station registered 2.12 inches of precipitation in a 3-hour period with a one hour measurement exceeding the 100-year 1-hour event for the site (NOAA 2008). The mine idled during this event for safety reasons so there are no photographs documenting water flows in the channels. A few days after the event, operations and environmental quality personnel inspected the mine area. The MMD performed an inspection three days after the event and found only two areas of the reclamation that needed minor maintenance attention. There were no significant failures of the reclamation. Figure 10 is a photograph of a watershed reclaimed in 2004 after July 2006 storm event.

Figure 10. Photograph of reclaimed watershed after July 2006 storm event.

Figure 11 is a photograph of the bottom of a reclaimed watershed after July 2006 storm event. The sediment was deposited in the bottom channel but did not cause any noted erosional features within the watershed. Areas that were in the process of being constructed were also inspected and found to have endured the rain event without damage.

Figure 11. Photograph of the bottom of a reclaimed watershed after July 2006 storm event.

Figure 12 is a photograph of a geomorphic channel after construction and prior to topdressing after July 2006 storm event. The channel is about 15 feet wide at the bottom. The debris from the upstream watershed marks the high water line.

Figure 12. Photograph of a geomorphic channel after construction and prior to topdressing after July 2006 storm event.

The successful implementation of geomorphic reclamation at LPM and SJM also allowed for the construction of a bluff area to replace some of the sandstone outcropping that was removed during mining. The author (D. Place) worked with MMD to modify the approved FSC to allow this feature to be constructed. Baseline wildlife studies documented raptor habitat and visits immediately east of the mining area. Jeff Mattern, BNCC Senior Geologist, performed slope stability analyses to determine whether the sandstone was competent and safe to leave exposed. The author (D. Place) and Greg Perkins, Production and Engineering Coordinator, developed a geomorphic design that would convey the water flowing over the bluff area down to the reconstructed main channel. Figure 13 shows a photograph of the completed Younger Bluffs area.

Figure 13. Bluff area at LPM.

Landform construction activities were completed at LPM in the winter of 2008 and seeding will be completed in the spring of 2009. A total of 1,400 acres have been reclaimed at LPM using the fluvial geomorphic approach. Figure 14 shows an orthophotograph of LPM taken in December 2008. SJM continues to implement the fluvial geomorphic approach to reclamation although the rate of construction is slower than at LPM because coal combustion by-products (CCBs) are being placed in the minefill. To date, a total of 400 acres have been reclaimed at SJM using the fluvial geomorphic approach.

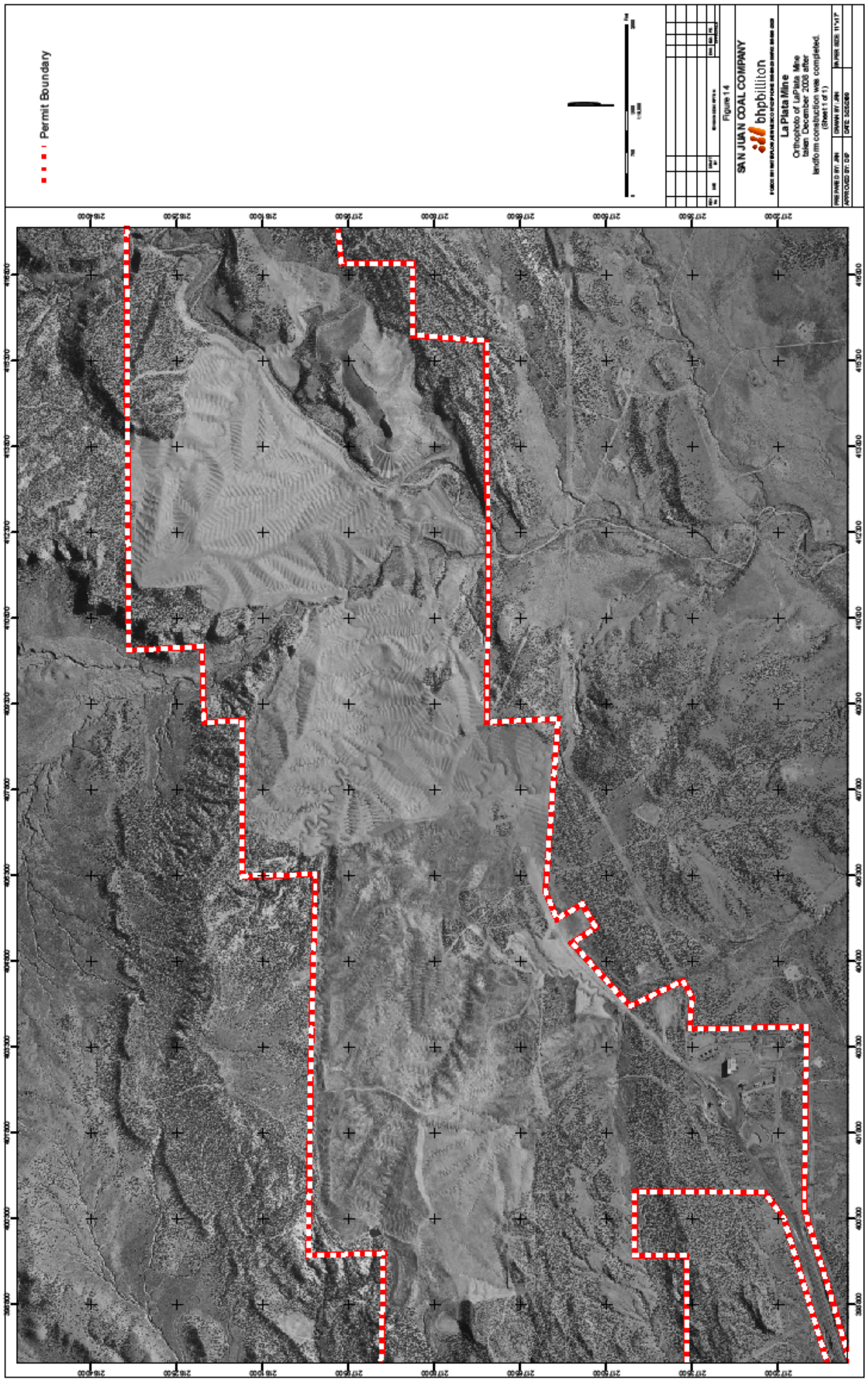

Figure 14 Orthophotograph of LPM taken December 2008 after landform construction was completed.

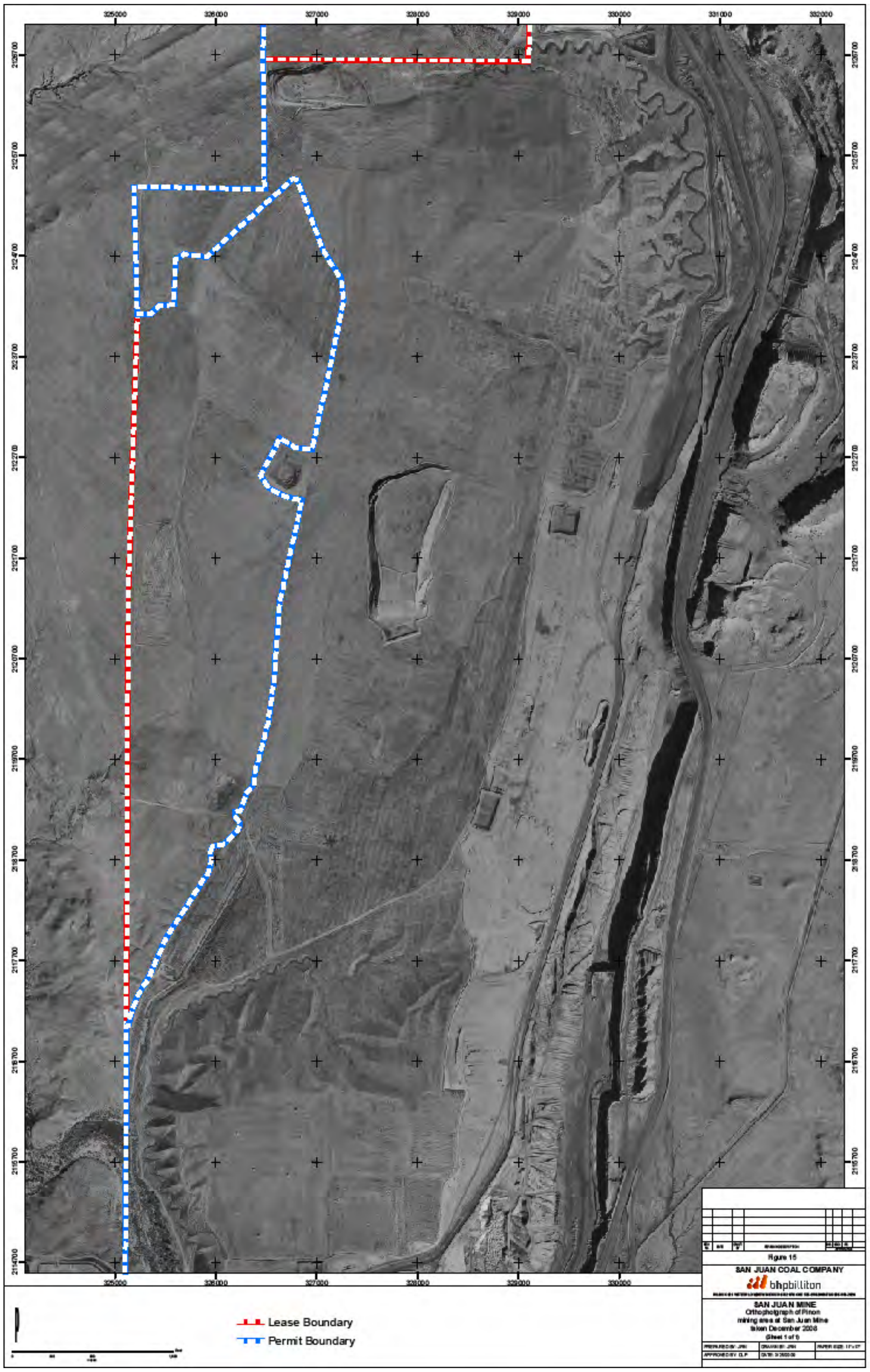

Figure 15. Orthophotograph of Pinon mining area at SJM.

Figure 15 shows an orthophotograph of an active reclamation area at SJM, Tumbleweed and Pinon mining areas. MMD's desire to see more natural, stable reclamation and their willingness to work with SJCC coupled with SJCC's commitment to do more than the minimum required reclamation paved the way for the SJCC operations to become industry leaders in fluvial geomorphic reclamation. In addition, we were able to support N. Bugosh during development of GeoFluv™ which has allowed many more in the mining industry to implement this award winning reclamation process.

BJP Navajo Coal Company

The topography of the BNCC lease area is generally defined by rolling terrain with areas of steep escarpments, badlands, sand dunes, and incised drainages and arroyos. The elevation within the permit area ranges between 5,300 and 5,600 feet. The area is bordered to the west by escarpments that are part of the ancient channel walls of the Chaco River. The lease area is characterized by relatively level, sparsely vegetated high desert terrain, punctuated by ridges and buttes and traversed by incised channels. Precipitation is low, averaging roughly 6 inches per year. Potential evaporation is high, averaging over 60 inches per year. While snowfall is not unusual during the winter months, snow rarely accumulates to any significant depth over the BNCC area. The average frost-free growing season is 146 days (BNCC 2004).

The BNCC lease area is located entirely on the Navajo Reservation and is regulated by the OSM. The lease area is divided into operational parts that include: Area 1, Area 2, Area 3, Area 4 North, Area 4 South and Area 5 (Figure 16). Areas 1, 2, 3, and 4 North comprise the Navajo Mine permit area, while Areas 4 South and 5 will comprise the NMEP. The permit boundaries coincide with the lease boundary. Navajo Mine has been operating since the late 1950s and has pre-law, interim law and permanent program lands. Mining began in the northern areas of the lease and have progressed to the south. NMEP will begin mining in Area 4 South and progress south into Area 5. Navajo Mine is and NMEP will be a multi-dragline operation. To date, Navajo Mine has reclaimed approximately 7,600 acres of disturbance.

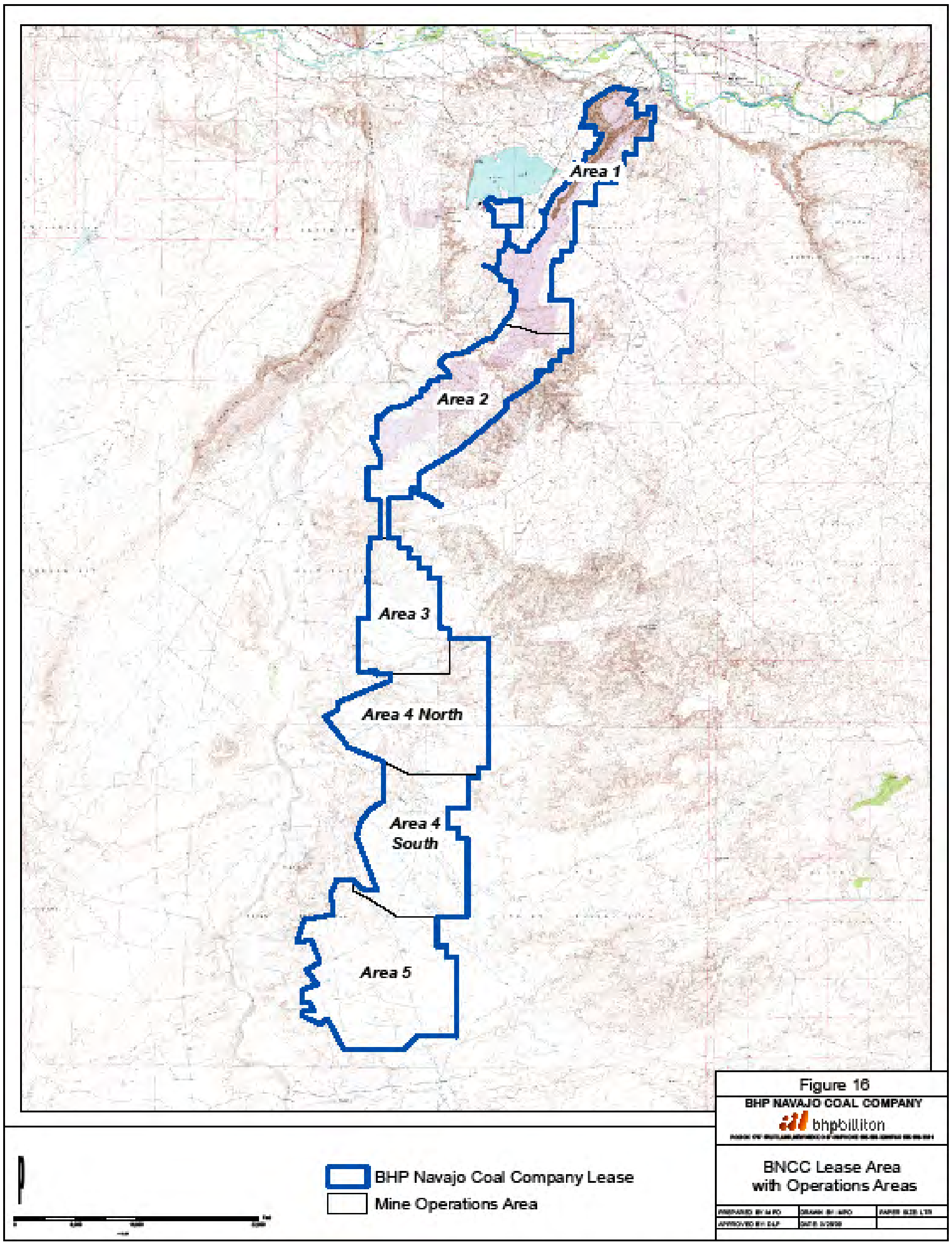

Figure 16 BNCC lease area with operations areas.

Navajo Mine

The successful implementation of fluvial geomorphologic designs at LPM and SJM has provided opportunities to consider applying fluvial geomorphic principles to reclamation designs at Navajo Mine. Navajo Mine began by selecting the ramp of a final pit as the potential test site for a fluvial geomorphic reclamation design. The BNCC Environmental Quality Department, management and Production Departments worked together to determine whether Ramp 3 of North Barber Pit would be a suitable area to implement and test a fluvial geomorphic reclamation design (Figure 17).

Figure 17. Aerial photograph of Barber Ramp 3 after primary regrade. Note reclaimed areas on either side of the ramp area.

Navajo Mine then requested permission from the OSM to implement a fluvial geomorphic design in North Barber Ramp 3 through a revision to the AOC for the area, prepared by Shawn Smith, Navajo Mine Environmental Compliance Specialist. This area consisted of approximately 42 acres of re-graded material that was confirmed as suitable root-zone material, per BNCC's SMCRA requirements. A valley-like landform was already established by re-grading to an approximate original contour surface (AOC). The ramp was initially re-graded to function as a drainage that would eventually convey water from southwest off-lease watersheds as well as watersheds of nearby reclaimed areas (Figure 18).

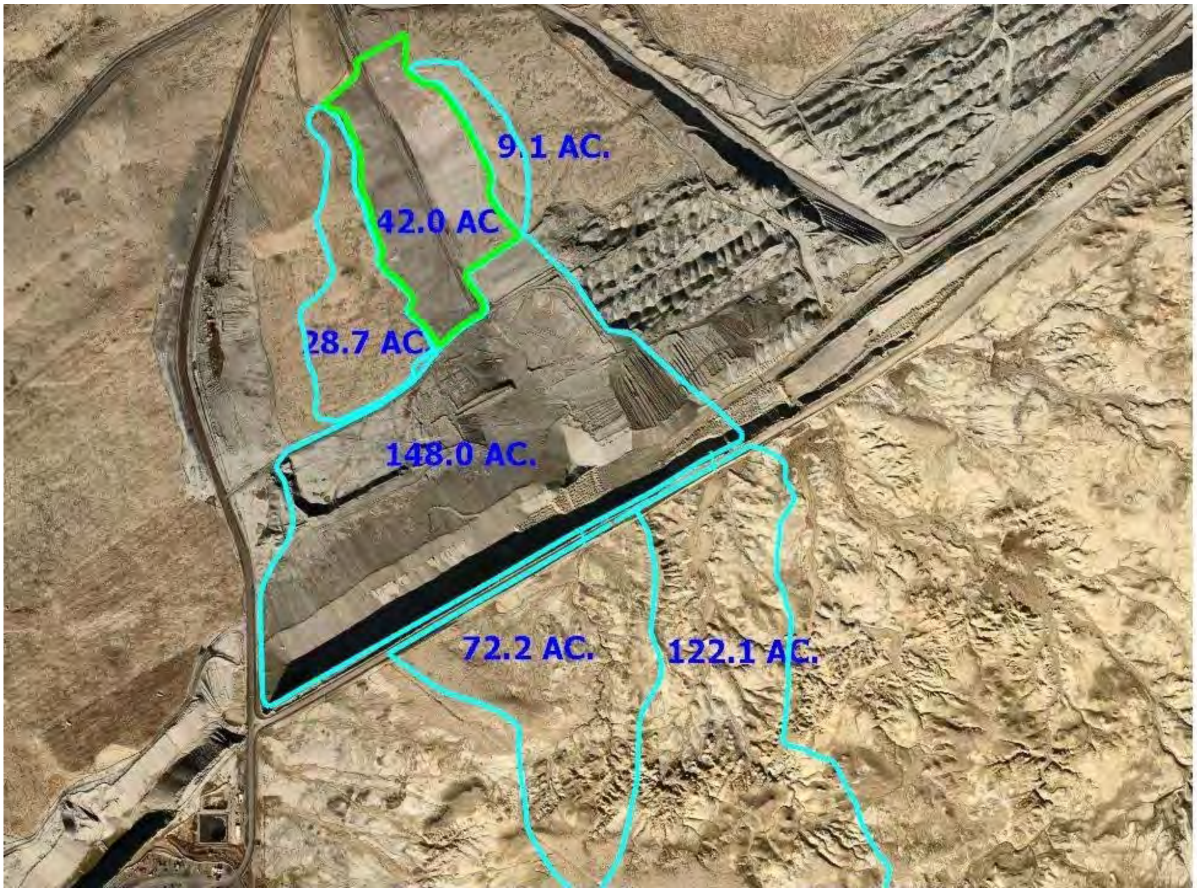

Figure 18. Watershed diagram of Barber Ramp 3 with acreages, including upstream off lease watersheds.

The goals of this project were to build and test a geomorphic reclamation design that would improve upon the effectiveness of the existing AOC surface. The slopes of North Barber Ramp 3 were beginning to show the signs of rilling and erosion from drainage originating from nearby reclaimed and re-vegetated areas. The bottom channel was more than 75 feet wide and approximately 10 feet deep and was beginning to show signs of sediment accumulation. The sedimentation occurring in the channel was characteristic of an over-designed channel that would not maintain adequate flow to carry away sediment during precipitation events. A design based on fluvial geomorphic principles would be able to remedy this problem. Instituting fluvial geomorphic design presented an opportunity to establish slope faces of varying orientation that would receive different amounts of sunlight and precipitation, thus supporting more diverse vegetation. It was also determined that North Barber Ramp 3 would only require minimal cutting and filling (± 10 ft) to achieve the proposed design (Figure 19).

Figure 19 Pre-construction Barber Ramp 3 valley. Note sediment deposition and channel braiding.

The author (C. Cooper) was the lead on developing the design for Barber Ramp 3. The design process began by identifying a main channel upstream elevation and slope (approximately -0.5% at 5,345 ft). This design constraint determines the upstream characteristics of the design, including sub-channel tie-in elevations. Sub-channel locations were then chosen to drain precipitation from existing depressions in the surrounding re-vegetated areas. The Rosgen classified A-type sub-channels were selected to fit drainages in the -4% to -14% slope category. The main channel was designed as a C-type channel that would be able to convey larger flow rates at a lower slope category (less than 4%). An additional upstream watershed area of approximately 342 acres was accounted for in the design of the main channel so that drainage from future reclamation areas can connect to the main channel of Barber Ramp 3.

The following are key design details that describe the size and scope of the design:

- Equipment Used – Caterpillar D11 and D10 Dozers, Caterpillar 637G Scrapers
- Main Channel Length - 2,900 ft.
- Sub-Channels (A-Type) - 6
- Acreage - 42
- Topsoil – 33,000 cyd.
- Re-grading – Aug. – Nov. 2008
- Topsoiling – Dec. 2008
- Seeding – Spring 2009

Once a final draft design was established, the authors conducted site visits during September of 2008 to LPM and SJM to observe existing designs and speak with operators familiar with fluvial geomorphic designs and their construction. A key learning from site visits was around the types of field controls being utilized for the construction of other designs and how they could be implemented at Navajo Mine. LPM used machine control which is comprised of in-cab GPS systems (Dozer 2000) on dozers to complete fluvial geomorphic designs. SJM used a combination of traditional survey cut-and-fill staking and Dozer 2000 as controls for fluvial geomorphic designs. The Navajo Mine Projects Engineering Department and Survey Department determined that Dozer 2000 would be used with survey cut-and-fill staking as a contingency. Navajo Mine operators responsible for the construction of the fluvial geomorphic designs were brought to LPM to observe designs that were in-progress as well as completed designs.

After the field visit to LPM, the operators were able to understand and implement the design concepts while constructing the Barber Ramp 3 fluvial geomorphic design. Use of in machine control was hampered by poor availability of the GPS systems signal and limited access to the GPS signal repeating equipment. To meet this challenge, cut-and-fill staking was used in absence of GPS coverage. This created extra demand on the Navajo Mine Survey Department. BNCC recognized opportunities to improve future fluvial geomorphic reclamation projects by purchasing GPS equipment that would be used exclusively by the geomorphic reclamation crews. Engineering staff were available during the dayshifts and partially during swing shifts for assistance and communication about the design requirements, but many nightshifts were not supervised by engineering staff. This challenge was remedied by taking pictures of the work area and using them in conjunction with sketches to create packets that could be distributed to nightshift foremen and operators. All shifts were sometimes preceded or followed with sand box modeling exercises.

In late November 2008 with completion nearing of regrading at North Barber Ramp 3, the design was inspected, and a dozer operator was present to handle any last minute work that was necessary to complete the design. Figures 20 and 21 show the project area after landform construction was completed.

Figure 20 Barber Ramp 3 during sub-channel construction

Figure 21 Barber Ramp 3 during sub-channel construction and prior to topdressing.

The design was then scheduled for topdressing in December 2008. This schedule was aligned with the arrival of three 637G scrapers from LPM along with their experienced operators. Topdressing was placed in accordance with BNCC's permitting requirements. Topdressing was not specifically placed in channel bottoms, as natural processes will influence its placement in these areas. Figures 22 and 23 show the north side of Barber Ramp 3 after topdressing has been laid down.

Figure 22. Barber Ramp 3 after topdressing

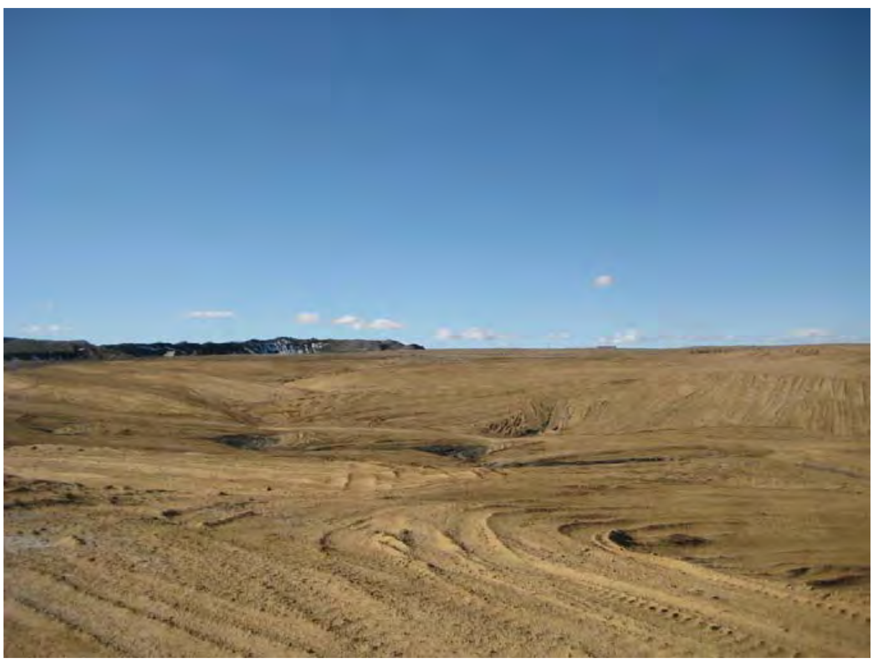

Figure 23. Barber Ramp 3 after topdressing

Barber Ramp 3 is scheduled for completion during the spring of 2009 with seed placement and irrigation treatment by Navajo Mine's revegetation crew. There have been challenges during BNCC's first attempt at fluvial geomorphic reclamation design, but the Navajo Mine staff has gained key learnings so that future fluvial geomorphic reclamation can be integrated as standard practice, where appropriate. BNCC will continue to evaluate the stability of this project after observing the area after several precipitation events and will hopefully demonstrate the effectiveness of fluvial geomorphic reclamation processes in regards to decreasing associated reclamation and maintenance costs, and effectiveness of the design to promote and maintain diverse vegetation.

Navajo Mine Extension Project

The NMEP is a proposed surface mine that covers 13,000 acres, located within Areas 4 South and 5 of the BNCC lease (Figure 1). The topography in the NMEP area is defined by generally rolling terrain with areas of steep escarpments, badlands, sand dunes, incised drainages and arroyos. The area is bordered to the west by escarpments that are part of the ancient channel walls of the Chaco River. There are two major arroyos that traverse the permit area and flow into the Chaco River, Pinabete Arroyo and No Name Arroyo. Area 4 South is divided into western and eastern portions by the Pinabete Arroyo (Figure 24). This arroyo has headwaters of about 44 square miles upstream, off lease to the east. It enters Area 4 South at the south east corner and exits at the northwest corner. The majority of terrain within Area 4 South drains to the Pinabete Arroyo. The No Name Arroyo traverses the north eastern portion of Area 5. The majority of Area 5 drains into No Name Arroyo. The No Name Arroyo has headwaters of about 2 square miles.

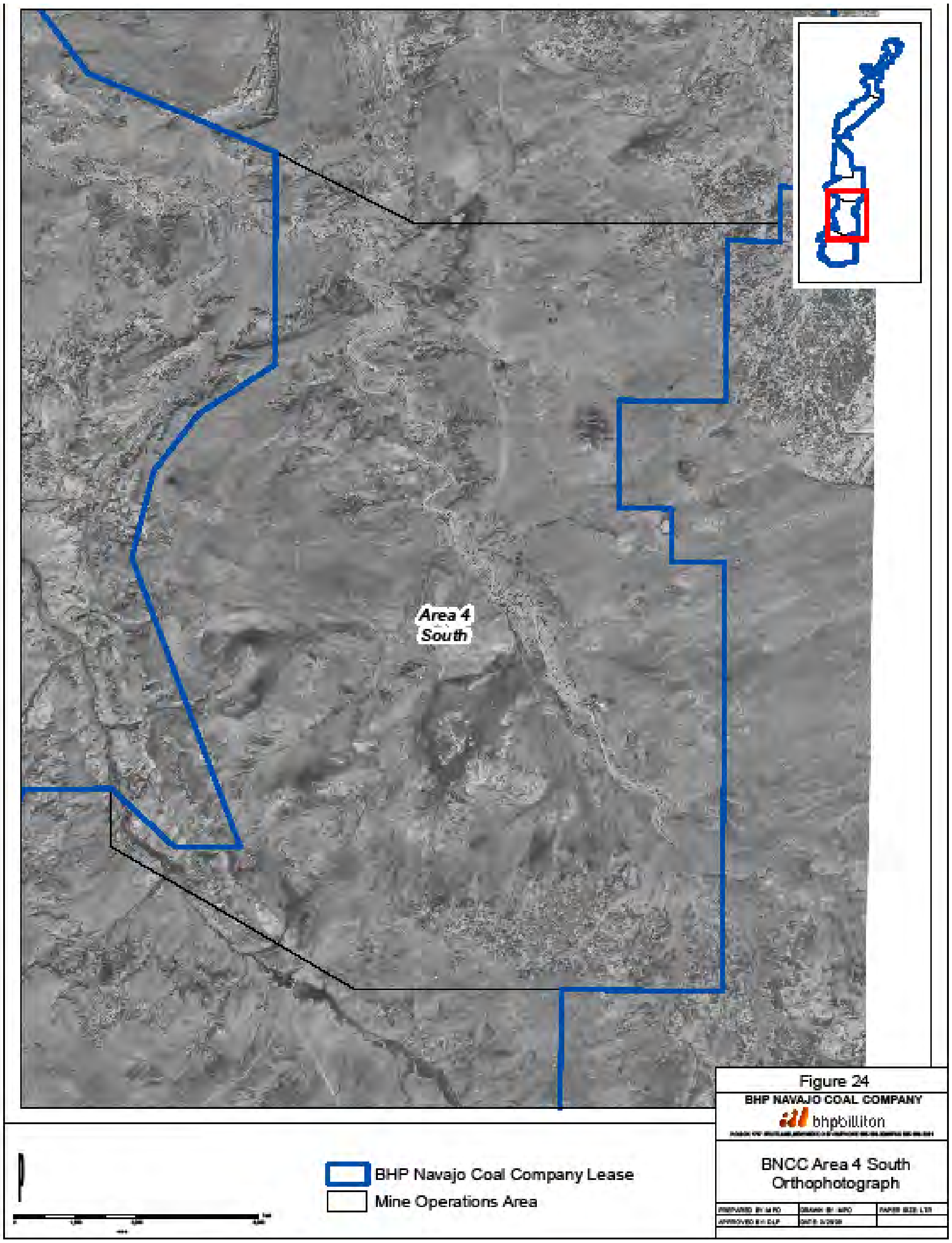

Figure 24. Orthophotograph of Area 4 South showing the major and minor ephemeral arroyos.

BNCC is in the process of developing the SMCRA permit for submittal to OSM. The conceptual mine plan includes two draglines that will mine from the outcrops on the western side of lease toward the center of the San Juan Basin to the east. Operations will begin in Area 4 South and move to Area 5. Based on conceptual mine plans, this proposed mine has an estimated mine life of approximately 35 years in Area 4 South and 15 years in Area 5. During mining operations, the Pinabete Arroyo will be mined through. In the interim, the Pinabete Arroyo will be temporarily diverted, via an engineered attenuation structure, into the No Name Arroyo. The conceptual reclamation plan for Area 4 South includes the reconstruction of the Pinabete Arroyo. BNCC used the Geofluv™ approach to develop the Area 4 South AOC surface and the Pinabete Arroyo reconstruction. The author (D. Place) was lead and worked with a consultant on the fluvial geomorphic design for Area 4 South.

Field reconnaissance studies determined the appropriate reference watersheds for obtaining site specific fluvial geomorphic input parameters. The field studies determined drainage density, A-channel reach, ridge to head of channel distance, as well as local base level elevation and slope. Drainage density was initially measured from orthophotography and field verified during reconnaissance. A-channel reach lengths were determined by walking up the channel to the uplands and ridges (Figure 25). Ridge to head of channel measurements were made at the top of these steep channels.

Figure 25. Field reconnaissance to determine A-channel reach length and ridge to head of channel length.

Sandstone knick points were noted in both steep and shallow channels throughout the study area (Figure 26). Some of these sandstone knick points created vertical drops from one to three feet. Local base level elevation and slope for the Pinabete Arroyo along with upstream base elevation and slope were measured using GPS equipment. Several profile and cross-sections were surveyed along the entire length of the Pinabete Arroyo within the lease boundary.

Figure 26. Sandstone knick points in a channel in Area 4 South.

Prior to beginning the design work for the AOC and Pinabete Arroyo reconstruction BNCC established a list of goals for the design. There were five mine related design goals for the AOC. These goals became the metric by which the alternatives designs were judged and the final selection was made. First, the design must comply with SMCRA by creating a stable landform supporting vegetation that is compatible, diverse, effective and permanent. Second, the design must incorporate fluvial geomorphic reclamation principles that are applicable to our site specific conditions. Specifically, the designed drainages need to convey water from both upstream watersheds and reclamation areas (constructed uplands). Third, the design must meet material handling goals by supporting optimized earth work and cut/fill depths. Fourth, the design and subsequent construction must provide for the stable and permanent placement of CCB in designated locations. Fifth, the design must be compatible with contemporaneous construction requirements.

The AOC and Pinabete Arroyo reconstruction presented in Figure 27 represents the design that best met all the goals and metrics established for the design. This design was tested through SEDCAD™ modeling to compare pre-mine sediment transport with post-mine sediment transport. The two significant challenges in the design were developing an arroyo design for a 50 square mile watershed and re-establishing drainages without the natural sandstone knick points that exist in the pre-mine terrain. The Pinabete Arroyo reconstruction is designed to pass 1,300 cfs for the bankfull events and 4,500 cfs for the flood prone events. The upstream watersheds on the east side of the permit area will be re-established when the temporary diversion is removed. This will allow the entire Pinabete Arroyo watershed to flow through the reconstructed channel to the Chaco River. The uplands on the west side of the permit area have relatively small watersheds when compared to the east side. These watersheds, along with watersheds of the reclaimed uplands will be connected to the reconstructed Pinabete Arroyo by a single major sub-channel. By routing the west side in this way, BNCC overcame the challenge of constructing channels to grade with the Pinabete in the absence of bedrock control while meeting contemporaneous construction requirements. The success of implementing a fluvial geomorphic approach to reclamation at the NMEP is evidenced by the successful design of a major arroyo and uplands in a configuration that allows for contemporaneous construction and facilitates operational surface water management.

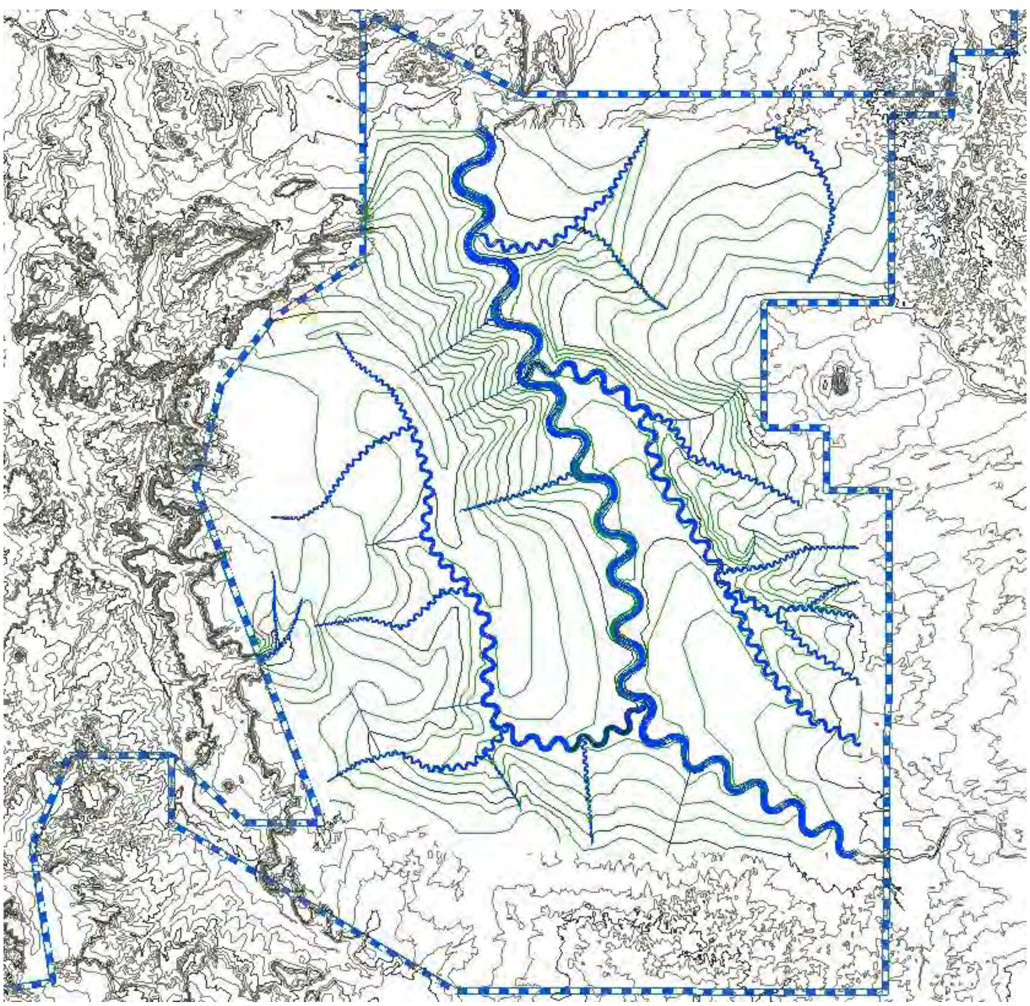

Figure 27 Conceptual AOC and Pinabete Arroyo reconstruction in Area 4 South.

Summary of Success, Challenges, and Future

BHP Billiton's New Mexico coal operations have achieved successes and overcome challenges in implementing the fluvial geomorphic approach in designing and constructing geomorphic reclamation. SJCC was selected to participate in the testing of the beta version of the Natural Regrade module during development through release in May 2005. SJM earned the Office of Surface Mining's 2004 National Reclamation Award and 2004 Best of the Best award for reclamation of a final dragline pit area in the South Lease Extension, known as Cottonwood. This reclamation demonstrated the successful implementation of both steep and flat slope geomorphic reclamation. In 2008, SJCC completed construction of 1,400 acres of geomorphic reclamation at LPM, including construction of bluff replacement features. BNCC completed design and construction of the first fluvial geomorphic reclamation design at Navajo Mine along a ramp in a final dragline pit with support from OSM in 2008. BNCC will submit a fluvial geomorphic based AOC and major arroyo reconstruction for approximately 7,000 acres in the coming year for NMEP.

SJCC and BNCC have overcome several challenges in implementing geomorphic reclamation. The operations continue to expand the skill sets of professional staff to include fluvial geomorphology and operational staff to understand the construction of such landforms. SJCC and BNCC have nine scientists and engineers who have completed the introductory GeoFluv™ course. Four of these individuals have completed designs that have been constructed. We identified challenges in communicating fluvial geomorphic designs and construction requirements to equipment operators and we implemented various methods to improve communication including the use of maps, photographs, and sandbox demonstrations. We utilize both traditional staking and equipment control to construct our designs. We have developed an operational staff of ten individuals who have worked on geomorphic reclamation construction projects. The skills we are developing will help us continue to be successful at identifying opportunities to implement the fluvial geomorphic approach in our reclamation activities.

The future of geomorphic reclamation at BHP Billiton's New Mexico coal operations is bright. We continue to improve our design and construction skills to achieve successful, sustainable reclamation and to identify opportunities to implement our geomorphic reclamation strategies. We are in the process of developing study plans to monitor the geomorphic reclamation at all three operations to extract key learnings that support continual improvement at implementing the fluvial geomorphic approach. These plans may include:

- Detailed sediment transport modeling and monitoring to compare predictions with measurements;
- Vegetation establishment as a function of slope and aspect;
- Determination of design and construction variances and their influence on reclamation performance; and
- Wildlife utilization of geomorphic terrain and habitat.

We also look forward to monitoring the performance of our geomorphic reclamation areas to quantify its success through maintenance cost reductions, improved bond release timing, and revegetation success.

Acknowledgements

We thank the men and women at BHP Billiton's New Mexico coal operations for their hard work and daily focus on Zero Harm, supporting our Charter and Sustainable Development Policy. We would like to acknowledge Mickey Ginn, Trevor Harvey, Jeremy Niemeier, Matt Owens, and Steven Perkins, for their contributions to this paper. We also thank the Office of Surface Mining Reclamation and Enforcement for providing the opportunity for members of academia, government and industry to come together to share and discuss fluvial geomorphic reclamation at coal mining operations in the U.S.

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Session 4

GEOMORPHIC RECLAMATION IN THE MIDWEST

Session Chairperson:
Bryce West
Peabody Energy
Evansville, Indiana

Anthropo-Geomorphology of Streams, Wetlands and Landscapes of the Illinois Basin, Data Collection & Restoration Techniques
Tim Sandefur, Wetland Services, Inc., Corydon, Kentucky

Current Stream Mitigation Requirements & Results
Mike Ricketts, US Army Corps of Engineers, Newburgh, Indiana

From Rip Rap to Riffles: The Evolution of Stream Reclamation In the Indiana Coal Fields
Ramona Briggeman, Indiana DNR, Division of Fish & Wildlife, Jasonville, Indiana

Western Kentucky Perspective: Past and Current Practices, Benefits and Challenges
David Lamb, P.E., Associated Engineers, Inc., Madisonville, Kentucky and Darrin Parrent, EIT, T.H.E. Engineers Inc., Lexington, Kentucky

Illinois Stream Restoration - Opportunities for Habitat Enhancement: Policy, Principles and Practices
Jack Nawrot, Cooperative Wildlife Research Lab, Southern Illinois University, Carbondale, Illinois
William G. O'Leary, Land Reclamation Division, Office of Mines and Minerals, Benton, Illinois
Pat Malone, Office of Realty and Planning Illinois Department of Natural Resources, Springfield, Illinois

Geomorphic Reclamation in the Midwest, Industry Perspective: Past and Current Practices, Benefits and Challenges
Scott McGarvie and Rich Williams, Peabody Energy - Midwest Group, Evansville, Indiana

ANTHROPO-GEOMORPHOLOGY OF STREAMS, WETLANDS, AND LANDSCAPES OF THE ILLINOIS BASIN, DATA COLLECTION AND RESTORATION TECHNIQUES

Tim Sandefur
Wetland Services, Inc.
Corydon, Kentucky

Abstract

The purpose of this presentation is to: (1) illustrate anthropogenic impacts and current geomorphic conditions of Streams and Wetlands in the Illinois Basin; (2) demonstrate data collection techniques and interpretation methodologies; and (3) apply those results to successful restoration strategies.

Modification of the vegetation, hydrology and topography of the Illinois Basin since European settlement has been extensive. The relatively flat topography from glacial, alluvial, and eolian deposition readily facilitated conversion of the region to modern land uses. These conversions generally include agriculture, river navigation, flood control, mining, and urban.

Large-scale delineation and assessment requires the use of advanced methods and technology to effectively gather, organize, and process large data sets. Microsoft Access databases were used to record, interpret, quantify, and correlate existing conditions.

The extent of conversion impacts, whether direct or indirect, is virtually all-inclusive, and leaves very little if any true reference area for use in restoration design. The advanced science and nature of wetland restoration can be used to target specific wetland types and functions without the use of traditional reference data.

Stream restoration however, does require reference data in the form of a regional curve along with various other Rosgen-based measurements. With the exception of several non-representative landforms, very few reference areas still exist for use in stream restoration design. As such, it has become necessary to base stream design on a combination of both regional reference data and reference data from other applicable eco-regions.

These data were considered and combined with a basic set of target parameters to produce a stream design process that is both replicable and modifiable to be site specific or updated as necessary. The long-term goal of this stream restoration process is the development of a free-form channel in dynamic equilibrium and with the ability to provide natural and sustainable stream function.

Introduction

Modifications to the Illinois Basin have been extensive because the area is relatively flat, fertile and in close proximity to navigable rivers which made it prime for settlement. The flat topography and unconsolidated surface materials readily facilitated conversion of the region over to today's modern land uses which generally include river navigation, agriculture, flood control, mining, and urban development.

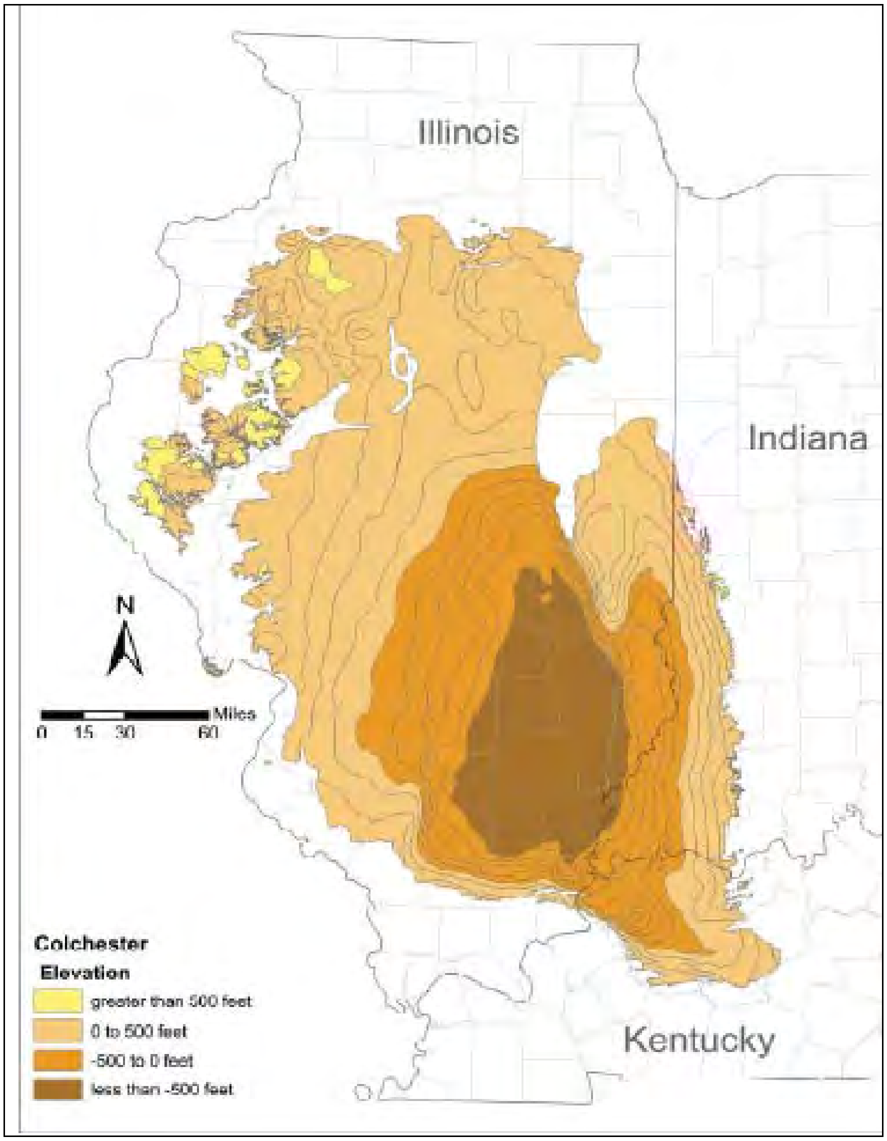

Figure 1. Illinois Coal Basin.

Wetland Services

Wetland Services specializes in Wetland Delineation and Stream Assessment, Permitting and Mitigation; with an end goal, of course, being mitigation in a manner that suffices regulatory requirements, and is also applicable in real-world scenarios.

Objective

Our Initial Objective was to conduct stream assessment, wetland delineation, RBP data and water quality sampling.

The first challenge we ran into was recording large data sets in remote locations, and needed to do so in a manner that facilitated post-processing of that data.

In Step 1, we began by modifying enclosed trailers (Figure 2) such that after equipment is unloaded they can serve as mobile offices. Field ecologists equipped with two-way radios report data back to a technician who loads it directly into a database. This precludes the use of paper data sheets or the need to carry sensitive electronics such as laptops into the bush.

Figure 2. Mobile office.

In step 2, the data technician (Figure 3), in combination with library references provides support to the field ecologist who can now travel light and focus his attention on the land. At the end of the day, the field ecologist returns with GPS tracks and photos that are loaded into the database and processed automatically.

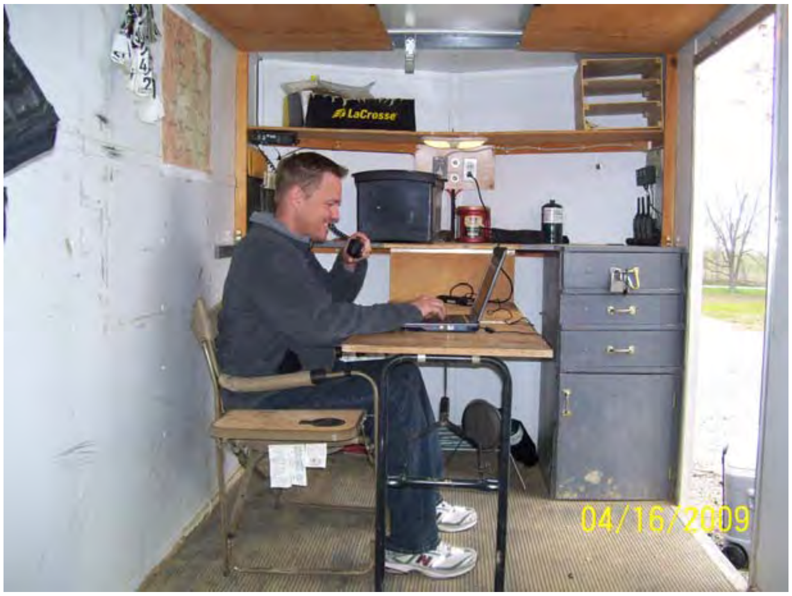

Figure 3. Data analysis.

Watershed Approach

We apply the Watershed Approach (Figure 4) to our project sites with a watershed being defined as any drain that leaves the permit boundary on its own accord. This project has two watersheds, 1 and 2.

Figure 4. Watershed identification.

Land Use

Land use designations were developed so we could look across a site and identify the various conditions in which the streams are developed. These conditions include reclaim, excavated, prelaw, agriculture, and mixed. Here in watershed 1, we have excavated wetland 3 and know this wetland was likely caused by or has been impacted by excavation. In fact, this particular area was completely cleared and farmed in the ‘60s and ‘70s. It was subsequently abandoned, likely due to wetness and marginal productivity.

Most of these land uses are self-explanatory. ‘Natural’ is one we reserved to depict undisturbed, closed-canopy forest conditions. Mixed is a land use designation where Agriculture and Natural occur in mosaic such that Agriculture is having a detrimental influence on otherwise natural streams.

Analysis

Back in the office, our database allows us to look at the individual parameters of each stream. We can also look at each streams functionality status (Table 1). Functionality is based on the State of Missouri stream mitigation method. The Missouri protocol was developed by a group of Corps districts west of the Ohio River. Being a Rosgen-based approach, this method allows us to simply conduct a standard Rosgen assessment while letting Access recognize impairments and assign functionality. We can look at the streams overall functionality status and also see which parameters caused that stream to be less-than fully functional.

Permitting

As we move to the permitting phase, we look at the Cumulative Stream Functionality across the entire site including linear-feet and/or percent of streams that are fully functional, moderately functional, and functionally impaired streams. We can also look at floodplain and riparian areas. Once we understand the existing conditions, we can develop a mitigation plan commensurate with the proposed impacts. This allows the Army Corps of Engineers to compare the Proposed Impacts to the Mitigation to ensure the project has a Cumulative net benefit in the watershed. On a degraded site, it doesn't take much mitigation to have a net benefit such that the project can be viewed as an opportunity for ecosystem restoration.

Table 1. Steam Functionality.

Unit Data	**Unit Functionality**	**Cumulative Functionality**
Length	Overall Stream	Linear feet of Fully Functional, Moderately Functional and Functionally Impaired Stream
Distance	Entrenchment	Average Floodplain Width
Sinuosity	Stream Type	Total Floodplain Area
Wbot	Vegetation Left Bank	Average Riparian Width
Wbkf	Vegetation Width	Total Riparian Area
Wfpa	Vegetation Right Bank	Existing conditions are compared to proposed mitigation to ensure a Net Cumulative Benefit in the watershed.
Dbkf	Vegetation Width	
Entrenchment Ratio	Bank Erosion	
Width/Depth Ratio	Channel Stability	
Classification	Aggradation/Degradation	
VegL	Alterations	
Width	Functionality determined by the Rosgen-based Missouri Protocol.	
VegR		
Width		
Flow		
Depositional Features		
Bank Erosion		
Agg/Deg		
Stability		
Alterations		
%Riffle		
%Run		
%Pool		

Figure 5. Stabilized stream channel in agriculture land use.

After we covered ~60,000-acres, we found that very few streams on low and moderate gradients remained completely undisturbed. Of the streams we encountered: 45% are Functionally Impaired; 45% are Moderately Functional; with the remaining 10% being Fully Functional. Of this 10%, about 1% were reference-quality. These impairments are mostly attributable to Agriculture that has resulted in Entrenchment and a lack of Riparian vegetation.

Mixed land use streams generally occur on wooded sideslopes below a ridge that's being farmed. Historically, these areas were used to graze livestock which are notorious for traveling single-file straight up and down which creates nick-points. After the days of cattle and hogs ended, the fences came down and modern Agriculture took over and now sends high-velocity, sediment laden runoff downslope. Over time erosional features form that begin to function as, or can be misconstrued as ephemeral streams. These areas of concentrated flow expedite the transport of water out of the watershed that could otherwise go to ground water to drive intermittent stream conditions lower down the valley drain. With that said, we need to be very cautious about reconstructing watersheds with highly dissected side slopes and a large percentage of ephemeral drains.

Figure 6. Mixed land use stream.

Streams in a Natural Land use generally still receive some degree of negative inputs similar to Figure 6. Logging combines with upstream agriculture to cause the majority of stream degradation in otherwise natural areas. This particular stream (Figure 7) has been flushed in a manner such that it has lost part of its ability to support intermittent flow conditions, which is why it's dry by mid-July.

Figure 7. Natural land use stream.

Streams (Figure 8) developed in prelaw spoil tend to be unstable, especially if the bank materials are inhospitable for vegetation. Over time, these gullies widen such that C or E channels often develop down inside of these larger cuts. Even though this stream may regain some degree of stability, not evident in Figure 8, this system has lost water table and other valuable ecosystem attributes.

Figure 8. Streams influenced by mining.

Figure 8. Landscape influenced by logging. Logging can make stream assessment very difficult, especially after the area revegetates for several years.


Figure 9. Channelized Stream. Excavation, channelizing, dredging, straightening negates stream function.

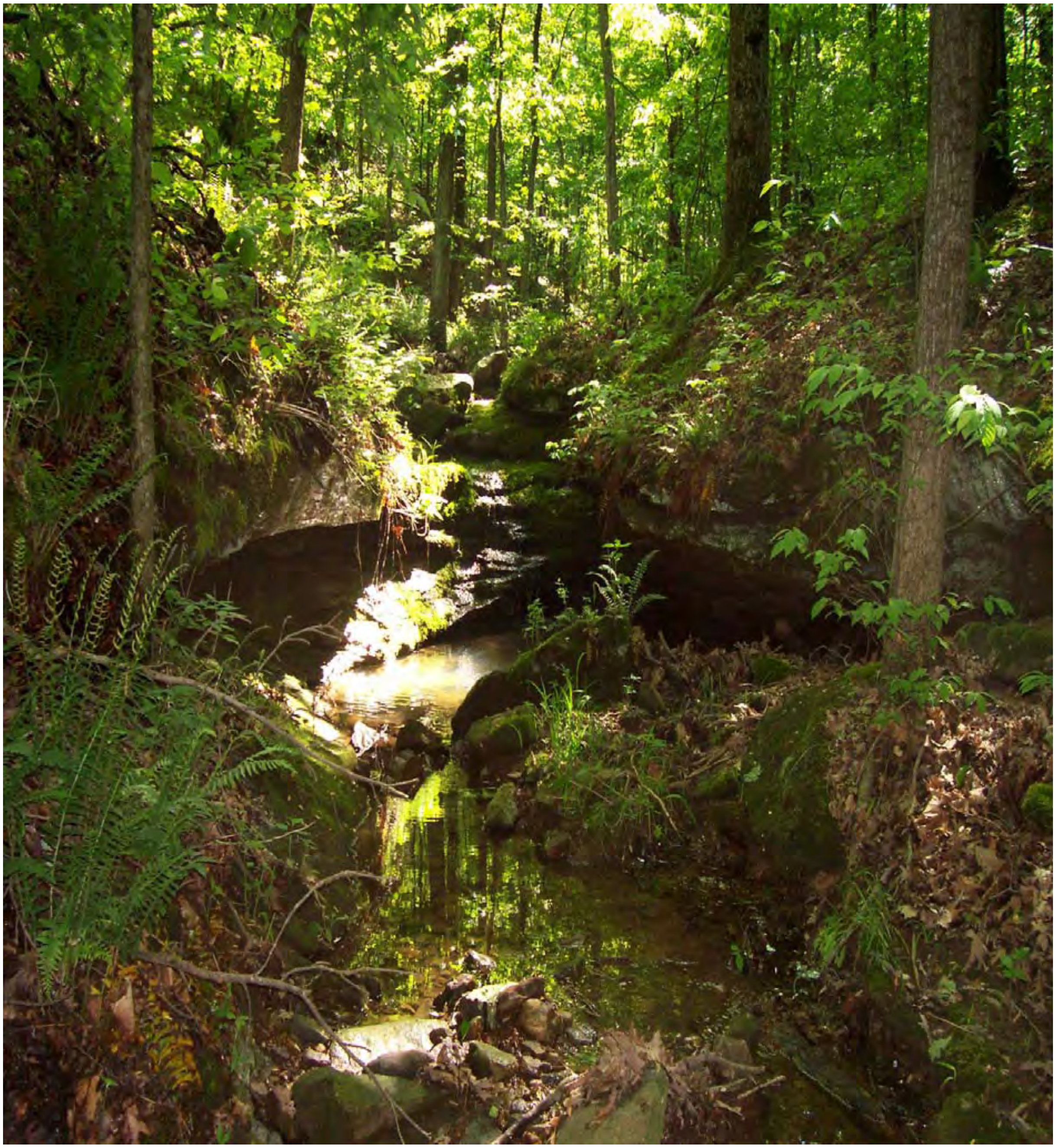

Figure 10. Reference stream conditions. Reference conditions are those perfect stream conditions we want to mimic in mitigation.

Reference Stream Design Parameters

Establishing Reference Stream Design Parameters is the first step in natural stream design. We used reference streams as well as stream mitigation sites to see what was working as well as what to avoid.

Steam Channel Design

Restoration Goal

Restoration Goal: To develop a replicable stream construction program that creates a free-form channel, in dynamic equilibrium, with the ability to provide natural and sustainable stream function.	
Reference Parameters	
Bankfull Volume	Average velocity
Return Interval	Average shear stress
Width to Depth ratio	Meander length (Lm)
Channel average depth (D)	Beltwidth (Wblt)
Channel top width - riffle (Wriffle)	Riffle length (Lriffle)
Channel cross-sectional area (A)	Run length (Lrun)
Channel depth - riffle (Driffle)	Pool length (Lpool)
Channel bottom width (Wbot)	Glide length (Lglide)
Wetted perimeter (P)	Run depth (Drun)
Hydraulic radius (Rh)	Glide depth (Dglide)
Floodplain width (Wfp)	Pool width (Wpool)
Channel slope (Save)	Pool depth (Dpool)

Regional Curve

We also developed a Regional Curve (Figure 11) for the Illinois Basin which came out on the high end along with other Agriculture dominated states subject to regular hurricane influence. Curves are used to determine a stream’s bankfull volume based on its drainage area. This volume of flow is a flood event that reoccurs every one to two years. Once we have this volume, we set the streams width to depth ratio, then all of the other design parameters tie back to either bankfull width or bankfull depth by ratio. In order to prevent erosion during early establishment, we undersize the channels slightly in order to get the water out of the channel and up on the floodplain. Containment of the 25-year flood event, generally required by SMCRA, now occurs in the flood prone area.

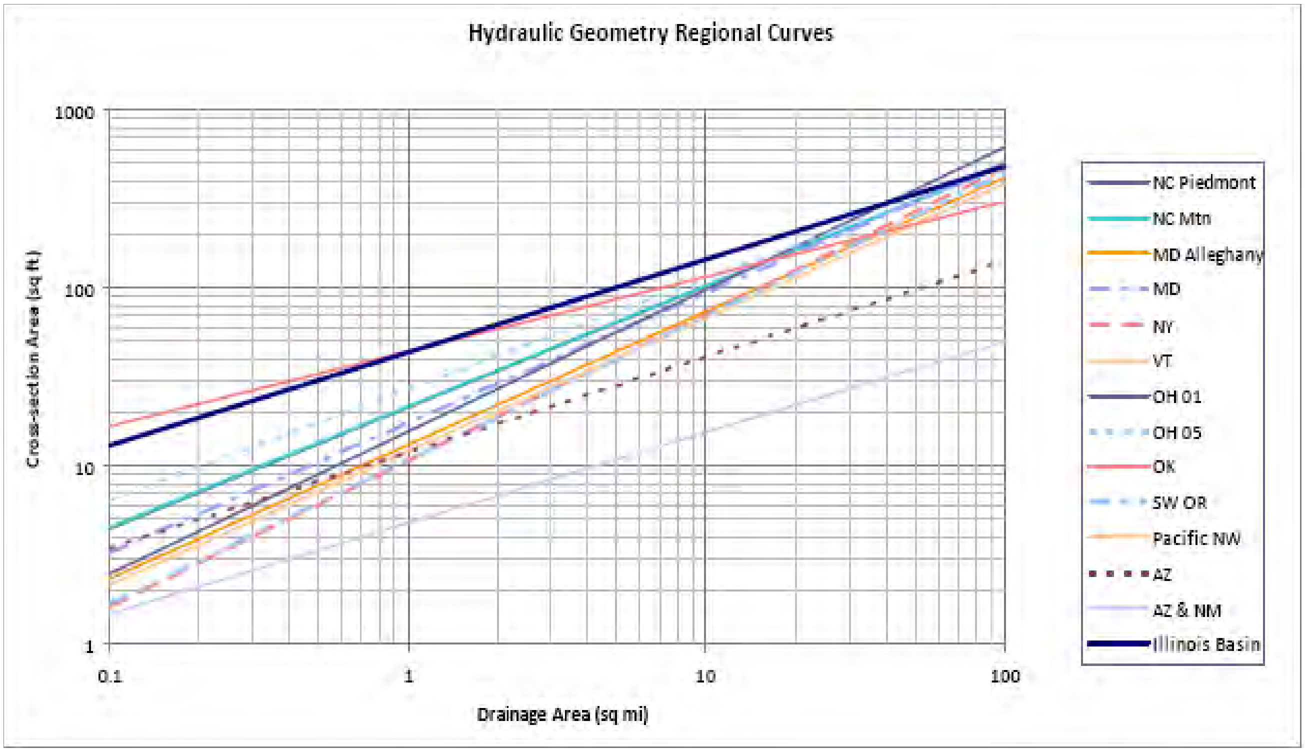

Figure 11. Hydraulic geometry regional curves.

<u>Stream Channel Design</u>

We took the Reference Parameters and Regional Curve data and applied them to a database so that we now only have to input the Watershed Area and Valley Slope. The software automatically outputs the design stream for that particular point in the valley.

Table 2. Stream Design Database

Site-specific Input				**Profile**		
Watershed area =	640	acres		L_{riffle} =	20	ft
Valley slope =	0.01	ft/ft		L_{run} =	9	ft
Reference Parameters				L_{pool} =	20	ft
Width/Depth ratio =	15			L_{glide} =	9	ft
Manning's n =	0.035			$D_{riffle\ =}$	0.9	ft
Channel side slope =	3	:1		$D_{run\ =}$	1.3	ft
Floodplain width ratio =	10			$D_{pool\ =}$	1.9	ft
Pool depth ratio =	2			$D_{glide\ =}$	1.3	ft
Point bar slope =	6	:1		**Plan View**		
Sinuosity =	1.3			L_m =	92	ft
Meander length ratio =	9			W_{blt} =	48	ft
				W_{fp} =	102	ft
Riffle Cross-Section				**Riffle Material**		
W_{fpa} =	102	ft		d84 =	64	mm
W_{riffle} =	10.2	ft		Substrate depth =	0.6	ft
W_{bot} =	4.6	ft		Riffle length =	20	ft
$D_{riffle\ =}$	0.9	ft		Riffle width =	4.6	ft
M =	3	:1		Volume per riffle =	2.2	cu yds
W_{fp} =	102	ft		**Erosion Control Specs**		
Pool Cross-Section				Average shear stress =	0.31	lbs/ft^2
W_{fpa} =	102	ft		Average velocity =	2.9	ft/sec
W_{pool} =	18.7	ft				
W_{bot} =	4.6	ft				
D_{pool} =	1.9	ft				
M =	3	:1				
B =	6	:1				
W_{fp} =	102	ft				

We then applied the database to a GIS system, in this case ArcView, which can read a digital elevation model of the existing topography to analyze the valley as it automatically resizes and configures the stream down slope. This design is uploaded back into GPS for layout and construction. These GPS files can also be used for in-cab monitoring or machine controlled excavation during construction.

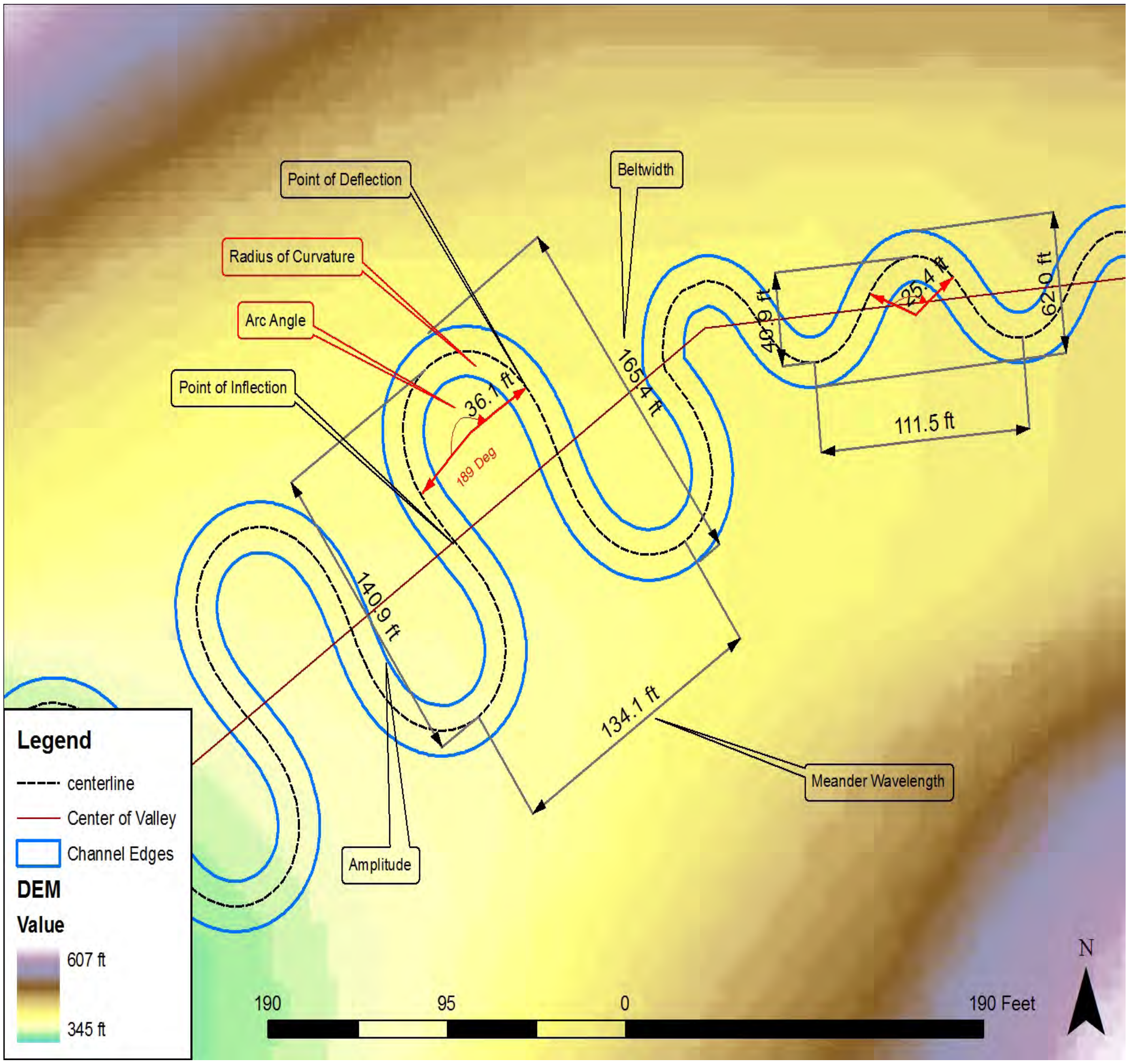

Figure 11. Stream channel design.

Stream Channel Construction

The most important first step is to reconfigure an alluvial valley during the backhaul process because we all know how expensive it is to double-handle material. You can see the sideslopes tailing down to the valley floor as the valley meanders nicely down slope. We then need to top-soil this valley as deep as possible in order to maintain the stream in a perched channel, then it needs to sit for a while, preferably thru a winter. We know there will be some degree of differential settling which also allows the soil to aggregate and build structure. And even though we'll disturb this area during construction at least there will be some vegetation.

Figure 12. Alluvial Valley ready for stream construction.

Whoever's lucky enough to build this stream has a diversion that's sending the water over to the next watershed which will let them work dry. After the stream's built, they may use an undersized pipe to allow a regulated amount of water to occupy the new channel to establish vegetation and stability before they release the full force of the watershed.


Figure 13. Stream channel during construction.

Layout and construction of the channel is very basic so long as we hit our target grades and install the structures properly. Materials including rock, logs, root wads should be spotted during the backhaul process. Rock can be substituted for most any log structure, but it's more tedious.

Figure 14. Three year old channel.

This three year old channel is shallow to the surface, with full access to a flood plain and a high degree of both bank and channel stability. New point bar development indicates that the channel is adjusting naturally and stably, and is transporting nutrients and sediment downstream sustainably.

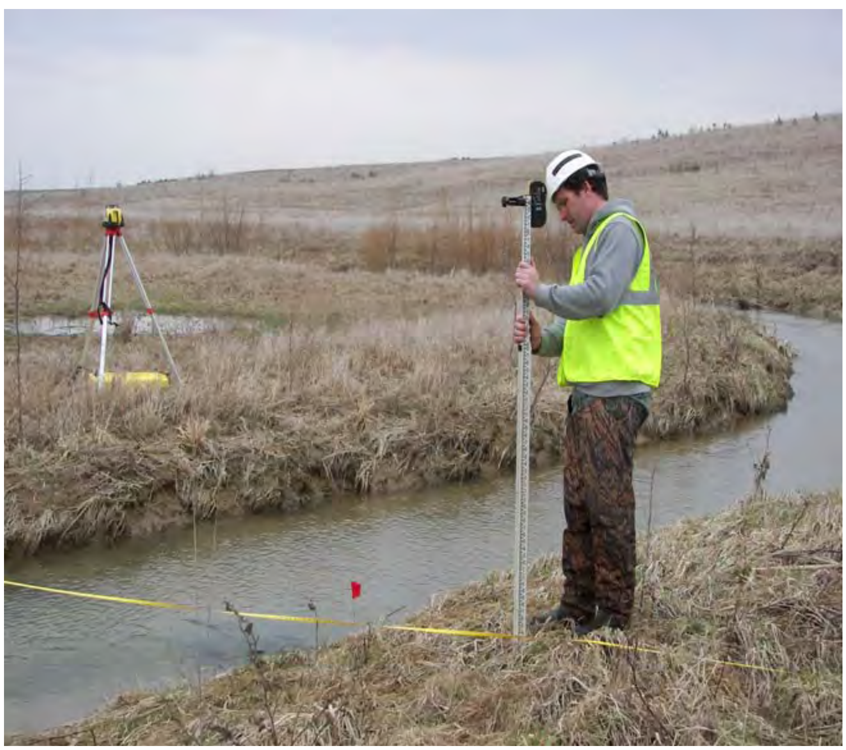

Figure 15. Vegetated stream banks.

Well vegetated bankfull indicators allow us to monitor morphologic development and success criteria. The inside bends of low-gradient streams make good locations for wetlands. This wetland will catch and store water. The wetland will then clean it up and meter it back into the stream to help drive intermittent flow conditions. The science and technology of stream mitigation on reclaim sites is developing such that we can mitigate in a manner that provides an ecological lift and Net Cumulative Benefits, especially to impaired watersheds.

Tim Sandefur is a managing partner of Wetland Services, Inc. He has been active in wetlands ecology either recreationally or professionally for over 23-years. Tim incorporated Wetland Services in 1997, and now maintains a wide range of regulatory services and clients. Wetland Services has conducted wetland and stream delineation, functional assessment, permitting and restoration (mitigation) on over 80,000-acres. He currently serves as a board member of the Pond Creek Watershed Conservation District, and is a board member and managing partner of Cypress Agricultural Services, LLC (a land trust company) and the Cypress Foundation (a 501c3 not-for-profit organization). His degree is a Bachelors of Science in Wetland Ecology from the University of Kentucky.

CURRENT STREAM MITIGATION REQUIREMENTS & RESULTS

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Abstract

The US Army Corps of Engineers is responsible for administering the permitting program for Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. Part of this responsibility includes working with Coal Operators to delineate "jurisdictional waters of the US," develop permitting standards, mitigation plans, and success standards. Jurisdictional waters of the US include wetlands and perennial, intermittent, and ephemeral streams as identified in the 2007 Rapanos Supreme Court decision. Natural Stream reclamation is a relatively new and developing science in the Midwest. Geomorphic reclamation techniques appear to have the potential to be a significant step forward in the process of returning mined lands to a more natural condition. Geomorphic grading could provide additional opportunity for successful natural stream restoration.

This presentation will provide a brief explanation of the 404 and 10 programs. Also a description of Rosgen methods to capture physical characteristics of streams as well as an overview of the evolving stream mitigation and restoration requirements of the Louisville District will be presented. In addition, the current techniques which appear to be headed for success and those which appear headed for failure will be discussed and illustrated.

Legal Requirements

The U.S. Army Corps of Engineers is responsible for administering two laws. The first is Section 10 of the Rivers and Harbors Act of 1899. Section 10 ensures that no project may impede navigation or interstate commerce in navigable waters. Section 10 involves the regulation of the placement of any structure or work that takes place in, under, or over a navigable water effecting course, location, or condition of navigable capacity.

The second law is Section 404 of the Clean Water Act. This involves the regulation of the discharge of dredged or fill material into all waters of the U.S., including wetlands. Other examples of water of the U.S. are streams including ephemeral, intermittent, and perennial. Also rivers are included. Additionally, some ponds and lakes may be considered and is dependent on their location in the landscape along with their use.

Dredged material and fill material are different based on their origin. Fill material is basically derived from upland locations while dredged material is from waters of the U.S. Precise definitions of fill material may be found in the Federal Register entitled definition of fill material and is dated May 9, 2002.

Permits

There are currently two types of permits that can be utilized for impacts to waters of the U.S. associated with coal mining. Nationwide Permits (NWP) such as 21 Surface Coal Mining Operations, 49 Coal Re-mining Activities, and 50 Underground Coal Mining Activities may be used but it's necessary for these permits to reach minimal impacts after considering mitigation. It's also important to understand that all NWPs have timeline restrictions. The NWP program is evaluated every five years. The current period is for 2077 – 2012.

Individual permits (IP) are the other instrument that may be used for impacts associated with mining. Unlike NWPs, the "bar" is lower in that it is only necessary to reach a Finding of No Significant Impact (FONSI). An advantage also for using IPs versus the NWPs is that an IP may be authorized for the life of the mine.

Mitigation

As previously mentioned, mitigation is often required to off-set impacts to waters of the United States. Also, understand that according to which permit type is used, the quality and quantity of mitigation is important.

According to the mitigation rule (33CFR 332) that was published April 10, 2008, there is a preference or hierarchy for mitigation. That hierarchy is:

1. Mitigation bank credits
2. In-lieu fee program credits
3. Permittee – responsible mitigation under a watershed approach
4. On-site and/or in-kind permittee – responsible mitigation
5. Off-site and/or out-of-kind permittee – responsible mitigation.

It is important to realize this hierarchy is not rigid and that any proposed mitigation should focus on the environmentally preferable choice. Risk and uncertainty should be considered in the thought process.

When developing a mitigation plan, there are certain key items and factors to consider. One very important item for consideration is the length or duration of construction. The mitigation rule does state that at least a five year period of monitoring should take place. However, this does not mean that the five year period could not be reduced if success is realized at a sooner pace.

An essential to commencing with the mitigation thought process is the work plan. At a minimum, the plan should consist of:

1. Construction methods, timing, and sequencing,
2. Boundaries of proposed mitigation site,
3. Elevations and slopes,
4. Hydrology and hydrologic source (watershed size, discharge, regional curves),
5. Connectivity to other waters,
6. Proposed plantings,
7. Control of volunteer and invasive vegetation,
8. Erosion control,
9. Geomorphology and special stream structures,
10. Site management, maintenance plan, and long term plan for site, and
11. Stream dimensions including bankfull width/depth, bank height ratios, etc.

Planting information should also be included with mitigation plans. For the most part, proposed plantings are targeting hard mast species, but can be project dependent. Also include rates to be planted. Usually bare root plantings are at a higher rate versus container plantings. Each Corps District may have differing requirements based on the geographic area that they regulate.

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FROM RIP RAP TO RIFFLES: THE EVOLUTION OF STREAM RECLAMATION IN THE INDIANA COAL FIELDS

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Abstract

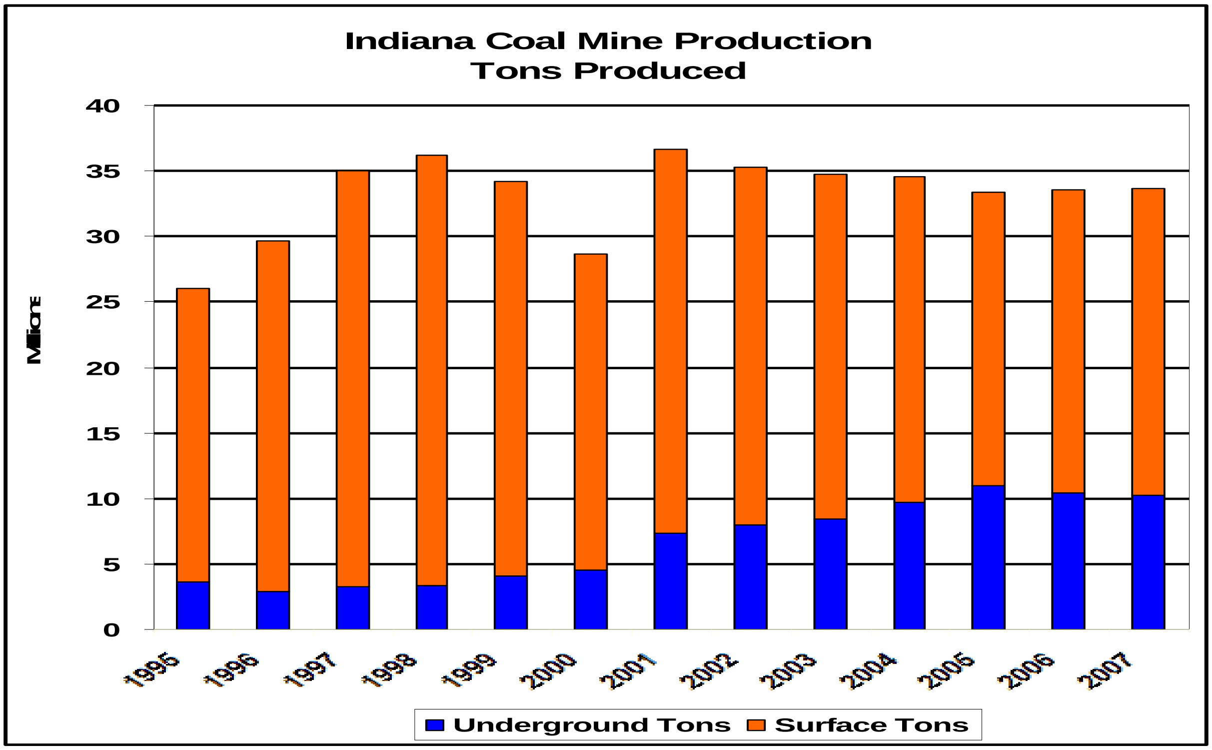
Restoring drainages has been a requirement for coal mine reclamation since the Surface Mining Control and Reclamation Act (SMCRA) was signed into law on August 3, 1977. Indiana achieved primacy in 1982. In the beginning, in highly agricultural Indiana, the major focus when constructing drainages was soil stability and water conveyance. Stream banks were heavily armored with rip rap. Rip rap check dams were installed to slow water velocities and ensure no erosion of soil would occur. Although this appeared successful from an erosion control and water conveyance standpoint, the wildlife value of these drainages had been lost or severely degraded. With the maturation of the program, wildlife related values are being given the same consideration as the others. Streams are being designed to mimic natural landforms. Structures are placed in the streams that not only slow water velocity but also increase wildlife habitat within the stream itself. Many benefits of this type of stream reclamation exist (increased wildlife habitat, less maintenance, aesthetics, better flood control, etc). However, many challenges also exist (land use restrictions, seemingly conflicting regulations, multi-agency jurisdiction, landowner concerns, the learning curve, etc). Mine reclamation is an opportunity to landscape on a massive scale. In regards to acres reclaimed, stream reclamation is only one small part of this process but can impact the success of the entire project. Geomorphic reclamation and natural stream design is a step in the right direction towards successful, sustainable reclamation.

Indiana Facts

Before a discussion on stream reclamation on Indiana coal mines can be discussed, I believe it is important to give some facts about Indiana itself and Indiana coal mining. Coal mining is big business in Indiana. All mining is located in the Southwestern part of the State, roughly a 24 county area. We are part of the Illinois Coal Basin which covers Ohio, Illinois, Indiana, Kentucky, and into Tennessee. We are usually 8th or 9th in the nation for production. Indiana generally produces 32-35 million tons of coal/year. Indiana is still mostly a surface mining state with 68% Surface Production and 32% Underground Production. However, there has been an increase in the number of underground applications in the last few years. 10,000 acres/year of mined lands are affected and reclaimed. 97% of Indiana's electricity is from coal. Generally surface coal reserves are <200 feet. Truck/shovel operations dominate the industry in Indiana. At this time, there are 2 draglines operating. There is no steep slope mining and no mountaintop mining. There is very little topographic relief. Underground depths range from 200' to 1000.'

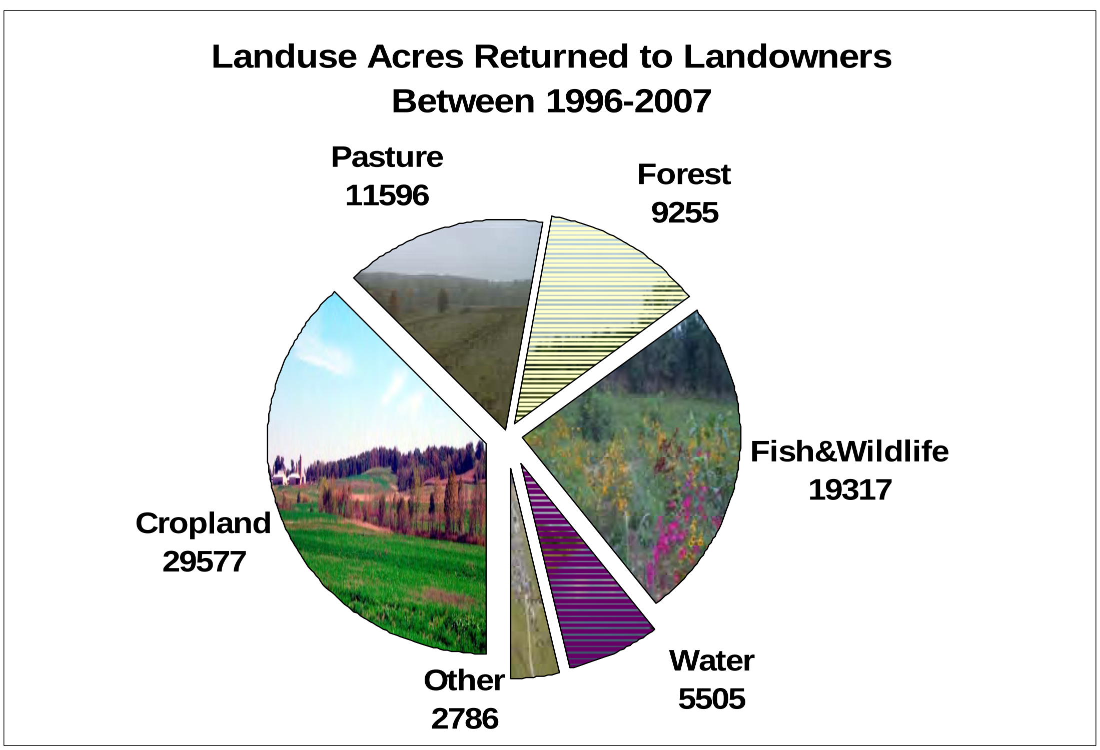
Underground mining access to coal is through the use of slopes or shafts. All of the underground mining in Indiana uses the Room & Pillar method of underground mining. There are no Long wall operations to date. Along with the underground mining, we also have to deal with coal refuse disposal.

The following chart shows the slow shift towards underground mining.



Surface water availability information consists of: (1) Annual Precipitation Ranges from 40-45 Inches; (2) 10yr/24hr Storm Ranges from 4.3 to 4.6 Inches; (3)100yr/24hr Storm Ranges from 6.0 to 6.5 Inches; and (4) “7day/10yr low flow values for the (Wabash) lowland are minimal, owing to the absence of surficial aquifers.”

The USGS Area 32 Report indicates that 62% of the land use is agriculture. Bond released land use acreage numbers are shown in the chart below:



As indicated in the chart, Indiana is highly agricultural. More than half of the land returned to landowners was either a cropland or pasture land use. The land use of "Other" covers residential, industrial, and other miscellaneous land uses. The fish and wildlife land use encompasses tree and shrub block or strip plantings, warm season grass prairies, wetlands, food plots, and open cool season herbaceous areas. Many of the stream reclamation projects also fall under the wildlife category.

Southwest Indiana from the air looks like a patchwork quilt. There are many agricultural fields bisected by fence rows and streams with an occasional woodland block. Most of the streams have been severely impacted by agriculture: channelized with steep slopes, no riparian vegetation, no sinuosity, and no riffle or pool structures. Other streams still maintain some natural configuration with a small wooded riparian corridor that are generally narrow, at less than 100 feet wide. Even the streams within relatively undisturbed woodlots appear impacted because of farming either upstream or downstream affecting water quality or quantity. With this understanding of the landscape in southwest Indiana, let's now look at past and current practices in stream reclamation and the benefits and challenges involved.

Past Practices

The Surface Mine Control and Reclamation Act (SMCRA) was passed in 1977. Indiana gained primacy in 1982. Prior to SMCRA, mining companies were required to do very little reclamation. Soil was lost. Water quality was degraded. Acid mine drainage affected everyone in coal country not just in Indiana. SMCRA was enacted to assure that while mining for an essential resource, the environment was protected and agricultural productivity was maintained. The main focal points, especially in the early years were soil stability, water transport, and water quality. The idea of reclamation was new to many. Reclamation techniques were "learn as you go" for both regulators and the regulated. Equipment was large and cumbersome. Many obstacles had to be overcome. Reclamation of drainages was done using rip rap to maintain soil stability. Terraces were important to effectively route water and stop erosion. Heavy seeding with quick growing and quick spreading vegetation was used to stabilize soils. Straight channelized ditches, that were easy to design, construct and maintain, were replaced in the landscape. Landowners who were generally farmers were happy with this development. This should not be considered "bad" reclamation. It was great reclamation in 1982. It was state of the art at the time. It was new and innovative. It was a vast improvement over what had come before. However, we can now do better for the land and environment.

Current Practices

SMCRA has not lost its original focus: soil stability, water transport, and water quality. However, it has stepped up and adjusted and now has another: wildlife values. Now instead of riprap and channelized ditches, natural stream channels are replaced. These reconstructed channels have sinuosity and meander along the replaced landscape. Natural structures such as pools and riffles are designed and constructed. More natural native rock is used in the stream bed versus using rip rap to build structures. Materials such as root wads, boulders, and logs are recycled and used as part of the stream design. These materials are saved during the grubbing process to be used in the stream reclamation projects. Other in stream structures such as j-hooks, weirs, rock or wood cross vanes, artificially constructed pools, and artificially constructed riffles are all installed as part of the initial design plan. The natural stream channels maintain a dynamic stability where there may be some short term changes in channel alignment, but over the long term, the stream channel maintains its profile, pattern and dimension. Flood plains are graded and planned. Native vegetation along the stream corridors is encouraged and being used. Wooded riparian corridors are being planted and established as part of the post mine land uses. Tree species that do well in wetter areas but can still withstand some drier conditions are specifically chosen.

Benefits

These new methods, if constructed correctly, can maintain soil stability, water quality and water transport capabilities while still addressing the need for wildlife in the post mining landscape. Natural stream channel design enhances wildlife habitat diversity. As mentioned in the paragraph above, using root wads, boulders and logs in the design creates instant habitat for species re-entering the reclaimed channel. They create shelter and safe foraging areas for many different species of fish, reptiles, amphibians and a variety of invertebrates. Pools are places fish species can survive during drier times. Riffles help oxygenate the water. Trees and other plants along the stream corridor help cool the water to enhance the in-stream habitat. Natural stream channel design is more aesthetically pleasing. Most people would rather look at a gently meandering babbling brook than look at a channelized, rip rap ditch. It just sounds more attractive also. A natural stream channel can actually provide better flood control than the traditionally constructed ditches by allowing water access to a floodplain. Therefore, slowing flash flood scenarios and allowing water to slowly advance down stream or infiltrate into the soil within the floodplain. This should all translate into less maintenance cost in the long term. However, there are still many challenges to overcome.

Challenges

Land Use Restrictions

The challenges come in many different forms. In Indiana, one of the difficulties we deal with is land use restrictions. In an agricultural state, cropland is at a premium. Prime farmland must not be lost and is even mandated by ISMCRA rule. Replacing formerly straight channelized drainages with meandering streams with 50 to 100 foot wooded buffers can remove significant acres from crop production and result in a net loss of prime farmland available. The prime farmland acres have to be replaced so some creative shifting of land uses is sometimes needed. Sometimes, the two are almost impossible to accommodate within the same SMCRA permit boundary.

Landowners

Many landowners that are farmers find that the natural stream channel design is not an easy fit into their cropping plans. With today's large farming equipment, replaced ephemeral drainages in agricultural fields cause excessive maneuvering of the equipment and lost planting acres. In an agricultural area, even most intermittent drainages have been straightened and channelized to maximize the cropable area. The idea of a gently meandering sinuous stream with a large flood plain and trees is not appreciated by most farmers who had a straight channelized ditch with little to no riparian corridor prior to mining. This results in loss of time and money for these landowners.

Multi Agency Jurisdiction

Another difficulty is multi agency jurisdiction. Streams on an Indiana coal mine have at least three (3) agencies reviewing their impacts and three different environmental permits. The SMCRA permit is reviewed by the Indiana Division of Reclamation. The Section 404 permit required under the Clean Water Act is reviewed by the Army Corp of Engineers. A Section 401 permit and a NPDES permit are required by the Indiana Department of Environmental Management. These individual permits are also reviewed by the US Fish and Wildlife Service. These multiple agencies are dealing with multiple laws and environmental regulations.

Conflicting Regulations

These sometimes come into play when dealing with multi-agency jurisdiction. As mentioned previously, there can be no loss of prime farmland in Indiana. There can also not be any erosion on site. Erosion in the past had been well controlled by the structures mentioned in our previous "past practices"- terraces, riprap drainages, heavy vegetation. All of these can interfere with establishing ephemeral drainages as part of the 404 permitting process. ISMCRA also requires at least 450 stems per acre on forest areas but many 404 permits recommend 50 container trees per acre. This would interfere with the bond release requirements for the ISMCRA permit. Ponds and lakes left after mining are designed and built to maintain pool stage with a set drainage area into the impounding structure. However, after ISMCRA bond release some permittees have been required by another agency to change the drainage area and reroute water from the impoundment. Due to the decrease in the volume of water routed to the impoundment, the structure may not maintain pool stage and fail. Post-mining drainages in SMCRA must be designed to meet a 100 year/6 hour precipitation event for drainages with a watershed of over one (1) square mile. This may conflict with requirements from other agencies.

Review Process Complexity

The complexity of the review process has also increased. Intricate pre-mine characterizations are needed to determine what mitigation will be required and what the post mining configuration will be. Finding the experts to do these pre-mine characterizations is also difficult. This is a fairly new, complex field and companies with the manpower and time to do the large mining permits are hard to find and also costly. Mining plans can also change when new leases have been acquired. This can cause difficulties if a permit is delayed. Thousands of feet of ephemeral streams must be properly assessed and those assessments reviewed by multiple people. Hundreds, if not thousands, of intermittent and perennial streams are also assessed and reviewed. Many different disciplines are required to accurately review a stream and evaluate restoration plans:

hydrology, engineering, soil scientist, surveyor, and several biological disciplines: botanist, macro-invertebrate specialist, fisheries biologist, ecologist and others. All this is not to mention the strong communication skills and an ability to put all this gathered information together into a format that is clear and concise. This has increased the time and money to put a permit together and also the time needed to review the application.

Learning Curve

The learning curve is also an issue. A more natural stream channel design is relatively new to many regulators, mine operators, and landowners. Not only does the channel need to be planned and designed properly, but the people building it in the field (a dozer or track-hoe operator) also need an understanding of the design. A straight V bottom or flat bottom ditch is much easier to design and construct than the very complex designs for a natural stream channel. It is much easier to visualize and build a channel that is always the same width and depth with little slope change that has no variation and with an occasional rip rap structure to slow water velocity. The dozer or track-hoe operator needs to be very precise and consistent. Stream restorations have been done in many areas but mining does have it own individual idiosyncrasies and obstacles to overcome.

Swell Factor and Contemporaneous Reclamation

Two factors that need to be taken into consideration when designing the stream restoration in a surface mine is the swell factor and contemporaneous reclamation requirement involved in large scale surface mining. Swell is defined as a measure in percent of volume increase experienced by material when loosened from its in-place position. (For example: when on vacation the clothes that originally fit in the suitcase at the beginning of the trip mysteriously no longer fit in the same suitcase at the end of the trip. It is the exact same material but unlike at the beginning of the trip when everything was meticulously folded and strategically placed- at the end of the trip; things are just thrown in and no longer fit as neatly together. Everything has been fluffed up.) Unlike most stream reconstruction which has an impacted area of stream between two points that are relatively established and stationary, mining reclamation is a continuously moving, evolving target. The valley configuration existing prior to mining may not be exactly the same after mining. Approximate original contour is a requirement; however with 20% or more of swell present in many mining operations, changes are expected. Most other contractors do not have this dilemma. Traditional stream reconstruction is usually an already existing stretch of stream that needs to be rehabilitated. Slopes are known. Original stream bed material and/or bedrock is there to use as advantageously as possible. Soil characteristics are known and stable. With surface mining, as each acre is disturbed in advance of the pit, reclamation and stream reconstruction is taking place behind the pit advancement. Today's mining companies keep very current on there reclamation. There is a minimum of unreclaimed area at any one time. So operators are trying to reconstruct streams in an area were all variables such as downstream characteristics are constantly evolving. Many modeling techniques for stream reconstruction utilize information that in a traditional setting is easy to measure and observe. With contemporaneous reclamation and swell your variables are changed from the original surface configuration. The type of stream that was present prior to mining may not be the channel type that would best fit in the post mining landscape. This requires flexibility within the design criteria so that when conditions change the design can be adapted to reflect that.

Personal Values

One last significant challenge to mention has no relation to the technical aspect of natural stream channel design. This challenge is all our own individual personal values. Each person involved in this process brings there own personal beliefs and values to the table. It doesn't matter if you are a mine operator, state regulator, federal regulator or a landowner, your own personal values will color how you look at natural stream channel design. Change is tough for everyone.

As mentioned in the paragraphs above, farmers trying to be the most efficient at their job as possible, typically do not embrace the natural stream channel design in their agricultural fields. Their job and mission is very important. It is to feed the nation. The importance of that can not be dismissed or trivialized. So although they may see the need for it in other places they don't see the value of this type of stream design in their crop fields. Other landowners may see wildlife reclamation (which natural stream channel design is part) as messy. Nature is not nice and neat. Some like the manicured golf course look. However, some do appreciate the wild more natural look. Many farmers and other landowners love wildlife and voluntarily enter into programs to increase wildlife habitat. Many also use conservation techniques in their general farming practices that benefit wildlife and the environment.

The mine operator has to worry about the bottom line. Mining companies are in the business to make a profit. They have to be able to economically mine the coal. Coal is a valuable energy resource to the nation. It's how we "keep the lights on" in 50-55% of our nation and in 97% of Indiana. At a time when energy independence is critical, this is a serious issue. Learning new techniques of reclamation and additional planning can be costly. This is not to say that these two groups do not value the environmental impact natural stream channel design can have. I know many mine operators that are "environmentalists" (although they may hesitate to use the word). I've heard dozer operators talk about how proud they are of the wetland and wildlife reclamation they have done on an area. They are anxious to see how it will look 20 years from now. They want to take their children out to show them these areas. They had contests or drawings to get the right to name each wetland constructed. People who work at the mines realize this is a legacy they are handing down to their children and they want to do the best job that they can. Mining companies in Indiana routinely go above and beyond by replacing much more soil back in the post mine landscape than what is required by law. They are only required to replace 12 inches of soil in wildlife and forest areas. It has become general practice for most to replace four feet or more. They have found this increases their chances of more consistent reclamation and timely bond release. Wildlife and the company both benefit from this practice.

State and federal regulators also bring their personal beliefs to the table. As the wildlife biologist in our office, I have had others come to me and say "you need to take a look at this area; it just doesn't look good." I'll go out and what I see is a wonderful diverse wildlife area. However, what that other person saw was a weedy out of control field or swamp. We have different values and look at the world differently. As mentioned before, nature is not nice and neat. The best wildlife areas do not look like a manicured golf course. Yet many people have been trained that a nice manicured look is the much better choice and more highly valued. As a regulator we have to be aware of our own values and not let that color the permitting process. Our jobs are to enforce and administer environmental laws that have been handed down to us. We should not impose our personal beliefs on the regulated community. We need to step back at times and ask "is what I'm asking for or requiring supported by the law?" When dealing with others, we all need to remember the world is filtered through our own individual experiences and biases. What we find important, others find trivial. It isn't so much that one answer is wrong and one is right. Sometimes the "right" answer is "wrong" in different circumstances. We need to be cognizant of others and the fact that they don't look at the world through the same filters. Sometimes it's hard to look through our own filters and find a balance and compromise to come up with a better solution.

Striking a Balance

We are all tasked with striking a balance between several objectives: environmental protection, maximizing coal recovery, landowner concerns, and actual administering environmental law and regulation. When I-SMCRA was first developed, the purpose for the legislation was put forth in the original document. One of those items states that I-SMCRA Law is to "Assure that the coal supply essential to the nation's energy requirements and economic and social well being is provided and strike a balance between the environment and agricultural productivity and the nation's need for coal as an essential source of energy." The intent of the law was not to stop mining but to insure that it was done in as environmentally sound manner as technologically possible. Technology and mining techniques have improved and evolved. Therefore, reclamation techniques have also continued to improve and evolve. Areas reclaimed 20+ years ago look differently than those reclaimed 5 or 10 years ago. Some newly reclaimed areas in Indiana you would never know were mined by just looking at the landscape and the crops produced from those areas. There is no doubt that mining impacts the environment. However, if done correctly, it is just a temporary negative impact. In Indiana, any one specific acre is disturbed for less than a year before it is reclaimed during normal pit advancement. That is why SMCRA was enacted in the mid 70's. Many acres of land had been left permanently destroyed in the pursuit of coal. The Title IV or Abandoned Mined Land section was designed to clean up these areas. The Title V or Permanent Program sections were set up to administer new coal mining permits. Anyone who has seen pictures or visited an abandoned mine land site from the time before SMCRA was enacted knows that the law has been a tremendous success. Now, a more natural stream channel design is part of that evolution. We as regulators, operators, landowners and others need to "strike a balance." Coal is a valuable resource and so is our environment. Responsible reclamation is a legacy for our children.

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WESTERN KENTUCKY PERSPECTIVE
PAST AND CURRENT PRACTICES, BENEFITS AND CHALLENGES

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Abstract

This paper will analyze the past and current practices of mine site reclamation, as it relates to stream restoration, in the Western Kentucky Coal field. The paper will explore both the past and future programmatic compliance as well as the utilization of Geomorphic Principals to achieve natural stream channel design. In the past it has been viewed by many that natural stream channel design techniques resulted in the design and construction of stream channels that increased reclamation cost and created problematic compliance issues with the Kentucky Division of Mine Reclamation & Enforcement. This paper will discuss opportunities for programmatic compliant, cost effective, sustainable design.

Introduction

In the past, standard practices on many mine sites in Western Kentucky requiring relocation or re-creation of stream reaches involved constructing relatively straight channels to convey water thru the mine site. The primary Channels were often designed to convey a particular storm event (10-, 25-, 50-year, *et cetera*), and usually were designed with such width to hold velocities below five feet per second, or lined with rock to prevent erosion and harden the channel in place. Although these newly-constructed channels successfully conveyed design flows, they were typically wider, uniform, and induced sediment deposition which often required maintenance to sustain desired flow capacity.

These practices served the need for maintaining flow and jurisdictional connectivity through the limits of projects, but provided minimal habitat and initiated stream evolution processes, often creating undesirable conditions upstream and downstream of the relocated sections beyond the original impact. Increased erosion throughout, excessive deposition downstream and head-cutting upstream are part of a process initiated by channelization as streams adjust to regain a natural slope and sediment transport balance. This results in the need for significant maintenance, and elevates the potential for adverse effect on the establishment of successful riparian vegetation, aquatic habitat and potentially tributary streams.

Historically, streams in western Kentucky were characterized by mild slopes, shallow pools, fine sediment, sinuous patterns, and valleys with wide floodplains. Today, many streams in the region have incurred physical impairments due to stream channelization. There are numerous activities that have historically impacted these streams. Agricultural practices in the region have historically modified the streams to minimize the real-estate consumed and to facilitate positive drainage. Mining, development, roadway construction, and logging have also played a role in the channelization of numerous streams in the region. Recognizing the need for a more holistic approach to mitigation that addressed permitted impacts and improved water resources in the region, an increasing number of regulatory agencies began to embrace a more natural method for stream mitigation around the year 2000. This approach took into consideration existing physical and biological conditions and functions relative to proposed conditions. In order to obtain necessary permits for projects that involve stream impacts, techniques were required that replicated natural conditions. Thus, natural channel design techniques have become a new standard for constructing stream channels. A significant driving force behind this new approach was a need to address aquatic habitat and general ecological loss from stream relocation, an idea not significantly considered within the majority of previous practices. The Western Kentucky Coal Field provides an especially fertile area for application of natural channel design principles. Many streams in the region are degraded and mine reclamation activities provide an opportunity to restore streams on a watershed scale. Furthermore when these procedures are implemented properly the maintenance of the facilities over the life cycle of the reclamation project has the potential to be reduced. In many cases the habitat enhancements that result from this approach also enhance the post reclamation value of the subject property.

However, to properly implement these principals it is necessary to approach the reclamation design and the regulatory compliance aspect of these projects from a different perspective than has been common in the past. It is necessary to view the stream reconstruction as the recreation of an ecological system instead of simply a means by which to convey storm water.

Existing Conditions

During Clean Water Act Section 404 permitting of fourteen coal mining projects in western Kentucky, the ***Associated Engineers, Inc*. / *THE*** team has delineated 99.5 miles of streams; 40 miles were formally assessed. These projects span four counties (Henderson, McLean, Muhlenberg, and Ohio) situated in the heart of the Western Kentucky Coal Field. Through this work, we have become intimately aware of impairments and potential threats to streams in the region.

Land uses in the Western Kentucky Coal Field region are predominantly forested and agricultural (approximately 47% each), while developed areas represent 2.4% of the area, and active mining occupies only 0.4% (USGS, 2000). Intense farming and channelization in the region have contributed to increased erosion, channel incision, degraded riparian zones, and tributary impairment. These physical impacts often are coupled with agricultural runoff, which can increase fine particle deposition and nutrient loading. Overall weighted means of EPA Rapid Bioassessment Protocol (RBP) scores (Barbour *et al*, 1999) and conductivity values show significant impairment of most of the streams we have assessed when compared to values for regional reference reaches (KDOW, 2002)(Figures 1 and 2). Because streams commonly are impaired, geomorphic reclamation has significant potential benefits in western Kentucky.

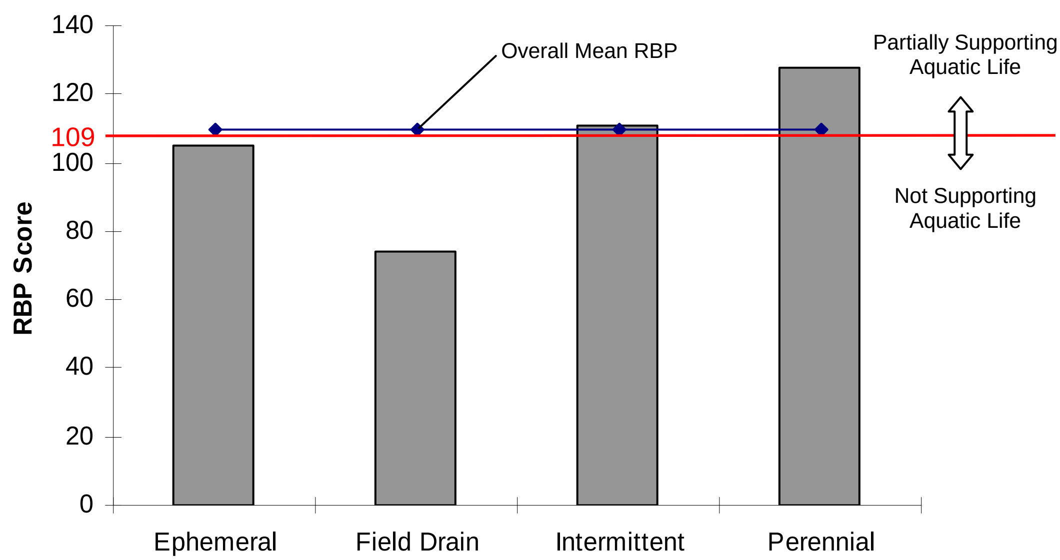

Figure 1. Weighted mean Rapid Bioassessment Protocol scores for 411 Western Kentucky Coal Field stream reaches. A score of 109 is the threshold for non-support of aquatic life in the ecoregion (KDOW, 2002).

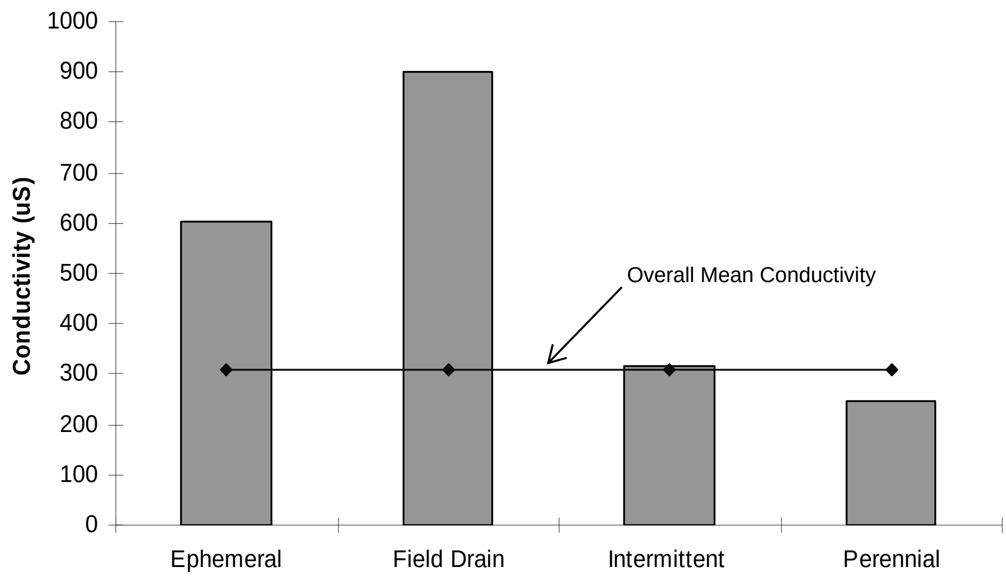

Figure 2. Weighted mean conductivity values for 296 Western Kentucky Coal Field stream reaches.

Working Explanation of Geomorphic Reclamation

Geomorphology generally is the study of landforms and the processes that shape them. This includes the substances that make up the land (i.e. rock and soil of various consistencies, hardness and cohesiveness) as well as the forces that act upon the substances (i.e. erosion forces such as wind and water and uplifting geological forces.) For our purpose, we are most concerned with the erosion capabilities of water and how it interacts with the substances that make up the land.

Reclamation in this case refers to the recovery of land that has been disturbed from its surface to very deep (several tens of feet) beneath the surface for the purpose of extracting coal at various depths. Recovery means that the land is restored to approximately the same elevations as previous to the impact. In this way, hills and valleys are replaced to appear and function as similar as possible to the pre-project landform, with similar drainage patterns (dendritic), drainage areas and, overland flows.

Just as the hills and valleys are reformed, the streams and/or wetlands must also be recreated in the reclamation process. Stream design and restoration is a complex process that involves predicting and creating a stream channel that conveys desired flows and sediment, has access to an active floodplain, is dynamically stable, has a healthy and diverse riparian zone, and provides abundant aquatic habitat. The end result should be a self-sustaining stream that is appropriate for the reclaimed valley and can convey the desired sediment without excessive erosion or deposition.

Benefits

The benefits of performing natural channel designs include: faster approval by regulatory agencies, potentially reduced maintenance costs and earlier bond release, improved water quality, increased ecological value, increased terrestrial and aquatic habitat, and improved post mine land use. Following are typical key features regulating agencies expect to be included in acceptable stream mitigation plans:

Natural stream stability

Stream bank erosion is a major contributor to stream sediment supply. Erosion and depositional processes are part of a natural, dynamic, stable stream system. Instability arises when these processes become excessive. The goal of natural channel design or stream restoration is to establish a naturally stable stream system that conveys the sediment and flow supplied by the watershed while keeping the deposition and erosion process in balance and creating desirable aquatic habitat. In order to achieve this, it is important to determine optimal potential stream type based on valley features and watershed conditions and establish the appropriate bankfull and floodplain dimensions, meander pattern, stream bed morphology, and profile.

Floodplain access

Providing adequate floodplain access for flows above bankfull is a critical component of natural channel design. Allowing flows above bankfull to spread out across a floodplain prevents water forces from exceeding critical shear stress and thus minimizes both stream bed and bank erosion. This in turn enables the stream to transport the desired sediment without excessive aggradation or degradation. Additionally, floodplains that the stream can access regularly help to disperse flood flow, acting as active storage areas and thus reducing the flood stage in the reach as well as the stream power downstream.

Aquatic Habitat

Enhancing macro-invertebrate habitat can provide significant ecological lift to an impaired stream reach. Common, obvious impairments from physical degradation include elimination of available niche space by choking large substrate interstices with fine sediments and physical removal of suitable substrates by altered flow regimes. Additionally, modified channels inappropriate for their geomorphic setting may also exhibit more subtle effects from altered nutrient cycles and organic matter input. Restoration of suitable habitat generally results in rapid recolonization of restored reaches by "higher quality" macroinvertebrate taxa (*i.e.* pollution-intolerant groups, EPT taxa, clinger taxa) and increased macroinvertebrate diversity (Moerke *et. al*, 2004; Herbst and Kane, 2009). Although different trophic groups respond on different spatial and temporal scales, increases in populations can cascade through the ecosystem, resulting in population density and species diversity at or exceeding pre-restoration levels (Moerke *et. al*, 2004).

Similar success can be found with vertebrate species. Introduction of habitat (*e.g.* through placement of root wads and large woody debris) and stabilization of substrates necessary for foraging, shelter, and spawning all benefit fishes in larger, more permanent water bodies. Headwater streams provide habitat for amphibians and heavily influence nutrient dynamics for fish populations downstream (Gomi *et al.*, 2002), so restorations in these areas can also positively influence vertebrate populations.

Riparian zone

A healthy, diverse riparian zone is important to stream function on a number of levels. In headwater systems, the influx of nutrients and coarse, organic particulate matter drives ecosystem function and also influences energy and nutrient cycling in downstream reaches (Vannote *et al.*, 1980; Gomi *et al.*, 2002). Physical influences include roots anchoring banks and increasing stability, as well as buffering the stream from sheet flow and regulating water temperature. These areas exert significant influence on the chemical balance of streams by reducing eutrophication, sedimentation, and pollutant loads. Riparian zones also provide the interface between aquatic and terrestrial habitats for both semiaquatic (salamanders, otter, beaver) and terrestrial vertebrates (red-backed vole, woodland jumping mouse) (Naiman *et al.*, 2005). Re-establishment of sufficiently wide, diverse riparian zones along restored streams significantly improves water quality and protects stream bank stability.

Challenges

There are a number of challenges to successfully implementing natural channel design. One is convincing the mining community that geomorphic design works and the benefits are worthwhile. Natural channel construction requires utilizing different equipment and construction methods. Equipment operator's implementation of these methods is essential to success and can only occur with the owner's "buy-in" to the process. Another challenge is that natural channel design involves creating a stream that is in balance with its valley type, slope, and sediment supply. On reclamation projects, the design must fit within a valley slope and sediment supply that will be created simultaneously with the stream. Field modifications to the reclamation plan may require engineered adaptations to the stream design to assure stream stability and project success. Finally, a continuing awareness of regulatory agency guideline changes must be maintained. The Corps of Engineers reviews and reissues Nationwide Permits every five years. The Division of Water may adjust Water Quality Certification requirements in response and will also periodically review and revise their regulations and guidelines. These periodic changes have, and may continue to have, significant impacts on final stream mitigation requirements.

Opportunities

In order to gain the most benefit from natural stream restoration techniques while maintaining regulatory compliance with all agencies, we must continue to change the way we define streams and stream restoration. In the past, in many cases, the mining industry has limited its view of streams to the channel that conveys precipitation events thru the property. This is due in no small part to the fact that The Kentucky Department For Surface Mining principally focused on the design capacity of the stream channel to convey the design storm event. Out of bank flow was viewed as a design deficiency and therefore not permitted. Over time we have evolved to view the entire stream system, which includes low flow channels, flood plains, and riparian zones, as the design stream. This acknowledgement allows innovative designs to be implemented. These designs result in stream corridors having higher ecological value and lower long term maintenance cost. It is essential that the mining community remains vigilant in its fight to achieve regulatory conformity which will allow the industry to continue to embrace innovative design methods to achieve higher quality reclamation.

Summary

Many watersheds in the Western Kentucky Coal Field have been significantly impacted by human activities in the past. Restoration of impacted streams offers a way to provide functional and ecological lift to the region, offsetting impacts from mining operations and returning stable streams to the landscape. Successfully restored streams offer a plethora of benefits to the area, including increased biological diversity, reduced erosion, stormwater buffering, reduced sediment and pollutant loads, as well as increased aesthetic value. Geomorphic reclamation of streams offers the best opportunity for success by creating the optimal stream type that best fits valley features and watershed conditions. However, the practice faces numerous challenges, with regulatory requirements perhaps the most significant. The theory and practice of geomorphic stream reclamation must therefore continue to evolve to meet these challenges.

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ILLINOIS STREAM RESTORATION - OPPORTUNITIES FOR HABITAT ENHANCEMENT: POLICY, PRINCIPLES AND PRACTICES

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Abstract

To facilitate large scale surface coal mining in southern Illinois during the late 1970's -1980's, temporary diversion and eventually relocation (restoration) of perennial streams was often required. Illinois' first stream restorations incorporated geomorphologic and ecological principles in their designs and construction to enhance their function and value as lotic and riparian habitats. IDNR's Office of Mines and Minerals (OMM) - Land Reclamation Division required (Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87) pre-disturbance stream restoration designs and plans as well as post-disturbance monitoring of the physical, chemical, and biological components of the stream community. The OMM interdisciplinary Stream Restoration Committee reviewed plans and provided technical input to the industry to ensure compliance with regulations and maximization of habitat enhancement opportunities. The Cooperative Wildlife Research Laboratory of Southern Illinois University Carbondale (CWRL) initiated stream diversion / relocation research in the early 1980's to assess stream restoration practices. CWRL evaluated ~ 18 miles of diversions and restorations associated with the Arch, AMAX, CONSOL mining complex in Perry County. In addition to the comparative evaluations of stream diversions and restorations (Bonace 1983, Bush 1989), CWRL research staff conducted long-term (1986 - 1994) monitoring of Pipestone Creek associated with the AMAX Denmark Mine (now part of the ~16,000-acre IDNR Pyramid State Park complex).

These early investigations of southern Illinois stream relocations and restorations provide an extremely valuable database for evaluation of the long-term geomorphologic and biologic recovery processes in previously restored stream habitats. This presentation will highlight the extent and distribution, restoration practices, and biological performance of these stream restorations initiated more than 25 years ago. A reassessment of these stream reconstructions that have undergone 10-20+ years of hydrogeomorphic adjustment and biological recovery can provide valuable insight into future stream habitat restoration practices.

Introduction

The first surface mining for coal in Illinois occurred in 1866 near Danville, Illinois. Shallow coal was extracted using horse drawn scrappers. As surface mining progressed within the Illinois Basin, deeper deposits of coal were mined using larger equipment (> 180 cu yd shovels and draglines). During the late 1970's and 1980s large scale surface mines in southern Illinois extracted coal from depths of 70 – 95 + feet. These large surface mine open cuts, extending > 1.25 miles in length, often encountered small tributaries and streams that required relocation around the active mining operation. Prior to regulation (< 1976) small streams were permanently relocated around the active mining operation as straight channel diversions. As stream protection regulations became more stringent, straight line temporary stream diversions were replaced with permanent relocations either within the reclaimed mine spoil or on un-mined soils outside of the active coal extraction area.

Illinois' regulatory programs (IDNR Office of Mines and Minerals), mine operators, and staff and students of the Cooperative Wildlife Research Laboratory of Southern Illinois University (CWRL) have been conducting environmental assessments of pre-mine stream corridors, temporary and permanent stream diversions, and permanent stream restorations for more than 30 years. These early investigations of southern Illinois stream relocations and restorations provide an extremely valuable database for evaluation of the long-term hydrogeomorphic and biotic recovery processes in previously restored stream habitats. This paper highlights the extent and distribution, restoration practices, and biological performance of these stream restorations initiated more than 25 years ago.

Stream Disturbance: Non-Mining

Streams and rivers throughout Illinois have been severely impacted for more than 100 years by channelization and dredging practices not related to coal mining. Many streams in southern Illinois have been degraded by agricultural practices (drainage, clearing, and dewatering). Southern Illinois' smaller streams have been channelized to support drainage to enhance agriculture. Larger streams and rivers in Southern Illinois have been dredged and channelized by the US Army Corps of Engineers (< 1980) to facilitate barge transportation, reduce flooding, and promote river commerce. Channel incision and instability due to downstream channelization projects, and uncontrolled sediment and nutrients from agricultural runoff have degraded most low gradient natural streams in Illinois. In many cases streams restored by mining during the current regulatory era (post PL 95-87), support better habitat and water quality than un-mined "natural" streams that have been impacted by past agricultural practices.

Permit Requirements: Regulations

Implementation of stream restoration guidelines and regulations during the late 1970's ended the era of channelized permanent stream diversions on reclaimed mined lands. Streams affected by mining would be required to "be put back" the way they were before mining. Stream restoration regulations and guidelines adhere to the Surface Mining Control and Reclamation Act (PL 95-87) permanent program administered by the Illinois Department of Natural Resources Office of Mines and Minerals Land Reclamation Division (IDNR OMM). Section 780.16 of OSM's regulations requires site specific resource information and protection and enhancement plans for "important" streams. Section 816.97(f) requires coal operators to avoid disturbances to riparian vegetation and to enhance where practicable, or restore, riparian vegetation.

Post-law stream restoration practices emphasize the design, construction, and maintenance of a "natural" meander channel within a restored riparian corridor protected by a vegetated buffer zone (Sec. 1816.43). Design components of restored streams include the reconstruction of a natural stable channel that supports a cross section profile, upstream downstream gradient, and channel meander ratio similar to the pre-mining condition. A well vegetated riparian corridor established within the reconstructed floodplain is required to provide sediment control as well as flood storage. Floodplain wetlands ranging from intermittently to seasonally inundated herbaceous or forested plant communities can be included in stream restoration plans to enhance wetland associated wildlife habitat. In-stream habitat features such as riffles and pools are included to increase diversity and enhance the aquatic habitat. Recognizing that restored streams must also provide the same hydraulic functions as pre-mine streams, flow capacity within the channel and floodplain storage must be designed to prevent both upstream and downstream flooding during a 100 year 6 hour precipitation event. To maintain the hydrologic balance (Sec. 1816.57) and ensure long-term protection of the restored stream channel and in-stream habitat features, a vegetated stream buffer zone extending from the top of bank to a minimum of 100 feet on both side of the floodplain is required.

Pre-construction geomorphic assessments are conducted to establish baseline conditions for designing hydraulic features such as bank height and angle, streambed width and profiles, upstream and downstream gradients, meander ratios, riffle and pool sequences, etc. Early stream restoration projects required pre-construction monitoring of water quality and the in-stream aquatic invertebrate and fish communities. Post construction monitoring to document successful restoration of the stream and its floodplain habitat was also required. Bond is released when all provisions of the approved plan have been implemented, the area is stable, and all regulations have been complied with. Early stream restoration projects of the 1980's and 1990's demonstrated that the coal industry was capable of restoring important hydrologic and biologic functions of streams after mining through the original channel. More recent permit approvals have not required the intensity of monitoring, since success of stream restoration techniques has been proven by several decades of past practices.

Stream Restoration Monitoring and Assessment: Illinois

Streams diversions and restorations associated with surface mines in Illinois have been assessed for more than 30 years. Pre-mine assessments and post–restoration monitoring has been conducted since 1979 by staff of the IDNR Mining Program-Streams Section (Pat Malone, Doug Carney, Randy Sauer). The IDNR Mining Program conducted pre-mining stream assessments as well as semiannual monitoring of the stream biotic community and water quality. Coal operators also conducted independent pre-mining assessments of the chemical, biological, and physical stream habitat conditions. Operators also monitored post-construction conditions for a minimum of 5 years to comply with state and federal regulations. Students and staff of the CWRL have conducted research to assess the recovery of stream restoration and diversion assessments since 1979. Collectively CWRL, IDNR, and Illinois coal operators have been compiling stream restoration baseline and post-construction data for 8 distinct streams during the past 30 years (Table 1). Despite the availability of fairly complete data sets for some Illinois streams, most of these short term assessments only represent "snapshots in time" providing a 2 or 5 year slice of data that focused on the pre-construction conditions or the immediate 5 years post-construction. Although the streams listed in Table 1 represent the majority of streams that have undergone diversion or restoration in southern Illinois, a full compilation of stream restoration sites in Illinois is needed to provided a baseline for future restoration efforts. However, these streams do provide an excellent opportunity to review stream restoration practices from both a historical and ecological perspective.

Table 1. Southern Illinois stream assessments[1]

	Stream	Assessment Dates
Diversions	Galum	1981-1982
	Panther Creek	1981-1982
	Pipestone	1983-1994
Restorations	Pipestone	1990-1994
	Galum ARCH	1981-1998
	Galum CONSOL	2002-2006
	Bonnie	2001-2006
	White Walnut	2002-2005

1 Assessments conducted by IDNR, CWRL, and /or coal operators.

Most importantly, the passage of time from active mining to 30 years post-construction provides stream ecologists and regulatory agencies the unique opportunity to view the ecological development within the restored riparian corridor that has occurred during the past 20 to 30 years. Stream restoration is a slow process that begins with the permit application process and requires extensive planning and patience that often requires 20 years from initial engineering and design to channel reconnection((Figure 1, a and b).

Figure 1a. CONSOL Burning Star 4 Mine. Galum Creek restoration integrating meander channel construction with active mining. (Photo Date1985).

Figure 1b. CONSOL Burning Star 4 Mine. Galum Creek restoration incorporating diverse reclaimed land use (rowcrop, forest, wetlands) with channel relocation (Photo Date2005).

As exemplified by the CONSOL Burning Star 4 Galum Creek restoration (Figure 1a and b) stream restoration does not wait until after mining. The entire restoration process of channel design and realignment must be integrated with the active mining processes of overburden removal and replacement. Rough and final grading must be conducted 'in the dry" while the normal stream flow is diverted through a temporary channel outside of the active mining area. The temporary diversion can only be reconnected after all of the restoration channel units and in-stream habitat features such as riffles and pools have been constructed; and, the riparian floodplain plant community has been established. Although, post reconnection monitoring begins after stream flow returns to the restored channel, this 5 year liability period provides only a brief glimpse of the actual stream restoration process. A "time lapse" perspective of the natural succession occurring within the riparian community and the restored channel is now available for more than 16 miles of southern Illinois stream meander channels that have been restored during mining and reclamation (Table 2).

Table 2. Southern Illinois - Stream Channel Restorations and Diversions.

Site	Channel Length- ft	Meander Length – ft (mi)	Meander Ratio	Buffer Width - ft
CONSOL 4				
Galum Restoration	13,443	22,702 (4.3)	1.72	300-500
Bonnie Restoration	11,842	19,311 (3.7)	1.63	500-750
Galum Diversion (permanent)	16,400			
ARCH Captain				
Galum Restoration	9,135	18,480 (3.5)	2.02	125-250
Pipestone Diversion (permanent)	11,342			85
AMAX Leahy				
Pipestone NW Diversion (perm.)	5,808			
Pipestone Restoration	16,685	24,288 (4.6)	1.45	300-750
Pipestone SE Diversion (perm)	4,115			
Pipestone Diversion Temporary	22,704			
Restorations *(n= 4)*	51,095	84,781 (16)	1.66	
Diversions Permanent (*n*=4)	37,665 (7.1 mi)		1.0	

During a ~ 20 year period from 1979 to > 1990 four southern Illinois streams located within a 40-square mile area of active surface mining in Perry County were restored to approximate pre-mine conditions (Table 2). Restorations encompassed more than 51,000 feet of channel reconstruction supporting average meander ratios of 1.66. Riparian buffers within the restored floodplains ranged in width from 300 to > 750 feet. Stream relocations in the 40 square mile area of active mining also included more than 37,000 feet of temporary and or permanent diversions. The permanent stream restorations occurred during Illinois' regulatory era of topsoil replacement and wetlands reestablishment. Consequently the permanent restorations represent some of the best examples of integrated land use in which reclaimed rowcrop agriculture adjoins forested and emergent wetlands that were established within the protected floodplain buffer zone.

Stream Restoration – Case Studies

Arch of Illinois: Galum Creek

The ARCH of Illinois Captain Mine was the largest operating surface coal mine east of the Mississippi River when Illinois' first stream restoration was initiated in 1979. To facilitate mining, ~ 3.5 miles of the original channel of Galum Creek was moved east of the active operations and relocated in unmined soils (Figure 2). The ARCH Galum Creek project represented the first stream relocation permit pursued by an Illinois coal operator under the IDNR permanent program. Stream restoration plans were developed by ARCH of Illinois' engineering and environmental staff and presented to the US Army Corp of Engineers and IDNR for review and comments in 1979. This early restoration plan encompassed less than 13 pages (including comments and responses) and 3 basic technical drawings illustrating channel features (bank height, width, buffer zone, riffles and pools), and floodplain tree planting specifications (Table 3).

Table 3. ARCH of Illinois: Galum Creek Stream Restoration – Reforestation Plan

Floodplain	Riparian Corridor	Transition Upland Forest
Bald Cypress	Bald Cypress	Pecan
River Birch	Sweetgum	Bitternut Hickory
Black Willow	Overcup Oak	Shagbark Hickory
Green Ash	Green Ash	Shellbark Hickory
Hackberry	Hackberry	Water Hickory
Cottonwood	Black Walnut	Black Walnut
Pin Oak	Pin Oak	Bur Oak
Silver Maple	Silver Maple	Cherrybark Oak
	Swamp White Oak	Schumard Oak
	Honey Locust	So. Red Oak
		Swamp Chestnut Oak

Figure 2. ARCH of Illinois Galum Creek restoration. Meander channel (4.3 miles) rerouted through unmined soils east of active mining area.

The USACE specified the following design criteria for the ARCH Galum restoration:

Channel Width – 30 to 50 feet
Buffer Zone – 300 feet
Channel Sinuosity – 2.0
Channel side Slope – 3H:1V
Channel (low flow) – 10-12 feet wide, 2 feet deep
Riffle intervals – 700 – 1,000 feet
Pool – 1.5 to 5 feet deep

The ARCH Galum Creek project was the first meander "restoration", although technically the stream was relocated to a portion of the watershed that was outside of its original channel corridor. Following state and federal agency review and revision, the restoration plan was presented at a public hearing in May 1979 to approximately 50 individuals who had "no outright objections" to the plan. Dr. W. D. Klimstra, Director of the Cooperative Wildlife Research Lab at SIUC viewed this initial stream restoration as a great opportunity.... "to study man's ability to change the course of a stream and rebuild life around it." Early baseline data (ca 1980) from CWRL graduate student research (Bonace 1983, Busch 1990) conducted on the stream community during the first years following the reconnection, can serve as a valuable benchmark for assessing restoration success after 30 years. Currently, the mature riparian forested buffer zone provides excellent vegetative cover for forest wildlife species and roost sites for Bald Eagles which forage in the adjacent reclaimed mine areas (Figure 3).

Figure 3. ARCH of Illinois Captain Mine. Galum Creek restoration (permit initiated in 1979, channel construction and reconnection completed 1981). (Photo Date 2005).

Consol Burning Star 4

Located approximately 11 miles upstream from the ARCH Galum restoration, the Consolidation Coal Company engineers and reclamation staff designed and planned the nations' largest stream restoration effort to reconstruct more than 7 miles of meander channels through reclaimed mine soils at the Burning Star No 4 Mine (Anderson 1987). Unlike the ARCH Galum Creek project, CONSOL's 4.3- mile Galum Creek restoration (Figure 4), and 3.7-mile Bonnie Creek restoration (Figure 5) were constructed through replaced mine soils in the approximate location of the pre-mine riparian corridor.

Figure 4. CONSOL Burning Star 4. Galum Creek 4.3- mile restoration relocated through reclaimed soils in the approximate pre-mine riparian corridor.

Figure 5. CONSOL Burning Star 4. Bonnie Creek 3.7- mile restoration relocated through reclaimed mine soils in the approximate pre-mine riparian corridor.

The complexity of integrating the restoration of 2 streams into the planning, mining, and reclamation process required 20 years from initial design to channel reconnection for Galum Creek (Table 4). The CONSOL Galum and Bonnie creek restorations clearly illustrated that stream restoration is a complex, long term hydrogeomorphic process. The initial stream restoration success can be defined when bond is released within 5 years after completing post- reconnection monitoring. However, the attainment of long term biologic success is fully appreciated after several decades when the riparian plant communities have matured and the stream channels reach a "dynamic equilibrium" similar to the pre-mine condition. The U.S. Office of Surface Mining National Award for innovative reclamation practices recognized the significance of the CONSOL Burning Star 4 stream restorations in September 2002. OSM noted that this was ... "*..........the first time in Illinois that two major streams in a minefield were diverted during mining and then restored to their original locations. ....reclaimed as a habitat for wildlife and waterfowl......"*

Table 4. CONSOL Burning Star 4: Stream Restoration Project Timeline.

Project Phase	Date
Design and Engineering	May 1979
Permit Approval	November 1982
Construction (8.0mi)	June 1984 - ~1998
Floodplain Restoration	1984 - 1998
Channel Reconnection	June 1999
Monitoring	2002 – 2006
OSM National Award	2002

The CONSOL Burning Star 4 award-winning stream restoration practices implemented at both Galum and Bonnie Creek enhanced wildlife habitat within the stream channel and the floodplain corridor. The restoration practices included construction of meander channels, riffles, pools, and deep water habitat. Deepwater habitat enhancement was provided by routing of and connection of the restored stream channel through deep water (> 75' deep) incline basins. In addition to enhancing base flow and aquatic species habitat during seasonal droughts, the connection of restored channels with deepwater pools and basins provided sediment control from unmined upstream rowcrop fields. The deepwater basins as well as the design of floodplain forested and emergent wetlands provide storm water retention for flood events passing thru the restored channel. Storm water retention capacity was designed to maintain upstream water level increases below 0.5 feet. Floodplain reclamation in the Galum Creek restoration provided forested wetland habitat that was designed to be inundated by a 2 year design storm. These storm water retention functions were provided by the design of a protected floodplain buffer zone in the Galum Creek corridor that ranged from 300 to > 500 feet wide. Similar to previous steam restoration plans, IDNR staff recommended the hand planting (7' x 7") of flood tolerant or adapted bare root forest seedlings in the floodplain (Table 5).

Table 5. CONSOL Burning Star 4 Stream Restoration.
Floodplain Forest Seedling Recommendation (IDNR).

Bald Cypress	Ash	River Birch
Pecan	Sweetgum	Cottonwood
Silver Maple	American Elm	Beech
Pin Oak	Red Maple	American Plum
Swamp White Oak	Hackberry	Box Elder
Sycamore		

Following the reconnection of the unmined upstream Galum and Bonnie creeks with the downstream restored sections, semi-annual (spring and fall) monitoring of water quality and stream biota was initiated in 2002 and continued through 2006. The 5-year Galum Creek (2002 -2006) and Bonnie Creek (2002-2006) monitoring reports submitted to IDNR by the operator represent excellent baseline documentation for a future 20+ year re-assessment of long term stream restoration processes.

Amax Leahy Pipestone Creek

The ~ 4.6-mile reconstruction of meander channels and riparian corridor of Pipestone Creek at the AMAX Leahy Mine in Perry County was the longest single stream restoration project on a reclaimed surface mine in southern Illinois. Similar to other (Galum and Bonnie Creek) post-law stream restorations, the Pipestone restoration followed the approximate original pre-mine floodplain location. Construction of the Pipestone Creek meander channels began in ~ 1979 with a small dragline, following grade and centerline profiles established by standard engineering practices of the 1970-80s. Meander channel segments of the Pipestone Creek restoration were constructed between 4 incline haulroads and vegetated as the active pit advanced beyond the future riparian corridor (Figure 6).

Figure 6. AMAX Leahy Mine. Pipestone Creek 4.6- mile meander channel restoration relocated in approximate pre-mine riparian corridor.

Meander channel construction incorporated an average sinuosity (ratio of stream length (thalweg) to valley length)) of 1.45 within the 300 – 750 foot wide Pipestone Creek corridor. Stream restoration plans often identify the construction of a “stable” channel as a design feature. Ironically, channel stability conflicts with the true hydrogeomorphic definition of “meander” as a verb rather than a noun. If the restored stream is truly “restored”, meandering of the channel within the floodplain should be expected to occur. A restored stream that meanders within its reclaimed floodplain is demonstrating the dynamic equilibrium that we expect to occur in natural streams. The lower reach of the Pipestone Creek restoration “meandered” within the floodplain, when storm flows rerouted the channel across the floodplain prior to reconnecting with an existing “meander” (Figure 7). This natural abandonment of a constructed meander channel provides a desirable succession from a lotic to lentic stream channel environment that diversifies wetland habitats within a functionally restored floodplain.

Figure 7. Pipestone Creek restoration. Channel “meander” (dashed black line).

Similar to the CONSOL Galum Creek restoration, the restored Pipestone Creek channel was designed to enhance deep water habitat connectivity provided by 3 incline lake basins. During the construction (ca 1980 – 1990) of more than 24,200 feet of meander channel stream restoration segments within the active mining complex, the main channel of Pipestone Creek was rerouted through a 22,700–foot straight-line temporary diversion that was constructed around the northern and eastern perimeter of the active surface mine. When all segments of the permanent restoration channel were completed (fall 1991) Pipestone Creek was reconnected to the 4.6- mile restored channel and inactive reaches of the temporary diversion were backfilled and reclaimed. Backfill conversion of portions of the temporary diversion channel to palustrine emergent season wetlands provided habitat for Illinois threatened and unique species such as the rice rat (*Oryzomys palustris*) and least bittern (*Ixobrhychus exilis*).

Water quality and stream biota in the temporary diversion; and, eventually in the restoration channel were monitored semi-annually (spring and fall) by CWRL staff and the coal operator from 1983- 1995. Unique species of aquatic invertebrates and fish more commonly associated with clear and cool flowing streams were recorded during monitoring of the channel reaches immediately below the incline basin sampling points and in the clear water below the last restoration channel segment. Reductions of stream water turbidity values from 36 NTU (upstream) to 8 NTU (below incline basin) were noted in those reaches of Pipestone Creek in which brook silverside (*Labidesthes sicculus)* minnows and stonefly (*Perlidae*) larvae were sampled during the semi-annual monitoring program. The occurrence of aquatic species indicative of high quality streams in a relatively short time following stream restoration suggests that physical features of stream restoration practices associated with deep water reconnection can provide immediate in-stream habitat improvement prior to longer term plant community development in the adjacent riparian corridor.

The streams, floodplain forested habitats, emergent wetlands, and rowcrop reclamation associated with the Pipestone Creek restoration corridor can now be viewed, 20 years post-construction, by visitors to the 16,000-acre IDNR Pyramid State Park (Denmark Unit). The AMAX Pipestone Creek restoration demonstrates the success of the Illinois stream restoration/reclamation program.

Summary and Recommendations

The Illinois stream restorations completed in the 1980's -1990's can all provide valuable baseline data. These 16 miles of stream channel restoration represent a unique large scale reestablishment of stream communities and riparian corridors that can be used to assess future restoration success. Unfortunately, some of the early permits documenting the stream design and engineering details and data have been lost after bond has been released. Efforts are needed to recover and protect missing stream monitoring data, compile all existing data, and document site history and project locations. Fortunately, Illinois' regulatory and natural resource agencies as well as CWRL have been involved in some of the earliest stream restoration and stream diversion monitoring. Secure archival storage of these historic restoration files is essential. Monitoring data and design information is still available for some sites. Former members (Doug Carney, Pat Malone, Randy Sauer) of the Illinois IDNR Stream Restoration monitoring program (now inactive) are now retrieving 20-25 year old stream sampling data to reestablish an archival stream restoration data set for Illinois.

Although regulations do not require long term monitoring, the 20 and 30 year-old Illinois stream restoration sites should be re-assessed through the OSM Applied Science Research Program to document the truly long term trends of stream restoration processes. A reassessment of these Illinois stream restorations that have undergone >20 years of hydrogeomorphic adjustment and biologic recovery can provide valuable insight into future stream habitat restoration practices.

The scope of the environmental challenges and engineering accomplishments of these previous stream restoration projects will probably never be repeated in the Midwest at this scale. Illinois' stream restorations represent living laboratories that should be preserved and protected. The regulations that required buffer zones during the restoration process should be strengthened to permanently protect the riparian corridor (both hydric and non-hydric plant communities) of restored streams, when feasible. Protecting these sites not only preserves and provides valuable habitat. Protection ensures that living benchmarks are available to stream ecologists and regulators. To facilitate future mining and environmentally responsible reclamation in the Midwest, regulators, engineers, coal operators, and scientists need stream restoration base-line data and long-term performance data to once again answer the invariable question ..." but can you restore the functions and values?........"

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Jack Nawrot is a Senior Scientist with the Cooperative Wildlife Research Laboratory's Mined Land Reclamation program at Southern Illinois University. Jack has been on staff with the Lab since 1974 BC (*before computers*). His professional responsibilities included the statewide inventory of Illinois mined lands, implementation of wetland mitigation and restoration practices, geochemical characterization of coal processing by-products, and direct vegetation establishment practices for coal slurry and gob. Jack has supervised Wildlife Lab students whose projects have assessed waterfowl, grassland birds, and Illinois threatened marsh birds and mammals that use Illinois' reclaimed mines. More than 25 years ago the Lab's students and staff conducted the first evaluations of temporary diversions and permanent stream restorations established on southern Illinois' mined lands. He holds a Bachelor's in Ecology from Blackburn College in 1972 and a Masters in Wildlife Ecology from Southern Illinois University at Carbondale in1974 and is currently working on a doctorate in Reclamation Ecology at SIUC.

William G. O'Leary has been on staff of the Illinois Land Reclamation Division, Illinois' SMCRA regulatory authority since 1983, where he currently serves as the agencies' wildlife and wetlands specialist. He grew up hunting and fishing in the large tracts of mined lands found in Southern Indiana. He recognized early the potential of these lands for fish and wildlife and associated recreational values. In addition to conducting research on wildlife management techniques on mined lands, he has worked as a consultant for OSM on experimental practices. He served on a joint OSM/USFWS committee to interpret the 1996 Biological Opinion and on a committee which developed OSM's class "SMCRA and the ESA - Implementing the 1996 Biological Opinion." He is an instructor for that class as well as OSM's "Wetlands Awareness" class. He received his Bachelor of Science from Indiana State University in Biology and Environmental Biology and his Master of Arts from Southern Illinois University in Zoology specializing in Wildlife Management.

GEOMORPHIC RECLAMATION IN THE MIDWEST INDUSTRY PERSPECTIVE – PAST AND CURRENT PRACTICES, BENEFITS AND CHALLENGES

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Abstract

Geomorphic Reclamation can be explained as *the process of restoring the earth's shape or surface to a suitable condition or use*. In the context of surface coal mining, Geomorphic Reclamation can be narrowed to mean the process of restoring disrupted ground conditions and landscape to a suitable post-mining configuration and use. The importance of geomorphic reclamation is creating topography and slope configurations that remain stable. Stable slopes follow natural hillside geometry more so than conventional grading designs and recreate natural drainage patterns rather than straight convex terraced slopes. Natural landform grading techniques and natural drainage development, if designed properly, yield a post-mining landscape that resists surficial erosion and mass wasting and increases the opportunity for more diverse vegetation.

If geomorphic land grading is preferred for successful surface mine reclamation, why haven't more operators and regulators considered the long-term environmental and aesthetic benefits of artificial reshaping and restoration of natural topography? This presentation will explore that question by identifying the evolutions of: 1) regulations promulgated under the Surface Mining Control and Reclamation Act (SMCRA) and Sections 401 and 404 of the Clean Water Act (CWA), 2) conventional mining and reclamation practices and 3) methods of restoring jurisdictional waters, i.e. wetlands and streams. The goal of this overview is to better understand the benefits and challenges of geomorphic reclamation at Midwest surface coal mining operations.

Introduction

The goal of this overview is to better understand the challenges and benefits of geomorphic reclamation at Midwest surface coal mining operations. To better understand the aspects of reclamation in the Midwest, one should have a basic understanding of coal mining in the Illinois Basin. The Illinois Basin covers most of Illinois, south central and southwestern Indiana and northwestern Kentucky. Topography varies from flat to rolling hills and valleys. Streams are low gradient and have developed dendritic drainage patterns that flow towards major rivers of the Ohio and Mississippi River systems. Typical elevations range from 300 to 600 feet above mean sea level. Landforms have resulted from the natural degradation processes of weathering, stream erosion and mass wasting. Soil type and land slope vary widely. Pennsylvanian age rocks contain numerous coal seams of varying depth, thickness, and quality. Primary coal seams, in descending order, mined in the basin are: Danville, Jamestown, Herrin, and Springfield. Coal is mined by both surface and underground methods. According to the National Mining Association, in 2007 approximate coal production in Illinois was 32 million tons, 35 million tons in Indiana and 28 million tons in Kentucky (not including Appalachia).

An example of regional climate is that of southwest Indiana (also typical of southeast Illinois and northwestern Kentucky), being a continental type influenced by cold polar air from the north and warm gulf air from the south. The average annual rainfall is 43.4 inches. Average annual runoff for undisturbed acreage is 14 inches. Precipitation is generally greatest in the late spring and early summer. The 24-hour precipitation event for the subject area ranges from 2.8 inches for a 1-year frequency event to 5.3 inches for a 25-year frequency. The 2-hour rainfall intensities range from 1.6 inches for a 1-year frequency to 2.9 inches for a 25-year frequency. Evapotranspiration averages approximately 29 inches annually.

Pre- and post-mining land uses in the Illinois Basin are dominated by agriculture (cropland and pasture), forest and woodland, urban and rural development and undeveloped. Lowland soils are capable of producing high yields if managed properly and soil conservation practices to retain topsoil are employed.

What is Geomorphic Reclamation?

The concept has been developed over the last decade by well known geomorphologists and engineers such as Horst J. Schor and Donald H. Gray (Landforming, John Wiley and Sons, 2007). In terms of mining reclamation, the technique was originally developed at active mining sites in New Mexico in 2006 (Carlson Software 'Natural Regrade'). Geomorphic Reclamation can be explained as the process of restoring the earth's shape or surface to a suitable condition or use. In the context of surface coal mining, Geomorphic Reclamation can be narrowed to mean the process of restoring disrupted ground conditions and landscape to a suitable post-mining configuration and use. The importance of geomorphic reclamation is creating topography and slope configurations that remain stable while not affecting the overall land capability. Stable slopes follow natural hillside geometry more so than conventional grading designs and recreate natural drainage patterns rather than straight convex terraced slopes.

Natural landform grading techniques and natural drainage development, if designed properly, yield a post-mining landscape that resists surficial erosion and mass wasting and increases the opportunity for more diverse vegetation. If geomorphic land grading is preferred for successful surface mine reclamation, why haven't more operators and regulators considered the long-term environmental and aesthetic benefits of artificial reshaping and restoration of natural topography? To fully answer this question we should also ask if some of the benefits of geomorphic reclamation may offset advantages of conventional reclamation. And, if we are to truly understand the application of geomorphic reclamation principles in the Midwest, then we must evaluate the practicality.

What are the issues?

There are a number of significant issues that must be considered when evaluating the practicality and applicability of geomorphic reclamation in the Midwest. Three primary considerations are: 1) regulations, 2) mining and reclamation practices, and 3) methods of restoring jurisdictional waters (i.e. streams and wetlands). The most pertinent regulations are those promulgated under the Surface Mining Control and Reclamation Act (SMCRA) and Sections 401, 402 and 404 of the Clean Water Act (CWA). We must understand the foundation and basis for each of these laws and we must also understand how each has evolved.

SMCRA requires that each mining and support area obtains a permit covering both surface affected areas and underground shadow area. Permitted surface areas require reclamation bond. A SMCRA permit may take more than 12 months from submittal to issuance.

Section 401 of the CWA requires a Water Quality Certification when permitted activities may affect the water quality of a receiving stream or when fill material is placed in a jurisdictional water of the United States. Under these circumstances a CWA Section 401 WQC is required in conjunction with a CWA Section 404 permit. A 401 WQC typically takes 9-12 months from submittal to issuance.

Section 402 of the CWA requires a National Pollutant Discharge Elimination System (NPDES) permit for any sediment basin and any other point source discharge. An NPDES permit typically takes 9-12 months from submittal to issuance.

Section 404 of the CWA requires a discharge of dredge or fill material permit to place fill in jurisdictional waters of the United States when disturbing certain existing surface water drainages or wetlands. A Section 404 permit is issued by the Army Corps of Engineers and can take from 12 to more than 18 months from submittal to issuance.

A complete understanding of the regulations promulgated under the laws of SMCRA and the CWA identifies conflicts and duplicity of these programs. One obvious and far reaching issue is the SMCRA requirement no net loss of prime farmland acreage (and no net loss of restored prime cropland to property owners) and the CWA requirement to restore ephemeral drainages and establish riparian buffers.

Along with reclamation and maintenance of cropland comes proof of productivity requirements for high target yields which require conventional tillage practices. Conventional tillage employs plowing and disking which increase erosion while conservation tillage leaves previous crop residue remaining on the soil after planting and limits use of soil conditioners and pesticides. Historically, agricultural ditches were cut along field borders to facilitate farming. Runoff from the exposed fields deposits sediment and soil amendments into streams. Recent trends point to an increase in conservation farming practices and a decrease in conventional tillage practices but sediment loss to streams remains an issue.

Property Ownership Issues and In-stream Impoundments

While, by regulation, cropland must be restored with no net loss to landowners, many landowners prefer other desirable land uses over increased riparian buffers. Landowners prefer lakes and farmable ground. Regulators do not allow streams to be routed through bodies of water. In-stream impoundments are beneficial in agricultural environments, providing sediment retention. In-stream water bodies also provide flood storage during high flows and base flow during dry periods. It is well known that reservoirs established in streams for flood control require periodic clean-out of sediment; evidence of high sedimentation loading to streams from agricultural areas. If sediment is not trapped prior to discharge it ends up in streams and rivers.

(©2007Google™)

Figure 1. Sediment loading from runoff (Ohio River between Newburgh, IN and Owensboro, KY.

As previously mentioned, NPDES regulations require disturbed mine surface drainage to be routed through sedimentation basins. Actively mined and reclaimed ground must be graded to direct drainage to these basins which complicates the restoration of streams in these same drainages that must later not intercept the basins. In many instances a sedimentation basin must be retained through, or almost through, final release of the SMCRA reclamation bond. Pre-mining land use situations do not typically require erosion and sedimentation control systems, so we must ask, why recreate existing erosion and sediment contribution by putting ephemeral streams back in crop fields? For a better understanding of this question refer to Figure 2 which shows eroded and entrenched drainages that have developed and are too deep to farm through. They can become vegetated and an impediment to efficient farming.

(©2007Google™)

Figure 2. No net loss off cropland.

Farmers must depend on successful reclamation of their land and the return of productivity. Successful reclamation of the property shown in Figure 2 is dependent on the specific plan that is developed and implemented. Many aspects must be considered to develop what is thought to be the best plan. Will a reclamation plan that follows conventional principles be most successful or will a plan that follows geomorphic reclamation concepts be more successful. Which plan will be more sustainable and which plan will the landowner prefer?

Farmers must maximize the usability and productivity of their cropland. At the same time, jurisdictional waters must be replaced typically in a fashion that restores, and most often increases, the pre-mining functionality. Often the very streams that must be replaced cause erosion and increased sediment loading. Figure 3 depicts the more geomorphic approach in the right panel and the more conventional approach in the left panel. The geomorphic approach will utilize dissected topography with ephemeral drainages extending into the crop fields. Crop rows must follow the land form contours as well as the configuration of the field. Farming efficiency may not be maximized. The conventional approach will utilize properly constructed terrace and tile systems which allow for more uniform land form contours and less dissected field configuration. Farming is more efficient and there is less potential for failure of the ephemeral drainages because of entrenchment and erosion.

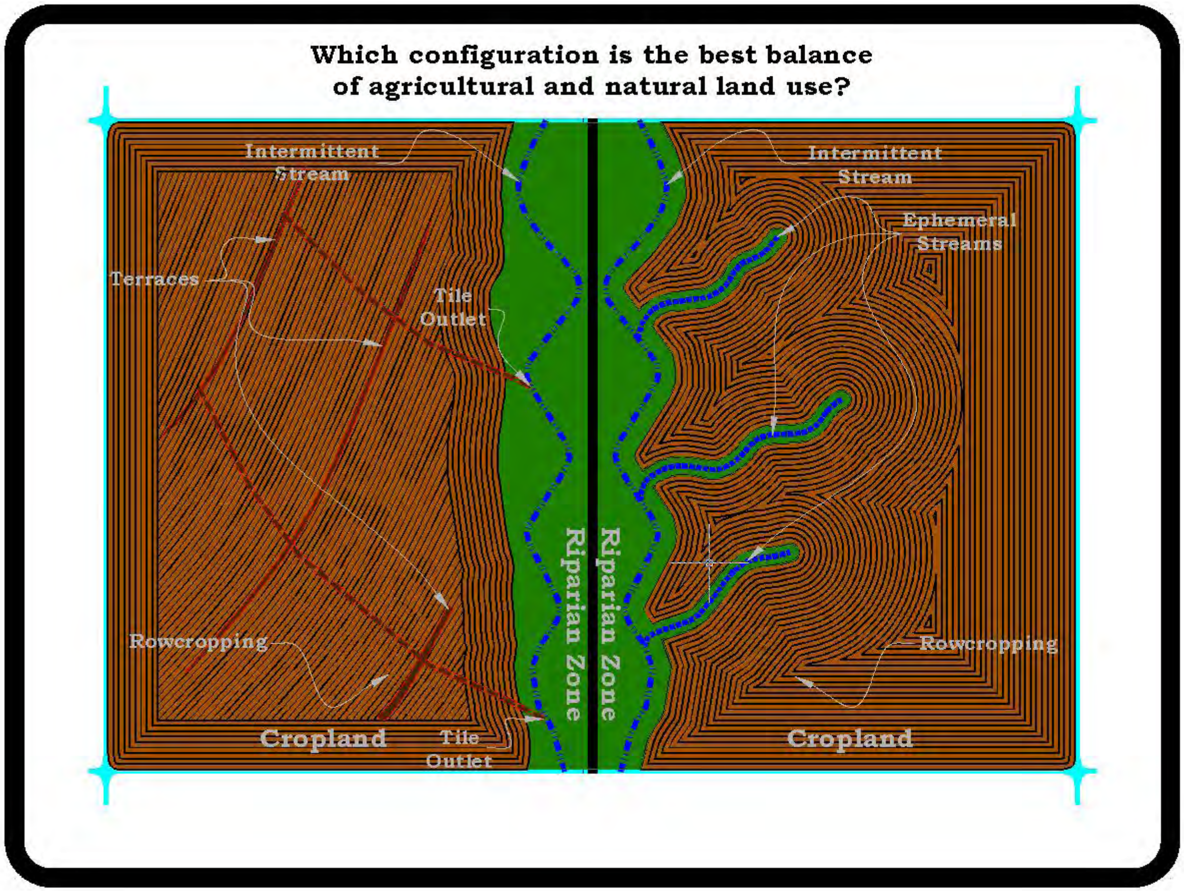

Figure 3. Landowners prefer to maximize farmable ground.

The balance of pre- and post-mining land uses is another very important consideration when developing a successful reclamation plan. Many surface properties are leased in the Midwest and the landowner expects the development and implementation of a plan that returns productive and usable ground. The landowner also expects that the ground support multiple land uses, sometimes in a configuration he prefers that varies from the pre-mining condition. Landowners understand the value of real estate, whether it be farm land or ground that can be used or developed for residential or recreational purposes. Most land parcels support a variety of land uses as can be seen in Figure 4. This aerial photograph shows cropland, pasture, rural residences, straightened agricultural ditches, eroded ephemeral drainages, an open water body, and an eroded, entrenched natural drainage with a wooded riparian corridor. The best reclamation plan would incorporate the desirable aspects of this landscape and eliminate or improve the undesirable aspects (Figure 5).


(©2007Google™)
Figure 4. Agricultural pre-mine land use.

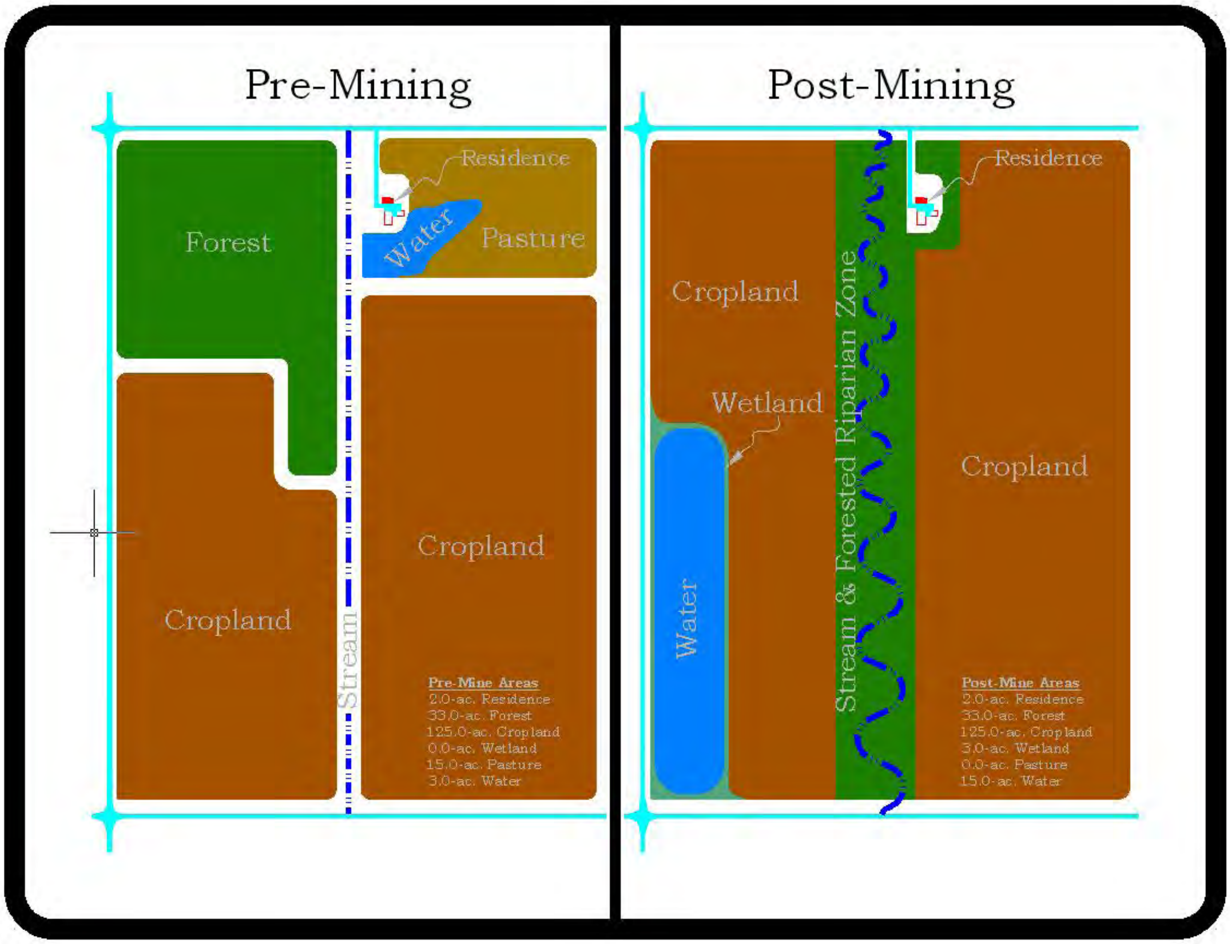

Figure 5. Balance and reconfiguration of post mine land uses.

Operating Difficulties

Geomorphic and conventional reclamation principles may not be as exclusive of each other as commonly thought. However, each may have advantages and limitations in certain reclamation environments. Surface coal mining in the Midwest is a continual cycle that moves through various phases of mining and reclamation and geomorphic reclamation may be the less flexible approach. The primary mining method is either by dragline, mobile equipment, or a combination. Typical dragline configurations include the Bucyrus Erie 2570 and typical mobile equipment fleets include bull dozers (Cat D10 and D11), dump trucks (Cat 789, 793) and shovels (Hitachi 3500 and 5500). This equipment operates around the clock and does not stop for pre-stripping activity (development of drainage control and removal of topsoil and subsoil) or reclamation. As areas are mined, they must be reclaimed contemporaneously as specified by SMCRA. Conventional reclamation methods as practiced in the Midwest may be more conducive to achieving ongoing reclamation than the land forming concepts of geomorphic reclamation.

Other factors that should be evaluated when considering geomorphic reclamation include significantly longer dozer pushes that result in less soil thickness (approximately one foot instead of four or more feet now typically placed) and increased compaction due to repeat tracking (as opposed to the advantage of trucks over scrapers for soil replacement with minimal compaction). Rock grade must enable mobile soil haulage (i.e. maximum grades of five to six percent are typically used for trucks dumping soil) and be conducive for operating rubber tired equipment. Other challenges include spoil swell (different at each location), safety issues, mechanical failure and low tire life.

Opportunities

Geomorphic reclamation concepts when evaluated and applied properly may provide opportunities or enhancements to conventional reclamation in the Midwest. These can be highlighted by:

- Advance grade plan with appropriate floodplains for primary streams to be replaced
- Plan for appropriate grades entering into floodplain area (dependent on pre-mine topography, swell, etc.
- Truck dump single lift of soil in planned forest/wildlife areas
- Minimal or no grading of replaced soils to reduce compaction and increase tree growth (OSM Midwest Forestry Reclamation Approach)
- Reconstruct tributaries in minimally graded soil
- Establish enhanced riparian buffers where opportunities allow
- Develop effective erosion control systems utilizing terraces, water and sediment control basins (WASCOBs), etc. in place of existing erosional features and ephemeral streams.
- Keep topsoil, fertilizer and pesticides in the field and out of the streams (sedimentation basins and vegetative buffers).

In particular, geomorphic principles may be applied to the restoration, creation and reconstruction of water resources and jurisdictional waters. These water resources may be streams, wetlands or open water bodies.

Stream Restoration

The stream restoration methodology recently preferred by regulatory agencies is natural channel design. The natural stream channel design concept is based on physical channel criteria best characterized by Luna Leopold and Dave Rosgen. The primary criteria include:

- Valley slope
- Channel type
- Meander patterns
- Flood plain and bank-full channel dimensions
- Bed stability

Wetland Restoration

The wetland restoration methodology preferred by regulatory agencies is bottomland hardwood plantations. These wetlands are created by establishing ground elevations and topography that will allow soil substrates to remain saturated long enough to become hydric. The hydric soils and saturated hydrology support the growth of hydrophytic vegetation which is primarily selected hard mast tree species such as oak and hickory.

Establishing Lakes and Impoundments

Post-mining open water bodies are planned prior to and during mining. Private land owners recognize the value added to real estate and the added recreational opportunities lakes and impoundments provide. Open water bodies may be completely formed in graded spoil or as an end- or final-pit impoundment with graded highwall and spoil slopes. Lakes and impoundments often have wetland features incorporated around the perimeter in shallow water fringe areas or adjacent bottomland areas.

Conclusion

Proper land forming and soil replacement yield productive reclaimed ground. Only thorough knowledge and evaluation of reclamation concepts will maximize the degree of success that the final plan and implementation will yield. Whether the plan is based on geomorphic or conventional reclamation principles, or a combination of both, the reclamation plan must be developed and implemented for success. Reclamation success equals productive land and productive reclaimed ground, wildlife habitat, and water resources are sustainable resources and valuable real estate.

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WHERE DO WE GO FROM HERE?

Forum Participant Recommendations

At the conclusion of the forum on April 30, 2009, the participants provided the following recommendations concerning issues or concerns deserving attention and efforts by the Geomorphic Reclamation and Natural Stream Design Steering Committee.

1. Develop workshops that are regionally focused.
2. Need a forum on aquatic organisms such as benthics and invertebrates and how they are impacted by mining and geomorphic reclamation.
3. Need to have talks on examples of geomorphic reclamation efforts that failed and why.
4. Need a training session or workshop on how what field inspectors need to know in order to evaluate geomorphic reclamation at the mine.
5. Need more information on a watershed approach to terrain analysis.
6. How could contemporaneous reclamation be an impediment to geomorphic reclamation plans?
7. How can regulatory programs be modified so that they would favor the use of higher quality reclamation techniques like geomorphic reclamation?
8. Identify regulatory barriers to improved geomorphic reclamation designs.
9. Need some research to look at long term (10,000+ years) implications of different types of reclamation technologies including geomorphic reclamation.
10. Need some research on documenting actual results in the field of examples of geomorphic reclamation.

PARTICIPANT SURVEY RESULTS
GEOMORPHIC RECLAMATION AND
NATURAL STREAM DESIGN AT COAL MINES

Total Participants	189	100%
Total Completing the Survey	76	40%
Level of Satisfaction With the Forum **Extremely Satisfied** **Very Satisfied** **Satisfied** **Dissatisfied** **Very Dissatisfied** **Average Level of Satisfaction 4.0 or Very Satisfied** **97 % Rated the Event Satisfied or Better**	 23 31 18 2 0	

Where Did The Participants Come From?

Participant Affiliation	Participant #	Participant %
Consultant	46	24
OSM	38	20
State Mining Regulatory Agency	36	19
Mining	31	16
University	19	10
US Army Corps of Engineers	11	6
Other	5	3
State EPA	2	1
US EPA	1	≤1

Who Did They Represent?

Regional Representation	Participant #	Participant %
East	122	65
Mid-Continent	36	19
West	29	15
International	2	1

Compliments

1. Forum had good format to keep the discussions on track.
2. The steering committee did an excellent job putting the program together.
3. As a person new to the coal regulatory field, I found the forum very worthwhile and a great jump start toward understanding the many pertinent issues. Quality of presentations was impressive.
4. Field trip was excellent. Good idea to have it first which allowed opportunity to meet people prior to forum.
5. I liked the panel discussion at the end of each session to make sure everyone had the opportunity to ask questions.
6. I thought the presentations covered the subject very well.
7. The academic speakers were great and provided a very interesting panel discussion. All regional sessions were well planned.

8. The forum was great! Good diversity of participants. Field trip was great exposure to some examples of Appalachian geomorphic reclamation. The balance of industry, regulatory, and academic speakers was great.
9. Overall a great conference with good diversity of presenters, backgrounds, and regions.
10. Really appreciate what OSM has done with this event. The forum was very useful as there is not enough readily available information on this topic.
11. The forum was very well organized the way the topics were presented and discussed.
12. The event was well attended with good representation and a very valuable discussion.
13. Forum was well organized, productive, and very informative. Excellent Job!

Participant Rating On Usefulness Of Talks

4.0=EXCELLENT
3.0=GOOD
2.0=FAIR
1.0=POOR

Session 1 Advances in Geomorphic Reclamation

Presenter	Average Rating	Rating Range
Dr. J. Steven Kite	**3.0**	**4-1**
Dr. Peter R. Wilcock	**3.0**	**4-1**
Dr. Keith N. Eshleman	**3.1**	**4-1**
Melissa Robson	**3.2**	**4-1**
Dr. Charles Yuill	**2.7**	**4-1**
Overall Session 1 Average	**3.0**	

Session 2 Geomorphic Reclamation in Appalachia

Presenter	Average Rating	Rating Range
Uranowski/Superfesky	**3.1**	**4-1**
Nicholas Bugosh	**3.1**	**4-1**
George Athanasakes	**3.4**	**4-1**
Dr. Richard Warner	**3.2**	**4-1**
Clark/Slone	**3.0**	**4-1**
Agouridis/Barton	**3.5**	**4-2**
Debord	**3.3**	**4-1**
Overall Session 2 Average	**3.2**	

Session 3 Geomorphic Reclamation in the West

Presenter	Average Rating	Rating Range
Golnar/Calabrese	**2.8**	**4-1**
Calle/Stauffer	**2.4**	**4-1**
Dave Clark	**3.4**	**4-2**
Daphne Place	**3.6**	**4-1**
Overall Session 3 Average	**3.1**	

Session 4 Geomorphic Reclamation in the Mid-West

Presenter	Average Rating	Rating Range
Tim Sandefur	**3.3**	**4-1**
Ricketts/Werner	**3.1**	**4-1**
Ramona Briggeman	**3.2**	**4-1**
Lamb/Parrent	**3.2**	**4-1**
Jack Nawrot	**3.5**	**4-2**
Scott Mcgarvie	**3.3**	**4-2**
Overall Session 4 Average	**3.3**	

Most Useful Topic

- Academic Speakers
- Non Academic Speakers
- Stream Design
- Advances in the technology
- Pros and Cons of Different Approaches
- Applied Geomorphic Case Studies
- Appalachian Case Studies
- Western Case Studies
- All Case Studies
- The Kentucky case study on recreating a headwater stream on a head of hollow fill.
- Presentation on Geomorphic Reclamation in State of New Mexico
- Presentation on "Natural Regrade" software.
- Seeing different regional approaches to geomorphic design was very helpful.
- Geomorphic Reclamation in general and Industry Perspective
- Really appreciated the diversity of speakers in each session
- Scientific and technical information and practical application

Suggestions

Future Forums or Workshops

- Beneficial Use and Risk Management in relation to CCB placement at surface mines.
- Provide Training opportunities on Natural Regrade Software.
- Provide shorter regional workshops with one day of talks and one day in the field.
- Region specific forum on the Illinois Basin
- Region specific forum on the Appalachian area
- Region specific forum to Southern States (AL, MS, LA, TX)
- Provide regional workshops on a regular basis with a national forum every few years.
- The current forum was good and necessary in terms of the topic, presentations, and networking opportunities. There needs to be follow-up events in the future to ensure this emerging science continues to move forward.
- Provide contractor/operator perspective on the construction phase of conducting geomorphic reclamation, stream bed construction, and earth work.
- Provide pre-conference workshops of geomorphic software.
- More information on conductivity and selenium issues.
- Limiting the number of people for the field trip meant that many people tried to drive their own vehicles and follow the vans resulting in a very poor experience at the beginning for those not able to be accommodated in the vans.
- Workshop on identification of aquatic benthic organisms and invertebrates
- Determine what individual states and Army Corp of Engineers districts are doing across the country and get them to integrate and coordinate their processes. Need an agency only meeting to discuss improved more integrated processes.
- Specific workshop or forum on Stream Restoration with examples of success and failures.
- Have breakout sessions for specific topics
- Provide a workshop with hands-on experience
- Regulatory strategy on how to address the geomorphic requirement and existing conflicts and discrepancies in regulations.
- Need more research and information on how geomorphic reclamation and natural stream design works over time.

Forum Content and Presentations

- Prefer case studies to product promotion
- More presentations with detailed examples and design techniques.
- Show lessons learned from failures as well as successes

- More on Appalachian case studies and steeper slopes
- Some speakers were poorly organized and did not leave time for questions
- Some of the talks had multiple presenters that usually resulted in the first speaker taking too much time and not leaving time for the other speaker.
- More Midwestern case studies
- Many presenters provided examples of "natural" streams in reclaimed areas, but their designs are "wrong" as they are not stable designs for the valley types they are designing.
- More information on specific stream design for perennial, intermittent, and ephemeral streams.
- Have the introduction at the beginning provide a summary of the forum issue to bring everyone up to speed.
- Stream restoration downstream from Acid Mine Drainage Treatment areas.
- Much of the Academic talks were not understandable by many in the audience
- More detailed info on non-Rosgen method of stream design from Rosgen critics.
- Academic speakers should attend all four levels of Rosgen training before making critical statements about it. Rosgen methods of stream design do take into account hydrology, valley type, watershed, sediment transport, habitat, predicted outcome, allows for adjustment and is practicable. Does not take years of study to complete a design.
- Academic speakers presented challenges to current practices but had no plan for solving the problems.
- More information on biological results in new stream channels.
- Presentation from US EPA and other State EPA speakers
- Presentation by USEPA Region III to tell us what they want for stream restoration and why.
- Need more information on steep slope situations including maintenance of slope stability and effects of flooding.
- Provide a CD of all presentations.

Additional Topics

- What is the OSM position on Geomorphic Reclamation?
- Regulatory interpretation of current requirements
- How do we get interagency coordination on this subject?
- How does the Federal Program in Tennessee do geomorphic reclamation and what type of guidance is available?
- Detailed discussion on energy dissipaters for geomorphic stream design
- More talks from stream restoration experts rather than practitioners
- Talks on stream habitat reconstruction not just channel reconstruction
- Talk on how a mine site is re-established/re-connected to its pre-existing hydrology
- Presentation by Horst Schor
- What is being done for stream restoration/mitigation when the headwater stream and its source is mined out and the source does not return?
- Need more information on water chemistry downstream from reconstruction.
- Monitoring of long term impacts to stream reconstruction
- Sediment basin design and function, water treatment methods/water chemistry/ runoff/ water quality from coal mine sites/sediment basin removal/creating wetlands in mitigation basins/steam restoration after removal of sediment basins
- How surface mines affect the water table and ground water.
- Need to find a way to educate land owners and operators.

Facilities

- Difficult to see slides in back of room
- Slides were not bright enough to see well in back of room
- Sound system was totally inadequate
- Food provided was poor
- Having food for breaks and lunch was good to keep the group together but quality was poor
- Elevators not working the first day

- Distracted by chairperson having to get up to check lights, etc.
- Location difficult and expensive to get to.
- Need a computer screen on podium so that speakers don’t talk to screen.

GEOMORPHIC RECLAMATION AND NATURAL STREAM DESIGN AT COAL MINES

SPEAKER BIOGRAPHIES

Dr. Carmen Agouridis P.E. is currently Assistant Research Professor, Biosystems and Agricultural Engineering Department at the University of Kentucky. Her research interests include stream restoration and assessment, mined land reclamation, riparian zone management, hydrology of surface waters, environmental impacts of animal agriculture. She is the recipient (as PI and Co-PI) of over $2.5 million in grants. She is an instructor for "Introduction to Stream Restoration (senior-level and graduate-level course)," Stream restoration training "Rosgen Levels I-IV courses at North Carolina Stream Restoration Program River Courses" and various conference workshops. She holds a Ph.D. in Biosystems and Agricultural Engineering and is a Professional Engineer.

George Athanasakes, ***PE*** has a broad range of experience in Ecological Restoration including the use of natural channel design, stream and wetland restoration, watershed master planning and dam removal. Over the past 15 years, George has served as Project Manager on numerous stream restoration projects throughout the United States. George also led the development of the RIVERMorph Stream Restoration Software and is responsible for software content, new releases and training. His career began with FMSM Engineers, where he led FMSM's Ecosystem Restoration Group. In 2007, FMSM Engineers was acquired by Stantec Consulting Services. George now serves as the Ecosystem Restoration Practice Leader for Stantec and is responsible for leading these services throughout North America. He holds a Bachelor's of Science and Master's of Engineering Degrees from the University of Louisville. He is also a Registered Professional Engineer in several states.

Dr. Chris Barton is an Associate Professor of Forest Hydrology and Watershed Management in the Department of Forestry at the University of Kentucky. As a Research Hydrologist with the USDA Forest Service (1999 – 2003), his research focused on hydro-chemical processes associated with restoration and remediation of disturbed and/or contaminated areas at the US DOE Savannah River Site, SC. Dr. Barton is currently focusing on work in the areas of ecosystem restoration and remediation primarily in stream and wetland habitats that have been altered by human-use activities. In addition, improved methods for preventing water quality degradation from logging and mining activities are currently being examined. Dr. Barton is currently serving as the co-Team Leader of the ARRI Science Team.

Mike Boulay is a registered Professional Geologist with 23 years of regulatory compliance experience within mining, oil & gas exploration and production, and manufacturing industries. Currently he is employed as an Environmental Protection Specialist for the Division of Reclamation, Mining and Safety for the State of Colorado, where his responsibilities include permit and mine plan review and approval, inspection, and enforcement for the coal mining industry. He holds a Bachelor of Science in Applied Geology, from Northern Arizona University, and a Master of Environmental Policy and Management, from the University of Denver.

Ramona Briggeman is currently the Reclamation Biologist with the Indiana Division of Fish and Wildlife. She serves as a field biologist in Indiana Division of Fish and Wildlife but is assigned to the technical services section of the Indiana Division of Reclamation. Prior to serving as the Reclamation Biologist, she was a Reclamation Specialist for the Indiana Division of Reclamation. With over 17 years experience with mining and reclamation, she is responsible for reviewing coal mining operations to evaluate environmental impacts, including effects on fish and wildlife resources (streams, wetlands, endangered species). She received her Bachelor of Science degree in Life Sciences from Indiana State University.

Nicholas Bugosh is presently the GeoFluv Technical Director for Carlson Software. He resides in Fort Collins, Colorado and is responsible for the development and promotion of the Natural Regrade fluvial geomorphic landform design module and Hydrology module worldwide. Natural Regrade is used across the United States, in Canada, Australia, and Romania. He has conducted field research on bedload transportation in mountain streams, worked for state agencies in South Dakota, Montana, and Idaho with mining and water quality regulation, worked as a hydrologic consultant on projects across the United States, and worked as Senior Hydrologist for the New Mexico operations of the largest mining company in the world. Mr. Bugosh has developed a new approach to land grading that returns disturbed lands to natural function and appearance that he calls GeoFluv™. This approach forms the heart of the new Carlson Software ***"Natural Regrade"*** module. His training in geology and hydrology includes a Bachelor of Science in Geology and a Master of Science in Earth Sciences.

Julian Calabrese works for the Montana Department of Environmental Quality, Industrial and Energy Minerals Bureau, as a Soil Scientist Reclamation Specialist. He has six years experience with the MDEQ Permitting and Compliance, two years in private environmental consulting; and is an Instructor for ArcPAD and mobile computing applications. He holds a B.S. Abused Land Rehabilitation from Montana State University.

Marcelo Calle is a Project Manager from the Wyoming Department of Environmental Quality – Abandoned Mine Land (AML) Program. Prior to employment with the Wyoming AML Program he provided technical support as a surface water hydrologist for Wyoming's Mine Regulatory Program. Currently, he works with environmental engineers and construction contractors to mitigate hazards and environmental degradation associated with historic mining. He is a graduate of the Watershed Science Program at Colorado State University in Fort Collins, Colorado.

Dave Clark is employed by the New Mexico Mining and Minerals Division. He is an Ecologist/Inspector with 17 years of experience regulating coal mines in New Mexico and

Montana. He holds a BS in Fish and Wildlife Management and a MS in Biological Sciences (Plant Ecology, Statistics, and Range Science) from Montana State University.

Jackie T. Davis is the Director of the Division of Mined Land Reclamation (DMLR), one of six divisions within the Virginia Department of Mines, Minerals and Energy (DMME). He has worked for the Department of Mines, Minerals and Energy for over 26 years as a Reclamation Inspector, and an Administrative services Manager. In 2008, he came back to the coal mine reclamation program as the reclamation services manager for inspection and enforcement activities and was promoted to his current duties in January 2009. He also worked in the Va. State Parks system for 8.5 years before transferring to DMLR. He is a 1974 graduate of Berea College, Berea KY, where he earned a degree in Agriculture.

Lance DeBord is an Environmental Scientist with D.R. Allen & Associates in Abingdon, VA. His current responsibilities there include fish and benthic macro-invertebrate assessments, fluvial geomorphic surveys, terrestrial plant and wildlife surveys, wetland delineations, mitigation design, and environmental permitting. Mr. DeBord has been involved with various natural resource issues in southwest Virginia since 1998. He holds a bachelor's degree in Environmental Science from University of Virginia's College at Wise.

Dr. Keith N. Eshleman is Professor at Appalachian Laboratory, University of Maryland Center for Environmental Science in Frostburg, Maryland. His professional expertise is in the field of watershed hydrology, having completed his doctorate in Water Resources at M.I.T. (Dept. of Civil Engineering) in 1985. He has published more than 40 journal articles in his career and is co-author of an undergraduate textbook entitled *Elements of Physical Hydrology* (with former colleagues from the University of Virginia, where he served on the faculty from 1988 through 1995). Dr. Eshleman's current research interests are in the areas of watershed and wetlands hydrology, groundwater/surface water interactions, biogeochemical processes in upland and wetland ecosystems, hydrochemical modeling, and ecosystem responses to disturbance and land use change.

Tom Golnar is the Surface Water Hydrologist for the Coal Regulatory Program of the Montana Department of Environmental Quality, and has been working with the Montana coal program, the mines, and the ephemeral drainages of Southeastern Montana for a little over 20 years.

Tom's academic interest in hydrology developed at Colorado State University in the late 1970's and early 80's, where he completed his Bachelor's degree in Watershed Sciences in 1982. He grew up in and loved the Colorado mountains, but Montana's remote siren call first lured him north in 1981 where he worked with chainsaws and high school kids as a stream rehabilitation crew leader in drainages torn apart by winter rain-on-snow flood events in the Kootenai National Forest. During the mid-1980's, Tom worked and studied in the mountain valleys, streams and lakes of northwestern Montana as a research assistant for the Flathead Lake Biological Station of the University of Montana, where he earned a Masters degree working in Limnology and Aquatic Ecology in 1986. During and afterwards he put in several years of fieldwork, analysis and lab time monitoring and studying a variety of lakes and streams with the Biological Station and the Flathead National Forest.

Dr. J. Steven Kite has taught in the Department of Geology and Geography at West Virginia University since 1983. His WVU courses include Geomorphology; Fluvial Geomorphology; Applied Fluvial Geomorphology, and Field Geology. He co-taught a series of workshops on Natural Stream Principles through the West Virginia Chapter of the American Council of Engineering Companies from 2002 to 2004, and also co-taught a series of workshops on Stream Processes and Ecology offered by the Canaan Valley Institute in 2007 and 2008.

His research interests include applied fluvial geomorphology, geoarcheology, and the late Cenozoic history of the Appalachian Mountains. He has authored 27 refereed articles, 70 published abstracts, and two lab manuals. He has supervised nearly 40 Masters and PhD. Degrees at WVU. He was a founder of the Southeastern Friends of the Pleistocene, and a former Chair of the Quaternary Geology and Geomorphology Division of the Geological Society of America and the West Virginia University Faculty Senate. A native Virginian, Kite earned a B.S. in Geology at James Madison University, a M.S. in Geological Sciences at the University of Maine, and a Ph.D. in Geology & Geography at the University of Wisconsin.

David A. Lamb, PE is the President of Associated Engineers, Inc in Madisonville, KY. He has over twenty years of consulting engineering experience related to the mining industry. He has been involved in reserve evaluation, mine planning, and all aspects of mine related environmental permitting ranging from DMRE to USACE. This broad base of experience founded on long term relationships with multiple coal company clients and regulatory agencies has served as the basis for the development of a unique perspective of past and present, policies, views, and operating procedures both the industry and the regulatory agencies who are charged with overseeing environmental compliance of mining operations in Kentucky. He is the Past President of Kentucky Society of Professional Engineers, Green River Chapter and member of the American Society of Civil Engineers and the West Kentucky Coal Association. In 2000, he was awarded Achievement in Mining Engineering Award Kentucky Society of Professional Engineers. He holds a B.S. in Civil Engineering from the University of Kentucky.

Scott D. McGarvie is Senior Environmental Manager for Peabody Energy's Midwest Operations in Evansville, Indiana. He worked for the USGS Water Resources Division from 1979 to 1981. In 1981, he began work as a hydrologist with Peabody Coal Company's Eastern Division and has worked for Peabody affiliated companies since then. Scott has worked with coal mining regulations since the early years of SMCRA and been involved in many aspects of environmental regulations and permitting including CWA Sections 401, 402 and 404. Scott is a registered Professional Geologist in IL, IN, KY, MO, TN and WI. He graduated with an MS Degree in Hydrology/Hydrogeology from Mackay School of Mines, University of Nevada - Reno in 1979.

Jack Nawrot is a Senior Scientist with the Cooperative Wildlife Research Laboratory's Mined Land Reclamation program at Southern Illinois University. Jack has been on staff with the Lab since 1974 BC (*before computers*). His professional responsibilities included the statewide inventory of Illinois mined lands, implementation of wetland mitigation and restoration practices, geochemical characterization of coal processing by-products, and direct vegetation establishment practices for coal slurry and gob. Jack has supervised Wildlife Lab students whose projects have assessed waterfowl, grassland birds, and Illinois threatened marsh birds and mammals that use Illinois' reclaimed mines. More than 25 years ago the Lab's students and staff conducted the first evaluations of temporary diversions and permanent stream restorations established on southern Illinois' mined lands. He holds a Bachelor's in Ecology from Blackburn College in 1972 and a Masters in Wildlife Ecology from Southern Illinois University at Carbondale in1974 and is currently working on a doctorate in Reclamation Ecology at SIUC.

Darrin S. Parrent, EIT is a civil/environmental engineer with T.H.E. Engineers, Inc. in Lexington, KY. He has over 7 years experience with the KY Transportation Cabinet, Division of Environmental Analysis and 5 years experience with T.H.E. Engineers, Inc. He has completed the design of over 40 stream restoration/mitigation projects utilizing natural stream channel design concepts for KYTC highway and commercial/residential development projects. In addition, he has completed the design of over 30 miles of streams on a watershed scale for several large coal surface mining projects. His stream related experience also includes construction observation and monitoring. He has experience preparing USACE Section 404 and KY Division of Water/KY Department of Mine Permits Section 401 permit applications. He has also prepared cumulative impact analysis and alternative analysis reports for several large surface mining projects. He holds a B. S. in Civil Engineering with Environmental Certificate from the University of Kentucky.

Daphne Place is an Environmental Specialist with BHP Billiton in Farmington, New Mexico. Her current role supports the development of a SMCRA permit for the Navajo Mine Extension Project in the areas of hydrology, reclamation, and geomorphic surface stabilization. In her previous role, she provided engineering and design support to the completion of geomorphic reclamation at La Plata Mine. She participates on closure planning and geomorphic reclamation implementation teams for BHP Billiton's New Mexico operations. Prior to working with BHP Billiton, Ms. Place worked for a consulting company as an Environmental Engineer and a domestic coal mining company as a Mining Engineer. She has enjoyed living and working in West Virginia, Virginia, Kentucky, Illinois, Wyoming, Colorado, and New Mexico. She holds a BS in Mining Engineering and Environmental Science, along with her MS in Environmental Science and Engineering. She is a member of the Society of Mining Engineers.

Mike Ricketts is West Section Chief for the US Army Corps of Engineers, Louisville District. His office is located in Newburgh, Indiana. His responsibilities include supervising a staff of seven technical professionals while managing section 404 and section 10 permit processing in western Kentucky, southeastern Illinois and southwestern Indiana. Prior to becoming West Section Chief in 2007, Mike served as a Senior Project Manager with both Louisville and St. Louis Districts since 1994. Prior to that, Mike worked for Soil Conservation Service as a Soil Scientist in Eastern and Northern Kentucky and as a cartographer with Defense Mapping Agency. Mike graduated from the University of Kentucky with a degree in Soil Science and Eastern Kentucky University with a degree in Remote Sensing/Cartography.

Melissa Robson, E.I. is a project engineer at Water & Earth Technologies, Inc. in Fort Collins, Colorado. Melissa has technical experience in watershed hydrology, hydraulics and surface water monitoring. She has worked with several different mining companies in the United States, Central and South America to develop post-mining geomorphic surfaces and runoff control systems using multiple software tools. Melissa has become proficient at developing solutions for a variety of reclamation challenges, including hard-rock mining with pits and waste-rock piles, and surface coal strip mining with trenches and extensive spoil piles. Her education background includes a bachelor's degree in Civil Engineering from Colorado State University.

Tim Sandefur is a managing partner of Wetland Services, Inc. He has been active in wetlands ecology either recreationally or professionally for over 23-years. Tim incorporated Wetland Services in 1997, and now maintains a wide range of regulatory services and clients. Wetland Services has conducted wetland and stream delineation, functional assessment, permitting and restoration (mitigation) on over 80,000-acres. He currently serves as a board member of the Pond Creek Watershed Conservation District, and is a board member and managing partner of Cypress Agricultural Services, LLC (a land trust company) and the Cypress Foundation (a 501c3 not-for-profit organization). His degree is a Bachelors of Science in Wetland Ecology from the University of Kentucky.

Tim Slone is president & CEO of IRTEC, Innovative Reclamation Technologies and Engineering Company, Incorporated. Permitting, reclamation plans and surveying are the mainstay of the company. He has a strong background in mining, especially underground mining where he worked from a general laborer up to Mine Foreman before becoming more involved with the engineering aspect. His underground experience includes coal seams ranging from 20" to 24 feet in thickness and involves working in mining operations in Western Kentucky, Eastern Kentucky, Virginia and Tennessee. Tim is a licensed professional engineer and land surveyor in several states and has numerous certifications associated with his extensive period of involvement with coal mining. He is a graduate of the University of Kentucky, College of Engineering.

Lois J. Uranowski, ***PE*** is Chief of the Ecological Services and Technology Transfer Branch, Technology Support Division, OSM in Pittsburgh, PA. Lois runs the Appalachia Region Technology Transfer initiative. She has spent 20 years working in coal mining reclamation covering both AML and active mining, and has provided technical assistance in the areas of slope stability, mine subsidence and as an instructor for several TIPS classes. Lois also has worked for an engineering consulting company. She holds a MS in Civil and Environmental Engineering.

Dr. Richard Warner is currently Extension Professor, Biosystems and Agricultural Engineering, at the University of Kentucky. He is the co-author of SEDCAD and has co-authored numerous books, chapters and publications. His research interest includes design and implementation of stormwater, erosion and sediment control systems for mining and construction sites with large scale land disturbance. He is a consultant/advisor to major mining corporations with mines in South America, Africa, Indonesia, South Pacific and throughout North America. He holds a Ph.D. in Environmental Systems Engineering from Clemson University.

Sam Werner is employed by U.S. Army Corps of Engineers since 2003 as a regulatory specialist administering Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899. Duties include reviewing project and mitigation plans, giving technical assistance, issuing permits, ensuring compliance with permit terms and conditions, and pursuing enforcement activities for violations. He was previously employed by USDA as a soil scientist, conducting on-site soil investigations, soil survey activities and publishing soil surveys throughout East Central Illinois (1998-2003); and Chestnut Ridge Consulting, Inc. as a soil scientist, contract mapping soil properties for use in growing timber for the paper pulpwood industry in KY, MO, and TN (1997- 1998). He graduated from Purdue University in 1997 with a Bachelor of Science Degree in Natural Resources and Environmental Science.

Dr. Peter R. Wilcock has taught at Johns Hopkins University for 22 years, specializing in erosion and sedimentation processes and their application to stream restoration and watershed management. He leads the Stream Restoration Project of the National Center for Earth-surface Dynamics, a Science and Technology Center funded by the National Science Foundation. He contributes to stream restoration and channel design classes taught at The University of Maryland, Utah State University, and The University of California Berkeley. He received his PhD in Earth Science at MIT in 1987.

Dr. Charles Yuill is Associate Professor at West Virginia University – Natural Resource Analysis Center (NRAC) and is also a partner in ShipShaper LLP , a consulting firm that specializes in areas including mine reclamation and water quality planning and high fidelity visualization with tools such as laser scanning. He has over 30 years of experience with surface mine planning and reclamation.

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