# P R O C E E D I N G S
**from an**

# I N T E R A C T I V E  F O R U M
# (A N D  R E L A T E D  A C T I V I T I E S)
**entitled**

# "S U R F A C E  M I N I N G  R E C L A M A T I O N  A P P R O A C H E S  T O  B O N D  R E L E A S E: C U M U L A T I V E  H Y D R O L O G I C  I M P A C T  A S S E S S M E N T  S U R F A C E - M I N I N G  A P P L I C A T I O N S  A N D  H Y D R O L O G Y  T O P I C S  F O R  T H E  A R I D  A N D  S E M I - A R I D  W E S T"

**held August 27 through September 1, 2000,**
**in Billings, Montana,**

**and co-sponsored by**
**the Office of Technology Transfer,**
**Western Regional Coordinating Center,**
**Office of Surface Mining,**
**Denver, Colorado;**
**the Montana Department of Environmental Quality,**
**Industrial and Energy Minerals Bureau,**
**Division of Permitting and Compliance,**
**Helena, Montana; and**
**the Montana Bureau of Mines and Geology,**
**Montana Tech of the University of Montana,**
**Butte, Montana**

**DISCLAIMER**

***The technologies described in these proceedings are for information purposes only. The mention herein, of the technologies, companies, or any brand names, does not constitute endorsement by the U.S. Department of the Interior's Office of Surface Mining.***

# A WORD ABOUT THESE PROCEEDINGS

*Reclaimed drainage, Area A,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "A Word about These Proceedings"

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| PREMINE DATA| PLANNING FOR RECLAMATION | RECLAMATION DESIGN I |
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| HYDROLOGY MODELING | MODELING WITH GIS | COAL-BED METHANE |
| FIELD TRIP TO ABSALOKA | FIELD TRIP TO ROSEBUD | OF GENERAL INTEREST |

## A WORD ABOUT THESE PROCEEDINGS

During the period August 27 through September 1, 2000, the Office of Surface Mining's (OSM's) Western Regional Coordinating Center, Denver, Colorado, the Montana Department of Environmental Quality, Helena, Montana, and the Montana Bureau of Mines and Geology, Butte, Montana, co-sponsored numerous workshops and mine field trips, as well as an interactive forum, that addressed surface mining reclamation approaches to the release from bond of coal mines operating in the arid and semi-arid West. (For a list of attendees at these activities, see appendix A, under "Of General Interest" in the proceedings that follow; for a copy of the agenda for the activities, see the next page.) The interactive-forum portion of this joint effort was the third in OSM's series of five annual forums regarding surface-mining bond-release topics. It was held in Billings, Montana.

Specifically, the 2000 forum covered cumulative hydrologic impact assessment and other assorted hydrology topics–among them data collection, modeling, prediction, and the mitigation of impacts associated with the processes of coal mining and reclamation–as these related to achieving bond release. Workshops addressed such disparate matters as spatial data for hydrology modeling, surface and subsurface modeling with GIS, and coal-bed methane. Field trips were to Westmoreland Resources, Inc.'s, Absaloka mine and Western Energy Company's Rosebud mine. (For abstracts of portions of the workshops, as well as certain forum presentations, see appendix B under "Of General Interest.")

The proceedings that follow constitute a partial compilation of the fruits of what proved overall to be a very valuable collaborative and multifaceted effort. Presentations at the forum were varied and quite interesting, and presenters were professionals possessing a wide range of diverse and divergent bond-release, reclamation, and hydrological expertise. Among these experts were representatives of Federal, State, and tribal governments, the coal-mining industry, and consultants to that industry; the attendance by these professionals, at field trips, workshops, and forum alike, was high.

It is with great pleasure that OSM offers the following compilation. With the exception of some stylistic changes made in the interests of uniformity of presentation, we have attempted to reproduce forum and workshop offerings verbatim. The field-trip summaries are our own. We would like to extend our sincere thanks to all who made presentations at or were otherwise involved with the 2000 interactive forum and related activities. It is both our hope and our strong conviction that colloquia such as these stand greatly to benefit the cause of successful reclamation in the arid and semi-arid West.

# F O R U M  A G E N D A

*Reclaimed drainage, Area A,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Forum Agenda"

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**SUMMARY – at a Glance!!**
**Workshops, Mine Field Trips, and Interactive Forum**
**SURFACE MINING RECLAMATION APPROACHES to BOND RELEASE: CUMULATIVE HYDROLOGIC IMPACT ASSESSMENT SURFACE-MINING APPLICATIONS and HYDROLOGY TOPICS for the ARID and SEMI-ARID WEST**

**August 27-September 1, 2000**
**Radisson Northern Hotel, 19 North 28th Street, Billings, Montana 59101**

*Co-sponsored by the Office of Technology Transfer, Western Regional Coordinating Center, Office of Surface Mining, Denver, Colorado; the Montana Department of Environmental Quality, Industrial and Energy Minerals Bureau, Division of Permitting and Compliance, Helena, Montana; and the Montana Bureau of Mines and Geology, Montana Tech of the University of Montana, Butte, Montana*

**Sunday, August 27, 2000**

Absaloka Mine, Westmoreland Resources, Inc., Pond No. 20 Field Visit
(see description and logistics information attached [attachment 1 to this agenda])

**Monday, August 28, 2000**

Spatial Data for Hydrology Modeling Workshop — 8:30 a.m. – noon
Richard Warner, Ph.D., and Mike Anderson, University of Kentucky
(see description attached [attachment 2 to this agenda])
Interactive Forum — 1 – 5 p.m.

**Tuesday, August 29, 2000**

Interactive Forum — 8:30 – 11:30 a.m.
Western Energy Rosebud Coal Mine Field Trip — 11:30 a.m. – 7:30 p.m.
(see description attached [attachment 3 to this agenda])

**Wednesday, August 30, 2000**

Interactive Forum — 8:30 a.m. – 4:30 p.m.
Surface and Subsurface Modeling with GIS Workshop — 6:30 – 9:30 p.m.
Michael Price, Mining Industry Solutions Manager, ESRI
(see description attached [attachment 4 to this agenda])

**Thursday, August 31, 2000**

Interactive Forum — 8:30 a.m. – 5 p.m.

**Friday, September 1, 2000**

Interactive Forum — 8:30 – 11:30 a.m.
Coal-bed Methane (CBM) Workshop — 12:30 – 5 p.m.
(see agenda attached)

**Workshops, Mine Field Trips, and Interactive Forum**
**SURFACE MINING RECLAMATION APPROACHES to BOND RELEASE: CUMULATIVE HYDROLOGIC IMPACT ASSESSMENT SURFACE-MINING APPLICATIONS and HYDROLOGY TOPICS for the ARID and SEMI-ARID WEST**

**Sunday, August 27, 2000**

***Field Trip to Westmoreland's Absaloka Mine***

Absaloka Mine, Westmoreland Resources, Inc., Pond No. 20 Field Visit: A Soil Bioengineering Alternative to Open-Channel Spillways for Upgrading Sediment Ponds to Permanent Structures for Bond Release Under the Surface Mining Control and Reclamation Act

(see description and logistics information attached [attachment 1])

**Monday, August 28, 2000**

**8:30 a.m. – noon**

***Workshop Presentation: Spatial Data for Hydrology Modeling Emphasizing New Developments in SEDCAD+ and GIS***

Workshop Presentation: Spatial Data for Hydrology Modeling Emphasizing New Developments in SEDCAD+ and GIS

(see description attached [attachment 2])

Richard Warner, Ph.D., and Mike Anderson, University of Kentucky

**1 – 5 p.m.**

***Opening Remarks***

Opening Remarks — Linda Wagner, OSM

***Background: Historical Perspective***

A Walk Through History — Joe Galetovic, OSM

Belle Ayr Mine Hydrologic Monitoring History — Phil Dinsmoor and Bob Stowe, RAG Coal West, Inc.

***Background: Premine Data***

Laboratory Data: Quality Assurance/Quality Control — Dave Poelstra, IML, Inc.

Adequacy/Utility of Premining Water-Resource Data — John Kern, Spectrum Consulting Services, Inc., and Dave Bickel, ND PSC

Graphic Analysis of Groundwater Responses — Dave Bickel, ND PSC, and Dennis R. James, Falkirk Mining Co.

Determining Soil Conservation Service Curve-Runoff Numbers for Mineland Conditions — Steve Schroeder, ND PSC

Climate, Bond Release, and the Concept of Minimum Liability Periods — Dave Bickel, ND PSC

**Tuesday, August 29, 2000**

**8:30 – 11:30 a.m**.

***Background: Premine Data–continued***

Alluvial Valley Floors: Reclamation Bond-Release Criteria Rich Chancellor, WY DEQ

Correlation between Natural Spring Flow and the Palmer Hydrologic Drought Index
Mike Suflita, UT DOGM, and John Kern, Spectrum Consulting Services, Inc.

***Planning for Reclamation***

Assessing Sedimentation and Landform Stability in Reclaimed Areas Using Baseline Sediment Data Collected in Receiving Streams
Ted Smith, Peabody Western Coal Co., and Alan Best, B&G Systems, Inc.

**11:30 a.m. – 7:30 p.m.**

***Field Trip to Western Energy Company's Rosebud Mine***

Western Energy Company Rosebud Mine Field Visit:** Highlighting the Reclamation Activities at the Mine in Support of Hydrologic Functions in Montana
Bob Postle, OSM (mine-visit coordinator), Robert Montgomery, Western Energy Co., and Tom Golnar, MT DEQ

The goal of the field visit is to see the progression in thought and application in the reestablishment of the hydrologic function of channels following mining. Specific onsite examples include drainages that were not planned and those that were created using ramp channels, point bars alone, meandering channels with and without point bars, and meandering channels of variable width. (For additional information, see attachment 3.)

**A sack lunch will be available to field-visit participants on the bus (pre-pay on Monday, August 28, at the registration table).

**Wednesday, August 30, 2000**

**8:30 a.m. – 4:30 p.m.**

***Planning for Reclamation–continued***

Probable Hydrologic Consequences
Marty Stearns, Kennecott Energy, and Doyl Fritz, WWC Engineering , Inc.

Wyoming Cumulative Hydrologic Impact Assessment Scott Miller, WY DEQ LQD

OSM's CHIA: Black Mesa/Kayenta Mines Phil Reinholtz and Brenda Steele, OSM

Recharge from Clinker in the Powder River Basin
Ed Heffern, Wyoming State Office, BLM

**Wednesday, August 30, 2000–continued**

**8:30 a.m. – 4:30 p.m.–continued**

***Planning for Reclamation–continued***

Use of a Localized Ground-Water Model to Predict Relative Impacts of the Life-of-Mine Plan for Rosebud Area D, Near Colstrip, Montana
Michael Nicklin, Nicklin Earth & Water, Inc., and Greg Liebelt, Western Energy Co.

***Reclamation Design***

Automatic Monitoring Systems for Reclamation Design
Richard Warner, Mike Anderson, and Frank Camargo, University of Kentucky

Seeps Below Sedimentation Ponds: Assessment of the Significance of Their Impacts to the Hydrologic Balance
John Cochran, Peabody Western Coal Co.

Reclaiming Montana Ephemeral Channels and Associated Side Slopes in Lands Disturbed by Surface Mining
Herb Rolfes and Steve Regele, MT DEQ

Drainages Are More Than Just Conduits for Water — Chris Yde, MT DEQ

Sediment Storage Design Considerations for Temporary Structures: SEDCAD 4 and RUSLE — Richard Warner, University of Kentucky

OSM's Guidance for Small Depressions on Indian Lands
Willis Gainer, OSM Albuquerque

**6:30 – 9:30 p.m.**

***Workshop Presentation: Surface and Subsurface Modeling with GIS***

Workshop Presentation: Surface and Subsurface Modeling with GIS
(see description attached [attachment 4])
Michael Price, Mining Industry Solutions Manager, ESRI

**Thursday, August 31, 2000**

**8:30 a.m. – 5 p.m.**

***Reclamation Design–continued***

Proposed Effluent Limitations Guidelines for the Coal-Mining Point-Source Category
William Telliard and John Tinger, EPA, Office of Water, Engineering and Analysis Div.

Hydro-Dat and Data Entry/Validation for CPR — Donald Jones, WWC Engineering

Antelope Coal Company's Best Management Practices for Sediment Control
Pat Baumann, Antelope Coal Co., and Dale Brown, WWC Engineering, Inc.

The Death Throes of Sedimentation Ponds: Removal of Primary Sedimentation Control, A Case History — Andrew Young, BHP Navajo Mine

**Thursday, August 31, 2000–continued**

**8:30 a.m. – 5 p.m.–continued**

***Reclamation Design–continued***

Using RUSLE 1.06 to Estimate Soil Erosion by Water on Minelands
Steve Schroeder, ND PSC

Long-Term Monitoring Results of Best Management Practice Applications
Norm Hargis, Bridger Coal Co. (invited)

Removing Sedimentation Ponds in North Dakota Larry Larson, ND PSC

Hydrologic Restoration Planning: A Design Consultant's Perspective
Marty Stearns, Kennecott Energy, and Doyl Fritz, WWC Engineering, Inc.

Using Chemical Data from Overburden Cores to Predict the Time Duration of Elevated Dissolved Solids in Colorado Coal Spoil Leachate
Tom Kaldenbach, CO MMG

Geochemical Modeling and Chemical Mass Balance of a Coal-Mine Pit Lake in Southeastern Montana
Warren Phillips, Department of Geology, Univ. of Montana, and John Wheaton, MBMG

Use of a Regional Ground-Water Model to Predict Relative Impacts of Life-of-Mine Plans for Rosebud Area C, Near Colstrip, Montana
Michael Nicklin, Nicklin Earth & Water, Inc., and Greg Liebelt, Western Energy Co.

Cumulative Hydrologic Response of Ground Water to Strip Mining at the Decker and Spring Creek Mines, 1972-98
Angela McDannel, MT DEQ

**Friday, September 1, 2000**

**8:30 – 11:30 a.m.**

***Databases***

Utah Water-Monitoring Database Dave Darby, UT DOGM

Montana Groundwater Information Center (GWIC) Database Tom Patton, MBMG

History of Gillette Area Groundwater Monitoring Organization (GAGMO) Data
Phil Murphree, North Antelope/Rochelle Complex

***Postmining Hydrologic Assessment***

North Dakota Postmining Hydrologic Assessments Dave Bickel, ND PSC

**12:30 – 5 p.m.**

***Workshop Presentation: Coal-Bed Methane***

Workshop Presentation: Coal-Bed Methane

The purpose of this workshop is to concentrate on the development of coal-bed methane in Wyoming and Montana, to present issues that appear to be of concern to coal-mine operators, and to provide an opportunity to discuss the hydrogeologic, biologic, and regulatory implications of coal-bed-methane development.

**Friday, September 1, 2000–continued**

**12:30 – 5 p.m.–continued**

***Workshop Presentation: Coal-Bed Methane–continued***

Overview of Coal-Bed Methane Development and Discussion of Montana Impacts
John Wheaton, MBMG

Biological Issues — Steve Regele, MT DEQ

Wyoming Coal-Bed Methane Hydrogeologic Impacts — Brad Dingee, Peabody, Group

Ground-Water Level Changes Associated with Coal Mining and Coal-Bed Methane Development in the Eastern Powder River Basin of Wyoming
Joe Meyer, BLM Casper Field Office

Geochemistry of Coal-Bed Methane Discharge Waters, Powder River Basin, Wyoming
John Mahoney, HCI, Hydrologic Consultants

Evaluating Coal-Bed Methane Impacts
Paul D. Williams, HCI, Hydrologic Consultants

Regulatory Issues — Steve Regele, MT DEQ

Living in the Coal-Bed Methane Neighborhood
John Wheaton, MBMG, and Steve Regele, MT DEQ

## ATTACHMENT 1

**Sunday, August 27, 2000**

**Absaloka Mine, Westmoreland Resources, Inc., Pond No. 20 Field Visit: A Soil Bioengineering Alternative to Open-Channel Spillways for Upgrading Sediment Ponds to Permanent Structures for Bond Release Under the Surface Mining Control and Reclamation Act**

**Field-trip description**

Final bond release, under the Surface Mining Control and Reclamation Act and the Administrative Rules of Montana, requires that engineered structures be either constructed of permanent materials or supported by maintenance in perpetuity. Any hydraulic structure must be able to withstand the stresses associated with a 100-year storm event. Often, sediment-storage ponds required to capture sediment and protect watersheds during mining and mining reclamation are incorporated into postmining land-use strategies, most often providing a watering source for livestock, which is the most common of these. Therefore, supporting postmining land use is an incentive to keep ponds. At the same time, the costs associated with upgrading structures to meet regulatory requirements can be a disincentive to keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures.

Pond No. 20 at Westmoreland Resources' Absaloka mine was designed with a flow-through culvert and a spillway that would safely carry flows associated with a 25-year storm event. The pond has an approximate 10,000 $ft^2$ surface area and is retained by an earth-embankment dam with dimensions as follows: 150 feet long, 20 feet high, 20 feet wide on the upper surface, and a 2.5H:1V (40-percent) slope. In order to construct a spillway capable of handling the larger 100-year storm event, the natural coulee below the dam would need to be disturbed and partially filled with riprap.

As an alternative to enlarging the spillway, Bitterroot Restoration, Inc., developed a design that uses the entire embankment surface as the spillway. In the event of a flood, the entire dam would be overtopped with a shallow flow, rather than concentrating the flow into a spillway. The overtopping alternative would be less expensive than a riprapped spillway, because of the high cost of importing riprap stone in eastern Montana. Also, by using plant material instead of rock, habitat quality was enhanced. This design was approved by both the Office of Surface Mining and the Montana Department of Environmental Quality. The project has been installed since spring of 1999 and is revegetating well.

**Field-trip leader**

Tom Parker, Director of Consulting, Bitterroot Restoration, Inc., will lead participants on this field trip. (Mr. Parker's forum presentation, entitled "A Soil Bioengineering Alternative to Open-Channel Spillways for Upgrading Sediment Ponds to Permanent Structures for Bond Release Under the Surface Mining Control and Reclamation Act," appears as appendix H to these proceedings. Click *here* to access this appendix.)

## ATTACHMENT 2

**Monday, August 28, 2000, 8:30 a.m. – noon**

**Workshop Presentation: Spatial Data for Hydrology Modeling Emphasizing New Developments in SEDCAD+ and GIS**

**Workshop description**

The purpose of this workshop is for participants to generate comprehensive hydrologic models using limited spatial data. Now more than ever, geographical information systems (GIS's) are providing their users the powers to manipulate spatial data and enhance visualization capacities. Through the current Wyoming Abandoned Coal-Mine-Land Research Program project "*Research and Development of a GIS-Based Data Management and Model Integration Tool for Coal-Mine Permitting and Reclamation,*" as well as through other programming advances, we are producing the next level of hydrologic modeling software with SedPrePro.

The SEDCAD preprocessor, or SedPrePro, is a customized graphical user interface that operates primarily within the ArcView desktop GIS environment. SedPrePro modifies and develops GIS functionality to assist in building complete hydrologic-model frameworks. New menus and tools walk both experienced and novice users through a series of steps that build digital-elevation models, superimpose various precipitation regimes, develop National Research Conservation Service curve numbers, derive SEDCAD structure networks, and delineate all corresponding watersheds. Each step is conceptualized with easy to follow *wizard*-type interfaces, dialog-specific help, multiple error checks, and complete visualization of each operation. SedPrePro also exports its hydrologic-design information to a SEDCAD hydrologic model.

Within the coal-mining community, SEDCAD is the Office of Surface Mining hydrologic-modeling application of choice, provided to 25 State regulatory authorities for hydrologic-design review. SEDCAD's functionality extends to runoff prediction, comprehensive design of storm-water controls, and hydrologic-system summary reporting. SedPrePro has been developed to operate as a preprocessor, as well as a potential postprocessor, for the SEDCAD model.

Although SedPrePro is still in the developmental stage, this workshop will demonstrate its current functionality and will discuss the seamless exportation of model parameters to SEDCAD. Presenters will use a surface-mining example to illustrate step-by-step SedPrePro inputs, along with a complete design of structures, including channels, culverts, retention basins, and plunge pools. In addition to the demonstration, there will be open discussions of proposed methods for SedPrePro's postprocessing. Presenters' goal will be to effectively create and visually represent the information necessary to build and interpret SEDCAD's model design and results, at the same time providing the means for optimal display and review.

**Workshop presenters**

Richard C. Warner, Ph.D., and Michael Anderson, both of the University of Kentucky, will address the issues described above in a presentation entitled "Spatial Data for Hydrology Modeling Emphasizing New Developments in SEDCAD+ and GIS." (Click *here* to access a PowerPoint version of this presentation.)

**Contact**

Joe R. Galetovic, Technical Coordinator, Office of Technology Transfer, Western Regional Coordinating Center, OSM (voice: 303-844-1448; e-mail: jgaletov@osmre.gov ; telefax: 303-844-1546)

## ATTACHMENT 3

**Tuesday, August 29, 2000, 11:30 a.m. – 7:30 p.m.**

**Western Energy Company Rosebud Mine Field Visit: Highlighting the Reclamation Activities at the Mine in Support of Hydrologic Functions in Montana**

### Field-trip description

The purpose of this field trip to Western Energy Company's Rosebud mine is to highlight reclamation activities at the mine that support hydrologic functions in Montana. During the afternoon field trip, field-trip leaders will head up a discussion of the progression in thought and application relative to reestablishing approximate premine morphology and hydrologic functions in reclaimed channels. The field trip will include visits to sites at the mine that represent older and newer approaches to drainage-basin and channel reclamation. Trip leaders will address lessons learned from both types of approach, including:

- earlier, unplanned reclamation and "ramp-road" channels;
- construction-channel features, including alternate berms (e.g., berms that initiate channel meandering and point-bar formation);
- large-scale valley and flood-plain meanders and their integration with adjacent topography (with and without constructed channel features);
- greater variability in valley-bottom width and side slopes; and
- maintenance, monitoring, and future directions.

### Field-trip leaders

Robert Postle, Ecologist, Western Regional Coordinating Center, Office of Surface Mining, will serve as mine-visit coordinator for the field trip. Robert Montgomery, Environmental Manager, Western Energy Company, Thomas Golnar, Surface-Water Hydrologist, Montana Department of Environmental Quality (DEQ), Chris Yde, Wildlife Biologist/Vegetation Specialist, Montana DEQ, and Mr. Postle will present issues associated with the activities described above.

## ATTACHMENT 4

**Wednesday, August 30, 2000, 6:30 – 9:30 p.m.**

**Workshop Presentation: Surface and Subsurface Modeling with GIS**

**Workshop description**

Digital data are available for locations at most surface minesites to support and enhance surface terrain and environmental modeling, as well as studies of subsurface geology. If adequate digital data are not immediately available at a given mine, they can be acquired at varying scales from Federal, State, and commercial data providers. The cost of data often reflects their scale, age status, and completeness. Topographic and cultural data at scales up to 1:24,000 may be obtained free or at a nominal charge from the U.S. Geological Survey or State agencies. Regional vector data are also available from government Internet sites. Large-scale, high-resolution terrain data are typically attainable at project sites as digitized contour lines or digital elevation models. Regional geologic data are often accessible through State and Federal agencies. Project-geology data can be available from various departments at the mine to which they pertain.

The purpose of this workshop is to demonstrate data acquisition and modeling for a large operating surface coal mine in the Powder River Basin, Wyoming. The presenter will compile and map regional data from several public sites; he will also compile and analyze detailed mine information. Analytical functions addressed will include slope analyses, cut-fill relationships, stripping and mining sequences, topsoil inventory, and revegetation strategy. Modeling software will include ESRI's ArcView GIS and several extensions developed to enhance GIS capabilities. Methods to import traditional CAD data from several sources will also be presented. The workshop will introduce participants to data acquisition, analysis, and modeling.

The 3-hour evening workshop will be presented in an informal lecture format.

**Workshop presenter**

Michael Price, Mining Industry Solutions Manager, ESRI, will address the issues described above in a presentation entitled "Surface and Subsurface Modeling with GIS: Surface Coal Mining, Powder River Basin."

# T A B L E  O F  C O N T E N T S

*Disturbed area, Area A,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

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[1]Note that Messrs. Dinsmoor and Stowe have prepared a PowerPoint presentation of the same title to supplement this paper. Click *here* to access this presentation directly.

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[2]Note that Mr. Larson has prepared a PowerPoint presentation of the same title to supplement this paper. Click *here* to access this presentation directly.

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*The Office of Surface Mining (OSM) and its collaborators would like to thank John Stucker, of the Navajo Nation Minerals' OSM, for providing the images that appear on ☞ hot-link pages (except the page related to the workshop presentation regarding coal-bed methane) throughout these proceedings. These images, which show various aspects of mining and reclamation activities at Western Energy Company's Rosebud mine in Montana, capture with great skill the results of both older and newer approaches to drainage-basin and channel reclamation at minesites in the arid and semi-arid West. We are grateful to John Wheaton for the image that appears on the ☞ hot-link page related to the coal-bed methane workshop. This image depicts Montana coal-bed methane wells. Mr. Wheaton works for the Montana Bureau of Mines and Geology, by whose courtesy the image appears.*

# O P E N I N G  R E M A R K S

*Reclaimed drainage, Area A,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Opening Remarks"

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| HYDROLOGY MODELING | MODELING WITH GIS | COAL-BED METHANE |
| FIELD TRIP TO ABSALOKA | FIELD TRIP TO ROSEBUD | OF GENERAL INTEREST |

## OPENING REMARKS

**Linda Wagner, Program Coordinator**
**Western Regional Coordinating Center**
**Office of Surface Mining**

Good afternoon and welcome to the Office of Surface Mining's (OSM's) fifth bond-release forum. I'm Linda Wagner, Program Coordinator in the Office of Technology Transfer of OSM's Western Regional Coordinating Center (WRCC) in Denver.

Previously, we have conducted bond-release forums in 1991, 1996, 1998, and 1999 and alternate sediment-control "topic" forums in 1992 and 1995. (The 1995 forum, you will remember, was held in Bozeman in January–the dead of winter!) For the first time this year, the forum has co-sponsors: Montana Department of Environmental Quality's Helena and Billings offices–Steve Welch's groups–and two contingencies from the Montana Bureau of Mines and Geology–Ed Deal's group out of Butte and John Wheaton's group out of Billings.

These co-sponsors have contributed significantly to all aspects of this week's activities. We also want to recognize the efforts of Westmoreland Resources and Western Energy for hosting the mine field trips. Coffee breaks are courtesy of Dri-Water on Wednesday and Energy Laboratories on Thursday.

The first bond-release forum, held in 1991, was planned and attended by both OSM staff and State staff from the 14 Western and mid-Western coal primacy State offices. Industry, consultants, and citizens were not invited until 1992. For 4 days during the 1991 forum, 90 participants, running concurrent sessions, discussed the elements and criteria of bond release.

At the 1996 bond-release forum, staff from the Western primacy States and OSM, along with representatives of industry from nine coal-producing States, consultants, and citizens, discussed existing bond-release guidance/guidelines, as well as the need for these. Attendees at this forum identified 22 items for further action, with revegetation issues receiving the most attention.

In 1991 and 1996 both, we identified hydrology as a topic for future discussion, and we started gathering topics for this week's presentation. We reviewed the comments submitted at the 1996 forum and have used them in the planning for this week.

The 1998 and 1999 interactive topsoiling and revegetation-type bond-release forums were more like symposia–25-minute presentations followed by 5-minute question-and-answer periods.

We intend this year's forum to revert back to the 1991- and 1996-type formats, with more interaction from participants. You will notice that there are no times specifically identified for interaction on the agenda. Presenters were given or asked for a number of minutes in which to present, in the expectation of audience participation. We do anticipate a smaller attendance this year, allowing for more such interactive participation.

A word regarding tomorrow's field trip: we will leave at 11:30 a.m. If you ordered a box lunch and have paid for it, please pick up your lunch as you board the bus. If you still need to pay–the cost of the lunch is $6–, please do so at the registration desk.

OSM has provided the opportunity for a very diverse group to convene this week. But the "real" work for our coming together has been done by the presenters, the work-shop instructors, the field-trip hosts, and our co-sponsors Montana's Department of Environmental Quality and Bureau of Mines and Geology.

OSM plans to sponsor two more bond-release forums in this series. Next year's forum–wildlife habitat 2001–will be in Gillette; the following year's–postmining land use 2002–will be in Bismarck. We hope to see you there!

# B A C K G R O U N D:
# H I S T O R I C A L  P E R S P E C T I V E

*Reclaimed drainage, Area C,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "A Walk Through History"
## "Belle Ayr Mine Hydrologic Monitoring History"

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# A WALK THROUGH HISTORY

**Joe R. Galetovic, Technical Coordinator**
**Office of Technology Transfer**
**Western Regional Coordinating Center**
**Office of Surface Mining**

## The Tour

Throughout the period 1972-77, when the Surface Mining Control and Reclamation Act (SMCRA; Public Law 95-87) was being written, statements of probable hydrologic consequence (PHC's) were envisioned as prudent exercises. Coal-mine operators were being required to prepare PHC's; the purpose was to provide hydrologic information to the coal-mine regulatory authorities (RA's), aiding them in their preparation of cumulative hydrologic impact assessments (CHIA's). To create the CHIA's, RA's entered data provided to them by coal-mine operators into hydrologic modeling tools, assessing the hydrologic balance in various cumulative impact areas and by extension validating the operators' proposed monitoring schemes. By means of models, the RA's were able to accept or reject operators' proposed mitigation, if and where necessary. The intended result of these efforts was to protect the environment and the areas adjacent to mines from offsite mining impacts.

Still today, PHC's and CHIA's are the tools that operators and RA's use to design measures intended to monitor and mitigate the effects of mining coal on hydrologic resources. The softwares and hardware that facilitate this design process have become more sophisticated through time, and they are constantly evolving. Many of you are familiar with the new modeling softwares Groundwater Modeling System, Ground Water Vistas, HEC-RAS, and others. I would like to take you on a short historical tour of the Office of Surface Mining (OSM) *vis à vis* these and other modeling tools.

As most of you know, some of you quite intimately, the knowledge base of scientists at large dealing with understanding the environmental impacts of mining expanded throughout the period 1950-70. The need for computer-calculated models arose, the increased need for hydrologists became evident, and the modeling and prediction science for mine-permit preparation as we know it today was born. Of considerable interest to surface-mining RA's were three publications: the Soil Conservation Service's *Urban Hydrology for Small Watersheds* (1975); the U.S. Geological Survey's (USGS's) *Finite-Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments* (Trescott *et al.*, 1976); and USGS's *Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water* (Konikow and Bredehoeft, 1978). (The complete citations for these three publications appear in the section entitled "References [Dated Prior to 1980] Cited," below.)

The need for increased knowledge and ability within the RA's, OSM among them, also grew throughout this period, and, in 1977, OSM hired many hydrologists, a large number of them from USGS and the U.S. Bureau of Mines. Specifically, OSM was seeking hydrologists with modeling skills. Our motive here was clear. For example, at that time, surface-water modeling

was being done using hand-held calculators, and the bureau needed to furnish its staff uniform instructions as to how to accomplish this. Accordingly, two of OSM's earliest publications were *Surface-Water Model Handbook* (1981; see below for a chronology of publications, including this and the other titles [dating from 1980 through the present] cited in this historical tour) and "Selected Hand-Held Calculator Codes for the Evaluation of the Probable Cumulative Hydrologic Impacts of Mining" (Hittman Associates, Inc., 1981). The Theis aquifer-analysis program, developed by the bureau's Denver staff person Gary McIntosh, was pump-test spreadsheet software designed to calculate drawdown in aquifers.

The only way an RA user could accept a single pump-test data for input into the database was first to "validate" it, a process that required the user to compare this data with regional-characteristics data pertaining to the area of his or her specific pump test, arriving thereby at "valid" numbers for input. The modeler would then use those aquifer characteristics to complete the CHIA model. Of course, regional-characteristics data do not consist of one or two points, but of tens, maybe hundreds, of points—hence the need for more data to fine-tune the models. Ground-water models in their infancy were crude at best: water coming into "one cell" was moved, according to hydrologic parameters, out of that cell and into the "next cell," and from that next cell into another, thence to a cell in another layer, and so forth. Altogether, the process was a fairly pedestrian affair. To name just a few constraints, cells did not have ability to allow for re-watering, boundaries were invariably deemed to be physical ("Berlin Walls"), and rivers that were actually in the vicinity of mines could not be modeled.

In 1982, USGS published procedures for assessing the impacts of surface mining on the hydrologic balance. OSM's Denver Western Field Operations (WFO) was in the process of reviewing Peabody Coal Company's application for a permit to mine the Black Mesa/Kayenta mine, Navajo and Hopi Indian Reservations, Arizona. WFO asked USGS for assistance; USGS responded by furnishing its sister bureau with an early version of MODFLOW (1983), to predict effects of mining at Black Mesa/Kayenta into the years 2023-56. (Subsequently, USGS developed "A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model MODFLOW," which was published by McDonald and Harbaugh in 1988 as book 6, chapter A1, of *The Techniques of Water-Resources Investigations of the United States Geological Survey*.) Modeling was done at USGS's PRIME computers in Menlo Park, California, at considerable cost to OSM, which had to pay for telephone-line time from Denver to Menlo Park.

In the early days of SMCRA, water-quantity and -quality models were run using limited data extrapolated over large areas, to the point that some State RA's made their geochemical predictions statewide. A certain number of RA's provided funding for USGS to assist them in assessing water quality and the possible effects of mining on the quality and quantity of water in their various regions. Other States realized that, to comply with the spirit of Public Law 95-87, they needed cumulative hydrologic impact models for single large watersheds, as well as models and studies for specific sites.

OSM was under mandate from SMCRA to offer technical assistance and technology transfer to the State RA's. In the western United States, compliance with this mandate took two forms. Many of you will remember that, in 1990, OSM's western region started an effort to develop a multi-level, technology-transfer program. In the beginning, both Linda Wagner and I worked in

what was then WFO's Technical Assistance Division, and our jobs were to provide technical assistance and support to our stakeholders. Depending upon the entity requesting it, this assistance and support amounted either to computer-application development, computer-applications training, or the distribution of research results. For the past 10 years, Linda has been directly involved in this program, and I have been directly involved for the last 8 years. In addition, both of us have worked to organize interactive forums and conference workshops, like this one, requested by the seven western State RA's. We have participated in exhibits and State reclamation workshops; and we have supported the American Society for Surface Mining and Reclamation, as well as Technical Information Processing System (TIPS) activities and outreach.

The second form of technical assistance and technology transfer to the State RA's has taken place by means of OSM's TIPS program. TIPS grew out of Denver technical staff assistance to the Black Mesa/Kayenta mine hydrology-modeling effort. In 1984, TIPS established itself with the goal of offering nationwide computer-modeling support; this goal was realized nationwide in 1987. Through TIPS, OSM furnished State RA's with readily available hardware and off-the-shelf softwares for their use in evaluating proposed minesites and in modeling environmental data that they, other agencies, consultants, OSM, and coal-mine operators had collected.

TIPS wisely decided to use off-the-shelf software packages, and MODFLOW, having just been released, was included as a part of the core software package distributed in 1988. However, until 1991, there were no modelers (hydrologists) in the States actually using MODFLOW, and OSM had no training program on its use. SMCRA was now 14 years old, and questions were starting to be asked: in point of fact, who out there was really *modeling* CHIA's? What *were* the watershed/aquifer material-damage criteria RA's and operators were to use in their mining and monitoring efforts? What were they to assume were the background characteristics of a particular watershed? And so forth.

As it turned out, this questioning was a great step forward, because it resulted in an acknowledgment that each State, each coal basin, and each watershed has different characteristics, be they physical, chemical, climatological, or all of the above. We were reminded of differences that Section 101(f) of SMCRA had already recognized, stating that, "because of the diversity in terrain, climate, biologic, chemical and other physical conditions in areas subject to mining operations, the primary governmental responsibility * * * should rest with the States." And, in fact, beyond this recognition, SMCRA (Section 515[b][10]) had gone on to require each coal-mine operator to "minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and ground water systems, both during and after surface coal mining operations and during reclamation * * *."

Having anticipated some of the questions that might arise in the course of running sophisticated models, and at the same time having some grounds to believe in the value of model output, OSM contracted to have a hydrology database designed that would address both data availability and data quality. The result was the hydrology database in ORACLE, which OSM made available for wide use in 1992, but which was beset with problems from the outset. In retrospect, it seems likely that the many problems inherent in this original ORACLE hydrology database were attributable to the steep learning curve faced by its creators. For example, because inputs into

the database had to be believable, verification checks were built into it. However, there were so many of these checks that the database quickly became virtually impracticable. An end user might find that, although the database would accept his or her chemical-analysis and other individual point data, it would not let the user actually see these data again if, on the basis of verification checks, it determined that some "needed" parameter was missing. OSM has since made the database (ahem!) user friendlier.

Five years after the contract for the hydrologic data management system had been let, an ORACLE database now known as the coal permitting and reclamation (CPR) database was delivered to OSM. A hydrology team at the University of Wyoming (UW) was assembled to assist the Wyoming Department of Environmental Quality (DEQ) in responding to OSM's 1992 hydrology oversight findings. (OSM hydrologists stated that, owing to the increase in mining activity in the eastern Powder River Basin, the existing 1988 USGS CHIA was now too general and, therefore, did not address all the issues potentially relevant to specific drainages.) The UW team used the modified CPR database, along with a state-of-the-art, off-the-shelf suite of softwares, to prepare hydrology models that became part of a Wyoming DEQ pilot CHIA for the Little Thunder Creek drainage.

Assisted by geologists, the team entered available Powder River Basin core-hole data into StratiFact software to validate correlations and to generate two-dimensional cross sections, from them creating quasi-three-dimensional fence diagrams. They then accepted or corrected the validity of geologic information for each x/y/z point of change or contact and transferred that information into a more robust software, earthVision, for coal-block visualization. The coal-block visualization, of course, gave them the structure, orientation of potential and existing aquifers, and direction and orientation of maximum K (hydraulic conductivity) values, as well as the statistical validity of those interpretations. Finally, the team used K-max directions both to orient the MODFLOW(R) model and to perform sensitivity runs (a much speedier process using today's faster computers), analyzing a large number of "what-if" considerations.

The number of hydrology-modeling softwares available today is considerable: depending on the complexity of his or her project, a modeler can use MODFLOW, MODFLOW(R), Model CAD, Graphic Groundwater, Groundwater Vistas, Groundwater for Windows, and/or Groundwater Modeling System, just to name a few.

This year, it is with great pleasure that OSM's Office of Technology Transfer, together with Montana DEQ, Industrial and Energy Minerals Bureau, Division of Permitting and Compliance, and the Montana Bureau of Mines and Geology, Montana Tech of the University of Montana, have assembled the agenda for the forum we are about to begin. We are proud to showcase for you the state-of-the-art hydrology modeling and expertise currently operating in the seven western coal-mining States. At the same time, we hope to provide an occasion for all of us to continue the dialogue as to how best to optimize our capabilities for visualization and prediction. Our task in all of this remains an important one: how best will we use our data throughout the lives of coal-mine permits? How will we validate, adjust, and fine-tune our models to reflect on-the-ground situations? And, finally, how can we advance our mutual goal of increasing our understanding of postmining conditions, the better to optimize our confidence at the time of bond release by operators and/or RA's?

**The Resources We Have Developed and/or Consulted Along the Way**

As we have noted, the knowledge base of scientists attempting to understand the environmental impacts of surface coal mining, in particular of these impacts as they pertained to the hydrology of cumulative impact areas, expanded significantly throughout the period 1950-70. In the years following the passage of SMCRA, Federal (and subsequently State) researchers and regulators were faced with the challenge of creating the resources that would allow them to consolidate and share their knowledge in this field, the better to improve it. Of course, as we all know, knowledge accretion is a process, and it occurs within a context. Accordingly, I give you this list of some of the key State and Federal hydrology publications, released since 1980, in chronological order of their release, in the hope that the flavor of this accretive and contextual process will emerge.

***1980:***

Betson, R. P., Bales, J., and Pratt, H. E., "User's Guide to TVA-HYSM – A Hydrologic Program for Quantifying Land Use Change Effects;" released as an Environmental Protection Agency publication.

Office of Surface Mining, "The Determination of the Probable Hydrologic Consequences (PHC)," In *Coal Mining and Reclamation Operations, Part I*, 19 p.; released as OSM publication No. 119.

***1981*:**

Office of Surface Mining, "Ground-Water Model Handbook:" based on Thomas Prickett and Carl Lonnquist, "Selected Digital Computer Techniques for Groundwater Resource Evaluation," 1971, Bulletin 55, Illinois State Water Survey.

Office of Surface Mining, "Surface-Water Model Handbook;" released as OSM publication No. 41.

***1982*:**

Lumb, Alan, "Procedures for Assessment of Cumulative Impacts of Surface Mining on the Hydrologic Balance;" 50 p.; prepared by USGS for OSM as Open File Report 82-334 and released as OSM publication No. 238.

Office of Surface Mining, "Selected Hand-Held Calculator Codes for the Evaluation of the Probable Cumulative Hydrologic Impacts of Mining;" prepared by Hittman Associates, Inc., and released as OSM publication No. 67.

***1983*:**

Humphreys, Carney P., Jr., "Identification of Hydrologic Data Sources for the Use in Mine Plan Review and Assessment of Cumulative Hydrologic Impacts of Surface Mining;"

compiled for OSM by USGS, Harrisburg, Pennsylvania, and released as OSM publication No. 192.

Herb, William J., "Methodologies for Determining the Cumulative Hydrologic Impacts of Surface Mining—Task III," 32 p.; compiled for OSM by USGS, Harrisburg, Pennsylvania, and released as OSM publication No. 200.

J. F. Sato and Associates, "Approaches for Conducting Cumulative Hydrologic Impact Assessments for Surface Coal Mining Operations;" prepared as a final report for OSM and released as OSM publication No. 12.

***1984*:**

J. F. Sato and Associates, "Methods for PHC Determination;" prepared as a final report for OSM and released as OSM publication No. 315.

J. F. Sato and Associates, "Appendix to Methods for PHC Determination," 128 p.; prepared as a final report for OSM and released as OSM publication No. 316.

Engineering Science (in cooperation with J. F. Sato and Associates), "Cumulative Hydrologic Impact Assessment with Respect to Hiawatha Mines Complex;" submitted to OSM as a hydrology report.

Office of Surface Mining, "Cumulative Hydrologic Impact Assessment in the Mud Creek Drainage Basin with Respect to Valley Camp of Utah's Belina Mines;"

***1985*:**

Office of Surface Mining, "A Manual Describing the General Procedures for the Cumulative Hydrologic Impact Assessment Under the Federal program for Tennessee;" prepared by the bureau's Division of Tennessee Permitting.

Richards, David B., "Ground-Water Information Manual—Volume I: Coal Mine Permit Applications;" prepared by USGS for OSM.

Office of Surface Mining, "Guidelines for Preparation of a Probable Hydrologic Consequences Determination (PHC);" draft report.

Office of Surface Mining, "Guidelines for Preparation of a Cumulative Hydrologic Impact Assessment (CHIA);" draft report.

Office of Surface Mining, "Appendices to PHC and CHIA Guidelines Documents;" draft report.

***1986*:**

U.S. Geological Survey, "Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin Northeastern Wyoming." This report was funded jointly by OSM and Montana DEQ; it used data produced under a project, funded by Congress, entitled "The Hydrology of U.S. Coal Provinces." (An example of other material published as part of this congressional project would be *Northern Great Plains and Rocky Mountain Coal Provinces (Area 50,)* which came out as Water-Resource Investigations open-file report No. 83-545.)

***1987*:**

Iowa Dept of Agriculture and Land Stewardship, "Handbook of Geologic and Hydrologic Data Requirements—For Preparation of the Probable Hydrologic Consequences of proposed Coal Mining and Reclamation Operations in Iowa;" published in cooperation with OSM.

***1988*:**

Office of Surface Mining, "Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/Kayenta Mine."

U.S. Geological Survey, "Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, Northeastern Wyoming;" published as Water-Resource Investigations Report No. 88-4046.

Office of Surface Mining, "General Procedures for the Cumulative Hydrologic Impact Assessment for the Federal Program for Tennessee;" prepared as a revised report by the bureau's Division of Tennessee Permitting.

***1989*:**

Office of Surface Mining, "Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/ Kayenta Mine."

Office of Surface Mining, "Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/ Kayenta Mine."

Railroad Commission of Texas, "Guidelines for Prediction of Probable Hydrologic Consequences of Coal Mining and Reclamation Operations in Texas;" published in cooperation with OSM.

***1990*:**

West Virginia Department of Environmental Protection, "West Virginia Cumulative Hydrologic Impact Assessment (CHIA)."

Office of Surface Mining, "Hydrology Handbook for the Federal Program for Tennessee."

National Research Council, "Surface Coal Mining Effects on Ground Water Recharge:" Washington, D.C.; provided to National Technical Information Service as OSM publication No. 568.

***1991*:**

Office of Surface Mining, "Managing Hydrologic Information in the Coal Mine Permitting Process—Guidance for PHC and CHIA;" draft report.

***1992*:**

Western Research Institute, "Hydrologic Data Management System;" report and software prepared for Wyoming DEQ.

***1997*:**

Office of Surface Mining, "Managing Hydrologic Information A Resource for Development of Probable Hydrologic Consequences (PHC) and Cumulative Hydrologic Impact Assessments (CHIA);" draft report.

***1998*:**

Office of Surface Mining, "Managing Hydrologic Information, A Resource for Development of Probable Hydrologic Consequences (PHC) and Cumulative Hydrologic Impact Assessments (CHIA);" draft report.

***2000:***

Office of Surface Mining, "Permitting Hydrology—Phase I, Baseline Data—A Guidance Document for Determination of Probable Hydrologic Consequences (PHC) and Cumulative Hydrologic Impact Assessments (CHIA);" draft document.

(*Editor's note*: The efforts on the parts of all entities party to the development, as well as the regulation of development, of the coal resource in the United States have, of course, continued since the 2000 bond-release forum whose proceedings these constitute. These efforts as they pertain to understanding and mitigating the impacts of mining on the hydrology resource of the Nation have resulted, among other things, in the creation of the following publications, which we add to the list:

***2001*:**

Office of Surface Mining, "Estimating Hydrologic Impacts;" information available on OSM's web page [www.osmre.gov].

Office of Surface Mining, "CHIA;" information available on OSM's web page [www.osmre.gov.

***2002*:**

Office of Surface Mining, "Permitting Hydrology—A Technical Reference Document for Determination of Probable Hydrologic Consequences [PHC] and Cumulative Hydrologic Impact Assessments [CHIA]—Baseline Data;" available on OSM's web page [www.osmre.gov/pdf/phcchiareport.pdf].)

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Soil Conservation Service, 1975, *Urban Hydrology for Small Watersheds*: Technical Release No. 55.

Trescott, P.C., G. F. Pinder, and S. P. Larson, 1976, *Finite-Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments*,

Konikow, L. F., and J. D. Bredehoeft, 1978, *Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water,* In Techniques of Water-Resources Investigations of the United States Geological Survey, Book1, Chapter 2: Washington, D.C.

# BELLE AYR MINE HYDROLOGIC MONITORING HISTORY

**Phil Dinsmoor,**
**Manager, Environmental and Mining Engineer,**
**RAG Coal West, Inc.;**
**Robert Stowe,**
**Senior Environmental Engineer, C.P.G.,**
**RAG Coal West, Inc.**

*(NOTE: The paper that follows is supplemented by a PowerPoint presentation. Click here to view this presentation.)*

## Introduction

The Belle Ayr mine is a Wyoming mine located in the central part of the Eastern Powder River Basin. It was initially permitted in 1972 through the State of Wyoming Open Cut Land Reclamation Act. The 14-page application had two paragraphs devoted to hydrology. Two commitments were listed: to divert Caballo Creek around the mine pit and to monitor the pH of pit outflow water before discharging it into either Caballo Creek or the diversion.

With that permit in hand, Belle Ayr started producing coal in October 1972. Mining has continued and hydrology requirements have increased since that simple beginning.

## SMCRA and the Wyoming State Program

In August of 1977, Congress passed the Surface Mining Control and Reclamation Act (SMCRA). To obtain primacy for its own coal-mining program, Wyoming immediately wrote its Land Quality Division (LQD) Rules and Regulations for coal mining. LQD obtained primacy in November of 1980.

With these new regulations came increased requirements for hydrology, including "[r]equirements for bonding of surface coal mining and reclamation operations." The permit requirements included "[d]escription of hydrology and geology: General requirements, ground water information and surface water information." The "Surface Mining Permit Application—Minimum Requirement for Reclamation and Operation Plan" has this hydrology requirement: "Reclamation plan: Protection of hydrologic balance."

In 1980, Jim Brown with the Carter Mining Company convinced other industry hydrologists that a joint ground-water monitoring effort should be made to generate tables of ground-water levels and maps depicting those elevations. A scientific data gathering and presenting group was born: the Gillette Area Groundwater Monitoring Organization, or GAGMO as it is now known. On or about October 1 of each year (the beginning of the water year in the Northern Hemisphere), to give a basin-wide snapshot of the overburden and coal aquifers throughout the Powder River Basin around Gillette, participating mines measure and record the ground-water levels for each of their monitoring wells, subsequently furnishing maps of the results to GAGMO. This

organization has continued to compile data and generate maps that many companies use to help document their impacts on the hydrologic balance.

In the early 1980's, in order for both industry to determine its probable hydrologic consequences (PHC) and LQD to make its cumulative hydrologic impact assessment (CHIA), LQD decided that it must receive uniform information from the various mines. Over a period of several months and during several meetings with industry, LQD established that it needed four maps from each mine to make a CHIA. The four maps should show: the furthest extent of 5 feet of drawdown in overburden resulting from a specific mine's activities; the furthest extent of 5 feet of drawdown in overburden that was attributable to the cumulative effects of the regional mines; the furthest extent of 5 feet of drawdown in coal that was attributable to the specific mine; and the furthest extent of 5 feet of drawdown in coal that was attributable to cumulative effects of the regional mines. In addition, the mines were to predict when ground water would recharge backfill and achieve an equilibrium condition (approximate premine levels). To make these projections, most companies took the approach of using digital models to determine the extent of the 5-foot drawdown contours and the time to return to an equilibrium condition. Existing well-monitoring data and pumping test results were used to set up the models and to calibrate them.

**Belle Ayr Monitoring During Mining**

From the original 14-page permit application, the Belle Ayr permit to mine application has expanded to now consist of 16 volumes of written text, tabular data, and maps. The mining hydrology and reclamation section has expanded from two paragraphs to three 4-inch binders with 40 maps and seven appendices.

Surface water.--Belle Ayr began constructing surface-water stations and monitoring wells in the early 1970's, before surface-water monitoring was required by regulation. In 1972, the mine's initial stream gage (90-degree, v-notch weir) to monitor stream flow and water quality was constructed just upstream of any mining activity. In 1975, the downstream gage was constructed. In March of 1977, a third stream gage was constructed above the first gage at the upstream lease boundary on Caballo Creek. After additional coal leases were considered for purchase, a final upstream gage station was constructed in March of 1981 at the western edge of the property.

Ground water.--The first well at Belle Ayr was drilled in 1972 to supply water to the mine facilities. In February of 1973, one overburden and three coal wells were drilled to monitor ground-water levels and chemical quality. The coal wells were drilled and cased to the top of the coal, cement was poured to seal the coal from the overburden aquifers, and a smaller borehole was drilled through the cement and the coal interval. A natural completion or open hole was left in the coal. The overburden well was cased to the base of the saturated sand zone. Perforations opposite the saturated sands were hand cut with a saw. Although neither well construction was very efficient, they did allow water levels to be measured and samples to be collected and analyzed. Baseline surface- and ground-water data establishment began in the early 1970's.

As time and laws passed, more wells were added in coal and overburden, and wells were also placed in alluvium, the baked porcelanite locally called scoria, and backfilled material. Wells were placed near lease limits to monitor off-lease and offsite impacts. Wells placed within the backfill were there to confirm that it would recharge in suitable quality and quantity to be used to water livestock, one of the permitted postmining land uses. Belle Ayr currently has 100 wells monitoring chemical quality and/or water levels in the alluvial, overburden, scoria, coal, sub-coal, and backfill aquifers.

Data.--Initially, surface- and ground-water data were kept in notebooks. Later, water-level information was stored in a spreadsheet program on the corporate mainframe computer. In the late 1970's, Amax wrote a program for the mainframe computer that established a database for water-quality information and printed out reports. This program was used until the mid-1990's, when the mainframe computer was shut down. A substitute program was sought to reside on a PC. HydroDat was chosen for its ability to store water-quality data, generate reports, and transmit data to both State and Federal agencies. We continue to use a spreadsheet program to store ground-water level data and to plot hydrographs.

**What do our data show?**

Surface-water flow data continue to be collected. The largest precipitation/runoff event known for the life of Belle Ayr mine (May 1978) was not gauged, because a large reservoir less than a mile above our upstream gage attenuated flows. This precipitation and runoff event has been estimated to have about a 12- to 15-year recurrence interval. In the other extreme, we have recorded many months with Caballo Creek having no flow entering the mine property.

Coal-bed methane (CBM) ground-water discharges into the Caballo Creek drainage have added to surface-water flows in recent years. In the 6 years prior to 1995 (1989-94), Caballo Creek flowed an average of 6.67 months per year. In the 5 years since, as CBM operations have become widespread, Caballo Creek has flowed an average of 10.17 months per year. Precipitation for the years 1989-94 ranged from 10.58 to 17.71 inches, with an average of 12.69 inches per year. From 1995 through 1999, precipitation ranged from 12.19 to 20.73 inches with an average of 15.91 inches. Total flow coming onto the minesite at the upstream gage has increased. From 1989 through 1994, flow ranged from 1.14 to 78.91 acre-feet per year and averaged 36.2 acre-feet. After CBM became widespread, flow ranged from 30.18 to 418 acre-feet per year and averaged 178.7 acre-feet per year. The relationship is not clear, but CBM appears to have increased the length of time and volume of surface-water flow on Caballo Creek.

Monitoring results show that water-quality chemical parameters on Caballo Creek are better at the outfall of the mine than the parameters measured for the creek entering mine property. Total suspended solids measured leaving the mine average 40percent lower than levels entering the property. Sediment ponds have captured a significant portion of the sediment load from waters emanating from disturbed land

Total dissolved solids (TDS) leaving the minesite are about 50 percent of levels entering the property. Ground-water pit inflows with lower TDS are added to the natural stream flow, resulting in these lower levels.

The median pH of water entering the Belle Ayr minesite (8.0) is slightly higher than median pH of water leaving the property (7.9). This is not significant for the postmining land uses.

Water quality in 11 of 13 backfill wells stayed well below the TDS limit of 5,000 mg/L for livestock. No chemical species or trace metals in toxic concentrations have been found in Belle Ayr backfill ground water. There have been a few samples with pH less than 6.5, which is the lower limit for livestock water quality.

Prior to 1995, our monitoring data indicated that the modeled 5-foot drawdown for coal extended farther than the actual observed drawdown in almost all cases. Modeled overburden matched closely what was being observed. Modeled impacts to offsite users were greater than what was observed in our monitoring wells.

Beginning about 1995, our coal-monitoring wells on the western side of the property began to show the impacts of CBM wells. Nine of 13 coal monitoring wells were emitting measurable amounts of gas. The 1996 GAGMO annual report, addressing October 1995 ground-water levels, incorporated some CBM monitoring wells in its maps. Those maps showed that a ground-water divide between Belle Ayr mine and the CBM wells to the west was beginning to develop more than a mile west of the Belle Ayr pit. Belle Ayr's 1996 annual report to LQD indicated that 1995 coal-water levels in the western wells dropped dramatically. The decline was attributed to the adjacent CBM operations. The 1999 GAGMO map of October 1998 data shows that CBM has caused almost 200 feet of drawdown west of Belle Ayr's coal-monitoring wells. Monitoring wells west of the divide now serve little, if any, useful purpose. The ground-water divide is now less than half a mile west of the Belle Ayr pit. Now it is impossible to determine our mine's offsite impact to the coal aquifer west of that divide. Significant overlapping drawdown from CBM will make LQD's task of determining future coal-mine CHIA-s very difficult.

Belle Ayr mine has amassed a tremendous quantity of surface- and ground-water quantity and quality information, 28 years of surface-water data, and 27 years of ground-water data. This information--collected before, during, and after mining--was to be used to help acquire future hydrologic bond release. Pumping and discharge at CBM operations have rendered coal-monitoring data useless in determining either the extent of offsite mining impacts to the coal aquifer or when existing impacts will be mitigated.

# B A C K G R O U N D:
# P R E M I N E  D A T A

*Reclaimed drainage, Area C,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

**"Laboratory Data: Quality Assurance/Quality Control"**
**"Adequacy/Utility of Premining Water-Resource Data"**
**"Graphic Analysis of Ground-Water Responses"**
**"Determining Soil Conservation Service Curve-Runoff Numbers for Mineland Conditions"**
**"Climate, Bond Release, and the Concept of Minimum Liability Periods"**
**"Alluvial Valley Floors Reclamation Bond-Release Criteria"**
**"Correlation between Natural Spring Flow and the Palmer Hydrologic Drought Index"**

# GRAPHIC ANALYSIS OF GROUND-WATER RESPONSES

**David Bickel, North Dakota Public Service Commission**
**Dennis R. James, Falkirk Mining Company**

Graphic data analysis and plots of water-level elevation against time (termed well hydrographs) are both fundamental tools for the time-series analysis of geohydrologic data; both are also integral parts of data exploration. Graphic data analysis can effectively address questions of trends and potentiometric surface responses to interventions in a manner readily understood by nonspecialists. For purposes of final bond-release, effective graphic analysis and interpretation of the results of such analysis can constitute adequate evaluation of hydrologic data in the absence of known or suspected problems. The following discussion considers plots of water-level elevations in ground-water monitoring wells as functions of time; however, most of the techniques the discussion touches upon are equally applicable to time and concentration plots of water-quality parameters and to graphs that show both quality parameters and hydraulic head data.

Annotating the hydrograph's axes with pertinent well and stratigraphic information--so that fluctuations in water level can be viewed in context of well construction, hydrostratigraphy, and events--can significantly increase its usefulness. The technique of expanding a hydrograph by means of additional data on the X- and Y-axes is becoming more widely used, because interpretation forces the human mind to visualize or make side-by-side comparisons between time series plots and other data. Information needed for these comparisons can be easily added to charts produced with commonly used software applications**.** The added data are typically hydrostratigraphy, well-construction details, events, system-control plots, and plots of other variables.
Hydrostratigraphy can be placed on the Y-axis and may include the base and top of the aquifer, ground-surface elevation, and other water-bearing units or aquitards. Well total depth and the screened interval are basic well construction details that can also be shown on the Y-axis. Comparing a screened interval, taken from well-completion reports, with stratigraphic information, taken from geophysical or driller's logs, is a basic but often overlooked step in data validation. Partially screened units, screens crossing several units, and correlation errors can be readily detected. Routinely presenting these data together on well hydrographs makes this aspect of validation a part of data management and provides the convenience and assurance of having the information available for any users of the well data.

Interventions are events that disrupt long-term patterns in well responses to seasonal or annual changes in the flow system, and these are typically mining or reclamation activities known or suspected of affecting the hydrostratigraphic unit being monitored. They are plotted on the X-axis as functions of time and can include starting dates of mining pits, distances to approaching and receding pits through time, dewatering events, backfilling and grading dates, and revegetation phases. Any mining and reclamation events that may have influenced well responses can be plotted on the time scale; however, the onset of pit operations and the time of pit backfilling are the most obvious and useful event markers for interpreting the responses of monitoring-well water levels to mining effects.

Plotting events on the time scale is necessary for graphically determining break points between (1) the premining state of a well and the point of mining influence and (2) active mining and the onset of postmining conditions. Defining break points can be done by visual inspection of the graphed data or by statistical methods for break-point analysis. Our experience has been that visual estimation of break points from accurately plotted data suffices for most mine hydrologic data. Determination of break points is essential for partitioning the data into premining, intervention, and postmining subsets and for making quantitative comparisons between the different states of the system.

Well hydrographs have always been used as system-control charts whereby well responses during or after mining can be visually compared with the baseline or premining portion of the curve to evaluate the extent of impact and recovery. Process-control charts have been used in industry for decades and are a common tool in water-quality monitoring. Well hydrographs or water-quality time plots can be extended into control charts by defining boundary values, termed upper and lower control limits, based on pre-mining data and then by adding lines through these values over the field of the chart. In classic process control, the boundaries are confidence limits on the mean, and the plot is called an X-bar chart. Depending upon the data and control objectives, the sample mean and confidence limits on this chart can be used with mine well data, or boundaries can be based on the sample range, quartiles, or variance (termed S-charts). The value of continually updated control charts is the quick visual evaluation they provide of current conditions during mining and reclamation. As an analysis tool for final bond release, they clearly show (1) the duration and degree to which conditions varied from an acceptable range during the intervention phase and (2) the extent of postmining recovery. Fitting a trend line to the subset of postmining data can illustrate improving or deteriorating conditions relative to a control boundary. It can also predict the approximate time when the response will move into or out of an acceptable range.

Adding a secondary Y-axis with Excel or most graphing packages to accommodate the different scale of a second data set allows comparison of a hydrograph with time-series plots of other variables such as climate or water-quality parameters. Stacked hydrographs of wells completed in different units at the same monitoring site or completed in the same unit at different sites generally can be plotted together by increasing the range of the elevation scale. However, multiple well responses, events, local stratigraphy, and a secondary axis presented together will quickly make a single plot too complex and detract from its usefulness, thereby leading to instability in some applications. Presenting busy, multivariate time-series data by means of a series of plots can usually increase data clarity and ease of preparation.

Automated production of hydrographs in Excel with Visual BASIC programs has allowed Falkirk Mining Company to rapidly produce hundreds of plots for timely response monitoring and database validation. Data validation is an important function of graphic analysis; for example, comparing screen and formation depths can uncover data problems that would not be otherwise identified. The proven value of the graphic data-validation process tends to integrate well construction details and aquifer properties in database structure and user perspective more than traditional approaches.

Traditional graphic models such as structural contour and potentiometric surface maps often do not clearly convey pertinent geohydrologic relationships. Although expanded hydrographs easily validate hydrologic data for use in more sophisticated 2- and 3-dimensional graphic models, the hydrograph is more than a handmaiden to spatial modeling. Expanded hydrographs and spatial models are complementary, in that spatial models can show detail and trends through space while the hydrograph can better show detail and system dynamics through time and the vertical dimension. Although a presentation method, the hydrograph remains directly associated with basic data and the data-acquisition site. Hydrographs can be presented on maps in the traditional manner, as insets, or with geographic information systems (GIS's), as attributes of well-location points. They provide a better understanding of in situ relationships, such as confined and unconfined conditions across the area of an aquifer, with greater detail than can other spatial models.

Falkirk Mining Company has integrated well-hydrograph analysis with conventional spatial modeling to produce a standard surface for evaluating aquifer responses to mining and reclamation at the Falkirk mine in central North Dakota. Because baseline data acquisition and mine development occur at different times across the extent of a large-area, large-scale surface mine, it is impossible for potentiometric surface measurements from a given date or time interval to form an accurate model of the premining state throughout the mine area. The solution is to develop a time-transgressive potentiometric surface to model the baseline state. Mine-disturbance maps showing the location and dates of pit operations and backfilling are used to annotate each hydrograph with the approach or onset of mining activity, and a break point is selected to identify data that preceded mining influence. An average premine water level and standard deviation is calculated from the premine data subset at each well, and a potentiometric surface for the premine average water level in each aquifer to be analyzed is built. Data from the current or any other year can then be gridded and the resulting grid subtracted from the premine grid to show its deviation from the premine average. It is also possible to generate contoured surfaces for control limits based on confidence intervals, standard deviation, or other sample statistics to serve as 2-dimensional control charts. As long as good monitoring coverage of all aquifers under study is maintained with wells beyond the radius of mining influence, the premine surface model can be reliably extended to cover new mine areas as they are developed. Falkirk uses AutoCad-SurvCADD Grid File Utility for griding and contouring, but any graphics-application, high-quality griding and contouring application could be used.

The average premine potentiometric surface is a sound empirical model and standard for evaluating mining influences, because it captures the central tendency and variance in available baseline data. The spatial model is strongly documented and linked to data sets by well hydrographs that, in turn, provide a model of temporal dynamics and site-specific, in-ground relationships. The full potential for quantifying drawdown and recovery responses by using griding volumetrics and statistical operations on grid data has not been explored to date. Falkirk has implemented the model as a standard in its annual ground-water report, which documents the state of ground-water resources at the mine. The technique will be central to the evaluation of ground-water conditions for final bond release, and observed results will be important evidence for future probable hydrologic consequences assessment.

For purposes of final bond release, a fully annotated and expanded hydrograph provides effective evaluation of ground-water responses to mining and offers the following advantages over other methods of analysis:

1. It is simple and straightforward; the minimum requirements are a basic personal computer and spreadsheet software.

2. It is a powerful database validation and data exploration tool.

3. It supports and integrates well with statistical techniques.

4. Its results are readily visualized and understood by nonspecialists.

5. Automated production is feasible, and plots of hundreds of wells can be quickly generated, making quarterly or annual updating of results relatively easy.

6. It provides the best analysis of single-well dynamics over time and is a necessary tool for decision-making in well decommissioning.

7. An array of hydrographs, presented alone or linked to graphic surface models, provides an excellent temporal-spatial stratigraphic model of a ground-water system and an information-rich GIS point attribute.

# DETERMINING SOIL CONSERVATION SERVICE RUNOFF CURVE NUMBERS FOR MINELAND CONDITIONS

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## Introduction to the Equation

One of the more commonly used methods to estimate runoff amounts is known generally as the Soil Conservation Service (SCS) curve number (CN) method (U.S. Department of the Interior, 1977). This method uses three variables in estimating runoff, namely, the hydrologic soil-cover complex, antecedent moisture, and rainfall. The method does not estimate runoff rates.

The hydrologic soil-cover complex is used to describe the two watershed characteristics that have major influences on runoff. Four major soil groupings are used to classify bare soils based upon the intake of water at the end of long-duration storms occurring after prior wetting and opportunity for swelling. These hydrologic soil groups are:

Group A (low runoff potential).—These are soils that have high infiltration rates even when thoroughly wetted. They consist chiefly of deep and well to excessively drained sands or gravel that have high conductivity rates.

Group B.—These are soils that have moderate infiltration rates when thoroughly wetted. They consist chiefly of deep and moderately well to well-drained soils with moderately fine to moderately coarse textures. The soils have moderate rates of conductivity.

Group C.—These are soils that have slow infiltration rates when thoroughly wetted. They consist chiefly of soils with some sort of restricting layer that impedes conductivity downward or of soils with moderately fine to fine textures. They have slow rates of conductivity.

Group D (high runoff potential).—These are soils that have very slow infiltration rates when thoroughly wetted. They consist chiefly of clay soils with high swelling potential, high water table, and claypan or clay layer near the surface, or of shallow soils over nearly impervious materials. They have very slow rates of conductivity.

Figure 1 illustrates these four hydrologic soil groupings.

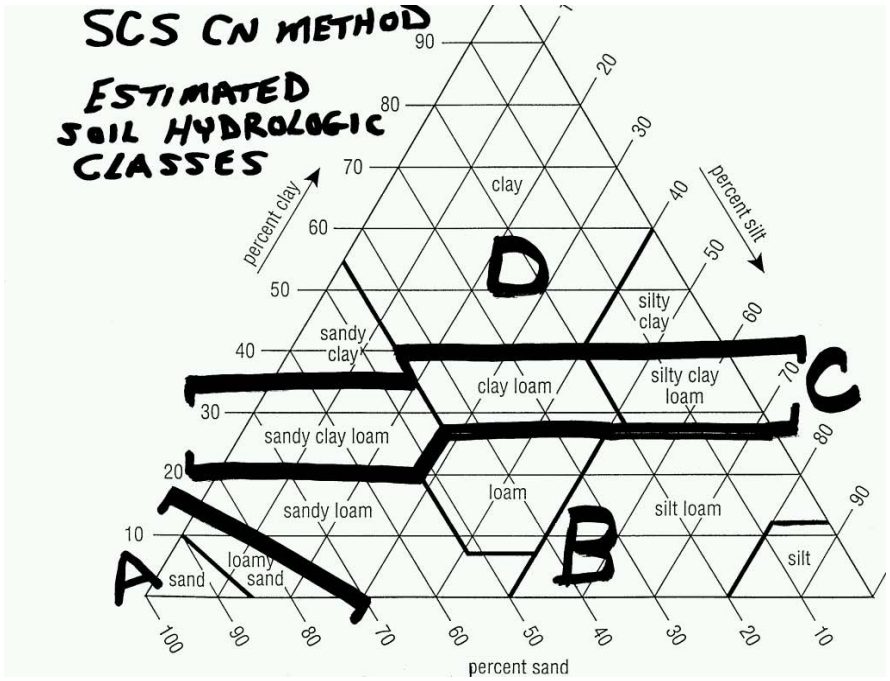


Figure 1.—Graphical illustration of soil hydrologic groups by texture.

Both the U.S. Department of the Interior (1977) and Haan and Barfield (1978) have listed major soils throughout the United States according to these groupings. The rating method adopted in these listings is based, in part, on the theory that soils of similar profile characteristics (in particular depth, texture, organic matter content, structure, and degree of swelling when saturated) will respond in essentially the same manner to a long storm of appreciable intensity.

The cover component of the soil-cover complex variable is based upon the type of land use and treatment classified on a flood runoff-producing basis. General land uses assumed in the classification system are fallow, row crops, small grains, close-seeded legumes or rotation meadow, pasture, permanent meadows, farm woodlots, farmsteads, and dirt roads. Several practices, such as straight row cropping, contouring, and terracing, along with the hydrologic condition for infiltrating, are then factored in with the hydrologic soil grouping to develop what is commonly known as a "curve number." These CN's show the relative values of the complexes as direct runoff producers. In other words, as the CN increases, the potential for a higher amount of direct runoff increases. Table 1 shows a few of these values (for factors AMC-II and $I_a$=0.2S, both of which are discussed later) assuming land uses of small grains and pastures.

Table 1.—*Runoff CN's for selected hydrologic soil-cover complexes*

| Land use | Practice | Hydrologic condition for infiltrating | Hydrologic soil grouping | | | |
|---|---|---|---|---|---|---|
| | | | A | B | C | D |
| Fallow | Straight row | | 77 | 86 | 91 | 94 |
| | | | | | | |
| Small Grain | Straight row | Poor | 65 | 76 | 84 | 88 |
| | | Good | 63 | 75 | 83 | 87 |
| | Contour | Poor | 63 | 74 | 82 | 85 |
| | Contour | Good | 61 | 73 | 81 | 84 |
| | | | | | | |
| Pasture | | Poor | 68 | 79 | 86 | 89 |
| | | Fair | 49 | 69 | 79 | 84 |
| | | Good | 39 | 61 | 74 | 80 |

The second variable that needs to be defined is the antecedent moisture condition (AMC). There are three potential AMC's; the AMC for any given time is based upon the 5-day rainfall amount preceding that time. These three types and their respective 5-day rainfall totals for the growing season are:

AMC I (lowest runoff potential).—Watershed soils are dry enough for cultivation to occur, but the soils are not at the wilting point. Rainfall total is less than 1.40 inches.

AMC II (average condition).—Average conditions have preceded the occurrence of the maximum flood on numerous watersheds. Rainfall totals are 1.40 to 2.10 inches.

AMC III (highest runoff potential).—Watershed soils are practically saturated from previous rains. Rainfall total is greater than 2.10 inches.

Previous research (Schroeder et al., 1990) has shown that the average condition, AMC II as defined above, was not truly "average" for a semi-arid climate like that of North Dakota. This research indicated that, for 5-day rainfall totals from April 1 to November 1 throughout the years 1948 through 1986, AMC I conditions were present 94 percent of the time (table 2). Accordingly, at least for semi-arid climates, to define AMC as equivalent to a 5-day rainfall total may not be a valid approach; if AMC II conditions are used to simulate average conditions, calculations based on the CN method incorporating such a definition may tend to overestimate runoff amounts, especially for undisturbed areas. As noted below, this may not be the case for leveled spoil and reclaimed grasslands. Therefore, care must be taken to assign a true and accurate AMC before proceeding. Tables are available (U.S. Department of the Interior, 1977) that allow for converting CN's for one AMC to those for another.

Table 2.—*Delineation of AMC groupings for various North Dakota cities*

(based on April 1 through October 31 data compiled for the years 1948 through 1986)

| AMC grouping (percentage of time) | | | |
|---|---|---|---|
| Location | I | II | III |
| Fargo | 93.7 | 3.9 | 2.4 |
| Mandan | 94.9 | 3.5 | 1.6 |
| Minot | 94.7 | 3.1 | 2.2 |
| Williston | 95.9 | 2.9 | 1.2 |

The last variable that needs to be defined is the rainfall amount. This value is generally set to some predetermined duration and return period specified in either State or Federal regulations for the design of sediment ponds. The value, however derived, is then entered into a runoff equation developed by the SCS to determine the ratio of actual to potential runoff, as follows:

$$(P - Q)/S = Q/P \qquad \text{Eq. 1}$$

where P is the storm rainfall (inches), Q is the direct runoff (inches), and S is the maximum potential difference between P and Q (in inches) at the storm's beginning. Thus, solving for Q gives the following relationship:

$$Q = P^2/(P + S) \qquad \text{Eq. 2}$$

Equation 2 is useful whenever there is a possibility of runoff from a storm. For the condition where Q=0 when the value of P is greater than zero, an initial abstraction term, $I_a$, is used to account for interception, infiltration, and surface depressional storage. Since $I_a$ cannot, by definition, be greater than P, equation 1 becomes:

$$((P - I_a) - Q)/S = Q/(P - I_a) \qquad \text{Eq. 3}$$

which, solved for Q, becomes:

$$Q = (P - I_a)^2/(P - I_a + S) \qquad \text{Eq. 4}$$

Because S includes $I_a$, equation 4 can be simplified to describe an empirical relationship between the two variables. Based upon data collected from various watersheds in different parts of the country, $I_a$ can be estimated as:

$$I_a = 0.2S \qquad \text{Eq. 5}$$

Schroeder (1994) found that this method for estimating $I_a$ generally overestimated the value from known research-plot data, for which the calculated field value was closer to 13 percent. This may be partially accounted for by the fact that research plots and their surface characteristics,

and hence the data describing these, differ considerably from watersheds and their descriptive data. Substituting equation 5 into equation 4 gives the standard form of the SCS runoff estimate equation:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad \text{Eq. 6}$$

Solutions to equation 6 are generally depicted on graphs plotting rainfall (P) on their x axes and direct runoff (Q) on their y axes. Delineating curves for various CN values are as shown in figure 2. A user of this method, once a CN value has been determined for the AMC condition present, can go directly to the figure and estimate direct runoff by inputting the storm rainfall.

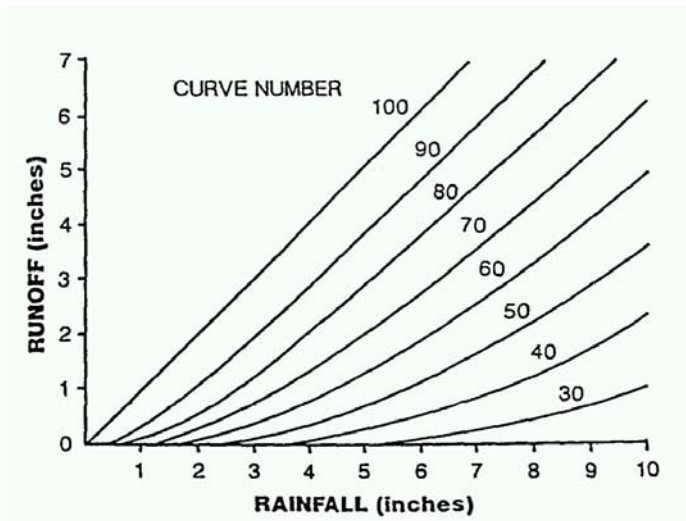


Figure 2.—Graphical illustration of the runoff equation $Q = (P - 0.2S)^2 / (P + 0.8S)$.

**Some Research Results**

As indicated above, major soils throughout the United States have already been listed (U.S. Department of the Interior, 1977; Haan and Barfield, 1978) as to their hydrologic groups. Table 3 illustrates this by showing the ratings for several undisturbed soils in North Dakota. This information, combined with the soil/cover complex shown in table 1, would allow for a CN estimate to be calculated. Either solving equation 6 or consulting figure 2 will yield an estimated runoff amount. This is the standard procedure for calculating runoff amounts for premine, undisturbed soils.

Table 3.—*Hydrologic class for selected undisturbed North Dakotan soils*

| Prime soils | Nonprime soils |
|---|---|
| Arnegard B | Cabba D |
| Bowbells B | Williams B |
| | Zahl B |

For a disturbed area in which the overburden is exposed or spoil has been leveled, the CN value can be estimated in a similar manner. Given that, following mining, the soil series present before mining are no longer present, the texture(s) of the overburden/spoil must be determined to estimate the hydrologic class or classes of postmining soils. Assuming a fallow condition for the AMC II class, a CN value can be estimated by means of a table such as table 1. Schroeder (1987) researched sites, including those listed in table 4, with either a disturbed or crusted surface for AMC I conditions. This research found that field-measured CN values are (1) larger than the tabular CN values for AMC I conditions and (2) generally more closely estimated by AMC II conditions. This was most likely the result of the higher bulk densities of the overburden/spoil materials, causing these materials to mimic the characteristics of materials saturated with water. Field CN values for the wet runs were, however, very close to the estimated AMC III tabular values.

Table 4.—*Estimated and field CN values for several spoil sites under varying surface conditions*

(all spoils were soil hydrologic group C, except those for which values are in parentheses, which were hydrologic group D)

| | Mean field CN values Rainfall application run | | | Tabular CN values for fallow surface conditions | | |
|---|---|---|---|---|---|---|
| Slope (percent) | Dry | Wet | Very wet | AMC I | AMC II | AMC III |
| Center: Disturbed surfaces | | | | | | |
| 0.6 | 90 | 94 | 96 | 80 | 91 | 97 |
| 4.9 | 89 | 96 | 97 | | | |
| 8.7 | 86 | 98 | 99 | | | |
| LSD[1] (0.10) | NSD[2] | NSD | NSD | | | |
| Center: Crusted surfaces | | | | | | |
| 0.2 | 90 | 95 | 96 | 80 | 91 | 97 |
| 3.2 | 93 | 96 | 96 | | | |
| 6.8 | 89 | 96 | 96 | | | |
| LSD (0.10) | 1.2 | NSD | NSD | | | |
| Beulah: Disturbed surfaces | | | | | | |
| 1.8 | 88 | 98 | 98 | 80 | 91 | 97 |
| 3.9 | 86 | 96 | 96 | | | |
| 11.0 | 90 | 98 | 97 | | | |
| LSD (0.10) | NSD | NSD | NSD | | | |
| Beulah: Crusted surfaces | | | | | | |
| 1.8 | 96 | 96 | 98 | 80 | 91 | 97 |
| 3.9 | 94 | 97 | 96 | | | |
| 11.0 | 94 | 96 | 95 | | | |
| LSD (0.10) | NSD | NSD | NSD | | | |

[1]LSD = least significant difference at the P+0.10 level.
[2]NSD = no significant difference.

Table 4 shows that the effect of slope on the field CN values was insignificant for all the rainfall applications for disturbed surfaces. Field CN values were only significant for dry surface.

conditions for crusted surfaces at Beulah. Again, the similarity in bulk densities across slope gradients resulted in nearly equal CN values. Sodium adsorption ratio, ranging from a mean of 4.2 at Center to 15.8 for the Beulah data, seemed to have had little effect on the field CN values. Thus, with care, CN values may be reasonably estimated for overburden and/or spoil, if the higher bulk densities, and thus lower conductivities, of the overburden/spoil are accounted for in either the hydrologic class or or the AMC.

Schroeder (1989) has shown that, under dry surface conditions, reclaimed grasslands have higher (though not always significantly higher) CN values than undisturbed grassland sites (table 5).

Table 5.—*Comparisons of reclaimed and undisturbed grassland CN values for selected sites in North Dakota*

| | | | | Mean field CN values Application run | | | Tabular CN values[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Age[2] | Cover (percentage) | Slope (percent) | Dry | Wet | Very wet | AMC I | AMC II | AMC III |
| Center | 2 | 63 | 0.8 | 81 | 90 | 92 | 50 | 69 | 84 |
| | | 99 | 4.7 | 66 | 90 | 92 | | | |
| | | 95 | 6.8 | 56 | 84 | 88 | | | |
| | | | LSD[3] (0.10) | 7 | 4 | NSD[4] | | | |
| | Undis[5] | 96 | 3.4 | 59 | 74 | 81 | 50 | 69 | 84 |
| | | 96 | 8.0 | 50 | 78 | 79 | | | |
| | | | LSD (0.10) | NSD | NSD | NSD | | | |
| GH | 4 | 76 | 3.2 | 66 | 88 | 90 | 50 | 69 | 84 |
| | | 80 | 6.1 | 76 | 89 | 90 | | | |
| | | 76 | 9.2 | 76 | 90 | 90 | | | |
| | | | LSD (0.10) | NSD | NSD | NSD | | | |
| | 7 | 98 | 3.3 | 48 | 82 | 88 | 50 | 69 | 84 |
| | | 100 | 5.7 | 56 | 82 | 92 | | | |
| | | 99 | 9.5 | 48 | 84 | 92 | | | |
| | | | LSD (0.10) | NSD | NSD | NSD | | | |
| | Undis | 100 | 3.2 | 48 | 64 | 71 | 50 | 69 | 84 |
| | | 100 | 5.8 | 47 | 64 | 65 | | | |
| | | 100 | 8.7 | 46 | 66 | 69 | | | |
| | | | LSD (0.10) | NSD | NSD | NSD | | | |

[1]As defined by their surface textures, all sites were in hydrology class B. Tabular values assumed pasture/rangeland under fair condition.
[2]Age = age, in years, from seeding date.
[3]LSD = least significant difference at the 10-percent level.
[4]NSD = no significant difference between mean values.
[5]"Undis" = undisturbed grassland.

Slope gradient shows little or no consistent effect on CN. CN values for wet reclaimed grasslands are nearly always significantly higher than those for undisturbed grasslands, generally due to differences in porosity. Reclaimed grasslands generally have a much higher proportion of micropores than of macropores, whereas undisturbed grasslands generally have exactly the opposite ratio. Accordingly, undisturbed grasslands have higher saturated conductivities, hence less runoff, than do reclaimed grasslands.

Agreement between the field and tabular values for undisturbed grasslands under both AMC I and AMC III conditions was remarkably good. Field values for reclaimed grasslands under dry conditions were generally much larger than tabular CN values except for the 7-year old site at the Glenharold mine. This indicates that, even under dry soil conditions, the conductivities of reclaimed grassland sites have been affected by reclamation techniques.

As reclaimed grasslands age, the effects of runoff seem to diminish, most likely owing to the formation of larger pores, as well as root channels, near the surface. However under wet soil conditions, the field CN values for reclaimed grasslands, regardless of age, still indicate that the tabular values for these would be underestimated by approximately 10 percent. This most likely indicates that the effects of reclamation on soil conductivities near the surface take much longer to show up and tend to penetrate much deeper than we have assumed.

Data from approximately 40 rainfall simulation plots on grasslands (including those described in table 5) show that the calculated CN value for AMC I conditions was within ±10 of the SCS CN value about 86 percent of the time using equation 6; the calculated CN value for AMC III conditions was within ±10 of the SCS CN value about 99 percent of the time (Schroeder, 1994). These findings suggest that the SCS CN runoff curve method might be used with respect to reclaimed minelands with a fairly high degree of reliability under the strict assumption of an equation estimate for runoff amount. However, if estimates are taken from tabular values and the effects of mining and reclamation are not taken into account, the SCS CN method may be less reliable.

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# CLIMATE, BOND RELEASE, AND THE CONCEPT OF MINIMUM LIABILITY PERIODS

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## Introduction

The North Dakota surface-mining rules (North Dakota Administrative Code [NDAC} 69-05.2) and statutes (North Dakota Codified Code [NDCC] 38-14.1), like all regulation based on the Surface Mining Control and Reclamation Act of 1977 (SMCRA), make little mention of climate or weather except in definitions such as those for hydrologic regime and steep slopes or as data to be recorded in blasting records. In spite of this, mining permits contain at least minimal information on climate, because of its importance in surface-water management, interpretating water resources data, and demonstrating revegetation success. Climate, especially the moisture regime, is the determining factor in vegetation and water-resources reclamation, as well as in attaining bond release in the western U.S. It is also probably the easiest factor about which to acquire information. Abundant data are available over the Internet at various National Oceanographic and Atmospheric Administration (NOAA) websites, and mines generally maintain rainfall gages at minesites.

This presentation proposes the Palmer drought indices as tools for evaluating relationships between climate and reclamation success, and it considers the 10-year minimum liability period an attempt by the authors SMCRA to cope with the potential influence of climatic variation on the permanence and stability of otherwise successful reclamation results in the semi-arid and arid West. Bickel (2000) showed the suitability of the Palmer Drought Severity Index (PDSI) for evaluating mine-related environmental data and compared the last 20 years of climate in west-central North Dakota—during SMCRA-based mining regulation—with climatic conditions over the past 308 years there.

The minimum reclamation liability period required by SMCRA is 10 years; on the other hand, high-frequency climatic cycles identified in west-central North Dakota and elsewhere in the West are typically from 20 to 23 years long. This fact, along with other evidence related in general to modern mine reclamation and regulation in the Western United States, suggests that Western coal-mining regulators may need periodically to check the success of reclamation over a period longer than 10 years to confirm compliance with the intent of the law. SMCRA and the resulting Office of Surface Mining (OSM) and North Dakota rules are silent about the rationale for a minimum liability period on reclamation bonds, and no measurement or specific requirement is associated with the time period. Information and recollections from the formative period of SMCRA, summarized by the National Academy of Sciences (NAS) in1974, suggest that the technical rationale for a 10-year minimum liability period came from reclamation research and State regulation, primarily of Montana. NAS (1974, p. 3) notes the absence of a climatic "safety factor" in the evaluation and regulation of reclamation practice, indicating that even supplying all the requirements for an apparently successful reclamation practice will not

guarentee stable and permanent results in all instances. It emphasizes that stability and permanence of successful reclamation must be determined by the proper application of proven techniques yielding acceptable results at all the "critical times" in regional climate.

**The Palmer Drought Severity Index**

The Palmer Drought Severity Index (PDSI) is an index to the departure of measured precipitation from an expected, "near-normal" moisture balance based on evaporation, soil moisture gain and loss, runoff, and precipitation. The calculation weights each value for its location in or between an established wet or dry period. The index scale varies roughly from +6 to –6; negative values denote dry conditions. In general terms, the index is calculated by subtracting evapotranspiration, soil moisture gain, and runoff from, and then adding soil moisture loss to, current precipitation. The resulting moisture anomaly index is used, along with the previous period's PDSI value and a moisture-balance term, to calculate a value for the current period. The moisture-balance term depends on a month falling within or transitioning from a wet or dry period. Values are calculated for each period for each of these three possible states (that is, the states of falling within or transitioning from a wet or dry period), and the value ultimately used is determined by conditions in subsequent months defining a wet or dry spell. Palmer (1965) and Guttman (1991) give details on computation of the PDSI.

The multi-month delays in getting a final PDSI value led to use of a modification, termed the Palmer Hydrologic Drought Index (PHDI), that avoids the PDSI's backtracking to define transitions between wet and dry spells and provides an immediately available final value. The two indices are identical during an established wet or dry period and differ only during transitions between wet and dry spells. The PHDI is more conservative than the PDSI in showing changes in the moisture regime and has been considered more representative of hydrologic systems. Correlation of both indices with mining-related data sets from quarterly and annual sampling periods showed that the PDSI generally provided correlations equal to the PHDI.

**Results and Discussion**

The PDSI is a valuable tool in baseline and bond-release evaluations for several reasons. Monthly PDSI, PHDI, temperature, and precipitation data for the National Oceanic and Atomospheric Administration (NOAA) climatic divisions of the U.S. are readily available from NOAA's National Climatic Data Center website www.ncdc.noaa.gov/onlineprod/drought/ftppage.html. North Dakota climatic Division 4 includes the west-central region of the State where mines and counties considered in this presentation are located. Annual PDSI values calculated from U.S. Weather Service data and reconstructed from tree-ring data (Cook et al., 1996) are available from the NOAA Paleoclimatology Program website at http://www.ngdc.noaa.gov/ paleo/usclient2.html. This data set is a nationwide, 155-point grid of multi-century PDSI reconstructions based on selected tree-ring chronologies that show strong responses to moisture conditions.

PDSI correlates well with reclamation-related environmental variables. Table 1 shows some of the water-resources data Bickel (2000) correlated with the Palmer Index. Bickel assumed that

local weather data would generally correlate better with local mine variables than would regional averages or indices. However, the PDSI provided better correlations with static water levels in shallow monitoring wells at Falkirk mine than with precipitation totals at nearby Underwood, North Dakota. It correlated poorly with the hydrograph from a deeper monitoring well, Well 92-1, which is completed in the lower of two lignites mined at Falkirk mine. It correlated better than did regional precipitation with North Dakota Pollutant Discharge Elimination System discharges and estimated county productions of wheat and hay.

Table 1.--*Examples of correlation of hydrologic variables with temperature, precipitation and the PDSI*

| Dependent Variable | Independent Climate Variable | Years of Run | Sample Periods | n | Correlation Coefficient | $R^2$ | F ratio (MSR/MSE) | p - Value | Relationship (p <.05 = signif. at 0.95 confidence level) |
|---|---|---|---|---|---|---|---|---|---|
| NDPDES discharges from all mines | Region 4 Precipitation | 1986-98 | annual | 12 | 0.4087 | 0.167 | 2.21 | 0.1655 | not significant |
| NDPDES discharges Falkirk Mine | Region 4 Precipitation | 1986-98 | annual | 12 | 0.2466 | 0.0608 | 0.71 | 0.4167 | not significant |
| NDPDES discharges Glenharold Mine | Region 4 Precipitation | 1986-98 | annual | 12 | 0.5061 | 0.2561 | 3.79 | 0.0766 | not significant |
| NDPDES discharges from all mines | PDSI | 1986-98 | annual | 12 | 0.8066 | 0.6507 | 20.49 | 0.0009 | significant |
| NDPDES discharges Falkirk Mine | PDSI | 1986-98 | annual | 12 | 0.8167 | 0.6671 | 22.04 | 0.0007 | significant |
| NDPDES discharges Glenharold Mine | PDSI | 1986-98 | annual | 12 | 0.6375 | 0.4064 | 7.53 | 0.0191 | significant |
| Falkirk Mine Monitoring Well 3-2 | PDSI | 1984-97 | quarterly | 75 | 0.4698 | 0.2207 | 20.96 | 0.0000 | significant |
| Falkirk Mine Monitoring Well 3-2 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.1873 | 0.0351 | 1.96 | 0.1670 | not significant |
| Falkirk Mine Monitoring Well 9-3 | PDSI | 1984-97 | quarterly | 72 | 0.4535 | 0.2056 | 18.38 | 0.0001 | significant |
| Falkirk Mine Monitoring Well 9-3 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.2967 | 0.088 | 5.21 | 0.0264 | significant |
| Falkirk Mine Monitoring Well 15-4 | PDSI | 1984-97 | quarterly | 60 | 0.5498 | 0.3023 | 25.56 | 0.0000 | significant |
| Falkirk Mine Monitoring Well 15-4 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.1015 | 0.0102 | 0.56 | 0.4568 | not significant |
| Falkirk Mine Monitoring Well 19-1 | PDSI | 1984-97 | quarterly | 57 | 0.3598 | 0.1294 | 8.33 | 0.0055 | significant |
| Falkirk Mine Monitoring Well 19-1 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.2685 | 0.0721 | 4.19 | 0.0454 | significant |
| Falkirk Mine Monitoring Well 19-2 | PDSI | 1984-97 | quarterly | 57 | 0.3151 | 0.0993 | 6.17 | 0.0160 | significant |
| Falkirk Mine Monitoring Well 19-2 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.2833 | 0.0802 | 4.71 | 0.0344 | significant |
| Falkirk Mine Monitoring Well 31-2 | PDSI | 1984-97 | quarterly | 51 | 0.3002 | 0.0901 | 4.95 | 0.0306 | significant |
| Falkirk Mine Monitoring Well 31-2 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 51 | 0.1705 | 0.02906 | 1.5 | 0.227 | not significant |
| Falkirk Mine Monitoring Well 92-1 | PDSI | 1984-97 | quarterly | 75 | 0.0713 | 0.0051 | 0.38 | 0.5407 | not significant |
| Falkirk Mine Monitoring Well 92-1 | Underwood, ND quarterly precip. | 1984-97 | quarterly | 55 | 0.3004 | 0.0923 | 5.36 | 0.0245 | significant |

The reconstructed annual PDSI allows long-term assessment of climatic patterns projected as far back as the 17$^{th}$ century (weather data regularly measured with instruments dates back only to the late 19$^{th}$ or early 20$^{th}$ centuries for most of the Western U.S.). The structure of the index makes analysis of intensity, duration, and frequency of wet and dry periods easy over this multi-century range. An analysis of runs of signs is an easy measure of duration using the Palmer Index. The pattern in the lengths of wet and dry intervals is the distinguishing characteristic of the years 1979-98 in west-central North Dakota. The first 9 years of the period were alternating 2-year wet and dry spells through 1987. These were followed by 5 dry years, 4 wet years, and 2 dry years (1997-98). The the total PDSI record from 1691 to 1998 has 177 wet and 131 dry years distributed in 104 alternating wet and dry spells of from 1 to 13 years in length. The 5-year dry spell from 1988 through 1992 ranked as the 5$^{th}$ longest in the record and above the 75$^{th}$ percentile

(the longest dry period in the record was the 12 years extending from 1929 through 1940). The 4-year wet period from 1993 through 1996 is ranked 15th longest (at the 75th percentile), with the longest wet spell running 13 years from 1770 through 1782.

The lengths of periods had a slight linear trend of decreasing period duration (slope of –0.01x) and seemed to show a transition to shorter climatic periods occurring near the beginning of the last quarter of the 19th century. Wet and dry spells 5 years long or longer are listed in table 2. With the exception of the 1929-40 drought, the latter part of the 19th and most of the 20th centuries appeared characterized by more frequent changes between wet and dry conditions than occurred prior to the 1880's. The periodic pattern in the length of spells seemed to agree with measured and reconstructed event frequencies reported by Michaelsen (1989) for the El Nino southern oscillation.

Table 2.--*Years of Events in the West-Central North Dakota Climatic Record*

| Correlation (.40-.78) of 1979-98 with 20-year intervals beginning: | Visual Curve Matching: 1979-98 with 20-yr. intervals beginning: | Periods of 5 or more Wet Years | Periods of 5 or more Dry Years | Severe Wet Years | Severe Dry Years |
|---|---|---|---|---|---|
| | | 1691-95 | | | |
| | | | 1704-08 | | |
| 1709 | 1711 | | | | 1718 |
| 1723 | | 1723-30 | | 1726-29, 33, 37-38, 40 | |
| 1746 | 1750 | 1750-55 | | 1754 | |
| 1763 | | | | | |
| 1772 | | 1770-82 | | 1767, 1775, 77-78 | |
| 1789 | 1775 | 1786-90 | | 1787 | |
| | | 1802-07 | 1815-20 | | |
| 1807 | 1808 | 1810-14 | | | 1817, 23 |
| | | 1825-35 | | 1828-30, 32-33 | |
| 1836 | | 1849-54 | 1859-66 | 1851 | |
| 1854 | | 1876-80 | 1869-75 | | |
| 1862 | 1865 | | | 1877-79 | 1865 |
| 1880 | 1883 | | | 1895-97 | |
| | | 1904-09 | | 1902, 07, 09, 16 | |
| 1924 | | | 1929-40 | 1927-28 | 1934, 36-37 |
| | 1935 | 1920-24 | | | |
| | | 1941-45 | | 1942-43 | |
| 1948 | 1952 | | | 1953 | |
| 1961 | | 1962-66 | | 1972, 75, 78 | 1961 |
| | | | | 1983 | |
| | | | 1988-92 | | 1988, 91 |
| | | | | 1993 | |

Severe drought or wet conditions are commonly defined as PDSI values at or more extreme than 3.0 or –3.0. Extreme years were identified in the data using these standards. The total record from 1691 to 1998 had 40 wet years and 10 dry years that represented severe to extreme conditions (table 2). The 1979-98 period had 2 severe wet years, 1983 and 1993, and 2 severe dry years, 1988 and 1991. Throughout the record, severe wet and dry years occurred during

multi-year periods of corresponding wet or drought. The exception was 1975, which was a single-year severe wet period. Events related to wet conditions rather than drought have characterized climatic history in the region for the past 300 years. Over the preceding 308 years in west-central North Dakota, there have been more wet than dry spells spanning 5 or more years, and there have been four times as many severe wet years as dry years.

The Palmer Index spanning years in which successful reclamation has occurred can be compared with long historic records using year-wise correlation. For west-central North Dakota, Bickel (2000) used Excel to correlate the PDSI record year-by-year for the period 1979 through 1998. Fourteen closely matching intervals with correlation coefficients of 0.40-0.78 were found in the record from 1691 through 1978. A time plot of all correlation values showed about 22 cycles over the 288-year record that could be modeled with a 12.8-year frequency. The climatic pattern in the west-central North Dakota PDSI from 1979 to 1998 has occurred multiple times in the reconstructed regional PDSI.

Cook et al. (1997) investigated drought rhythms in the Western United States using the grid network of proxy PDSI records reconstructed from the tree rings mentioned above. They counted the number of points each year with a PDSI less than -0.1 as a measure of drought conditions, and most of North Dakota was outside the more drought-prone areas. Their analysis of periodicity found significant spectral peaks in the data at 20 through 23, 7.8, 4.1, and 2.5 years. Bickel (2000) made a spectral analysis of the west-central North Dakota grid point in that data set (point 65) and found proximate fits for the 20- through 23-, 7.8-, and 4.1-year periods Cook et al. (1997) observed in the larger Western U.S. data set. Periodogram evaluation and fitting of a spectral model (fig. 1) after removal of a slight linear trend found significant periods of 4.1, 7.5, 8.3, 9.3, 12.8, 19, 22, 23 and 61.6 years in the data set.

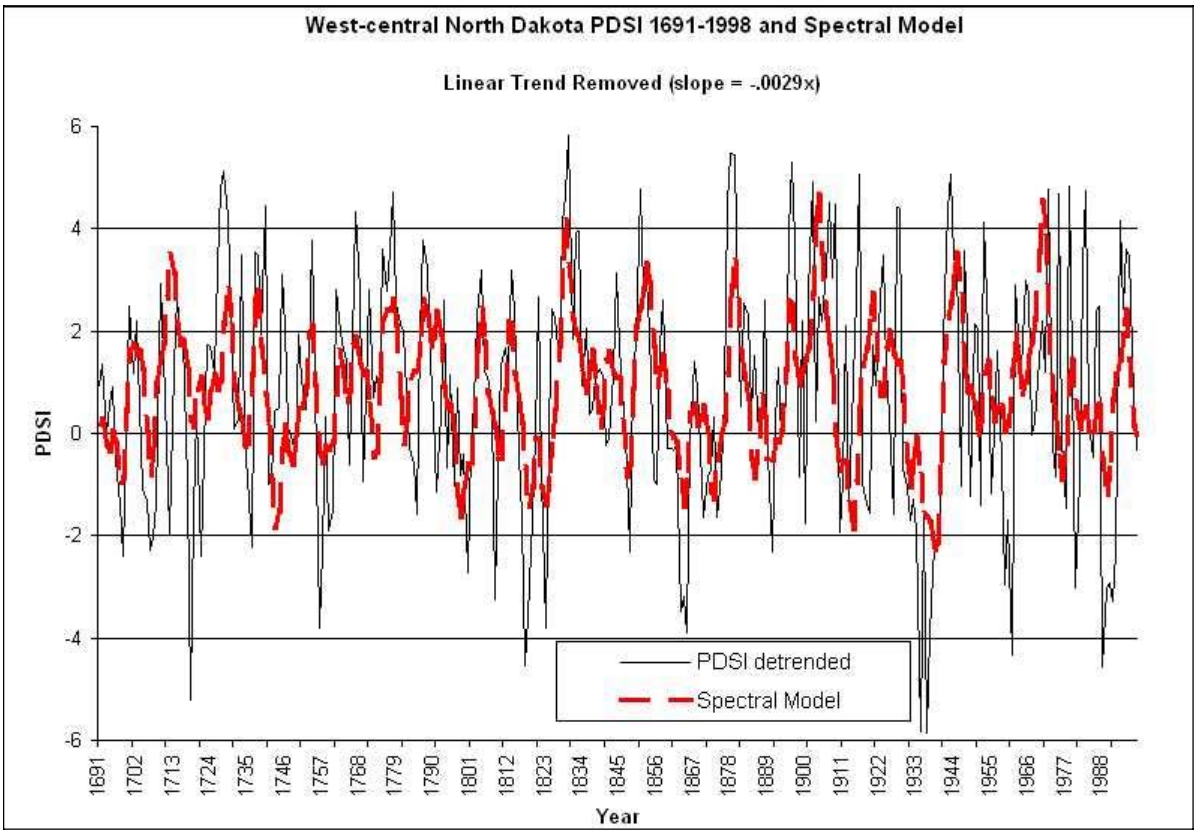


Figure 1.--West-central North Dakota spectral model and PDSI, 1691 through 1998.

Given the long life of western mines, as well as the role of climatic variability in their operation and reclamation, analysis of climate is an essential aspect of evaluating reclamation success. The results this presentation sets out suggest that an analysis of PDSI can provide more useful baseline and final bond-release information than can an evaluation of temperature and precipitation data:

1. The regional seasonal and annual moisture regime can be succinctly characterized.

2. An analysis can provide historical insights for mine and reclamation planning relative to water management, surface stability, revegetation, and the public perception of mining effects on water resources.

3. Palmer Indices can provide substantive data for probable-hydrologic-consequence assessment of stream flows, spring flows, well responses, recharge fluxes, drought, and water-use patterns.

4. The long-run data sets available provide a sound historical basis for defining abnormal dry or wet conditions and making climatic comparisons over time.

5. Since the Palmer Indices generally correlate well with mining-related environmental variables, they are useful for separating climatic effects from the effects of mining.

6. Successful reclamation results, and the moisture events throughout which they have persisted, can be compared to historic records as indicators of the probable long-term stability and permanence of reclamation.

The mining and regulatory communities in each distinct coal-producing region quickly develop a set of successful reclamation practices in response to the performance requirements of regulations. With only slight variation, these are common knowledge and are used throughout the regional industry. This common usage of successful practices in a particular district extends beyond reclamation and is as old as mining itself. The concern during the formation of SMCRA was that reclamation practices that produced successful results for a few initial years would not be consistently successful or their results could not persist through the variations in the arid and semi-arid climate of the Western U.S. Thus a minimum liability period was imposed on each instance of reclamation in the absence of (1) a body of regulation to prescribe and measure reclamation and (2) a means of evaluating and predicting stability and permanence. With respect to the first of these points: a system of massive regulation is now well established through Federal and State SMCRA-based regulations, and successful reclamation for final bond release is actually controlled by a large and detailed set of performance standards--about 75 to 80 major checklist items in the North Dakota regulations--specific to vegetation, hydrology, soils, land stability, and wildlife. With respect to the second of the points: climatic analysis, particularly of moisture regime variability, provides a means of assessing the stability and permanence of reclamation practices and of inferring their persistence through future variations in regional climate.

The data to carry out sound temporal analysis are generated by mines as extensive baseline and life-of-mine environmental data to meet permit requirements. Long-run data sets exist in established mining districts to evaluate stability and permanence of reclamation during variations in wet and dry conditions in the regional climate. Once the products of a set of reclamation practices have been proven successful under Federal or State regulations, and they have persisted through the high-frequency cycles of regional climate, there is no need to attach to each land tract through mine life a time-period requirement in addition to performance-standard and guideline requirements.

A logical alternative to the present liability-period requirement for each reclaimed tract is feasible. Each distinct climatic and coal-producing region can logically have a 10-year minimum liability period in force until successful reclamation results, from the set of common SMCRA-based practices, have survived variations in drought and wetness on the scale of high-frequency cycles in the regional climate. Once a set of successful reclamation practices and the persistence of their results can be demonstrated, the 10-year minimum liability period can be eliminated and bond release controlled solely by the performance-based requirements in regulations. West-central North Dakota is an example of a Western coal-producing region that had established surface-mining and reclamation laws prior to SMCRA. However, the 20-year period from 1980 to the present can be considered the period of SMCRA-based reclamation. Successful reclamation both of water resources and to postmining land uses has been proven during this interval. Extensive and detailed data are available to show application of these reclamation practices and the survival of their successful results through stresses of regional climate

variation. The high-frequency cycles in the regional PDSI record range up to about 23 years. Drought and wet periods of notable duration and intensity have occurred from the late 1980's through the present and are well documented in the regional PDSI. Therefore, removal of the 10-year minimum liability period in about 2005 would be feasible.

The blanket 10-year delay in bond release can hamper the formation of logical ownership and agricultural management units for efficient bond release. Removal of the 10-year minimum liability period would aid bond release by allowing more orderly formation of logical land-use units for release out of the patchwork of reclamation dates, land use, and ownership characteristics of large-scale Western mines. The approach provides a direct measurement of reclamation stability and permanence closer to the intent of SMCRA. A climatic analysis of reclamation results is more grounded in science and reclamation technology than is an arbitrary 10-year period, which, by itself, is not linked to any measured performance requirement. Also, the approach doesn't alter the performance standards that actually control regulatory compliance and bond release.

This alternative has some disadvantages, not the least of which is the fact that the 10-year minimum liability period is a cornerstone of SMCRA whose alteration seems highly improbable. A 10-year period is unambiguous, while a climate-based alternative requires the detailed analysis and interpretation of environmental data. The minimum liability period has always been a part of the SMCRA landscape, and the time requirements in a few performance standards are based on the assumption that a minimum liability period would be in place. These requirements would have to be revised to periods dictated by applied science and the technology of the fields to which the performance standards pertain. A strong factor against near-term consideration of an alternative to the 10-year minimum liability period is that the need for change is not great at present because of the low volume of final bond release in Western States. As large Western mines mature, and the need to accelerate bond release increases, the ineffective delays from a minimum liability period applied to proven reclamation will be less tolerated by stakeholders.

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# CORRELATION BETWEEN NATURAL SPRING FLOW AND THE PALMER HYDROLOGIC DROUGHT INDEX

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## Introduction and Purpose

The Utah Department of Natural Resources, Division of Oil, Gas, and Mining (DOGM), is a regulatory agency whose mission is to enforce provisions of the 1977 Surface Mining Control and Reclamation Act on behalf of the U.S. Department of the Interior's Office of Surface Mining (OSM). As a regulatory agency, Utah DOGM is generally not involved in research. However, it is often involved in situations where mining may appear to have impacted water resources such as springs, wells, and streams. These impacts may result in a reduction in the amount of water available to users. There are often many plausible explanations for such a decrease, including a simple long-range reduction of precipitation, that is, a drought.

The purpose of this study is to provide an analysis tool with which to evaluate the importance of factors that may affect spring flow (SF) at a particular site. This tool incorporates multiple factors that may affect water sources, allowing regulatory decision-makers to evaluate the likely causes of changes in SF.

To demonstrate the methods, a case study is presented based on SF's at Colton Springs in Price, Utah. The hydrologic factors that may be important determinants of SF's at this particular site include fluctuations in climatic conditions, Price River flow (PRF), the capacity of Scofield Reservoir (CSR), and occasional pumping of wells thought to be completed in the same aquifer supplying water to Colton Springs. It is shown that SF's can be predicted from linear functions of these variables.

It is recognized that each situation may have its own unique combination of geologic formations, structure and faulting, and other factors affecting flows; however, the methods proposed in this report are general. It is also recognized that at some sites the available information may be restricted to drought indices and SF records. In such situations, the seasonal variations in SF's that might otherwise as a function of available physical variables can be modeled using appropriately chosen combinations of sine and cosine functions. Models based on trigonometric functions are referred to as Fourier, or trigonometric, expansions (Burden et al., 1981). Although not as readily interpretable as models based on physical characteristics, models based on trigonometric expansions provide a basis against which to evaluate SF fluctuations.

The basic idea is, first, to establish that SF's can be predicted from climatic fluctuations and other measurable site-specific factors and, second, to evaluate changes in flow relative to flow that would be predicted by the model. Changes in flow should be consistent with natural

fluctuations in modeled factors. If not, it would be appropriate to look for other explanations for the changes in flow.

In this report, two empirical models are developed to predict flows at Colton Springs: one model is based index-to-climate and other physical factors, and the other model based on index-to-climate and trigonometric functions. The trigonometric-expansion model is also applied at an additional site to evaluate the potential for application to other sites in general.

This analysis tool should prove useful to hydrologists, water-user associations, municipalities, mine operators, and anyone interested in comparing water flows to natural fluctuations in wet and dry periods. The statistical approach is based on multiple-regression (Neter et al., 1996) and time-series methods known collectively as spectral analysis (Diggle, 1990).

**Methodology: Concept Formulation**

Fluctuations in SF's may be due to natural fluctuations or to human-induced activities such as mining or irrigation pumping and diversion. In order to evaluate fluctuations in SF's, a method is needed to differentiate between natural fluctuations and those that may be due to human activities. We hypothesize that empirical relationships between drought indices as well as other natural and human induced factors could be used to predict SF's. To evaluate this hypothesis, a spring was sought that had reasonably well-understood, human-induced impacts, but no apparent mining impacts. The premise of this study is that the method should be demonstrated in an unimpacted setting prior to its application in a contentious regulatory setting. If a predictable relationship could be developed in this setting, then similar statistical models could be applied at sites where mining impacts are postulated.

Colton Springs, culinary water supply for Price City, Utah, was identified as a good candidate for such a trial. This spring is influenced by human activities, although records are available to document those activities. Factors thought likely to be associated with (not necessarily controlling) spring discharges at Colton Springs were the PRF, CSR, the pumping of two water wells near the springs, and recent climatic conditions. As an index to climatic conditions, we used the Palmer Hydrologic Drought Index (PHDI; Palmer, 1965). Correlation with PHDI is important, because this index is a regionally based index that should be available at most sites where regulatory decisions are to be made.

An initial comparison between Colton Springs discharge and the PHDI yielded promising results (fig. 1).

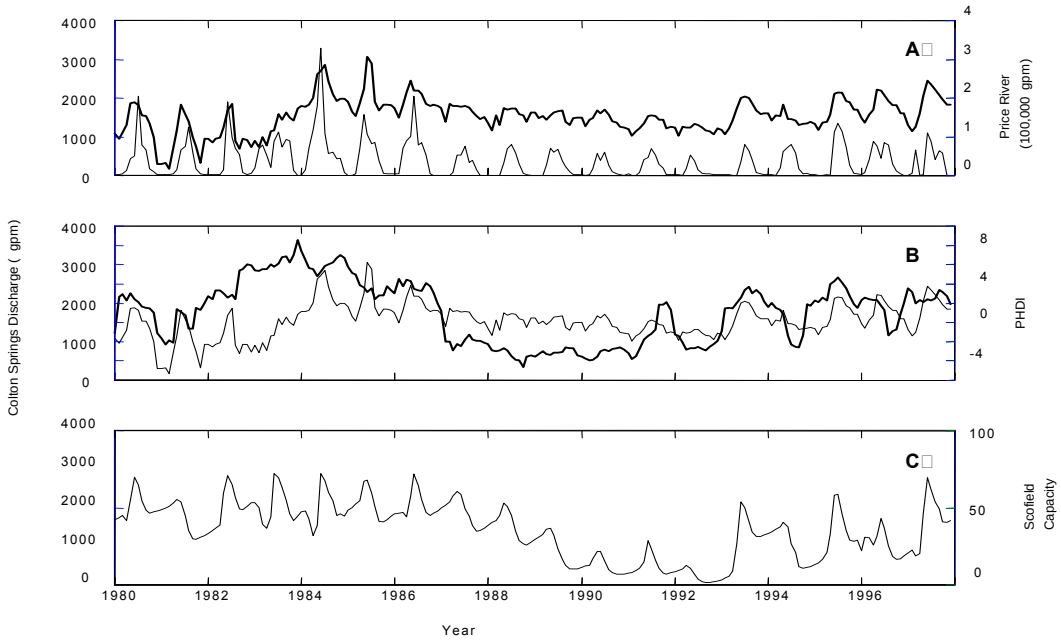



Figure 1.—Colton Springs discharge (—) and Price River discharge (A: —), PHDI (B: —), and SRC (C: —), near Price, Utah.

**Methodology: Physical System**

*Structure and faulting.* —The local area is part of the north-to-northeast trending Beaver Creek Syncline. Rocks dip towards and down the plunge of the syncline, but are affected commonly by faulting. The Forge Mountain Fault is the largest fault in the area, and Price River follows the fault over part of its extent. Based on field reconnaissance, surface outcroppings showed well-developed fracturing, although systematic distributions of fracturing were not noted. It is thought that fractures are probably related to faulting and the syncline. The river flows between the two sets of springs forming Colton Springs, and the Forge Mountain Fault coincides with the river along this segment. Several faults of various orientations are located between the springs and the Utah Power and Light Company (UP&L) wells. For more detailed discussions of the geology of the area, see Henderson (1964), Walton (1959), Moussa (1965), and Doelling (1972).

*Colton Springs*.—Colton Springs is made up of two sets of springs, separated by about 1,500 feet. One set is located west of the Price River, and the other set is located east of the river. Springs located west of the river are somewhat higher in elevation and further from the river than those east of the river. It is not known whether both sets of springs issue from the same geologic formation. The springs on the east originate from the Flagstaff Limestone while those on the west come from the alluvium adjacent to the river near the junction of the Flagstaff and Colton Formations. Field observations showed that in the developed springs water comes up directly from bedrock rather than percolating through alluvium as would be the case in an undisturbed setting.

Colton Springs is the main source of culinary water for the city of Price, Utah. Their flow averaged 1,541 gallons per minute (gpm) over an 18-year period from 1980 to 1997. Flows from the springs are not restricted in any way and free-flow by gravity-fed pipeline from the several springs down the canyon to the water-treatment plant. The water right for the spring was established in 1919, and records were available from 1938 to the present. Water records from 1980 through 1997 were used in this study.

*UP&L wells*.—UP&L drilled two wells near Colton Springs, and proof-of-appropriation records show that water was first conveyed in June 1954 for both wells. Well logs for UP&L well Nos. 1 and 2 show the Flagstaff Limestone, North Horn Formation, and Price River Sandstones, although the perforated zone at well No. 1 is unknown. Well No. 2 has its perforated zone immediately above, and just into, the Price River Sandstone.

During dry periods, discharge from the springs may not be sufficient to supply the water demands of Price, which augments their flows with water from the Price River (downstream of the springs) or from UP&L well No. 1. The SF's are reduced when the well is pumped, although the flow reduction is thought to range from 1 to 9 percent of the springs' total flow. For these studies, SF's were adjusted to account for reduced flow in times when well No. 1 was pumped.

*Scofield Reservoir*.—Scofield Reservoir is located about 7 air miles southwest of Colton Springs and is situated on the faulted and fractured Castlegate Sandstone and Blackhawk Formations. The reservoir is of interest because it is about 422 feet above the springs' elevation and could provide ground water to the springs. Rocks dip from the reservoir toward the springs; however, the area is faulted and fractured. It has been reported locally that, when the reservoir is at low capacity, the springs flow less. The reservoir is controlled by demand for water downstream; thus, the correlation could be a natural coincidence of less water in the reservoir and less water available for the spring, or it could be a cause-and-effect scenario. The empirical methods proposed herein are applicable in either case.

If the reservoir is supplying water to the springs, given the distance between them, it would be expected that there would be considerable time lag between reservoir-capacity changes and SF changes. The strike and dip of the formations and surface topography suggest the possibility of recharge. The Castlegate Sandstone that lies under the reservoir is below the Price River Sandstone at the bottom of UP&L well No. 2.

*Price River*.—The Price River originates from the outlet of Scofield Reservoir and flows east and then northeast for about 9.5 miles to join the White River, before turning east again and flowing down the Price River Canyon into Price City. Colton Springs is located about 1,500 feet upstream from the junction of the Price and White Rivers. The Price River is of interest because the river flows along the Forge Mountain Fault and between the two sets of springs that together form Colton Springs. It is possible that changes in river flows may affect SF's through the alluvium in the river channel. Water chemistry of the Price River and Colton Springs could be studied to evaluate this situation.

*PHDI*.—The PHDI is a series of numbers generated each month by the National Climatic Data Center in Ashville, North Carolina. Positive numbers indicate wet times, and negative numbers indicate dry times. There are several types of drought indices, and the PHDI was selected because it is a hydrological rather than meteorological index; is based on moisture inflow (precipitation), outflow, and storage; and does not take into account the long-term trend (Karl and Knight, 1985). The PHDI responds slowly to changes in climate regimes, because it is closely tied to water storage. For a complete discussion of drought indices in general and the PHDI in particular, see Palmer (1965), Alley (1984), and the National Climatic Data Center website at http://www.ncdc.noaa.gov.

**Methodology: Statistical Model**

Preliminary investigations and graphing showed that Colton Springs' flows are cyclical may be correlated with PHDI, CSR, and PRF. The time-series technique known as spectral analysis was used to investigate the cyclical nature of the SF's, PRF, and CSR. Multiple-regression models were used to estimate SF from CSR, PRF and PHDI. Important cyclic patterns identified through spectral analysis were used to develop a model, a Fourier or trigonometric expansion (Burden et al., 1981), of SF as a function of periodic trigonometric functions. This approach was included in anticipation of situations where record of related physical variables may not be available to model fluctuations not accounted for by the PHDI.

*Spectral Analysis*.—Figure 1 shows that each of the measured variables, SF, CSR, PRF, and PHDI, exhibit periodic fluctuations of varying frequencies. For example, figure 1 shows that CSR clearly exhibits annual cycles probably associated with seasonality in the demand for water for irrigation. Although less obvious, the other variables also appear to be composed of one or more cyclical components. Spectral analysis, a standard time-series approach, was used to identify important cyclic patterns in each time series. Once identified, these cyclical patterns were modeled using linear combinations of sine and cosine functions. To determine the "best" combinations of sine and cosine functions, the power spectrum was used to estimate which frequencies are important components of a particular time series. Importance of a particular periodic component was judged based on the percentage of total variation explained by each component. The power spectrum provides a means to estimate the percentage of variation explained by trigonometric functions at individual frequencies. This is analogous to using the $R^2$ statistic to judge the strength of association between dependent and independent variables in a regression analysis.

*Mathematical details*.—Define $Y_n$ to be a sequence of equally spaced numbers indexed to time such that $Y_n = f(n \times \Delta t)$ for $n=0,1,2,\ldots N-1$. $Y_n$ is typically referred to as a time series and may represent measurements of water quality or quantity, and $\Delta t$ represents the sampling increment. For example, in mining applications, ground-water systems are often monitored monthly or quarterly. Colton Springs was monitored monthly. Let the sequences of real numbers $U_m$ and $V_m$ be

$$U_m = \Sigma Y_n \cos(2\pi nm / N)$$
$$V_m = \Sigma Y_n \sin(2\pi nm / N).$$

The power spectrum is defined as

$$S_m = \{U^2_m + V^2_m\}/N,$$

for m= 0, 1, 2, …., N-1. The power spectrum represents the magnitude of the variance (square of the amplitude) of cycles at each frequency, $f = m \times \Delta f$, where $\Delta f = 1/(N \times \Delta t)$. For example, $S_m$ would be large for $m \times \Delta f = 1/12$ for a time series of monthly readings with strong annual cycles. The sum of all $S_m$ is the total variance of the time series, so the power spectrum provides a decomposition of the total variance into components described by periodic cycles. When no periodic cycles exist, the power spectrum is theoretically constant except for sampling variation. By investigating plots of the power spectrum, important periodic cycles can be inferred. For this application, the power spectrum was inspected visually, and regression analysis was used to test the statistical significance of identified periodic components. The spectra can be tested directly, although specialized statistical software is typically required to calculate significance levels. Testing the significance of each sine and cosine component in a regression analysis is equivalent, but can be conducted with any standard regression-software package. The spectrum is used in this context to guide the search for important periodic functions.

*Multiple-regression models*.—Two multiple-regression models were developed for prediction of SF. The first model included the dependent variable SF as a linear function of the independent variables CSR, PRF, PHDI, and an indicator variable coded as 0 for the first 80 months and 1 for the second 80 months. This indicator variable, $\Phi(80)$, was used to model a change in PHDI at approximately the 80-month time step. This is approximately the point in time at which the climatic regime changed from predominantly wet years to a series of predominantly drier years. The model is given by the following formula.

MODEL I:

$$\begin{aligned} SF = {} & b_0 + b_1\,\Phi(80) + b_2\,(PHDI) + b_3\,(PRF) + b_4\,(CSR) \\ & + \Phi(80)\times\{b_5\,(PHDI) + b_6\,(PRF) + b_7\,(CSR)\} \\ & + b_8 \cos(2\pi\, t / 76) + b_9 \sin(2\pi\, t / 76) \\ & + \Phi(80)\times\{b_{10} \cos(2\pi\, t / 76) + b_{11} \sin(2\pi\, t / 76)\} \end{aligned}$$

The regression coefficients were estimated by minimizing the sum of squared errors (least squares). In addition to the physical variables, low-frequency (76-month) periodic components were included to improve the model fit.

The second model was for prediction of SF as a linear function of sine and cosine functions identified in the spectral analysis as well as the indicator variable, $\Phi(80)$, described above. The general formula for a trigonometric expansion is given as model II.

MODEL II:

$$\begin{aligned} SF = a_0 &+ a_1\cos(2\pi\, t / N) + b_1\sin(2\pi\, t / N) \\ &+ a_2\cos(4\pi\, t / N) + b_2\sin(4\pi\, t / N) \\ &\ldots\ldots \\ &+ a_{N-1}\cos((N-1)2\pi\, t / N) + b_{N-1}\sin((N-1)2\pi\, t / N) \end{aligned}$$

Inclusion of the indicator variable was to incorporate differences in the periodic cycles during the first several wet years versus the later series of predominantly dry years.

To test the applicability of the method at other sites, a partial set of flow data from an additional spring was obtained from Utah DOGM, and the model II was applied with an additional term for the PHDI. Because the data are partial, and because this investigation does not represent a regulatory decision or interpretation, the identity of the spring is not reported. For purposes of this report, the spring is referred to as No-Name Spring.

**Results**

*Spectral analysis for Colton Springs*.—Each of the physical variables exhibited apparently cyclic patterns and visually appeared to loosely track the Colton Springs, flows. To gain an understanding of each time series, the power spectra were calculated and plotted in figure 2. The vertical scale of each plot is in units of variance, i.e., the square of measurement units. The primary features present in the Colton Springs' spectrum (fig. 2, panel A), are peaks associated with 12-month, 76-month, 24-month, and 6-month cycles. The 12- and 76-month cycles account for the majority of the total variation. This suggests that regression models for prediction of Colton Springs should contain similar cycles.

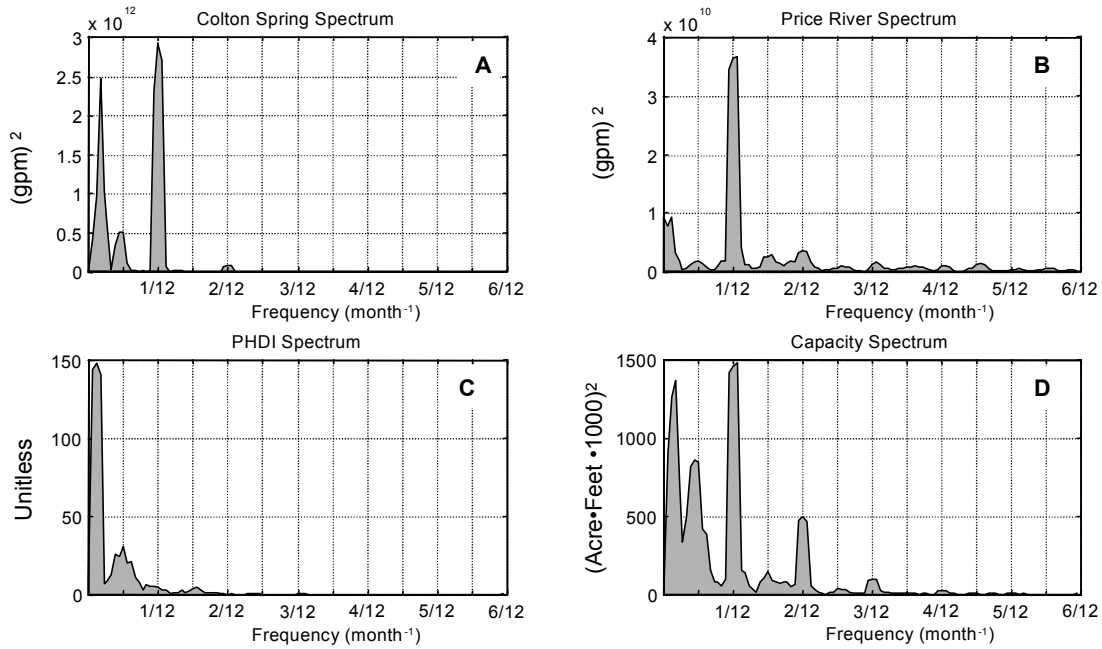



Figure 2.—Estimated power spectra for Colton Springs, flow (panel A), PRF (panel B), PHDI (panel C), and CSR (panel D).

The PRF power spectrum (fig. 2, panel B) shows that the Price River is composed primarily of a single 12-month cycle, suggesting that the 12-month cycle in Colton Springs' flow may be predictable from that in the PRF. However, predictions of 76- and 24-month cycles would require additional information not contained in the PRF time series.

Panel C, figure 2, shows that the PHDI is composed primarily of a low-frequency (approximately 15-year) cycle as well as a 24-month cycle. This suggests that the PHDI may be a useful predictor for the 24-month cycles present in Colton Springs' flow.

The CSR is composed of a combination of several periodic components, including approximately 72-, 24-, 12-, and 6-month cycles (fig. 2, panel D).

In summary, the predominant features in the Colton Springs' flow should be predictable from the other physical variables, because those variables in aggregate exhibit most of the cyclic behavior present in the springs. One exception would be the 76-month cycle in the SF. The CSR contains a 72-month cycle, which may serve as an adequate proxy for the 76-month cycle in the SF.

*Physical variable model (model I) for Colton Springs*.—A multiple-regression model was developed for Colton Springs' flow as a function of the physical variables, CSR, PHDI, and PRF (fig. 3). Colton Springs' flow was linearly correlated with each of the physical variables ($p < 0.05$; adjusted $R^2$=0.57). Since none of the physical variables exhibited the

76-month cycle present in the SF, sine and cosine terms with 76-month periods were added to the multiple regression, improving the adjusted $R^2$ to 68 percent.

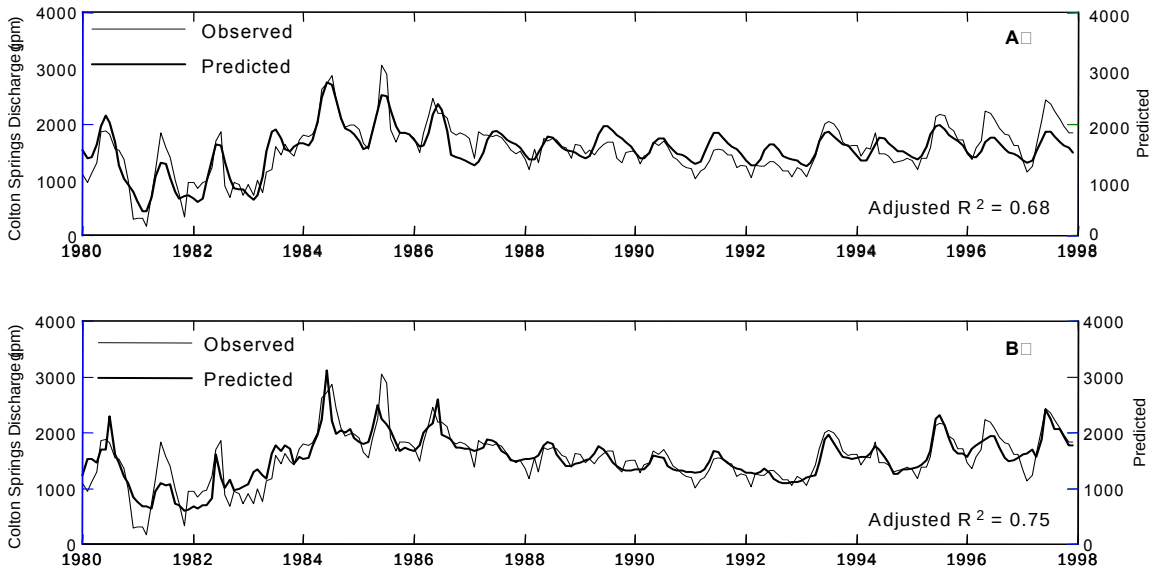



Figure 3.—Observed and predicted flow from Colton Springs using the trigonometric-series expansion model (panel A) and the multiple-regression model (panel B).

*Trigonometric-series model (model II) for Colton Springs*.—A trigonometric series was fit to the Colton Springs' data with 76-, 24-, 12-, and 6-month cyclical components (fig. 3). These cycles were selected to coincide with the peaks of the Colton Springs' power spectrum (fig. 2; panel A). Each cycle was found to be statistically significant at the 5-percent level of significance, with an adjusted $R^2$ of 75 percent.

*Spectral analysis for No-Name Spring*.—A spectral analysis was conducted for No-Name Spring, and significant peaks were observed at periods of 76, 12, and 6 months, with the strongest peak at 12 months (fig. 4). The presence of these cyclic components suggests that the PHDI, in combination with trigonometric functions with 76-, 12-, and 6-month cycles, could be used to develop a predictive model of No-Name Spring.

*Trigonometric-series model with PHDI for No-Name Spring*.—A trigonometric series with 76- and 12-month cycles and the PHDI was fit to the No-Name SF (fig. 5). In anticipation of the effects of a change in climate regime similar to that noted at Colton Springs, a 0/1 indicator variable was also included in the model, allowing the relationship between SF and the predictors to change at the 80-month time step. The PHDI and each periodic cycle was correlated with the No-Name SF at the 5-percent level of significance with a model adjusted $R^2$ of 84 percent.

Figure 4.—Power spectrum for No-Name Spring.

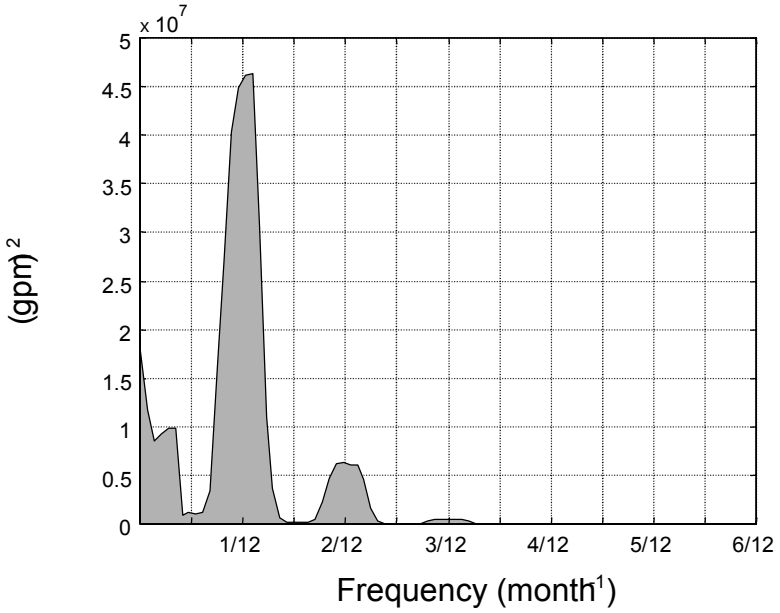
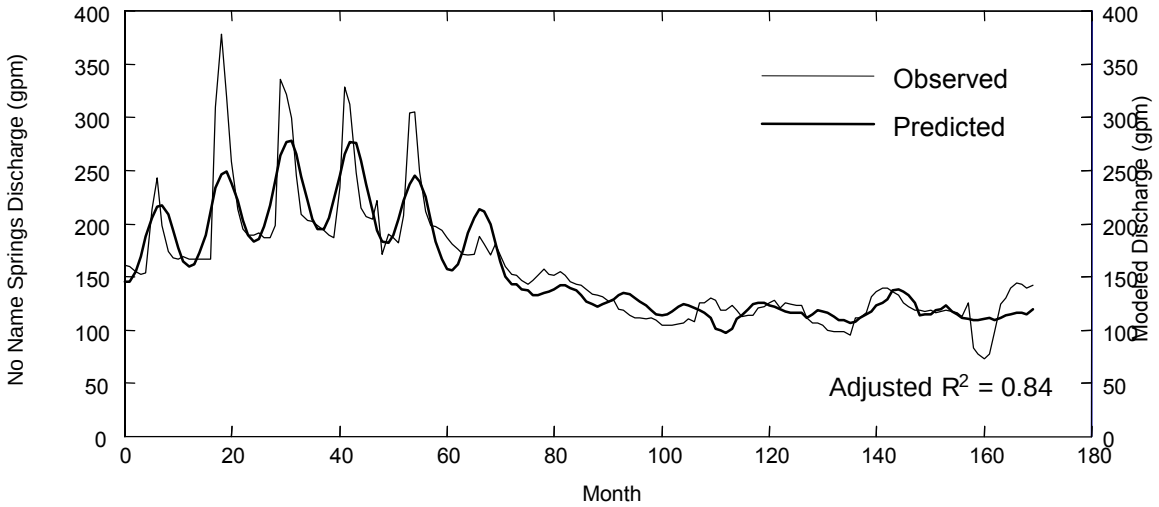



Figure 5.—Observed and predicted flow from No-Name Spring using the Fourier expansion model.




## Discussion

This investigation was conducted to evaluate the potential to use the PHDI and other physical factors to model spring discharges at Colton Springs. It was found that SF's were sufficiently

well correlated with physical factors that empirical models could be used to predict SF's. If SF's were to change in the future at Colton Springs, these models could be used to evaluate whether a change in physical factors could explain the change or if there might be some additional impact on the flows. In the context of regulatory actions, this approach provides a mechanism to objectively evaluate whether changes in spring discharges might be due to mining impacts or to other natural causes.

The same approach was applied at No-Name Spring, where only the SF and PHDI data were available. A model including the PHDI and some trigonometric functions was found to be strongly associated with SF's. It is interesting to note that the model fit was better at No-Name Spring than at Colton Springs, where the model was first developed. A substantial change in flow was observed at close to the 80-month time step, similar to when a change was noted at Colton Springs. The fact that both springs exhibited a significant reduction in flow at nearly the same point in time would indicate that the reduction in flow may be due to a change in climatic regime. If mining impacts are suspected at the same time, simple analysis of flow would not be sufficient to differentiate between mining impacts and fluctuation in climate or other factors. To avoid naïve interpretation of SF records, changes in flow should be evaluated relative to changes in other factors using the multiple-regression and/or trigonometric-expansion models.

In the regulatory setting, pumping records from the mines should be included as independent variables in the models to determine if the change in flow can be predicted from the pumping rate. For example, if a reduction in mine-pumping rate coincided with a reduction in SF, one could conclude that there may simply be less water available in the aquifer for both the spring and the mine. However, if the mine-pumping rates increased at the time when SF's decreased, one might infer a mining impact. Analysis of these factors in a multiple-regression framework will facilitate accurate evaluation of mine impacts after adjustment for other factors such as climate.

It is important to note that these methods do not require that causative relationships be identified. What is important is that factors not likely to be impacted by mining, such as the drought index and the capacity of a reservoir, can be identified as being associated with SF's. These factors, while not causative, are thought to be driven by the same processes that drive SF's. Identification of this association allows one to use the predictive factors in the same way that an unimpacted spring would be used as a reference against which to compare. The methods are also general in their application. They may be applicable to flow and quality in springs and streams thought to be impacted by human causes.

**Acknowledgements**

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# P L A N N I N G  F O R
# R E C L A M A T I O N

*Area C,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

**"Assessing Sedimentation and Landform Stability in Reclaimed Areas Using Baseline Sediment Data Collected in Receiving Streams"**
**"Probable Hydrologic Consequences"**
**"Wyoming Cumulative Hydrologic Impact Assessment and Coal-Bed Methane"**
**"The Hydrology and Hydrologic Effects of Mining in the Decker, Montana, Area, 1972-98"**
**"OSM's CHIA: Black Mesa/Kayenta Mine"**
**"Recharge from Clinker in the Powder River Basin"**
**"Use of a Localized Ground-Water Model to Predict Relative Impacts of the Life-of-Mine Plan for Rosebud Area D, Near Colstrip, Montana"**

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# R E C L A M A T I O N
# D E S I G N: P A R T I

*Impoundment, Area E,*
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*August 2000.*

**"Automatic Monitoring Systems for Reclamation Design"**
**"Seeps Below Sedimentation Ponds: Assessment of the Significance of Their Impacts to the Hydrologic Balance"**
**"Reclaiming Montana Ephemeral Channels and Associated Side Slopes in Lands Disturbed by Surface Mining"**
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| FIELD TRIP TO ABSALOKA | FIELD TRIP TO ROSEBUD | OF GENERAL INTEREST |

# RECLAIMING MONTANA EPHEMERAL CHANNELS AND ASSOCIATED SIDESLOPES IN LANDS DISTURBED BY SURFACE MINING

**Herb Rolfes and Steve Regele**
**Montana Department of Environmental Quality**

## Introduction

Ephemeral channels are often the most commonly encountered and hydraulically important features to replace in reclaimed, arid landscapes. As Tarquin and Baeder (1983) note, "[t]he design and reconstruction of lower (first and second) order stream channels presents a unique problem since these channels comprise the majority of the total stream length on premining surfaces and usually occur on the steepest slopes (1983)." The importance of ephemeral channels is owing not only to their sheer number and their contribution to overall drainage density, but also to the role channel and sideslope features play in creating microsites for vegetation and wildlife.

Drainage channels are a very dynamic part of any landscape and have significant influences on ecosystems and hydrologic systems. These facts are important with respect to the reclamation of drainages in drastically disturbed lands. Drainages must be reconstructed to pass water into, through, and off the disturbed area. Reconstruction of drainages must be compatible with protection of the hydrologic balance, the reestablishment of essential ecological functions, and proposed postmining land-use goals.

Concave longitudinal stream profiles are necessary to establish dynamic equilibrium, thereby reducing erosion, and are directly applicable to the design of a stable post-mining topography (Bishop, 1980). Watershed divides may need to be adjusted, but the approved postmine topography should closely approximate premining topography (Montana Department of Environmental Quality, 1999). Usually, this is accomplished through a comparison of premine and proposed postmine contour maps, noting the locations, lengths, and orientations of each channel and its respective watershed areas. It is widely accepted, and important to the postmine hydrologic and ecologic functions, that postmining drainage densities be at least equal to premining densities (Bauer, 1980; Stiller et al., 1980; Bishop, 1980; and Gregory et al., 1987) and that channel sinuosities comparable to premining sinuosities be restored (Shields et al., 1995a; Welford,1993; and Bishop, 1980).

Because all of these factors must be considered in the evaluation of ephemeral channel designs, input from multiple and overlapping natural-resource disciplines is required. This can make the design of drainage channels in land disturbed by surface mining challenging and complex.

## Requirements

Montana coal rules and regulations (Administrative Rules of Montana [ARM], Title17, Chapter 24, Subchapter 6) require that the "[c]onstruction of reclaimed drainages must emphasize channel and floodplain dimensions that approximate the pre-mining configuration and that will blend with the undisturbed drainage system above and below the area to be reclaimed." ARM 17.24.634 further states that:

> "the channel and floodplain must be [designed and] constructed to * * * establish or restore the drainage channel [to its natural habitat or characteristic pattern with a geomorphically acceptable gradient as determined by the Montana Department of Environmental Quality (DEQ), to] * * * allow the drainage channel to remain in dynamic equilibrium with the drainage basin system without the use of artificial structural controls unless approved by the department, [to] * * * improve upon unstable conditions which existed in the drainage system prior to mining where practicable in consultation with and upon approval by the department, [and to] * * * restore, enhance where practicable, or maintain natural riparian vegetation in order to comply with" revegetation and postmining land-use requirements and standards.

## Evaluation and Goals

Individual operators will need to evaluate premining channel and sideslope features taking into consideration that, as Pinet (1997) notes, channels are not "things in space" but rather "processes through time." Once a channel is evaluated, and criteria such as the size of its postmine drainage basin and revegetation and habitat restoration plans are known, its appropriate postmining size and shape can be formulated, as can complementing sideslope features. A detailed examination of characteristics of each premining drainage channel to be disturbed by a given mine may not be necessary with the derivation and approval of generic designs. As Goodwin (1999) notes, the classification of channels based on relative and absolute size factors may prove especially beneficial for reclamation purposes. Montana DEQ has developed a guideline to facilitate determining which ephemeral drainage channels need designs. The guideline indicates that, for most basins, first-order (order 1) channels will not need a detailed design, but second- (order 2) and greater order drainage channels most likely will. The level of detail required must remain case- or category-specific (Montana Department of Environmental Quality, 2000).

Given the nature of strip mining, the derivation and application of some generic channel-design criteria may be acceptable. Preceding actual mining, vegetation, soil, and overburden are removed from most, if not all, of a drainage basin. Only after the coal is removed will a mined area within a basin be backfilled, regraded, topsoiled, and seeded. Because the impact that strip mining has on ephemeral drainage basins is drastic, and because the reclaimed surface configuration of a given basin will only be an approximation of what once existed, detailed premining channel studies and analyses are of limited value in arriving at designs for postmining channels. Of critical importance in the postmine landscape is the replacement of channel and sideslope features that compliment such features in their undisturbed upgradient and downgradient states and that meet approved postmining land uses.

A primary goal of reclaiming drainage channels is to provide suitable habitats for aquatic and riparian vegetation, which are often found as linear features along drainage channels. Such habitat features are often associated with both irregular drainage sideslope topography and irregularities in the channels themselves. The creation of drainage-area microsites promotes vegetation and habitat diversity, the importance of which is often overlooked during both channel-design processes and the physical work of reclamation. Although premine diversity is often noted in baseline data, described in permit application narratives, and labeled on maps as "drainage bottom types," "riparian types," and "herbaceous bottom," (with additional subtypes described as "overflow," "marsh," "wetland," and "subirrigated"), appropriate consideration of the need to recreate such niches is often overlooked. It is important that ephemeral drainage-channel designs provide for microhabitat features for vegetation, and that these features be replaced in the postmining landscape.

In conjunction with other Montana coal-mine reclamation requirements, revegetation plans are directed towards reestablishing diverse, effective, and permanent vegetation of the same seasonal variety and utility as vegetation native to the land to be disturbed. Properly constructed channels and sideslopes help fulfill this goal by creating a landscape that promotes vegetation community types such as grassland, conifer woodland, wooded drainage, and riparian/aquatic. The problem with rigorously engineered channels is that, whereas they may be functional in terms of transporting water, they do not contain the ecological properties of native channels (Anderson, 1994). Designs are complicated by the reality of inherent channel instability, large fluctuations in discharge, and a complex ecology (Shields et al., 1995a). Yet if channels are appropriately designed and revegetated with riparian species, artificial erosion and sediment-control measures should not be necessary (Stiller et al., 1980). Therefore, efforts made towards natural channel restoration can produce immediate benefits for mine operators.

**Common Problems**

Reconstructed channels and sideslopes may not always closely resemble premine dimensions, and designs generally cannot take into account all hydraulic influences on these reclaimed features. Following mining, what was once an undisturbed watershed has been backfilled with unconsolidated material, usually to a depth of 100 feet or more, spoil graded, topsoiled, seeded, and perhaps planted with shrubs and trees. After the upstream drainage channel is reconstructed, or perhaps reconnected with undisturbed portions of the basin, runoff is once again allowed to flow across the landscape. Runoff at this time, and until a stabilizing vegetative cover has been established, initiates the fluvial processes of erosion and deposition. It often takes e or more years for vegetative cover to become established on reclaimed sites, and, according to Martin (Martin et al., 1988), it may take 6 years for infiltration and runoff to return to normal.

Constructed drainage channels are usually overly wide and simplified in comparison to what once existed, because channels are often located along former haulroads (a placement attributable, at least in part, to perceived or real equipment constraints). All too frequently, channels are reclaimed as straight, broad swales, even though they may be replacement features for coulees or small, incised channels that frequently exhibit considerable sinuosity and despite the fact that most naturally occurring streams, viewed in cross-section, are not parabolic or semicircular in shape (most natural stream channels are generally trapezoidal in straight reaches

and asymmetric at curves and bends [Leopold, 1994]). The construction of broad swales results in the creation of ecologically limited sites compared to the diversity found in sinuous, irregular shaped channels (Shields et al., 1995b). Although broad swales may achieve a suitable level of stability once vegetation becomes established in them, their initial lack of vegetative cover and absence of meanders often results in their severe erosion, the formation of braided channels, and the need for significant maintenance during the first few years. For example, channels viewed on a small-scale map may show only macro-meanders; however, these same channels viewed on the ground may evince meso- and micro-meanders as well. All too often in the past, meanders of any scale simply were not replaced. It is the experience in Montana that meso-meanders need to be replaced to prevent erosional problems, whereas, in a relatively short period, micro-meanders will form by themselves. Along with the problem of erosion is the limited ability of broad swales (as compared to coulees and small, incised channels) to achieve appropriate and diverse revegetation and wildlife habitat. The loss of microhabitat results in the loss of plant and animal diversity and in limited ecologic function.

**Suggested Practices**

Material can be placed in the overly wide channels to reduce channel width, thereby obtaining the appropriate width to depth ratio in reclaimed channels. Features such as point bars or meander points act as energy dissipaters and help to establish a meandering channel pattern. Narrowing drainage-channel width does not necessarily infringe upon the required discharge capacity of a given channel; rather, it creates the proper channel width for a limited flow length. As McIntosh (1989) notes, "[m]inor flows which contacted a bar eventually made an adjustment from relatively straight to sinuous as low flow water was guided around the tip of each bar. Major floods coursed over the bars. Thus the bars, rather than bed slope inconsistencies, dictated low-flow channel shape, and a return to pre-mine sinuosity resulted." Deflecting flows along a stream course delimits channel downcutting, thereby allowing lateral erosional processes to enhance sinuosity. The end point of the lateral process is a meandering channel pattern (Hupp and Simon, 1991). When drainage channels and floodplains are reclaimed to an appropriate width and configuration during rough regrading, additional soil or overburden material, as well as engineered structures, may not need to be placed in the channel to form meander points. As Leopold and Wolman (1960) indicate, "[t]he most characteristic features of all stream channels, regardless of size, are the absence of long straight reaches and the presence of frequent sinuous reversals of curvature."

Without meander points, or some other appropriate means of delimiting and deflecting stream energy, reconstructed channels tend to downcut, or braid, extensively, acquiring in the process the potential to become excessively unstable and to erode and gully. While other acceptable methods of delimiting and deflecting stream energy and creating suitable reclaimed channel sinuosity are available, establishing meander points in reclaimed drainage channels has proven to be beneficial. Erosional concerns and loss of habitat dictate that both meso- and macro-meanders be constructed. With appropriate meander points in place, events greater than bankfull discharge are forced to flow over these low features, dissipating energy. Meanders should be angled so that the channel's downstream face remains perpendicular to the desired direction of flow. This will direct the flow of water towards the center of the channel, away from the embankment, thereby further reducing the potential for erosion (Reichmuth, 1991). The spacing

between meander points can be based on the relationship between meander length and bank-full channel width (Leopold and Wolman, 1960), the relationship between meander length and bank-full discharge (American Society of Civil Engineers, 1997), or the use of pertinent aerial photographs. Bank-full discharge is often approximated by the 2-year annual peak flow event (Lowham and Smith, 1993).

The spacing of meander points in reclaimed drainages should provide a semblance of a naturally occurring meander pattern. It is not expected that this reconstructed pattern will be a Aperfect fit@ within the hydraulically influenced landscape, or that localized erosion and aggradation will not continue to occur, especially during the first few years after reclamation. However, when properly placed, meander points can direct channel formation to an appropriate and acceptable level of relative stability and functionality in a reasonable timeframe. Without meander points, reclaimed channels often degrade into discontinuous and parallel gullies, with associated and unacceptable levels of erosion, possibly requiring years of maintenance work along with the accompanying delay in achieving postmining land-use goals and bond release.

The use of meander points is a somewhat limited approach to proper drainage-channel reclamation and does not compensate for improperly constructed flood-prone areas or sideslope features. If reconstructed channels, flood-prone areas, sideslopes and side tributaries were to more closely resemble their premining counterparts, the ability to achieve many reclamation goals and requirements would be further enhanced.

Meander points can provide a niche for planting trees and shrubs (e.g., stilling pools form at the junction of placed material and an embankment, resulting in the deposition of sediment suitable for planting); some enhanced or variable moisture gradients, and; in general, microsites that allow for the establishment and survival of diverse vegetation. When trees, shrubs, forbs, and grasses that may require such niches become established, they contribute towards a sustainable level of channel stability and can enhance the ability of reclaimed landscapes to achieve overall revegetation and reclamation goals and standards.

The creation of features such as snow catchments, small depressions, and playas, all of which collect and retain moisture, as well as cutbanks, rock-armored embankments, and deeply incised channels, all of which are areas wherein wildlife and livestock can take shelter from sun, wind, and observation, also needs to be considered during channel reconstruction. As Brookes (1995) notes, “improvement in ecological integrity will follow re-creation of physical characteristics.”

There are a number of ways to estimate what the width, depth, and meander patterns of a reclaimed channel should be. Estimates can be based on actual measurements taken in channels prior to their disturbance and on regional regression equations, used to calculate channel dimensions. However, because reclamation occurs after strip mining, the proposed postmine topography of a given minesite should be considered in its channel design. There may be significant differences between the premine and postmine landscape for a particular watershed, especially for the smaller basins. For such watersheds there may be relatively large gains or losses in drainage area, as well as an overall change in the drainage-channel slope and the length of flow from the drainage divide to the watershed outlet. Therefore, methods for designing channels may need to incorporate computer modeling to predict what the bank-full flow will be

in the altered watershed, based on the reclaimed postmining topography.

The use of bank-full flow data for designing channel dimensions and form is preferable to most other methods, as this value is the end product of numerous factors (drainage area, slope, flow length, soil type, vegetation, etc.). Generic designs could be created and categorized by various ranges of bankfull flow. Using predicted bank-full flow to design channels has to date resulted in reconstructed drainage channels that quickly achieved overall stability and functional use, at the same time allowing ongoing channel shaping geomorphic processes to proceed. Final channel shape will be influenced by initiation of erosional processes preceding the development of a stable and permanent vegetative cover.

## Conclusion

If relevant hydrological and ecological data are evaluated sufficiently and if appropriate science and engineering is applied to channel design, the likelihood of returning reclaimed drainages to an acceptable and appropriate level of stability and functionality is enhanced. It is very important that reclaimed channels and surrounding landscapes are properly regraded, and in particular that drainages have a concave longitudinal profile with appropriately restored macro- and meso-channel sinuosity. If regrading has left knickpoints, if an appropriate meandering pattern has not been incorporated into the channel design, if the vegetation does not "take," or if a large storm event occurs during the early stages of revegetation, fluvial processes will likely cause severe erosion, requiring significant and repeated maintenance work. As Stiller et al. (1980) note, successful reclamation depends both on planning and on the integration of the reclaimed surface and drainage network into the surrounding landscape.

Derivation and application of some generic or categorical channel-design criteria may be relevant and useful in reclamation. Designs could be derived that would adequately represent the majority of drainage channels that are to be reclaimed. However, there will always be instances when such generic designs are not adequate for achieving prescribed goals and functions. For example, case- and site-specific design criteria will likely be necessary when drainages are to be reconstructed in steep landscapes or when special hydrological or ecological requirements must be met. In other cases—for example, for small watersheds or for the upper reaches of a watershed, usually a first-order (order 1) channel—designs may not be needed at all. In such instances, it may be appropriate to construct swales or to allow for short reaches of steep-sided and comparatively erosive channels (Montana Department of Environmental Quality, 2000).

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## OSM'S GUIDANCE FOR SMALL DEPRESSIONS ON INDIAN LANDS MINES

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The Office of Surface Mining (OSM) is the regulatory authority for coal-mining operations on Indian lands in the southwestern United States. Backfilling and grading operations at most mines on these lands offer opportunities to create or retain small depressions in backfilled areas. OSM regulations at 30 CFR 816.102(h) allow the construction of small depressions. Over the years, many questions–such as, for example, what types of small depressions can be authorized by the regulatory authority to remain–have arisen regarding the definition of small depressions. OSM believes that small depressions can serve important purposes for water retention, vegetation enhancement, and the creation of wildlife habitat. Currently, OSM is proposing guidance for the review and authorization of small depressions to answer many of the questions for Indian lands mines.

Appendix F to these proceedings contains information, along with frequently asked questions, related to this proposed guidance. Click *here* to access this appendix. To access the information and frequently asked questions online, go to http://www.wrcc.osmre.gov/Guidance/SmllDepGuidnc.htm.

# R E C L A M A T I O N
# D E S I G N: P A R T I I

*Reclaimed drainage, Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Proposed Effluent-Limitation Guidelines for the Coal-Mining Point-Source Category"

## "Using RUSLE, Version 1.06, on Minelands"

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# USING RUSLE 1.06 TO ESTIMATE SOIL EROSION BY WATER ON MINELANDS

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## Introduction

As infiltration rates decrease and runoff rates increase, the possibility of runoff water picking up and transporting soil particle increases. Thus, water erosion may be simply defined as the movement of soil particles in the field, by surface runoff, from one point to another point (removal from the field itself is not a requirement). Many factors—including, among numerous others, rainfall rate and duration, soil infiltration and conductivity rates, soil texture, organic matter, slope gradient and length, and cover and tillage—influence erosion.

If the flow of runoff is concentrated, its removal of soil can result in the presence of rills and gullies that can affect farming operations. In addition, by removing sediment from fields, water erosion can cause drainageways to become less efficient or even plugged, resulting in the loss of nutrients and pesticides applied to these fields. Such losses, in turn, can precipitate high maintenance costs to clean the plugged drainageways, productivity losses, and eutrophication of the receiving lakes where the runoff water ends up.

Scientific planning for soil conservation and water management requires knowledge of the factors that affect infiltration and runoff and that cause the loss of soil and runoff water. Accordingly, establishing a methodology for improving our knowledge of infiltration and runoff is quite important. By studying the factors affecting infiltration and runoff, we can come to conclusions concerning their possible effects on soil erosion.

## Historical Estimates of Soil Erosion by Water

Estimation of soil erosion by water is, by most accounts, an inexact science. Most attempts to model soil erosion have been made on the basis either of the surface-flow characteristics of runoff or of rainfall characteristics in conjunction with factors describing soil, topography, and vegetative cover. These models must consider not only the detachment of soil particles but also the transport of sediment. The detachment factor must take account of both the kinetic energy of the falling raindrops and the shear capacity of the runoff. The transport factor must include an analysis of the suspended sediment load as well as bedload. This paper will not describe the particulars of interactions within these factors.

One of the first models for soil erosion was developed on plot studies by Musgrave (1947). The Musgrave equation related soil loss to rainfall energy and intensity, soil cover, slope gradient and length, conservation practices, and a measure of soil erodibility. However, this equation was somewhat constrained by geographic considerations.

Wischmeier and Smith (1965) improved upon Musgrave's equation using additional data from 48 locations in 26 States. They also proposed the use of nomographs for several of their model factors. Because the Wischmeier/Smith equation was not constrained, like Musgrave's, by geography, it became known as the Universal Soil Loss Equation (USLE) and is expressed as:

$$A = RKLSCP \qquad \text{Eq. 1}$$

where A is the computed gross soil loss per unit of area (tons/acre), R is the rainfall factor expressed as the product of the rainfall energy times the maximum 30-minute intensity for a given rainstorm, K is the soil erodibility factor, LS is a dimensionless length-slope factor accounting for differences in slope length and slope gradient, C is a dimensionless cover factor relating the effect of vegetation on reducing erosion, and P is a dimensionless conservation practice factor compared to fallow. Haan and Barfield (1978) have written a very good, detailed accounting of this equation.

Extensive research on additional plots over time has led to many further improvements in the original USLE. These improvements were incorporated into an updated version of the equation published as Handbook No. 537 (Wischmeier and Smith, 1978). Improvements since 1978 have been made and incorporated into the model, but these are too numerous to detail here. In 1997, Renard et al. published the newest updated handbook (Agricultural Handbook No. 703 for the Revised Universal Soil Loss Equation [RUSLE]), which supersedes Agricultural Handbook No. 537.

Given the amount of disturbance involved with mining, it was not unexpected to find that the USLE, as well as early versions of RUSLE, did not always give reliable soil-loss estimations. Nor were users making a smooth transition to working with RUSLE, even for undisturbed soils. In 1997, a working group was created under the auspices of the U.S. Department of the Interior's Office of Surface Mining to develop a separate model of RUSLE just for disturbed lands. This effort led to the development of RUSLE, version 1.06, which is now the best currently available model for use on mined lands, construction sites, and reclaimed lands. While not perfect (because, as yet, no empirical model is perfect), this version of RUSLE is a marked improvement for estimating not only soil loss but also sediment-delivery ratios and sediment yields. The changes in the model from the undisturbed soils version of RUSLE were based directly upon research data from disturbed soils. The definitive manual for version 1.06 became available in 1998 (Toy and Foster, 1998).

**Advantages of Using RUSLE 1.06 for Minelands**

Toy et al. (1998, 1999) have described extensively the advantages of RUSLE 1.06 over both USLE and RUSLE 1.04. Among these advantages are:

I. Soil loss estimation (A)
  a. Acurracy has been somewhat improved on the basis of additional data
    i. $1<A<4$ t/ac/yr = ± 50 percent
    ii. $4<A<30$ t/ac/yr = ± 25 percent

iii. 30<A<50 t/ac/yr = ± 50 percent

b. Least accurate for A<1 or A>50 t/ac/yr

II. Rainfall/runoff erosivity factor (R)

a. Includes a greater number of city codes for the western United States
b. Computes greater erosivity for higher intensity storms
c. Decreases for surface ponding
d. Includes 15-day erosivity indexes to identify the most potentially erosive times
e. Most accurate where rainfall is greater than 20 in/yr

III. Soil erodibility factor (K)

a. Accounts for presence of rock fragments in the soil profile
b. Accounts for consolidation of the soil with time
c. Includes 15-day erodibility indexes to identify when the soil is most vulnerable to erosion
d. Adjusts K to account for climate differences among different locations
e. Accuracy has been improved on the basis of additional data
    i. Most accurate for medium-textured soils
    ii. Moderately accurate for fine-textured soils
    iii. Acceptable for coarse-textured soils

IV. Topography factor (LS)

a. Value reflects the differential effect of hillslope length on rill and interrill erosion rates by means of a rill-to-interrill ratio
b. Effect of hillslope gradient is based upon a much larger database
c. Can accomodate very short and steep slopes
d. Can define slope length in up to 10 segments to better describe convex, concave, linear, and/or complex slopes
e. Accuracy has been improved
    i. Most accurate for lengths 50 to 300 feet and gradients of 3 to 20 percent
    ii. Moderately accurate for lengths of 20 to 50 and 300 to 600 feet and gradients from 1 to 3 percent and 20 to 35 percent

V. Cover-management factor (C)

a. Accounts for soil-loss protection from rock fragments on the surface
b. Includes a time-variant or time-invariant option
c. Accomodates changes in support practices
d. Allows either the user to define the rill-to-interrill ratio for soil-cover effectiveness or the equation to define the ratio according to the soil texture, hillslope gradient, and cover
e. Very easily handles multi-year rotations
f. Computes 15-day intervals for determining when a surface is most vulnerable to erosion

VI. Support practice (P)

a. Uses a subfactor approach for:

i. Time invariant options for contouring and terracing
ii. Time variant options for contouring, permanent barrier strips, and terracing

b. Accomodates changes in support practices and their effectiveness with time
c. Uses percentage cover and roughness as descriptors of surface conditions
d. Incorporates a sediment-delivery ratio by using this factor to describe contouring and terracing, depending upon the size and density of particles in transport, estimated on the basis of soil-texture data

**Some Mineland Research Examples**

Soil loss generally increases as runoff increases and has been measured at higher rates for reclaimed versus undisturbed soils. Hofmann et al. (1983) found that removing cover by grazing significantly increased the soil-loss rates of reclaimed pastures as compared to undisturbed pastures. This research also indicated that live surface cover estimates were poor measures of how susceptible reclaimed or native pastures may be to runoff or erosion.

As reclaimed soils become wet and runoff increases, these soils become much more erodible. Toy (1983) found that the soil loss on a reclaimed site at one mine was four times greater than that on a natural site under wet conditions. However, Schroeder (1987, 1989) found that this trend was not apparent on reclaimed grasslands and spoils, where the first rainfall on newly established dry surfaces resulted in greater soil-loss rates than on wet surfaces. Schroeder attributed this not only to a longer initial rainfall application but also to the amount of loose soil materials on the (dry) surface at the start of rainfall. Subsequent rainfalls had to disperse the soil before it could be eroded, because all easily transported soils/spoil particles had all ready been eroded. This meant less soil loss (but greater runoff rates), because of factors such as cover.

Increasing slope gradient generally increases the amount of soil loss. Schroeder (1987, 1989) showed that, on both spoils and reclaimed grasslands, soil loss increases with slope gradient, although not always significantly. Much of this is owing to increased runoff amounts and surface-runoff velocity (which in turn increase the transport capacity and the energy of the surface runoff to disperse additional surface soil particles). This effect of slope gradient on soil loss has also been documented by McIsaac et al. (1987), who showed that, for short slopes with less than 9-percent slope gradient, there was close agreement between the observed effects of slope steepness and effects predicted by the USLE slope-steepness factor. The USLE tended to overestimate the observed slope steepness for longer and steeper slopes.

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# RECLAMATION DESIGN: PART III

*Reclaimed drainage, Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

**"Removing Sedimentation Ponds in North Dakota"**
**"Hydrologic Restoration Planning:**
**A Design Consultant's Perspective"**
**"Using Chemical Data from Overburden Cores to Predict the Time Duration of Elevated Dissolved Solids in Colorado Coal Spoil Leachate"**
**"Evaluation of Mine-Pit Impoundments in Coal Strip-Mine Reclamation in Southeastern Montana"**
**"Geochemical Modeling and Chemical Mass Balance of a Coal-Mine Pit Lake in Southeastern Montana"**
**"Use of a Regional Ground-Water Model to Predict Relative Impacts of Life-of-Mine Plans for Rosebud Area C, Near Colstrip, Montana"**
**"Cumulative Hydrologic Response of Ground Water to Strip Mining at the Decker and Spring Creek Mines, 1972-98"**

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# REMOVING SEDIMENTATION PONDS IN NORTH DAKOTA

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*(NOTE: The paper that follows is supplemented by a PowerPoint presentation. Click here to view this presentation.)*

The ultimate goal of reclamation laws is to regulate the return, in a timely manner, of lands disturbed by mining activities to a productivity equal to or better than that which the lands exhibited prior to such disturbance. Reclamation should include the restoration of sedimentation ponds constructed to keep the sediment coming off disturbed areas from contaminating adjacent landscapes. Realistically, such ponds are located at the lowest points in their watersheds. Accordingly, any given reclaimed pond area is subject to the same or greater erosional forces than is the remainder of its reclaimed watershed. Many sedimentation ponds have been successfully reclaimed in North Dakota since 1987.

In 1987, the Reclamation Division of the North Dakota Public Service Commission, along with the Water Quality Division of the North Dakota State Department of Health (which is the regulatory agency for the U.S. Environmental Protection Agency in North Dakota) and companies mining coal in the State, developed joint policy memorandum No. 19 to establish the procedures for reclaiming sedimentation ponds. The removal of ponds under these guidelines has worked well for over 13 years. More than 50 sedimentation ponds have been successfully removed since the 1987 implementation of the guideline. The smallest removal area to be reclaimed was only a couple of acres; the largest area included the pond and associated stockpiles of overburden, subsoil, and topsoil, all of these together covering over 100 acres.

The guidelines set forth the requirements of the law that must be met before an application to remove a sedimentation pond can be approved. The first two such requirements are (1) that a pond must remain in place for at least 2 years after the last augmented seeding and (2) that the pond not experience any major violations during the 24 months preceding its removal (North Dakota Administrative Code 69-05.2-16-09-22). Third, the reclaimed rangeland portions of the contributing watershed must have both adequate vegetative cover to control erosion and no signs of recent erosion. On the basis of a visual assessment during an inspection of the contributing watershed after the application is received, the vegetative cover of the watershed must appear to be dominated by seeded species, and all seeded species should be present. The mining company submitting an application for removal can also submit information to document that rangeland areas within the contributing watershed have achieved a 73-percent live basal and litter cover or an 83-percent first-hit cover (Hofmann et al., 1983; Ries and Hofmann, 1984). (These were the original cover requirements set forth in the policy memorandum and are the requirements for third-stage bond release for revegetation establishment.) Finally, the company must demonstrate that either normal agricultural practices or the precropland grass and legume mixture have been established and are controlling erosion on reclaimed cropland portions of the watershed. Any remaining suitable plant-growth material stockpiles or other small areas of associated

disturbance must either have their own in-place sediment control (established in accordance with best management practices [BMP's]) or be well vegetated.

To apply to remove sedimentation ponds from lands disturbed by mining, the mine operator submits site-specific applications to both the Reclamation Division and the Water Quality Division requesting approval to remove the ponds and to release from bond the point-source discharge point for them. The request includes a reclamation plan and supporting documentation consisting of a description of the mining and reclamation history and a summary of the current conditions in the contributing watershed. The reclamation plan includes appropriate maps of the ponds, contributing watershed boundaries, all structures within the watershed, and the proposed final grade, generally in the form of a contour map. The plan includes procedures to be used, proposed sedimentation controls and the locations of the controls, access routes, and a schedule for completion of the work.

The plans are simultaneously reviewed by both divisions. In addition, typically, the Reclamation Division and the Health Department complete a joint field review within about 2 weeks of receipt of the request and reclamation plans. (Thirty days are allowed to make the inspection and to evaluate the reclamation plan according to the policy memorandum or as time and seasonal limits otherwise allow.) After the office and field reviews, the Reclamation Division and the Health Department prepare a letter stating whether the request and plan are approved or denied and, if necessary, asking for additional information upon which to base a final approval decision. The letter may contain special conditions imposed by the Reclamation Division or Health Department to address specific conditions at the site or downstream of it; the letter may also contain recommendations. The goal of these entities is to respond to requests for removal within 30 days after they are received. Generally, regulatory agencies know when a mining company is contemplating submitting a request for a pond removal, so that a coordinated effort can be put forth by all involved in the matters of reviewing and responding to the submittal. The vegetative cover within a watershed is the single most important determinant with respect to when a pond-removal request will be submitted. The establishment of cover is usually not difficult because of the amount of topsoil available for reclamation in North Dakota.

Water remaining in a sedimentation pond must meet the requirements of the discharge permit when it is removed from the pond prior to pond reclamation. Once water removal is complete, the disposal of the sediment is addressed. In the case of an incised pond, sediment material is usually buried in place. For ponds with only an embankment, the material must be hauled away or buried near the pond reclamation site. In the case where mining has been completed and the mining areas reclaimed, the only alternative is to bury the sediments onsite. This has been the most difficult part of pond reclamation at North Dakota sites to date.

A mining company is required to place BMP's (in-place sediment controls) in appropriate downstream locations before the reclamation grading process begins. The Reclamation Division, in coordination with the mining company, generally makes field inspections to grant a verbal approval of the grading before the subsoil and topsoil are respread on the reclaimed pond area. Pieces of erosion-control fabric (or mats) are installed as needed in the main drainage through most of a given reclaimed pond site to aid in the establishment of vegetation and to protect the waterway from erosion. On steeper sites, the fabric joints are generally overlapped with a

shallow depression at the overlap. Rocks are placed in the depression to create some of the effect of a rock check dam. With the emergence of vegetation, the site begins to blend into the surrounding area so that hardly any trace of the former pond is present.

Most sites are generously mulched with hay or straw after the respreading topsoil and seeding. Well crimped-in mulch has been successful in reducing wind and water erosion within the reclamation program in North Dakota. Rates are about 2 tons per acre in pond areas. The sites are monitored closely for erosion, especially until vegetation has established to control it. Erosion rills are promptly repaired.

The Public Service Commission may grant a final bond release in less than 10 years for small reclaimed areas within a larger surrounding tract. The areas eligible for this variance include only reclaimed ponds, diversions, stockpiles, and their associated access trails. Any such area must meet the revegetation standards of the tract surrounding it to be included on the application for release from bond for that tract. Several reclaimed sedimentation ponds have been released under this guideline, which was developed as policy memorandum No. 20 in 1989 by the Public Service Commission. Most of these small areas were reclaimed for nearly 10 years before the variance has been granted.

Policy memoranda Nos. 19 and 20 appear in their entireties on the North Dakota Public Service Division Reclamation Division website at .http://www.psc.state.nd.us/psc/jurisdiction/reclamation/files/policy-memoranda.html

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# USING CHEMICAL DATA FROM OVERBURDEN CORES TO PREDICT THE TIME DURATION OF ELEVATED DISSOLVED SOLIDS IN COLORADO COAL SPOIL LEACHATES

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## Introduction

Elevated concentrations of dissolved solids in ground water are some of the longest-term hydrologic impacts caused by surface coal mines in the Rocky Mountain/Northern Great Plains States. The dissolved solids are produced by a variety of chemical processes that occur as ground water passes through the mine spoil in a backfilled pit (for example, Groenewald, 1983; Martin et al., 1988; Williams and Clark, 1994; Clark, 1995). The resulting spoil leachate can contaminate adjacent aquifers or surface waters if it discharges from the spoil.

No one is certain of how long after mining the dissolved solids in coal spoil leachate will remain elevated. The uncertainty is due to the fairly short historical record of hydrologic impacts from backfilled surface coal mines. Although large-scale surface coal mining had begun in the mid-Western States by 1900, surface mining and the backfilling of pits did not become a regular practice in the Rocky Mountain/Northern Plains States until at least the 1930's. The oldest hydrologic monitoring data collected from coal mines in these Western States span less than 40 years. Of the six Colorado mines where coal spoil leachates have been monitored for more than 10 years, none show a long-term decreasing trend in dissolved solids concentration (based on data in each mine's annual hydrology reports). Long-term concentrations have also been reported as not declining at one Montana mine (Wheaton and Van Voast, 1998).

Despite the uncertainty in predicting the duration of coal-mining-caused elevated dissolved solids, regulatory agencies that implement the Surface Mining Control and Reclamation Act of 1977 (SMCRA; Public Law 95-87) are required by law (at least implicitly) to predict how long mining-caused water pollution will last. The requiring laws are:

Section 510(b)(3) of SMCRA.--Requires an agency to assess "the probable cumulative impact of all anticipated coal mining in the area on the hydrologic balance" prior to approving a coal mining and reclamation permit. ("Hydrologic balance" refers to the relationship between water quality and quantity.)

30 CFR 800.40(b)(1).--Requires an agency to predict "the probability of future" water pollution prior to approving the release of a reclamation bond.

## Duration Predictions in Mining Permits and Technical Publications

SMCRA also requires that each coal-mining permit contain a description of the mine operator's projection of the probable hydrologic consequences caused by the mine. In this description in existing permits in the Rocky Mountain/Northern Plains States, any projection of the duration of elevated dissolved solids in spoil leachate typically is stated in only general terms. Although some permits explain that the spoil contains enough soluble minerals for dissolved solids to remain high for decades or centuries, wording commonly is vague, similar to the following:

> "For a period of time following mining, the concentrations of dissolved solids in the ground water in backfill will remain above the baseline concentrations of ground water in undisturbed bedrock aquifers. The concentrations in the backfill are expected to gradually return to the baseline levels."

Duration estimates for elevated dissolved solids have been quantified to varying degrees in technical publications. For example, Martin and others (1988) noted that it may take tens to hundreds of years for dissolved solids in Powder River basin spoil leachate to reach equilibrium. This prediction was based on how long it takes for one pore volume of water to pass through the spoil. Groenewold et al. (1983) concluded that concentrations could remain high for hundreds and possibly thousands of years in western North Dakota leachates. Williams and Clark (1994) predicted durations of hundreds to thousands of years for elevated dissolved solids at the Seneca II mine in northwest Colorado. This prediction used a geochemical mass-balance approach.

## Application of Williams and Clark's Duration Predictions to Other Colorado Mines

Summary of Williams's and Clark's method of predicting duration.--In their study, Williams and Clark (1994) collected spoil leachate from the downgradient ends of the reclaimed mine pits using concrete boxes outfitted for water sampling (lysimeters). They had full-suite analyses performed on the leachate samples, and then used the WATEQF computer program for calculating the degree of saturation (the saturation index) of each of the most abundant chemical species in the leachate. Saturation indices may be used to indicate if a mineral will dissolve into or precipitate out of a solution.

The saturation indices indicated that for the prevailing pH between 6.8 and 8.0, total dissolved solids (TDS) concentration in the leachate could not increase much above the existing concentration of around 4,000 mg/L. They calculated that there is enough pyrite in the spoil for dissolved solids to remain elevated at around 4,000 mg/L for hundreds to thousands of years, and then the supply of pyrite in the spoil will begin to be depleted. Oxidation of pyrite was considered to be the chief source of the dissolved solids in the leachate.

As part of their study, Williams and Clark calculated pyrite exhaustion times for spoil of various pyrite contents (table 1). The mass of pyrite in the spoil is sufficient to maintain dissolved concentrations up to the level allowed by the prevailing pH. They considered their approach to predicting the duration of elevated dissolved solids in leachate to be only a rough estimate.

Table 1.--Estimated time required for oxidation of all pyrite in spoil at the Seneca II mine, Routt County, Colorado (modified from Williams and Clark, 1994)

| Pyrite content of spoil, in percent (by weight) | Time for oxidation of all pyrite, in years |
|---|---|
| 3.0 | 5,000 |
| 1.0 | 1,600 |
| 0.2 | 300 |
| 0.02 | 30 |

Mine similarities that justify application of Williams and Clark's pyrite exhaustion times to other Colorado mines.--The Colorado Division of Minerals and Geology has used Williams's and Clark's pyrite exhaustion times (table 1) for predicting the duration of elevated dissolved solids in leachates at five other surface mines in Colorado (fig. 1). The predicted durations for the five Colorado mines where the method has been applied ranged from 400 to more than 1,000 years (fig. 1).

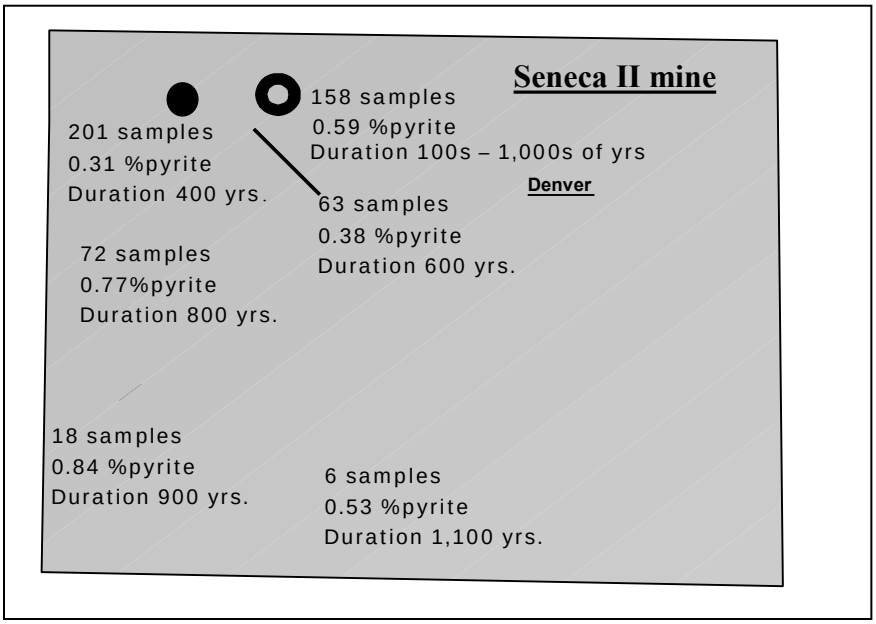



Figure 1.--Map of Colorado showing the locations of the Seneca II mine and the five mines where pyrite exhaustion times have been applied. Shown next to each mine are (1) the number of overburden core samples from which the spoil pyrite content was determined, (2) the spoil pyrite content, and (3) the predicted duration, based on the pyrite content.

Each of the five mines is closely similar to the Seneca II mine in terms of:

Overburden depositional history.—The mines' overburden was deposited in coastal swamps near a marine shoreline (Weimer, 1960; Kauffman, 1969), presumably resulting in similar spoil mineralogy.

Existing bedding attitude.—Coal beds at the mines dip more than 5º, resulting in an inclined pit floor on which spoil is backfilled and forms a large semi-saturated spoil mass upgradient from a smaller saturated spoil mass in the toe of the pit (fig. 2). The semi-saturated spoil provides a perennial flow of infiltrating, oxidized meteoric waters that oxidize pyrite in the spoil and produce sulfate.

Observed leachate chemistry.--Leachate waters at the mines are of a calcium-magnesium-sulfate type, with pH between 6.5 and 8.0.

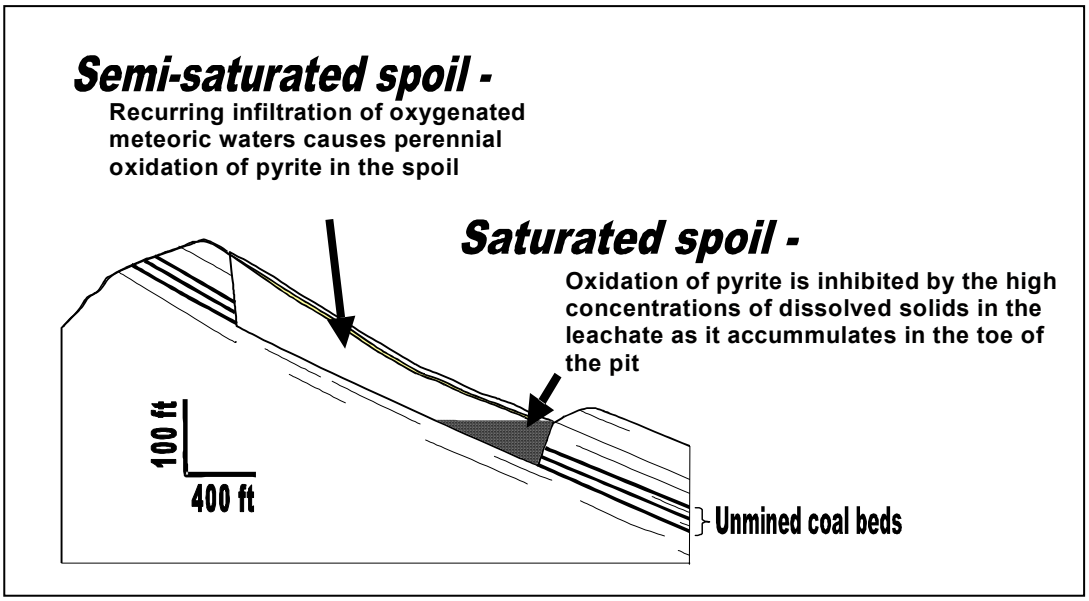



Figure 2.--Schematic cross-section of a typical Colorado pit. Pit excavation in a dipping coal sequence (and subsequent backfilling) results in a spoil mass that is segregated into an oxidizing zone and a non-oxidizing zone.

The similarities appear close enough that oxidation of pyrite can be assumed to be the dominant source of elevated dissolved solids in spoil leachate at the five mines, as it is at the Seneca II mine. Consequently, predicting the duration of elevated dissolved solids in spoil leachate at one of the mines is chiefly a matter of determining how much pyrite a spoil contains compared to the spoil at Seneca II mine.

Use of pyritic sulfur contents of overburden cores reported in mining permits.--At each of the five mines, the pyrite content of spoil was estimated from the pyritic sulfur content of overburden cores reported in the mining permit. These data have been in most mining permits since the permits were first issued. The original use of the overburden core data

was to determine the acid-producing potential of the spoil and, in some cases, the suitability of the spoil as a growth medium for the mine's revegetation. Using the overburden core data for predicting the duration of elevated dissolved solids in spoil leachate is a new use of these previously collected data. Figure 1 shows the average pyrite contents at the five mines and the Seneca II mine.

Reliability of the method.--The method of predicting duration, as described below, draws on Williams's and Clark's (1994) mass-balance approach. They considered their approach to be only a rough estimate of duration. The method described here is simply the application of Williams's and Clark's method through analogy, and should be even less reliable than their method. The method may be reliable enough, however, for discriminating between relatively short-term durations of a few decades and longer-term durations measured in centuries. Extreme values for pyrite content at a mine (either low or high) would suggest durations significantly different from those at the Seneca II mine. Despite its imprecision, the method provides the regulator and the mine operator a semi-quantitative basis for making a long-term prediction of the duration of elevated spoil leachate concentrations.

Prediction procedure.--The duration estimate for a mine is accomplished in five steps:

**Step 1.--Calculate the average (arithmetic mean) of pyritic sulfur content, by weight, reported for overburden/interburden core samples on the mine.** Data for coal seams are excluded, because coal seams are not spoiled during mining. Non-detects are counted as one-half the minimum detection limit.

**Step 2.--Convert the average percentage *pyritic sulfur* content of the spoil to the average percentage *pyrite* content of the spoil.** This is done by dividing the pyritic sulfur percentage by 0.53 (pyrite is 53 percent sulfur by weight). (Laboratories determine pyritic sulfur percentage by extracting iron from a sample with nitric acid, and then make the assumption that all of the iron comes from pyrite. The method is subject to a significant error owing to extraction of non-pyritic iron or incomplete dissolution of iron [Chou, 1990]. This analytical error is ignored, because it would apply equally to all core samples.)

**Step 3.--Find in Williams's and Clark's table 18 (reproduced in modified form as table 1, above) the number of years necessary to exhaust the percentage pyrite determined in step 2.**

**Step 4.--Adjust the number of years found in step 3 for any difference between the 17 inches of average annual precipitation at Williams's and Clark's study site and the subject site.** This adjustment is necessary because the amount of pyrite oxidation in the spoil varies directly with the amount of water infiltrating through the spoil. Annual infiltration is assumed to vary directly in proportion to

annual precipitation. The adjustment would be, for example, 88 percent if the subject site's precipitation is 15 inches (15/17 = 88 percent).

**Step 5.--Reduce the number of years of exhaustion for piping through the spoil.** Williams's and Clark's study assumed uniform oxidation of pyrite in the semi-saturated zone within spoil. They did not reduce their duration estimate for pyrite in the spoil that is not contacted by water as a result of piping (preferential flow through the more permeable parts of a spoil mass). Piping through coal spoil has been documented in eastern U.S. coal spoil (Caruccio et al., 1984; Hawkins, 1998). An arbitrary 25-percent reduction for piping seems reasonable and has been used on some of the Colorado mines.

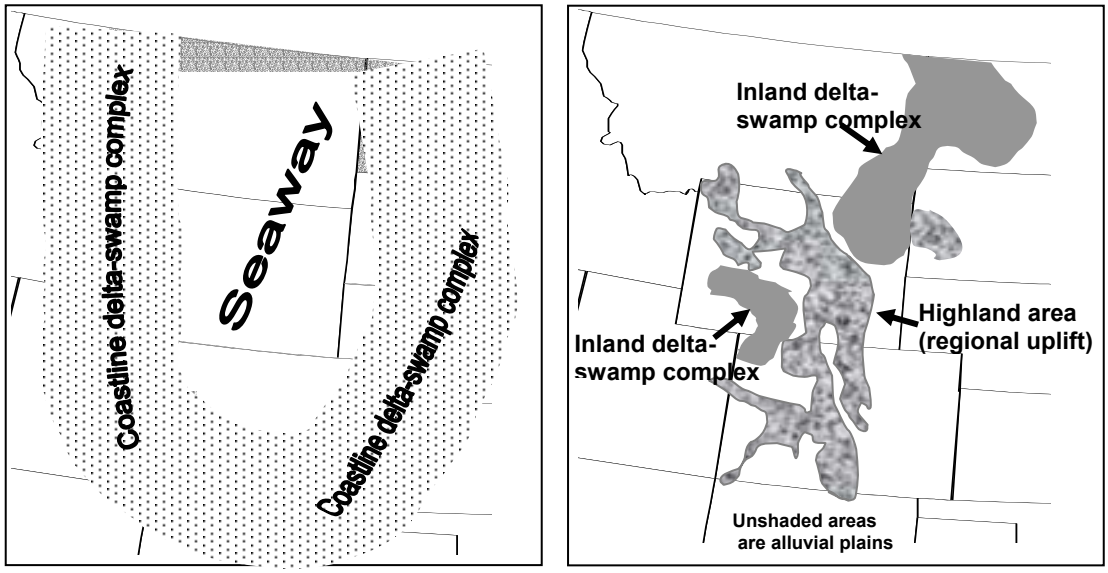
Sample wording of a prediction.--The wording of a prediction in the probable hydrologic consequences section of a permit, or in permit review correspondence, can be similar to the following:

"The U.S. Geological Survey projected a time period of "hundreds to thousands of years" for elevated TDS levels in spoil leachate at the Seneca II mine in Routt County (Williams and Clark, 1994) This projection may be applicable to the subject mine, as follows:

> "Williams and Clark suggest on page 56 of their report that oxidation of pyrite in spoil is the primary reaction that produces increased TDS in Seneca II mine leachate. The sulfur released by pyrite oxidation combines with oxygen to form sulfate in the spoil aquifer water, thus increasing the concentration of TDS. TDS levels remain high until the available mass of pyrite is exhausted. Williams and Clark calculated that, for spoil containing 1.0 percent pyrite (by weight), it takes 1,600 years to oxidize all of the pyrite (their table 18).
>
> "The subject mine is similar to the Seneca II mine in terms of depositional history, existing bedding attitude, and observed spoil leachate chemistry. These similarities indicate that the oxidation of pyrite can be assumed to be the main source of increased TDS in spoil-aquifer water at the subject mine.
>
> "The pyritic sulfur content in the subject mine's spoil averaged 0.11 percent (by weight) in the overburden core samples whose analyses are reported in the permit application. Pyrite is 53-percent sulfur (by weight); therefore, the 0.11-percent pyritic sulfur content indicates that roughly 0.21 percent of the mass of the subject mine's spoil is pyrite. Applying Williams's and Clark's 300-year exhaustion time for 0.20-percent pyrite, the subject mine's spoil can be expected to generate high sulfate concentrations for at least 300 years.

"This projected 300-year duration is reduced to 212 years when reductions are taken into account for piping through the spoil (assumed to be 25 percent) and lower annual precipitation (16 inches at the subject mine vs. 17 inches at Seneca II)."

Applicability to other Rocky Mountain/Northern Plains coal mines.--The method described above for predicting the duration of elevated dissolved solids may be a valid approach for other surface mines in the Rocky Mountains and Northern Great Plains that are developed in coal sequences of Cretaceous age (for example, Dakota, Mesa Verde, and Fruitland Formations). These coal sequences have depositional histories similar to that of the Seneca II mine and consequently may be expected to result in spoil that is mineralogically similar to spoil at Seneca II. The overburden sequence was deposited within a coastal swamp system located immediately landward of a marine shoreline (fig. 3).




| | | |
|---|---|---|
| ***Geologic time period shown in map:*** | **Cretaceous (71 to 136 million years ago)** | **Tertiary (65 to 38 million years ago)** |
| ***Depositional setting of coal:*** | **Swamps immediately inland from the shoreline of a broad seaway** | **Swamps next to rivers in isolated basins between regional uplifts ( by this time the Cretaceous seaway had withdrawn to the present-day Gulf coast area)** |
| ***Elevation of coal swamps:*** | **Near sea level** | **A few thousand feet above sea level** |

Figure 3.--Comparison of regional depositional settings of Cretaceous (Colorado, Utah, New Mexico) coals and Tertiary (North Dakota, southeastern Montana, northeastern Wyoming) coals. Lateral shifting of the Cretaceous coastline resulted in coal deposition throughout the Rocky Mountain/Northern Plains region. After the seaway withdrew,

Tertiary-age coal beds were deposited in isolated inland basins (compiled from McDonald, 1972, and McGookey, 1972).

Also, as previously explained in this paper, structural tilting at these mine locations of more than 5º at the end of the Cretaceous has resulted in backfilled mine pits that have a thick mass of semi-saturated spoil lying upgradient from a saturated mass of spoil in the toe of the pit. The semi-saturated spoil provides a source of oxidized infiltrating meteoric waters for oxidizing the pyrite in the spoil.

The method probably is not transferable to those mines developed in Rocky Mountain/Northern Plains coal sequences that are younger than Cretaceous (for example, the Tertiary-aged Fort Union and Wasatch Formations in Wyoming, Montana, and North Dakota, and the Denver and Arapahoe Formations in Colorado). These coal sequences have depositional histories that are significantly different from the coastal marine setting of the older Cretaceous rocks. The Tertiary-aged coal/overburden sequences were deposited in and near swamps within lacustrine deltas and alluvial fans on continental floodplains that formed between uplifted regional structural blocks (fig. 3; Glass, 1977). The mineralogy of these continental coal sequences can be expected to differ significantly from the coastal deltaic sediments of the Cretaceous coal sequences. The two depositional settings had contrasting sediment sources, climates, and water circulation. After burial, the Tertiary-aged rocks were subjected to significantly lower geothermal temperatures than the Cretaceous rocks (Choate and Rightmire, 1982), which may have resulted in different diagenetic histories for the two ages of overburden. Finally, the Tertiary rocks in most places are structurally tilted only 1º to 2º, resulting in a nearly flat-lying pit floor on which all of the spoil backfill eventually becomes saturated, leaving no semi-saturated backfill where free oxygen can oxidize the pyrite in the spoil (fig. 4).

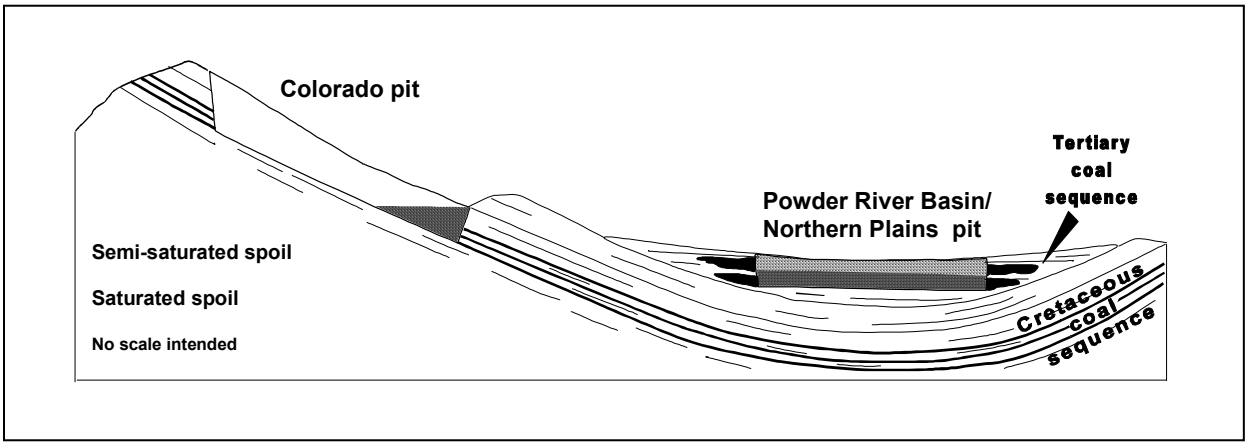



Figure 4.--Schematic cross-section showing (1) the expected broader extent of saturated spoil on the nearly flat-lying pit bottom of Powder River Basin/Northern Great Plains pits as compared to the inclined pit bottom of Colorado pits (note that the cross-section shows the two pits in close proximity only for the purpose of comparison and does not depict an actual location) and (2) the wide regional extent, and thinness, of Cretaceous coal

beds compared to the limited areal extent, and great thickness, of the younger Tertiary-age coal beds.

**Summary**

Although SMCRA regulations indirectly require the prediction of duration of elevated solids in coal spoil leachate, the prediction is difficult to accomplish given the short history of leachate monitoring. Durations have been estimated at five Colorado mines using analogies with the Seneca II mine, for which a published lysimeter study is available. The analogies were based on the pyrite content of spoil, as indicated by overburden core samples. The estimates of duration at the five mines are probably less reliable than the published lysimeter study, but provide a semi-quantitative approach nevertheless. The analogy to the Seneca II mine may be extended to other mines that are geologically similar.

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# EVALUATION OF MINE-PIT IMPOUNDMENTS IN COAL STRIP-MINE RECLAMATION IN SOUTHEASTERN MONTANA

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## Introduction

The coal region of southeastern Montana is surface-water poor, but rich with grazing land. A primary focus of ranch work is developing and maintaining water supplies. Within ranching areas of southeastern Montana, coal-strip mines spend millions of dollars reclaiming mine pits that in some instances receive sufficient ground and surface water to form a viable reservoir if left open.

Strip mining typically proceeds from near the coal crop toward areas of thicker overburden in long pits that roughly follow the land-surface contours. The overburden from each successive pit is used to backfill the preceding pit. This process continues until the ratio of stripping depth to coal recovered becomes uneconomical. Spoils material is then moved from the spoiled areas to backfill the final pit, and the entire area is smoothed to a land surface that approximates original contours. Mine reclamation is regulated by the Federal and State Surface and Underground Mine Reclamation Act (Montana Code Annotated 82-4). Alternate reclamation practices are allowed under certain situations, if the alternate plan is defensible as being environmentally sound.

Hundreds of pit lakes have been created in the Appalachian and Midwest coal regions (Gibbs and Evans, 1978). Some of these lakes are acidic and contain high levels of dissolved solids (Campbell and Lind, 1969; Goering and Dollhopf, 1982; Anderson and Hawkes, 1985; Brugam *et al*., 1987; Blevins, 1991; Blevins and Ziegler, 1992). Others meet or exceed water-quality standards. In Germany and Canada, coal mine-pit lakes are deliberately constructed to function as fish and wildlife habitat and to provide recreational opportunities (Bilkenroth, 1993; Sumer *et al*., 1995).

The purpose of this project is to evaluate existing mine-pit impoundments and to use that evaluation to determine confidence in predicting water-level stability and water-quality usability in advance of mining. Coal seams and overburden sandstone units are the primary aquifers in much of southeastern Montana. Mine pits encounter ground-water inflows from the coal seams and sandstone in the overburden. After reclamation, ground water flowing in the mined coal seam and overburden recharges the spoils. Leaving portions of the final pit open provides a storage reservoir where ground water in coal and overburden aquifers can be put to beneficial use as a surface-water resource. In order to permit such a reclamation practice, however, regulators must know in advance if the water levels and water quality in the reservoir will be stable and usable.

## Physical Setting

The primary study site for the project is located in southeastern Montana near the town of Colstrip, within the Powder River Basin. The Powder River Basin is a roughly north-south trending syncline extending from near Casper, Wyoming, to the Yellowstone River in Montana. There are approximately 570 billion short tons of coal resources in Montana and Wyoming within the Wyodak-Anderson zone and the Ashland and Colstrip coalfields (U.S. Geological Survey, 1999). Coal has been mined in the basin since 1886. Currently, coal mined in the basin is used primarily for electrical power generation. During 1998, 305 million short tons of coal were mined at 25 mines from the Wyodak-Anderson and the Rosebud coal zones (U.S. Geological Survey, 1999). This coal was used at 144 electric generating plants located in 26 States and 3 foreign countries.

Coal seams mined in Montana are subbituminous and are in the Tongue River Member of the Paleocene Fort Union Formation. The Fort Union Formation, composed of shales, sandstones, and coal seams, is exposed at ground surface over most of the coal-mining region of Montana. The remainder of the surficial geologic units is alluvium and clinker, with minor areas of overlying Eocene Wasatch Formation. Clinker is overburden sandstone and shale that has been baked and broken as a result of the natural burning of underlying coal.

Mines in the Colstrip area target the Rosebud coal, near the bottom of the Tongue River Member. The Rosebud coal seam averages about 25-feet thick (Matson *et al*., 1973). The stratigraphically lower McKay seam, typically 8 to 10 feet thick, had been mined near Colstrip, but, owing to poor coal quality, mining was discontinued.

Ground-water recharge occurs along topographically high ridges where clinker is exposed, at areas where coal seams and sandstone units crop out, and in some locations where surface water and alluvial water cross outcrops of sandstone and coal. Ground water infiltrates downward to recharge stratigraphically deeper aquifers. Where the discharge areas of these units crop out, they provide baseflow for local springs and regional streams and rivers. Owing to chemical reactions with the surrounding material, ground-water quality changes along the flow path from calcium-magnesium bicarbonate to sulfate to sodium bicarbonate ionic domination (Van Voast and Reiten, 1988). Near the mines at Colstrip, ground water is dominated by ions of magnesium, calcium, and sulfate, which represent the chemistry of local recharge water.

Southeastern Montana, typical of the Northern Great Plains, is semi-arid: most areas receive less than 15 inches of precipitation per year. Most moisture is received during the spring, particularly May and June, with winter being the driest season. Average annual temperature at Colstrip is 46.2˚F. January is the coldest month, with an average temperature of 20˚F, and July is the warmest month, with a temperature of 71.8˚F.

## Recommendations and Conclusions

Final-mine pit impoundments represent a possible method of alternative reclamation that increase water availability for future land users, while decreasing reclamation costs. Stable impoundments with water of usable quality now exist in mined areas and provide examples of

final-pit and surface-runoff reservoirs. Some sites, though not in final reclamation, can still provide useful information about water quality and quantity for future reclamation plans.

Impoundments in reclamation areas, whether or not they are in direct communication with bedrock aquifers at the highwall, can provide additional recharge to spoils aquifers. The impoundments may accelerate flushing of the soluble salts in the spoils aquifer, allowing water quality to return to premining conditions quicker than in areas without impoundments. Additional research is needed to verify and model this concept. It is important to note that impoundments not adjacent to bedrock aquifers at the final highwall will receive all ground-water inflow from the spoils aquifer. This was not studied in this project and may create a pond with higher than desirable salt concentrations if implemented without careful design considerations.

Final-pit impoundments can provide wildlife water and stock water, as well as support aquatic species. In certain settings, they may provide wildlife viewing, fishing, and other sporting opportunities in an otherwise dry area.

Final-pit impoundments are not appropriate in every reclamation plan. Sufficient watershed area must be available for individual impoundments to provide surface runoff to maintain a positive inflow to the pond. Ponds with large watersheds may provide too much recharge to spoils, potentially causing water-logged soils and saline seeps downgradient. No example of soil saturation, however, was noted during this project. Where mine-floor aquifers do not result from the mining process, impoundments should probably be designed for areas with fairly sandy overburden to increase ground-water seepage from the pond. Areas with naturally high ground-water flux in bedrock units, rather than areas with little or no such flux, should be considered for impoundment sites. Evaporation from the impoundments does represent a net loss of water from the watershed that must be considered in reclamation planning. This loss can, however, be estimated in terms of percentage of total flux through the system, and the use of an impoundment can be compared to the quantity of reduced surface runoff. Where, as near Decker, mine-floor aquifers exist at the base of spoils, circulation of pond water/ground water should not be a problem, and postmining spoils-water quality will likely be little influenced by additional salts.

Properly designed impoundments do not appear to interfere with downgradient water resources. The studied impoundments increase ground-water flow through the system by intercepting surface water. The quantity of surface water intercepted was small compared to the overall drainage and did not appear significantly to alter stream flow. The recharge to spoils may eventually become part of the shallow flow system that provides baseflow to receiving streams.

Additional research is needed to quantify water-quality impacts to spoils aquifers, particularly with respect to the possibility that impoundments in reclaimed areas may accelerate the rate at which salts are flushed through the system and the timing of water-quality improvements in spoils aquifers. Research is also needed on the affect of pond orientation on evaporation rates. This is particularly important in cases where a highwall or bluff extension may be left adjacent to a final-pit impoundment.

As part of baseline data collection and mine permit studies, companies considering final-pit impoundments should gauge streamflow and precipitation at several sites to provide good direct-proportion ratios for runoff calculations. Aquifer tests in several areas upgradient of a future impoundment site should be performed in each saturated zone. During mining, pit inflow rates and ground-water gradients in adjacent bedrock units can provide good final data for water-budget calculations.

Paste-extract data should be collected to approximate spoils water quality and verify the lack of available toxic trace metals. In the alkaline setting of southeastern Montana, metals are not a water-quality concern. No mine pits were found with water-quality problems or dissolved-constituent levels related to toxic metals that made the water undesirable.

Based on documentation at the study sites and data collected at other sites, reclamation plans can be designed to include final-pit impoundments. Water levels and water quality can be predicted with sufficient confidence to ascertain that the designed impoundment will fall within the normal range of stock and wildlife ponds outside mined areas of southeastern Montana.

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# P O S T M I N I N G
# H Y D R O L O G I C  A S S E S S M E N T

*Reclaimed drainage, Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "North Dakota Postmining Hydrologic Assessments"


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# NORTH DAKOTA POSTMINING HYDROLOGIC ASSESSMENTS

**David Bickel**
**Reclamation Division**
**North Dakota Public Service Commission**

## Introduction

A postmining hydrologic assessment (PHA) is the report and part of a mining permit that addresses hydrologic requirements for final bond release, that is, requirements related to water resources rather than the management and reclamation of surface-water handling facilities on the mine. It is the final accounting of water-resources protection and reclamation for a mine area that describes the postmining hydrologic environment and makes comparisons with premining or undisturbed conditions or with standards. Unlike the probable hydrologic consequences (PHC) analysis and cumulative hydrologic impact assessment (CHIA), it is primarily a descriptive, historical, and comparative analysis of existing water resources rather than a predictive document. The PHC and CHIA are intended to be predictive and dynamic throughout the phases of mining and reclamation. Both must be modified in the permit-revision process, as data are acquired during mine operations, into more descriptive and comparative studies of the nature and extent of mining impacts on the assessment area. If material damage or other serious impacts occur, they must be dealt with promptly and their mitigation or permanent effect weighed as part of the approval process for continued or expanded mining. Properly maintained PHC's and CHIA's evolve into more accurate predictors of permanent hydrologic effects through the life of a mine.

## Origin of the PHA

The need for a final evaluation of hydrologic conditions before release of a permittee's bond is intuitively obvious, but the timing, scope, and format of such an evaluation are not. In North Dakota, the PHA grew out of a need to justify on hydrologic grounds the end of water-resources monitoring. North Dakota operators moving into final bond release wanted approval to decommission ground-water monitoring wells in and around tracts nearing final bond release. Together, revegetation success standards and the 10-year minimum liability period control planning for final bond release. When a number of tracts is nearing the end of the 10-year liability period, the mining company begins to organize, or collect, data on vegetation success and to plan for final bond release. This activity seems to trigger plans for phasing out ground- and surface-water monitoring programs as well as for decommissioning monitoring sites.

A uniform policy was needed for the timing of monitoring termination and reclaiming ground- and surface-water monitoring sites. Allowing termination of a tract at final bond release or at an arbitrary time such as the end of the minimum liability period was illogical. Arbitrary time periods do not relate to the condition of hydrologic systems, and many monitoring sites are off permit areas and not associated with individual bond-release tracts.

At most large-scale Western mines, ground- and surface-water monitoring networks are for mine areas and cover thousands of acres, whereas typical bond-release tracts cover a few hundred acres defined by ownership and land use. The only logical course was to allow termination of monitoring at a site only when it had produced enough data to address the hydrologic requirements for final bond release.

This meant that operators wishing to down-size or terminate monitoring programs in a coherent manner would have to address the hydrologic requirements for bond release perhaps years before application would be made for final bond release on many tracts. Initial concern was that mining companies might perceive this timing as too stringent. However, North Dakota considers preparation of a comprehensive PHA an option for the industry with the alternative forcing a permittee to meet the same requirements (1) by making the same analyses for each monitoring site or group of sites to be removed and (2) when applying for bond release on each land tract. It was clear that preparation of a PHA would provide time and cost savings in the bond-release process, as well as a superior constructive record of compliance for large-scale mines with multiple permits and mining areas.

**The PHA in North Dakota**

Comprehending the scale differences between hydrologic flow systems and mining permit areas or bond-release tracts is central to understanding the PHA process in North Dakota. Surface- and ground-water baseline data acquisition, PHC analysis, plans for annual monitoring, and evaluation are all designed mine-wide, or for mine subareas when these are hydrologically distinct units, without regard for individual permit-area boundaries.

When selected by operators as an option to address hydrologic bond-release requirements, the PHA is submitted as a stand-alone revision to all the affected mining permits. The operator first reviews with North Dakota Public Service Commission (PSC) staff the scope and types of analyses that seem appropriate to the mine area and available data, and the assessment approach is agreed upon. The PHA is prepared and submitted as a stand-alone revision to all the affected mining permits and is reviewed, modified, and approved as an insignificant permit revision. The approved document exists as a separate volume (or volumes) clearly marked as a revision to each permit it affects, and the volume is shelved with the most recent permit covered. Each permit in turn refers to the separate document as a revision.

Format and structure of the PHA is left to the operator; however, the hydrologic requirements in the North Dakota law and regulations normally guide report structure. Checklists to cover all regulatory requirements have been abstracted directly from regulations to guide applicants in the bond-release process. No items are included that are not required by regulation. Many PHA topics, such as summaries of historic well-certification results and water-supply replacement actions, are not explicitly required by regulation but serve to document successful compliance with some of the broadly stated requirements for water-resources protection. Some aspects of the analysis are generally formulated on a case-by-case basis, rather than by formal guidelines, in discussion during

the PHA planning process between North Dakota PSC's Reclamation Division and the mining company.

Once approved, the PHA serves as a basic reference document that is cited and summarized in all bond-release applications so that the applicants for small bond-release tracts do not have to prepare and formalize similar hydrologic information. Hydrologic information specific to individual bond-release tracts, such as specialized livestock water needs, may be added and addressed in applications. Because years may pass between initial PHA preparation and complete termination of all monitoring, a PHA document is commonly updated and revised with newer data. It serves as a convenient and coherent location for hydrologic information, such as well abandonment reports, that must be made part of the permanent mine-reclamation record.

**Results and Discussion**

North Dakota has four active large-scale surface lignite mines that recover most of the 30 million tons per year produced in the State. Two smaller operations mine weathered lignite, termed leonardite, for use as additives to drilling mud and soils. Eight medium- to large-scale mines are in final reclamation. Four are covered by single permits and are either too far along in final bond release or too small to benefit from producing a PHA, but three of these mines elected to address hydrologic requirements and monitoring termination through permit revision prior to bond release. The resulting permit revisions were smaller but appropriately scaled versions of the PHA.

Four of the large-scale mines in final reclamation will benefit from developing a PHA, and two of these have approved assessments in place. The one for Glenharold mine covers all permits at the reclaimed mine. At the reclaimed Indian Head mine, the existing PHA covers one of two hydrologically separated mining areas, and a similar document is planned for the second area. Most of the permitted acreage under the first Indian Head mine PHA has been successfully released from bond. PHA's are planned or considered for the other two mines in final reclamation. Within the next 5 to 10 years, one or more of the large active mines will have hydrologically separated mine areas in final reclamation, and PHA development for those areas is anticipated.

Use of the PHA in North Dakota has shown some distinct values for mine operators. The need to commit in-house staff or employ consultants occurs at an early but reasonable time in the final bond-release process. A comprehensive analysis prior to decommissioning monitoring sites minimizes the chances of later discovering a problem that might require reestablishment of monitoring sites that had been removed and reclaimed. The PHA expedites bond release by accommodating scale differences between bond release tracts and ground- and surface-water flow systems. The numerous bond-release applications needed to cover the patchwork of land use and ownership tracts typical of a mine area do not have to repeat evaluations of the same hydrologic information in order to meet bond-release requirements.

The PHA makes the evaluation of water-resources reclamation comprehensive and locatable within a mining permit document rather than disjoined and distributed through a series of bond-release applications. Stakeholders--such as other government agencies, environmental groups, or landowners--who are concerned with water resources and need hydrologic information can access it conveniently. Evaluating data on scales appropriate to ground- and surface-water flow systems keeps emphasis on recovery and hydrologic interactions and effects and, by addressing both on- and off-permitted areas, avoids fragmenting data in order to relate them to a small area. The PHA also tends to keep water-resources requirements from being overlooked or made secondary to measuring vegetation success and addressing land-use requirements as these issues move to the forefront in final bond-release applications.

# WORKSHOP PRESENTATION: SPATIAL DATA FOR HYDROLOGY MONITORING EMPHASIZING NEW DEVELOPMENTS IN SEDCAD+ AND GIS

*Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Spatial Data for Hydrology Monitoring Emphasizing New Developments in SEDCAD+ and GIS"

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# WORKSHOP PRESENTATION:
# SPATIAL DATA FOR HYDROLOGY MODELING EMPHASIZING NEW DEVELOPMENTS IN SEDCAD+ AND GIS

## Workshop description

The purpose of this workshop was for participants to generate comprehensive hydrologic models using limited spatial data. Now more than ever, geographical information systems (GIS's) are providing their users the powers to manipulate spatial data and enhance visualization capacities. Through the current Wyoming Abandoned Coal-Mine-Land Research Program project "*Research and Development of a GIS-Based Data Management and Model Integration Tool for Coal-Mine Permitting and Reclamation,*" as well as through other programming advances, we are producing the next level of hydrologic modeling software with SedPrePro.

The SEDCAD preprocessor, or SedPrePro, is a customized graphical user interface that operates primarily within the ArcView desktop GIS environment. SedPrePro modifies and develops GIS functionality to assist in building complete hydrologic-model frameworks. New menus and tools have walk both experienced and novice users through a series of steps that build digital-elevation models, superimpose various precipitation regimes, develop National Research Conservation Service curve numbers, derive SEDCAD structure networks, and delineate all corresponding watersheds. Each step is conceptualized with easy to follow *wizard*-type interfaces, dialog-specific help, multiple error checks, and complete visualization of each operation. SedPrePro also exports its hydrologic-design information to a SEDCAD hydrologic model.

Within the coal-mining community, SEDCAD is the Office of Surface Mining hydrologic-modeling application of choice, provided to 25 State regulatory authorities for hydrologic-design review. SEDCAD's functionality extends to runoff prediction, comprehensive design of storm-water controls, and hydrologic-system summary reporting. SedPrePro was developed to operate as a preprocessor, as well as a potential postprocessor, for the SEDCAD model.

Although[, as of late 2000,] SedPrePro was still in the developmental stage, this workshop demonstrated its current functionality and discussed the seamless exportation of model parameters to SEDCAD. Presenters used a surface-mining example to illustrate step-by-step SedPrePro inputs, along with a complete design of structures, including channels, culverts, retention basins, and plunge pools. In addition to the demonstration, there were open discussions of proposed methods for SedPrePro's postprocessing. Presenters' goal was to effectively create and visually represent the information necessary to build and interpret SEDCAD's model design and results, at the same time providing the means for optimal display and review.

**Workshop presenters**

Richard C. Warner, Ph.D., and Michael Anderson, both of the University of Kentucky, addressed the issues described above in a presentation entitled "Spatial Data for Hydrology Modeling Emphasizing New Developments in SEDCAD+ and GIS." Click *here* to access a PowerPoint version of this presentation.

# WORKSHOP PRESENTATION: SURFACE AND SUBSURFACE MODELING WITH GIS

*Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Surface and Subsurface Modeling with GIS"

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## WORKSHOP PRESENTATION:
## SURFACE AND SUBSURFACE MODELING WITH GIS

### Workshop description

Digital data are available for locations at most surface minesites to support and enhance surface-terrain and environmental modeling, as well as studies of subsurface geology. If adequate digital data are not immediately available at a given mine, they can be acquired at varying scales from Federal, State, and commercial data providers. The cost of data often reflects their scale, age status, and completeness. Topographic and cultural data at scales up to 1:24,000 may be obtained free or at a nominal charge from the U.S. Geological Survey or State agencies. Regional vector data are also available from government Internet sites. Large-scale, high-resolution terrain data are typically attainable at project sites as digitized contour lines or digital elevation models. Regional geologic data are often accessible through State and Federal agencies. Project-geology data can be available from various departments at the mine to which they pertain.

The purpose of this workshop was to demonstrate data acquisition and modeling for a large operating surface coal mine in the Powder River Basin, Wyoming. The presenter compiled and mapped regional data from several public sites; he also compiled and analyzed detailed mine information. Analytical functions addressed included slope analyses, cut-fill relationships, stripping and mining sequences, topsoil inventory, and revegetation strategy. Modeling software included ESRI's ArcView GIS and several extensions developed to enhance GIS capabilities. Methods to import traditional CAD data from several sources were also presented. The workshop introduced participants to data acquisition, analysis, and modeling.

The 3-hour evening workshop was presented in an informal lecture format.

### Workshop presenter

Michael Price, Mining Industry Solutions Manager, ESRI, addressed the issues described above in a presentation entitled "Surface and Subsurface Modeling with GIS: Surface Coal Mining, Powder River Basin."

# W O R K S H O P  P R E S E N T A T I O N:
# C O A L - B E D  M E T H A N E

***Coal-bed methane wells, Montana.***

## "Coal-Bed Methane"

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# WORKSHOP PRESENTATION:
# COAL-BED METHANE

## Workshop description

The purpose of this workshop was to concentrate on the development of coal-bed methane in Wyoming and Montana, to present coal-bed-methane issues that appear to be of concern to coal-mine operators, and to provide an opportunity to discuss the hydrogeologic, biologic, and regulatory implications of coal-bed-methane development.

## Workshop presenters

The workshop was given by a number of presenters, each with expertise in matters related to coal-bed methane. John Wheaton, Montana Bureau of Mines and Geology (BMG), opened with an "Overview of Coal-Bed Methane Development and Discussion of Montana Impacts." Steve Regele, Montana Department of Environmental Quality, followed with a presentation on "Biological Issues." Brad Dingee, Peabody Group, discussed "Wyoming Coal-Bed Methane Hydrogeologic Impacts." Joseph F. Meyer, Bureau of Land Management, Casper Field Office, addressed "Ground-Water Level Changes Associated with Coal Mining and Coal-Bed Methane Development in the Eastern Powder River Basin of Wyoming." John J. Mahoney, Ph.D., Hydrologic Consultants, Inc., described the "Geochemistry of Coal-Bed Methane Discharge Waters, Powder River Basin, Wyoming;" Paul Williams addressed "Evaluating Coal-Bed Methane Impacts." Mr. Regele followed with a description of "Regulatory Issues." Finally, Messrs. Wheaton and Regele concluded the workshop with a look at "Living in the Coal-Bed Methane Neighborhood."

Working under the auspices of Montana BMG, John Wheaton is editing and compiling into a discreet publication the eight presentations that constitute this workshop. We hope to include that publication as part of these proceedings at some point in the future.

# FIELDTRIP TO WESTMORELAND'S ABSALOKA MINE

*Wetland, Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Field Trip to Westmoreland's Absaloka Mine"

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# FIELD TRIP TO
# WESTMORELAND'S ABSALOKA MINE

## Field-trip description

Final bond release, under the Surface Mining Control and Reclamation Act and the Administrative Rules of Montana, requires that engineered structures be either constructed of permanent materials or supported by maintenance in perpetuity. Any hydraulic structure must be able to withstand the stresses associated with a 100-year storm event. Often, sediment-storage ponds required to capture sediment and protect watersheds during mining and mining reclamation are incorporated into postmining land-use strategies, most often providing a watering source for livestock, which is the most common of these. Therefore, supporting postmining land use is an incentive to keep ponds. At the same time, the costs associated with upgrading structures to meet regulatory requirements can be a disincentive to keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures.

Pond No. 20 at Westmoreland Resources' Absaloka mine was designed with a flow-through culvert and a spillway that would safely carry flows associated with a 25-year storm event. The pond has an approximate 10,000 $ft^2$ surface area and is retained by an earth-embankment dam with dimensions as follows: 150 feet long, 20 feet high, 20 feet wide on the upper surface, and a 2.5H:1V (40-percent) slope. In order to construct a spillway capable of handling the larger 100-year storm event, the natural coulee below the dam would need to be disturbed and partially filled with riprap.

As an alternative to enlarging the spillway, Bitterroot Restoration, Inc., developed a design that uses the entire embankment surface as the spillway. In the event of a flood, the entire dam would be overtopped with a shallow flow, rather than concentrating the flow into a spillway. The overtopping alternative would be less expensive than a riprapped spillway, because of the high cost of importing riprap stone in eastern Montana. Also, by using plant material instead of rock, habitat quality was enhanced. This design was approved by both the Office of Surface Mining and the Montana Department of Environmental Quality. The project has been installed since spring of 1999 and is revegetating well.

## Field-trip leader

Tom Parker, Director of Consulting, Bitterroot Restoration, Inc., led participants on this field trip. Mr. Parker's forum presentation, entitled "A Soil Bioengineering Alternative to Open-Channel Spillways for Upgrading Sediment Ponds to Permanent Structures for Bond Release Under the Surface Mining Control and Reclamation Act," appears as appendix H to these proceedings. Click *here* to access this appendix .

# FIELD TRIP TO WESTERN ENERGY COMPANY'S ROSEBUD MINE

*Area E,*
*Western Energy Company's Rosebud mine.*
*August 2000.*

## "Field Trip to Western Energy Company's Rosebud Mine"

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# FIELD TRIP TO WESTERN ENERGY COMPANY'S ROSEBUD MINE FIELD

## Field-trip description

The purpose of this field trip to Western Energy Company's Rosebud mine was to highlight reclamation activities at the mine that support hydrologic functions in Montana. During the afternoon field trip, field-trip leaders headed up a discussion of the progression in thought and application relative to reestablishing approximate premine morphology and hydrologic functions in reclaimed channels. The field trip included visits to sites at the mine that represent older and newer approaches to drainage-basin and channel reclamation. Trip leaders addressed lessons learned from both types of approach, including:

- earlier, unplanned reclamation and "ramp-road" channels;
- construction-channel features, including alternate berms (e.g., berms that initiate channel meandering and point-bar formation);
- large-scale valley and flood-plain meanders and their integration with adjacent topography (with and without constructed channel features);
- greater variability in valley-bottom width and side slopes; and
- maintenance, monitoring, and future directions.

## Field-trip leaders

Robert Postle, Ecologist, Western Regional Coordinating Center, Office of Surface Mining, served as mine-visit coordinator for the field trip. Robert Montgomery, Environmental Manager, Western Energy Company, Thomas Golnar, Surface-Water Hydrologist, Montana Department of Environmental Quality (DEQ), Chris Yde, Wildlife Biologist/Vegetation Specialist, Montana DEQ, and Mr. Postle presented issues associated with the activities described above.