Proceedings

from an

Interactive Forum

entitled

"Approaching Bond Release: Revegetation, Reclamation Issues, and Surface-Mining Applications in the Arid and Semi-Arid West"

held September 20 through 24, 1999,
in Flagstaff, Arizona,

and sponsored by

the Office of Technology Transfer,
Western Regional Coordinating Center,
Office of Surface Mining,
Denver, Colorado

Table of Contents

Preliminary Pages

- ☞ **A word about these proceedings**
- ☞ **Forum agenda**
- ☞ **Table of contents**
- ☞ **"Opening Remarks"**
- ☞ **"Forum Summary"**

A Word About These Proceedings

During the period September 20 through 24, 1999, the Office of Surface Mining's (OSM's) Western Regional Coordinating Center, Denver, Colorado, sponsored an interactive forum that addressed bond release as it relates to revegetation issues on surface coal minesites in the arid and semi-arid West. (For a list of attendees at this forum, see appendix A; for a copy of the forum agenda, see the next page.) This forum was the second in what OSM hopes will become a series of five annual forums regarding surface-mining bond-release topics. It was held in Flagstaff, Arizona.

Among the revegetation topics covered at the 1999 forum were soil, overburden, microclimate, site engineering and other management techniques as these pertain to plant materials, and culturally and historically significant plants. The forum also covered bond release criteria–including characterization and measure and evaluation criteria–and spoke to other issues related to achieving bond release.

The proceedings that follow constitute a partial compilation of the fruits of what proved to be this very valuable interactive forum. They consist of everything from the opening remarks of the Chairman of the Hopi Tribe on through some 50 presentations made by professionals possessing a wide range of diverse and divergent bond release, reclamation, and revegetation expertise. Among these experts were representatives of the coal-reclamation staff of six of the Western coal-primacy States, the Navajo Nation Historic Preservation Department, the Hopi Tribal Office, the U.S. Department of Agriculture's Agricultural Research Service, the Natural Resources Conservation Service, the U.S. Forest Service, the Flagstaff Arboretum, OSM, and the coal industry and its consultants.

It is with great pleasure that OSM offers the following compilation, which–with the exception of some stylistic changes made in the interests of uniformity of presentation–we have attempted to reproduce verbatim. We would like to extend our sincere thanks to all who made presentations at or otherwise attended the 1999 interactive forum. It is both our hope and our strong conviction that colloquia such as this one was stand greatly to benefit the cause of successful reclamation in the arid and semi-arid West.

Summary – at a Glance!!
Workshops and Interactive Forum
Approaching Bond Release: Revegetation —
(Native Plants, Native American Culturally Significant/Historical Plants),
Reclamation Issues, and Surface Mining Applications in the Arid, Semi-Arid West

September 20-24, 1999
Little America Hotel
2514 E. Butler Ave., I-40 exit 198, Flagstaff, AZ 86004, 1-800-352-4386
sponsored by the Office of Technology Transfer
Western Regional Coordinating Center
Office of Surface Mining (OSM), Denver, CO

September 20, 1999, Monday 8:30am - Noon
Infiltration & Runoff Workshop: A General Overview
Dr. Stephan Schroeder, ND Public Service Commission, Div. of Reclamation

September 20, 1999, Monday 1-5pm, continuing September 21, Tuesday, 8am-Noon
Revised Universal Soil Loss Equation (RUSLE) Vers. 1.06 -- Workshop
Dr. Richard Warner, University of Kentucky

September 21, Tuesday 1pm - 5:30pm Bond Release Interactive Forum

September 22, Wednesday

8am-5:30pm Bond Release Interactive Forum

6:30-9:30pm GIS and Spatial Applications for Surface Mining: Focus on Reclamation, Mike Price, ESRI Mining User Group Manager

September 23, Thursday, 8am - 5:30pm Bond Release Interactive Forum

September 24, Friday, 8am - Noon Bond Release Interactive Forum

September 25, 1999, Saturday, 8am-5:30pm - Field Tour Peabody Western Coal Company's Black Mesa/Kayenta Mine Complex

Agenda
for the OSM-sponsored
Interactive Forum
September 20-24, 1999

Monday, September 20, 1999 **8:30am - Noon**

Infiltration & Runoff Workshop: A General Overview
Dr. Stephan Schroeder, ND Public Service Commission, Div. of Reclamation

Revised Universal Soil Loss Equation (RUSLE) Vers. 1.06 **1-5pm**
Workshop, (continuing Tuesday, 8am-Noon)
Dr. Richard Warner, University of Kentucky

Tuesday, 1999 September 21, 1999 **8am-Noon**

(continuing) Revised Universal Soil Loss Equation (RUSLE) Vers. 1.06 – Workshop
Dr. Richard Warner, University of Kentucky

Bond Release Interactive Forum Welcome and Opening Remarks **1pm**
Wayne Taylor, Jr., Chairman, The Hopi Tribe

Plant Materials

Revegetation on the Cyprus Tohono Mine **1:15pm**
Mark Pater, NRCS, Tucson Plant Materials Center

Botanical Survey of Arid Land Native Species **1:45pm**
Ed Kleiner, Comstock Seed

Native Plants

Use of Native and Introduced Species in Colorado Reclamation **2:15pm**
Larry Routten, Colorado Minerals & Geology

Woody Stem Materials

Direct Seeding Establishment of Sagebrush: Research Advances **2:45pm**
Gerald Schuman, USDA-ARS, Cheyenne

Break **3:15pm**

Culturally Significant/Historical Plants

Treatment of Culturally Significant Resources: An Example from McKinley Mine **3:30pm**
Jim O'Hara**,** NM Mining & Minerals Division

Hopi Uses of Culturally Significant Plants AML Sites Reclamation Using Culturally Significant Plants **4pm**
Ralph Lamson, Gavin Seweyestewa, Max Taylor, Bob Flowers
Hopi Tribal Office

Listed, Rare, Threatened and Endangered Plants **4:40pm**
Dr. Joyce Maschinski, The Arboretum at Flagstaff

Wednesday, September 22, 1999

Welcome and Opening RemarksArvin S. Trujillo **8am**
Executive Director, Dept. of Natural Resources, The Navajo Nation

Cultural Plants Restoration: Status of Our Knowledge **8:15am**
Eric Bronston, Vern Pfannenstiel, Peabody Western Coal Co.

Traditional Culture Program of the Navajo Nation **8:45am**
Steven Begay and Timothy Begay, Historic Preservation Department

Diversity

OSM's Revegetation Success Outreach Initiative **9:15am**
Bob Postle, OSM, WRCC, Program Support Division

Building a Foundation for Diversity **9:45am**
Bruce Buchanan, Buchanan Consultants, Ltd.
Tim Ramsey, San Juan Coal Co.
Doug Romig, NM Mining & Minerals Div.

Break **10:15am**

Wyoming's Approach to Diversity **10:30am**
Rick Chancellor, WY DEQ, Land Quality Division

Using Montana Wetland Vascular Plant Communities to Understand Diversity Indices **11am**
Tom Parker, Bitterroot Restoration

Overview of Statistical Methods for Measuring Diversity **11:30am**
Richard Prodgers, Big Horn Environmental Quality Control
John Kern, Ph.D., Western Ecosystems Technology, Inc.

Lunch **Noon**

Evaluating Bio-diversity on Reclaimed Mined Lands **1pm**
Dr. Gary Wade, US Forest Service

Vegetation Representation through Geographic Information System(GIS) **1:30pm**
Mike Price, ESRI Mining User Group Manager
Greg Jones, Powder River Coal Co.

Applying Probe 1 Airborne Hyper-spectral Maps in Land Use Management **2pm**
Robert Stewart, Joe Zamudio, Earth Search Sciences, Inc. (ESSI)

Break **3pm**

A Comparison of Cover Sampling Methods **3:15pm**
Richard Bonine, Horizon Resource Management

Soil, Overburden, Growth Medium

Nutrient Management

Root Zone Reconstruction, Soil Handling and Potentially Acid/Toxic Forming Materials (PATFM) Relating to Successful Establishment of Vegetation
Greg Fenchel, New Mexico Plant Materials Center **3:45pm**

Toxicity

Bio-geochemical Considerations for the Use of Overburden, Waste Rock, and Leached Ore in Mine Land Reclamation **4:15pm**
Lewis Munk, D.B. Stephens & Associates, Inc.

GIS and Spatial Applications for Surface Mining: Focus on Reclamation,
Mike Price, ESRI Mining User Group Manager **6:30-9:30pm**

Thursday, September 23, 1999

Mycorrhizae

Establishment of Mycorrhizae Shrubs at Seneca Mine, Colorado **8am**
Len Ballek, Mike Thomas, Bitterroot Restoration

Micro Climate, Site Engineering, and Other Management Techniques

Weed Control

OSM Noxious Weeds Notebook for State of Washington and Tribal Lands; Sources of Technical Information Available to Plant Scientist **9am**
Rebecca Siegle, OSM-WRCC, Denver

Grazing Panel Discussion Moderator: Gary Wendt, Peabody West **9:15am**
O. J. Estrada, BHP New Mexico Coal
Roy Liedtke, Jacobs Ranch Mine, Kennecott Energy
Reg Hoff, Big Sky Mine
Vern Pfannenstiel, Peabody West

Break **10am**

Range Management

National Range and Pasture Handbook (1999 edition) **10:15am**
Steve Barker, USDA NRCS

Water Management

Extreme Surface Roughening: A Technique for Establishing Natives on Arid Lands and Slopes **10:45am**
Susan White, UT Div. Oil, Gas & Mining

Erosion Control Field Trials of DriWater Applications (University of Idaho) **11:15am**
Deborah Stokes-Haglund

Lunch **11:45am**

Erosion Control

American Society for Testing Materials (ASTM) Regulations/ Standards and Testing of Erosion Control/Bio-engineering **12:45pm**
Dwight Cabalka

Considerations for Arid, Semi-arid Designs **1:15pm**
William Agnew, Granite Seed

Application of RUSLE and SEDCAD+ for Design of Contour Furrows and Terraces to Minimize Sediment Yield **2:15pm**
Dr. Richard Warner, University of Kentucky

Continuation of Other Topics (scheduling conflicts)

Non-parametric Vegetation Evaluation for Bond Release **2:45pm**
Richard Bonine, Horizon Resource Management

Break **3:15pm**

Breeding and Selection of Plants that are Diverse, Effective and Permanent **3:30pm**
Howard C. Stutz, Ph.D., Prof. Emeritus,
Brigham Young University

Bond Release Criteria/Bond Release Achievement

Measurement/Evaluation

Build It and They Will Come: Successful Bond Release Begins with the Post Mining Topography (PMT) **4:30pm**
Chris Yde, MT DEQ Industrial & Energy Minerals Bureau,
Permitting & Compliance Div.

Black Mesa Culturally Significant Plant Seed Collection **5pm**
Len Ballek, Mike Thomas, Bitterroot Restoration

Friday, September 24, 1999

Reverse-null Hypothesis Testing for Bond Release in New Mexico **8am**
Dave Clark, NM Mining & Minerals Div.

Environmental Data Collection: Plants Species/Wetland Delineation **8:30am**
Michael Maier, Condor Earth Technologies, Inc.

Final Colorado Bond Release Case Studies **9:15am**

The Canadian Strip Mine Bond Release Case Study
Sandra Brown, Colorado Minerals & Geology

Red Canyon Mine Phase II and III Bond Release Study
Dan Mathews, Colorado Minerals & Geology

Break **10am**

Why Are Vegetation Data Non-Normally Distributed? **10:15am**
Robyn Tierney, Tierney and Associates

Inspector's Role in Bond Release **10:45am**
Willis Gainer, Field Office Director, OSM Albuquerque Field Office

Philosophy and Flexibility in Bond Release **11:15am**
Wanda Burget, Peabody Western Coal Co.

Forum Summary Brent Wahlquist, Regional Director, WRCC **11:45am**

Arboretum at Flagstaff – Organized General Tour **2-4pm**

September 25, 1999, Saturday, **8am-5pm - Field Tour**
Peabody Western Coal Company's Black Mesa/Kayenta Mine Complex

(For copies of photographs of the reclamation seen on-the-ground during this field tour, see appendix B of the interactive forum proceedings.)

Workshop & Field Tour Descriptions

September 20, 1999, **Monday 8:30am - Noon**

Infiltration & Runoff Workshop: A General Overview

Dr. Stephan Schroeder, ND Public Service Commission, Div. of Reclamation

Workshop will include an overview of Infiltration -- into the soil, through the soil matrix, mathematical estimations, factors affecting infiltration, field and laboratory measurement techniques, and mineland field data examples. Runoff portion will include mathematical estimations, curve runoff method, time of concentration, peak runoff rate, runoff volume, factors affecting runoff, field measurement techniques, and mineland field data. Water erosion estimation with peak runoff rate will be discussed.

September 20, 1999, **Monday 1-5pm, continuing Tuesday, 8am-Noon**

Revised Universal Soil Loss Equation (RUSLE) Vers. 1.06 -- Workshop

Dr. Richard Warner, University of Kentucky

Workshop is specifically designed to familiarize the users with the new Revised Universal Soil Loss Equation (RUSLE) Vers. 1.06, modified to account for mining, reclamation and construction site-specific conditions. RUSLE 1.06 is a powerful program that enables the user to take credit for numerous erosion control measures that are commonly applied in (coal) mining and reclamation scenarios. Workshop will instruct participants on how to develop better predictions of soil loss, and through implementation of erosion protection measures, model the reduced quantity of sediment being transported off site or to a sediment basin.

September 22, 1999, **Wednesday, 6:30-9:30pm**

GIS and Spatial Applications for Surface Mining: Focus on Reclamation

Mike Price, ESRI Mining User Group Manager

Workshop showcasing latest ArcView and other utilities for mining applications.

September 25, 1999, **Saturday, 8am-5pm – Field Tour**

Peabody Western Coal Company's Black Mesa/Kayenta Mine Complex

Participants will observe current mining and reclamation operations at the Black Mesa/Kayenta Coal Mine Complex located on Black Mesa in Northern Arizona.

Of particular interest will be the ongoing work in establishing culturally significant native plants on reclaimed lands. Both established stands and recently seeded areas will be visited. The visit will offer an opportunity to discuss identification and collection of culturally significant native plant species and the various techniques that have been used to establish them on the mine.

Contents

(Note to readers: You may access the proceedings detailed below directly, from this and the next three pages, by means of the ☞ hot links that appear throughout the table of contents. Click on any ☞ image in the contents to link to the section of the proceedings associated with that image.)

Page

☞ **Preliminary pages**

☞ A word about these proceedings iii
☞ Forum agenda iv
☞ Table of contents xiii
☞ "Opening Remarks," by Wayne Taylor, Jr. xvii
☞ "Forum Summary," by Brent Wahlquist xx

☞ **Plant materials**

General
"Cyprus-Tohono Mine Revegetation Trials," by Mark Pater 3
"Desert Reclamation," by Ed S. Kleiner 22
Native plants
"Native and Introduced Species in Colorado Reclamation," by Larry Routten 55
Woody stem materials
"Direct Seeding Establishment of Wyoming Big Sagebrush: Research Advances," by Gerald E. Schuman 67
Culturally significant/historical plants
"Using the Study of Cultural Landscapes to Develop Postmining Land-Use Plans," by James O'Hara 84
"Small Area Reclamation on the Hopi Reservation and Hopi Uses of Culturally Significant Plants for AML Sites Reclamation," by Ralph Lamson, Gavin Seweyestewa, Max Taylor, and Bob Flowers 91
Listed, rare, threatened, and endangered plants
"The Endangered Species Act of 1973," by Joyce Maschinski, Ph.D. 97
Diversity
"OSM's Revegetation Success Public Outreach Initiative: An Assessment of the Need to Revise the Federal Revegetation Success Regulations," by Robert C. Postle 100

Page

☞ **Plant materials–*continued***
Diversity–*continued*
"Building a Foundation for Diversity: Topdressing Variability for Distinct Plant Communities," by Bruce Buchanan, Tim Ramsey, and Douglas Romig 114
"Wyoming's Approach to Species Diversity," by Richard A. Chancellor 122
"Applying a Method for Quantifying the Diversity of Montana Wetland Plant Communities to Understanding the Diversity of Plant Communities within Surface Mining Reclamation Units," by Tom Parker 139
"Overview of Statistical Methods for Measuring Diversity," by Richard Prodgers and John Kern, Ph.D. 147
"Evaluating Biodiversity of Reclaimed Mined Lands," by Gary L. Wade, Ph.D 148
"A Comparison of Cover Sampling Methods," by Richard Bonine 154

☞ **Soil, overburden, and growth media**
Nutrient management
"Establishing Desirable Vegetation in the Southwest," by David R. Dreesen, Gregory A. Fenchel, and Joseph G. Fraser 157

☞ **Microclimate, site engineering, and other management techniques**
Weed control
"OSM Noxious Weed Guides for the State of Washington and Tribal Lands: Sources of Technical Information Available to Plant Scientists," by Rebecca Siegle 164
"Update on Reclamation Grazing at Jacobs Ranch Mine," by Roy Liedtke 166
Range management
"National Range and Pasture Handbook (1999 edition)," by Steve Barker 172
Water management
"Extreme Surface Roughening: A Technique for Establishing Natives on Arid Lands and Slopes," by Susan White. 178
"Initial Evaluation of Shrub Transplanting Programs for Highway Slopes," presented by Debbra Stokes-Haglund (authored by Stanley Miller and Charles Rountree) 180
Erosion control
"The Future of Erosion Control on Mine Projects: NPDES and ASTM D-18.25," by Dwight Cabalka 186

Page

☞ **Microclimate, site engineering, and other management techniques–*continued***

Erosion control–*continued*

"Considerations for Arid and Semi-Arid Designs," by William Agnew 195

"Terrace Design Using RUSLE and SEDCAD 4" presented by Richard C. Warner, Ph.D. (authored by Richard Warner, Ph.D. and Daniel C. Yoder, Ph.D. 208

"Non-parametric Vegetation Evaluation for Bond Release," by Richard Bonine 209

"Breeding and Selection of Superior Plants for Use in Reclamation," by Howard C. Stutz, Ph.D. 210

☞ **Bond-release criteria/bond-release achievement**

Measurement/evaluation

"Build It and They Will Come: Successful Bond Release Begins with Postmining Topography," by Chris Yde 213

"Reverse Null Testing for Bond Release in New Mexico," by Dave Clark 226

"Geographic Information Systems: Increased Use and Applications," by Michael R. Maier 234

"Final Colorado Bond Release Case Studies: The Canadian Strip-Mine Bond Release Study," by Sandra Brown 236

"Final Colorado Bond Release Case Studies: Red Canyon Mine Phase II and III Bond Release Study," by Dan Mathews 244

"Suggested Readings for Western Ethnobotany," by Robyn Tierney 250

"OSM's Role in Enhancing Bond Release on Indian Lands and in Federal Program States," by Willis Gainer 252

"Philosophy and Flexibility in Bond Release," by Wanda Burget 261

☞ **Workshop presentations**

Infiltration and runoff

"Infiltration and Runoff: A General Overview," by Stephan A. Schroeder, Ph.D. 265

RUSLE

"RUSLE Version 1.06," by Richard C. Warner, Ph.D. and Mike Anderson 294

☞ **Of general interest**

Appendix A. Interactive forum attendees A-1

Appendix B. Field Tour of Peabody Western Coal Company's Black Mesa/ Kayenta Mine Complex B-1

Page

☞ **Of general interest–*continued***

Appendix C. Plants for Western land reclamation (1994 edition) C-1

Appendix D. Contact and web-page listings: Noxious weed control in coal mining regions of the West D-1

Appendix E. A guide to noxious weeds of the Navajo Reservation E-1

Appendix F. A guide to noxious weeds of the Centralia mine, Washington State F-1

Appendix G. Breeding and selection of superior plants for use in reclamation G-1

OSM would like to thank the following schools of higher education, organizations, and individuals for providing the plant images that appear on divider pages throughout these proceedings:

The University of Arizona College of Agriculture; Arizona State University Life Sciences; USGS Northern Prairie Wildlife Research Center; Illinois Natural History Survey, Kenneth R. Robertson; and Southern Nevada Wildflowers, Phil Koch.

These images capture with great skill what is often the striking beauty of the native plant life used to reclaim minesites in the arid and semi-arid West.

Opening Remarks

Wayne Taylor, Jr.
Chairman, The Hopi Tribe

Good afternoon, Ladies and Gentlemen. On behalf of the Hopi Tribe, I welcome you to Nuvatukyaovi, home of the Katsina spirits. Flagstaff, as the rest of America knows it, is located at the base of the San Francisco Peaks in the largest Ponderosa pine belt in the world. The peaks are sacred to the Hopi. The Hopi Katsina spirits come to the Hopi mesas each February bringing many gifts, including much needed rain, and return once again to Nuvatukyaovi in July following the home dance.

Our homeland is located 90 miles northeast of here in a semi-desert environment where average rainfall is 6 to 14 inches annually. Twelve villages located on three mesas are home to the Hopi people. The three mesas are extensions of the Black Mesa, on which active mining is occurring 60 miles north of there.

The Hopi Tribe is a union of the twelve autonomous villages. Each village has the opportunity to send representatives to the Hopi Tribal Council. Each village retains control over certain local matters.

The Hopi aboriginal lands encompass the Four Corners region, which includes the entire Black Mesa. Since time immemorial, we have survived in the harsh environment, lived in harmony with the environment, and practiced our religion. Our ancestors, whom we know as the Hisatsimon, lived off the land as farmers and gatherers. Plants were gathered for food, medicinal use, religious use, tool making, and craft making. We are known worldwide for our dry farming techniques. Our corn, melons, beans, and squash are adapted to our harsh environment and are bountiful even during drought years. We continue our practices, just as our ancestors did, even though we live in a modern age.

Prior to the large surface-mining operations on the Black Mesa, our ancestors were mining coal locally for use in firing pottery and heating homes. In fact, the village of Awatovi, a site that was occupied by early Spanish explorers in the 1500's, mined in excess of 100,000 tons of coal during the 1200 to 1500 A.D. time period.

Much later, the Bureau of Indian Affairs operated mines in the local village areas to provide coal to the schools for use by steam plant facilities. With the advent of Peabody Western Coal Company’s (PWCC’s) mining operation on the Black Mesa-Kayenta leasehold, the local mines were abandoned, creating unsafe and environmentally polluted conditions. The Hopi abandoned mine lands (AML) program was organized to begin the successful closure and reclamation of abandoned coal mines. The AML program utilized local Hopi labor to minimize unnecessary surface disturbance and to also provide jobs to the local economy. The reclamation process

included the reseeding of native plant materials and included culturally important plants. The careful hand-seeding techniques produced a diverse plant community that blends in with the surrounding area at each of the reclamation sites.

The area of Black Mesa currently being mined by PWCC is one of the largest surface mines in the country. The coal supplies two power-generating stations through long-term delivery contracts between the Hopi and Navajo Tribes and utility owners. The Black Mesa unit coal train delivers approximately 7 million tons of coal to the Navajo Generating Station near Page, Arizona.

A coal slurry pipeline delivers approximately 5 million tons of pulverized coal to the Mojave Generating Station in Laughlin, Nevada, a distance of some 270 miles. The coal slurry uses approximately 4,000 acre-feet of ground water, pumped from the Navajo sandstone aquifer, annually. This is the same water used for domestic purposes by both the Hopi and Navajo Tribes. The Hopi Tribe is concerned that much of the future groundwater resource is leaving the reservation and that the aquifer cannot withstand the pumping rates of withdrawal without having a serious impact to the regional hydrology. The concern is of such significance that the Hopi Tribal Council disapproved a life-of-mine permit in 1990, until an alternative water supply could be secured. As I speak, the operation for the Black Mesa portion of the mine continues under an interim mining permit, until the use of a water supply other than the N-aquifer can be obtained.

The Hopi Tribe is actively pursuing a settlement of the Little Colorado River Stream Adjudication, which involves construction of the Lake Powell Pipeline Project. The pipeline will serve to deliver Colorado River water to the Hopi villages and portions of the Navajo Reservation; it will include a spur to the Black Mesa mine for use in the coal slurry operation. PWCC and the major utilities have participated in the settlement and negotiation of the Little Colorado River water-rights case. Until recently, PWCC has supported the draft legislation by agreeing to contribute a significant portion of funds to the construction of the Lake Powell Pipeline.

Mining on the Black Mesa plays an important role in our economy. Revenues received as royalty payments are generated from mining and are used to fund essential governmental programs–such as health care, education, law enforcement, and so forth–for the Hopi population. However, we must be mindful that land sustains life not only for the Hopi but also for all creatures and plant life. So it is imperative that the land be restored back to approximate original contour so that all life can benefit from it.

During mining, a relatively small area is disturbed in order to reach the coal. The area is cleared of all vegetation, topsoil, and overburden. The topsoil is stored onsite, to be returned to its original location following mining. After removal of the coal, reclamation of the area starts. Good planning and cooperation are essential for successful reclamation, in order for the area to return to its original conditions or better.

To many in the outside world, the plants we regard as culturally important are considered noxious weeds, or have little value economically. However, to the Hopi, they have tremendous values and uses. Some plants can be found in abundance everywhere, while others require special or sensitive growing conditions. It is these areas that require protection or special attention for, without it, the plants will become extinct, and the Hopi Tribe will have lost an important piece of its cultural connection.

Cooperation between PWCC, OSM, and the Tribe has resulted in a seed mixture for reclamation that includes cultural and historic plant seeds for revegetation on reclaimed areas. This is a positive step that must be fostered to protect and maintain a sustainable environment on the Black Mesa leasehold.

I understand PWCC maintains a cultural and historic plant demonstration project, for which it received a national award. I applaud them for a well deserved award. I encourage those of you who deal with mining on Native American lands to work cooperatively with the landowners in this respect. By working together cooperatively, we can overcome the many obstacles that may stand in our way.

During this conference, the Hopi Office of Mining and Mineral Resources staff will do a presentation on the uses of culturally important plants. There will also be a display booth where you will have the opportunity to observe these uses.

Thank you for inviting me to say a few words. I hope you enjoy your stay in Flagstaff, and I hope you will also take time to drive out to visit our homeland.

Forum Summary

Brent Wahlquist, Regional Director
Western Regional Coordinating Center
Office of Surface Mining (OSM)

I appreciate the opportunity to provide a summary at the close of this interactive forum. I also appreciate those of you who have stayed here till the bitter end to hear it. It has been an excellent conference. I have been very impressed with the attendance, the caliber of the presentations made, and the questions and interaction that has occurred with each presentation.

This forum has focused on achieving final or phase III bond release. Yet, I think we all recognize that the real goal is sustainable reclamation. It is somewhat analogous to the comparison between getting an education and a diploma. The school's job and goal is to educate its students. Awarding a diploma is an indication that an acceptable level of education has been achieved. So it is with phase III bond release.

We have a statutory standard for successful revegetation of mined lands, which is **diverse, effective, and permanent vegetative cover, at least equal to premining cover, that is capable of self-regeneration and plant succession**. Species of the same seasonal varieties native to the area should be used. However, introduced species may be used where necessary and desirable to achieve the approved postmining land use. We are also to achieve enhancement of fish, wildlife, and related environmental values where practicable. That is our standard. It is established by statute. And it is noteworthy that the first item mentioned in that statutory standard for vegetation is **diversity**, which is also key to enhancing wildlife and related environmental values.

Based upon the presentations I have attended, and looking over the agenda for the ones I missed, it appears to me that this conference has touched on five basic aspects of reclaiming lands disturbed by surface coal mining operations: (1) establishing the postmining topography, (2) replacing the soil substrate, (3) managing precipitation, (4) planting plans for reestablishing vegetation, and (5) managing the vegetation until final bond release. I would like to briefly touch on each of these as it relates to that statutory standard:

Topography –A key aspect of reestablishing diverse vegetation is creating diverse topography. Yet, the topography of reclaimed lands is often much more uniform than is the premining topography of these lands. I appreciated the efforts of the State of Montana regulatory staff–described in their presentation "Build It and They Will Come"–to increase topographic diversity and habitat niches during the regrading process. We all need to look for ways to encourage such efforts and eliminate impediments to greater topographic diversity. It is an essential step to increased vegetative diversity and the long-term success of our reclamation efforts.

Soils –In the natural premining state, there is considerable variability in the soils across a minesite. There were presentations here which recognized that uniform distribution of topsoil may not always be the best approach and that–by tailoring our topsoil redistribution to match topographic sites and create habitat niches–we could probably be doing better than we have done. If we simply put down uniform topsoil, we may be inhibiting restoration of the natural diversity associated with premining soils, which are often found in a predictable relationship with the topographic relief.

Precipitation management –There were several presentations here that dealt with what I will call precipitation management. That is, how to maximize the life-giving benefit of precipitation while minimizing its potentially destructive force. Controlling precipitation is critical not only to the reestablishment of vegetation but also to the long-term stability of reclaimed lands. Much can be gained from the application of the principles discussed here.

What, when, and how to plant –Obviously, when it comes to vegetation, what you plant is key to what you get. And there were many excellent presentations that addressed this issue. I am very encouraged by the range of different things being tried and the interest in a wide range of vegetation. I particularly enjoyed Dr. Stutz's presentation. I don't think I had heard terms like gamete and polyploid since I last sat in his classes over 30 years ago.

Vegetation management –Finally, those who have been exposed to range management principles in the West fully realize that, over time, grazing can have a dramatic impact on vegetative composition as well as cover. There were presentations addressing weed control and how to utilize managed grazing to help achieve vegetation goals.

All five of these aspects of the reclamation process are key to reestablishing a diverse and effective vegetative cover. There is much to be gained from effective application of the principles presented here related to each of the five aspects.

However, there was another overarching issue that dominated much of this forum. That was: ***How do we measure success??*** While most of the concern was expressed about the statistical aspects of evaluating revegetation success, presentations also touched on the standards for judging the regraded topography, topsoil replacement, water management, and what to plant, as well as was that planting successful.

By regulation, OSM has expanded on the rather subjective statutory standard for evaluating vegetation success. Those regulatory standards introduce the concept of **productivity** and require statistical validity for vegetation measurements. One of the major concerns I have had, particularly since attending the bond release forum a year ago in Denver, is that our regulatory

emphasis on statistically valid measures and vegetative productivity may actually be frustrating the statutory standards of diversity and the capability for natural succession into the desired climax plant community. I think we all understand that a hardwood forest in Appalachia is not reestablished in 5 years nor is a shrub/grassland community in the semi-arid West fully reestablished in 10 years. These reestablished communities will continue to evolve and change over time as they mature. Which is why the statutory standard for revegetation includes the capability for self-regeneration and plant succession.

Yet, what is measured is what operators will try to achieve. While there is value in bright-line objective criteria in determining whether or not an operator has qualified for the diploma of phase III bond release, we need to be very careful that those criteria don't actually frustrate the goal of long-term reclamation. Detailed, statistically valid descriptions within 10 years after planting are just snapshots in time of a plant community in transition. Requiring such descriptions is a bright-line standard that is easy to conceptualize, even though it may be very expensive and time consuming to apply. However, requiring such descriptions, together with an emphasis on productivity, may actually discourage efforts to increase vegetative diversity. Within the past year, we have conducted an outreach effort on this very issue. A preliminary summary of that effort has been presented here. We have also heard several other presentations regarding how to evaluate vegetative success and raising concerns with the current emphasis on statistics and how they are used. I share those concerns.

Please understand: as Regional Director, I am very committed to the reestablishment of vegetative communities that will stand for generations to come. I am also convinced that a key aspect of achieving this goal is increasing the vegetative diversity in our reclaimed areas, so that they will be better able to adapt to pressures and changes we cannot yet foresee. Achieving the goal involves all five of the reclamation aspects discussed above. I also recognize that achieving a regulatory standard is only an imperfect measure of whether or not we have achieved the statutory goal. While I do not anticipate a change in OSM's national rules, which rely on statistical analysis, I am concerned that those rules may tend to inhibit achievement of the statutory goal of diversity. However, we can approve individual State standards that are quite different from OSM's rules so long as they are supported by a clear rationale showing that they will be no less effective than our rules at achieving the statutory standard highlighted at the beginning of this presentation. I have signature authority for approving State program changes and would be very interested in considering changes to State revegetation standards toward that end. I would urge every State to work with its academic community in developing State-specific standards suitable for the plant communities found in that State, together with a rationale as to why those standards will be no less effective than OSM's rules at achieving the statutory standard.

Again, thank you all for your participation and for hanging around until the end.

Plant Materials

- ☞ **General**
- ☞ **Native plants**
- ☞ **Woody stem materials**
- ☞ **Culturally significant/historical plants**
- ☞ **Listed, rare, threatened, and endangered plants**
- ☞ **Diversity**

General

Blue grama
Bouteloua gracilis

"Cyprus-Tohono Mine Revegetation Trials"
"Desert Reclamation"

Cyprus-Tohono Mine Revegetatation Trials

Mark Pater, Operations and Research Coordinator
U.S. Department of Agriculture
Natural Resources Conservation Service
Tucson Plant Materials Center

Introduction

The Cyprus-Tohono Mine is located in the Phoenix Desert Shrub, Major Land Resource Area 40-2, between 1,800 and 2,252 feet in elevation. The mine is located approximately 32 miles southwest of Casa Grande, Arizona, on Highway 15 on the southwestern side of the Slate Mountains.

The objectives of this project are to conduct trials and evaluate methods for revegetating overburden and mine-processed material using native plant materials. The information acquired from these trials will provide Cyprus-Tohono Corporation with a prescription for large-scale revegetation, in accordance with agreements made with the Tohono O'Odham Nation. Information gained from this project may also aid in improving conservation practices elsewhere in the southwestern United States. The primary goal for revegetating the overburden and mine processed material is to stabilize the slopes to prevent erosion and to blend the overburden piles with the surrounding, undisturbed slopes.

The use of native plant materials will eventually promote the utilization of the overburden slopes as territorial and forage locations for native wildlife species. Animals thought to directly benefit from revegetation include mule deer, javalina, Gambel's quail, desert cottontail, and various reptiles and arthropods.

The objectives of this project are also designed to meet the concerns of North Komelik Village and the Sif Oidak Grazing District, in relation to improving the aesthetic appearance of the mine as viewed from North Komelik Village and Highway 15. Revegetation of slopes facing North Komelik Village is the desired goal for Cyprus-Tohono Corporation.

The soils and bedrock were analyzed and found to be calcareous. Soils in the disturbed areas will be affected by the removal of vegetation, excavation and the storage of topsoil. The potential for erosion is high on the non-vegetated 4:1 slopes. Some evidence of rill erosion is apparent on newly created and exposed slopes. Potential for gully formation is great once the summer rains begin. Sheet and rill erosion are also a concern during medium to heavy precipitation events. Wind and water erosion can be evaluated using the Revised Wind Erosion Equation (RWEQ) and the Revised Universal Soil Loss Equation (RUSLE). There is no evidence of compacted layers that will restrict water or root penetration. No evidence of crusting has been observed. No excess of natural or applied chemicals or elements such as boron, selenium, or other heavy metals have been found. The potential for surface water quality impact is low due to the

ephemeral nature of surface water at the site. There are no aquatic organisms observed near the site. Groundwater quality is monitored by the mine on a recurring basis. The air quality at this site may be affected by the activities at the mine. Strong winds are common and airborne particulates can obstruct vision. The planting site does not significantly contribute to air quality problems due to its small size and low amount of fine particulate matter in the soil substrate.

Dominant plants currently surrounding the site include: littleleaf palo verde, ironwood, triangle-leaf bursage, white ratany, creosote bush, ocotillo, and saguaro and hedgehog cacti. Plant species needed to stabilize the site must be native to the Sonoran Desert ecosystem with emphasis on species occurring in the U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Range Site Description for MLRA 40-2. Plant species may include triangle-leaf bursage, creosote bush, littleleaf palo verde, purple threeawn, brittlebush, white ratany, and fourwing saltbush.

Methods and Materials, 1996 Planting

The March 18 through 29, 1996, planting was made using 1,374 containerized plants that were propagated at the Tucson Plant Materials Center (PMC). The three container sizes were: Tree Pots™ (532 cubic inches), Deepots™ (40 cubic inches), and Conetainers™ (15 cubic inches). Approximately 2 gallons of water was poured into each hole immediately before transplanting each containerized plant. Table 1 lists the species used in this planting.

Table 1 —Species propagated for the 1996 planting

Scientific Name	Common Name
Acacia constricta	whitethorn acacia
Ambrosia dumosa	white bursage
Atriplex canescens	fourwing saltbush
Baileya multiradiata	desert marigold
Cercidium microphyllum	littleleaf palo verde
Encelia farinose	brittlebush
Larrea tridentate	creosotebush
Lupinus arizonica	lupine
Prosopis juliflora	mesquite
Sphaeralcea ambigua	desert globemallow

Plant height and canopy cover data were collected on a monthly basis beginning in April 1996 through August 1996. Survival data were collected in September 1996.

Methods and Materials, 1997 Planting

The 1997 spring and summer plantings are organized as Randomized Complete Blocks design. Each treatment area has four randomized complete blocks (planting plots) containing each of the five species to be planted. Each randomized complete block was replicated 4 times: 4 randomized complete blocks x 2 treatment areas x 2 planting times = 16 total plots. Each plot contains 5 species, 10 individuals per species = 50 plants per plot; 16 total plots at 50 plants per plot = 800 plants.

The spring planting was divided into two treatment areas, fertilized versus not fertilized, to determine if fertilizer application at the time of transplanting aids in transplant survival. The summer planting did not involve any fertilizer treatments.

The plants for each species were propagated at the Tucson PMC. At the evaluation site, the plants in each replicated plot were transplanted by hand. Each planted row for all replicated plots is 50 feet in length and spaced 10 feet apart. Each plant within each row within all replicated plots is spaced 15 feet apart. The plants will be evaluated on a monthly basis for growth and survival.

Methods and Materials, 1998 Planting

The FY 1998 planting was planned to be a large-scale planting using a more natural planting layout relative to the block designs used in the past. The proposed planting site is located on a former water tank storage site. This storage site is located on top of a small hill and is approximately 1/2 acre in size. Evaluation criteria for this planting include survival percentage and growth rate. Data will be analyzed and interpreted by Tucson PMC personnel.

The primary objective for the FY 1998 planting is visual mediation using native species. The species for the FY 1998 planting include: creosote bush, whitethorn acacia, mesquite, palo verde, ironwood, globemallow, fourwing saltbush, brittlebush, desert marigold, and purple threeawn. These species were propagated in Deepot™ containers at the Tucson PMC.

At the time of the planting installation, Cyprus Tohono Corporation will provide: (1) protective wire cages for each plant or fence the entire area in order to reduce damage by small animals, (2) one 500 gallon water tank with hose in order to water the transplants at the time of installation, (3) sufficient labor to properly execute the planting. Prior to planting the site will need to be contour-graded and ripped. Prior to planting, soil samples will be obtained and evaluated for pH and soil fertility. The optimum planting period would be after the onset of the summer rains (July-August). This time of year is generally characterized as having lower daytime temperatures, higher relative humidity and greater potential for precipitation as compared to the months of April through mid June. A supplemental watering system may be installed at the discretion of the Cyprus Tohono Corporation.

It is estimated that 1,500 plants will need to be propagated. The planting design will try to be laid out to give a natural appearance and blend in with the undisturbed vegetation next to the planting

site. All plants will be spaced approximately five to ten feet apart, this should allow for 1,500 plants to cover a total area of 37,500 ft^2 (0.86 acres).

Status of Knowledge

Surface mining removes vegetation that protects soil against erosion. Surface mined areas that have not been reclaimed usually become a wasteland of rubble and waste dumps. Runoff erodes these areas, carrying sediment, and in some places chemical pollutants to surface and groundwater. In addition, unprotected sites are sources for blowing dust, thereby degrading air quality (U.S. Department of Agriculture, 1973). The visual aesthetics of the mined areas have a negative effect upon urban and recreation areas. Over 80 percent of surface mines in the U.S. are within 10 miles of population centers, and 60 percent are visible from public use areas (Copeland, 1973).

Seeding critical areas has historically had limited success primarily due to a lack of adequate precipitation. The Tucson PMC decided to evaluate the use of containerized plant materials to determine whether this could be an effective method of revegetation on mined lands. Containerized stock should have a higher establishment success rate over direct seeding primarily because the period from seeding through seedling emergence and establishment is completed in a relatively low stress nursery setting. Containerized planting stock can be grown relatively quickly. The developed root system is generally well protected during the planting process and therefore survival rates of the transplanted material are generally increased. A disadvantage of containerized planting stock is that the materials can be quite heavy and difficult to handle. Proper storage areas, watering facilities, and daily care also increase the cost of producing this type of materials (Monsen and others, 1979).

The application of fertilizer on nutrient-deficient soils may improve plant establishment and growth. Consideration must be given to the nutrient requirements of the species being planted. Some plant species have lower nutrient needs than others and thus may not require fertilizers. Soil nutrient deficiencies need to be determined by field and lab soils tests in order to best determine the type and amounts of fertilizer required. Nitrogen (N) and phosphorous (P) are the nutrients most often deficient in semi-arid regions. Potassium and other nutrients are usually adequate in soils from the Sonoran Desert region (Tucker and Day, 1980).

Arid and semiarid lands are characterized by low levels of organic matter and consequently low nitrogen reserves since soil organic matter is the nitrogen carrier. Vegetation is characteristically sparse and moisture is limiting. Calcareous soils are very common throughout the arid southwest. They contain calcium carbonate throughout the plant-root zone in quantities ranging from a trace to over 50 percent by weight. Interspersed with these calcareous soils are sodic and potassic soils with relatively high pH values. Accumulations of soluble salts and various cation and anion combinations also occur. Some of these salts are sufficiently abundant to adversely affect nitrogen transformations as well as absorption of nitrogen by plants (Fuller, 1963). Native species found growing on these sites are well adapted to these soil conditions.

According to Munshower (1994), the application of fertilizers in disturbed land rehabilitation is a common practice. Nitrogen is the most commonly applied plant nutrient on disturbed sites. This element may be added to disturbed soil in any of the forms shown in Table 2. Nitrogen application rates need to be balanced with the species being seeded along with the particular soil being seeded into. Nitrogen application rates depend on the organic matter content of the soil as well as the amount of NO_3-N in the soil. Native, perennial vegetation indigenous to environments with low nutrient availability usually have much lower nitrogen requirements than agronomic species.

Table 2 — Common fertilizer forms of nitrogen (Munshower, 1994)

Name	**Chemical Formula**	**% Nitrogen**
Urea	NH_2CONH_2	46
Ammonium nitrate	NH_4NO_3	35
Anhydrous ammonia	NH_3	82
Ammonium phosphate	$NH_4H_2PO_4$	12 (27% P)
Diammonium phosphate	$(NH_4)_2HPO_4$	21 (23% P)
Ammonium sulfate	$(NH_4)_2SO_4$	21 (25% S)

Munshower (1994) also states that researchers in Colorado did not recommend the addition of N to native grasslands when the soil organic matter exceeded 2 percent (Farmer and Richardson, 1980). When the organic pool in a soil was less than 1 percent and soil nitrates were less than 5 μg/g, Farmer and Richardson (1980) recommended only 40 lbs/acre of N-fertilizer. Additional research by others also supports this small to no nitrogen application rate for grass species seeded on topsoiled mined materials in Western coal fields (Richardson and Farmer, 1983; Daily Post, 1972). Another study by Bjugstad (1979) in southeastern Montana showed that the main responses to nitrogen applications were an increase in annual grass or annual weed production and decreased diversity. Legumes used in revegetation programs are beneficial nitrogen fixers and have a biological advantage over non-nitrogen fixing species (Munshower, 1994).

As with nitrogen fertilization, phosphorous amendments should also be based on soil nutrient analyses. Good quality topsoil should meet the phosphorous requirements of most native species. Phosphorous deficiencies can often be observed in vegetation growing on disturbed soils in more mesic areas, on hard rock wastes, or on acid soils (Munshower, 1994). Phosphate fertilization on semiarid coal mine soils commonly increased the production of annual grasses and weedy forbs and produced little or no response by the more desirable perennial grasses (Tripodi and Cheremisinoff, 1980). Phosphorous is tied up by heavy metals in acid soils. Phosphorous amendments in these types of soils should prove beneficial. Since phosphorous is less soluble than nitrates, it must be incorporated into the soil to ensure good soil-root-phosphorous contact (Munshower, 1994).

In general, soil amendments are not necessary or effective in arid, desert environments in promoting or enhancing plant growth. A revegetation test program by the Bureau of Land

Management (BLM) in California on the Soledad Mountain Project (1997) showed that the addition of soil amendments was not beneficial. Recommendations by the Desert Restoration Task Force (Bainbridge and others, 1995) also states that soil amendments and mulches are often unnecessary in desert environments, although the addition of organic matter may increase seed germination and establishment. Mulch can provide protection from wind, reduce evaporation, increase infiltration and rainwater retention, reduce erosion, and improve plant microclimate. Materials with lots of lignin and high carbon to nitrogen ratios appear to be desirable in most desert soils. These materials provide a long-term food source for fungi and subsequent grazing by microarthropods. This grazing activity makes nitrogen available to plants. Mulches can also be used to tie up available nutrients so that the site is less suitable for invasive exotics. Native plants in the southwestern deserts are generally adapted to relatively low nutrient sites and do not respond well to the application of fertilizers. Invasive exotic species, in contrast, are often from areas of high disturbance and/or high fertility and respond very strongly to the application of fertilizers (Bainbridge, 1995; St. John, 1987).

Results, 1996 Planting

White bursage was propagated in both Deepots™ and Tree Pots™. Declining plant heights and canopy cover was observed during the months of June and July, 1996 and was attributed to a lack of precipitation and high summer temperatures. The plants appeared to begin to recover with the arrival of summer moisture during the month of August (Figure 1). Six months after transplanting, white bursage from the Tree Pot™ containers had a significantly higher 91 percent survival over the white bursage from the Deepot™ containers which exhibited a 71 percent survival. Survival counts were conducted again at the end of December 1998. Survival for the white bursage remained at 91 percent for the Tree Pot™ containers and 71 percent for the Deepots™.

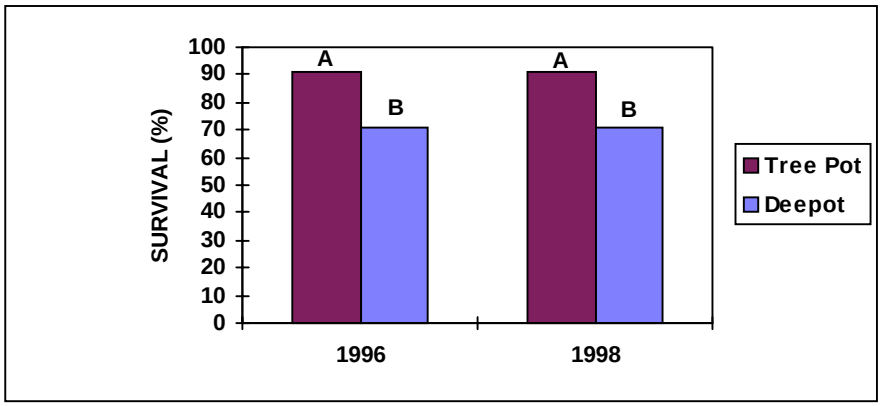


Figure 1 — March 1996 planting, survival comparison with two plant container sizes for white bursage (*Ambrosia dumosa*). Percentages with different letters are significantly different at the 0.05 level.

Fourwing saltbush was also propagated in both Tree Pots™ and Deepots™. Despite a lack of substantial precipitation during the months of June and July in 1996, plant growth did not

noticeably decline. However, a decrease in canopy cover was noted during this period in the plants propagated in Tree Pots™ (Figure 2). Six months after transplanting, fourwing saltbush from the Tree Pots™ had 100 percent survival while those from the Deepot™ containers had a 96 percent survival. At the end of 1998 the survival for this species had declined to 59 percent for the plants from the Tree Pots™ and 41 percent for the Deepots. The 1998 survival for the Tree Pots™ was significantly greater than the survival for the plants from the Deepots™.

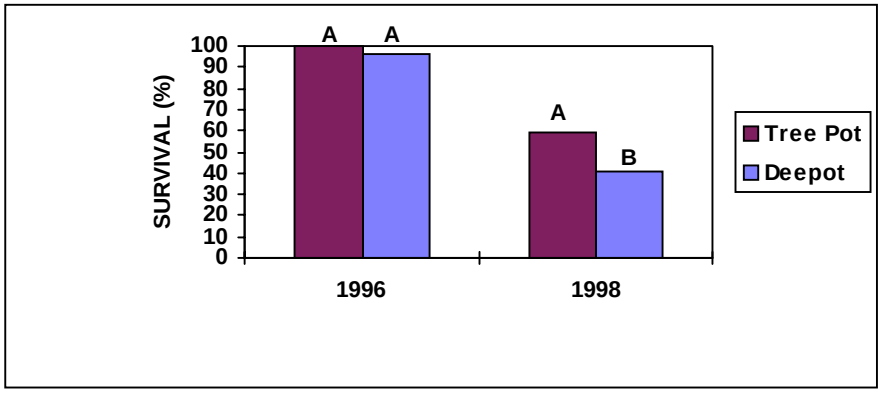


Figure 2 — March 1996 planting, survival comparison of two plant container sizes for fourwing saltbush (*Atriplex canescens*). Percentages with different letters are significantly different at the 0.05 level.

Brittlebush was also propagated in both Tree Pots™ and Deepots™. This species usually drops most of its leaves during hot, dry periods to better tolerate dry conditions (Figure 3). Survival evaluations six months after transplanting revealed the brittlebush from the Tree Pot™ containers to have a significantly higher--100 percent--survival over the brittlebush from the Deepot™ containers, which displayed a 91 percent survival. Survival for this species also showed a decline by the end of 1998. The plants from the Tree Pots™ still exhibited a significantly higher--90 percent--survival over the Deepot™ plants, which showed a 71 percent survival.

Creosote bush was propagated in Tree Pots™, Deepots™, and Conetainers™. This species tolerated the transplant process well despite the hot, dry period during June and July in 1996 (Figure 4). Six months after transplanting was 94 percent survival from the Tree Pot™ containers, 100 percent from the Deepot™ containers, and 80 percent from the Conetainers™. This species showed a slight decline in survival at the end of 1998. The Tree Pot™containers had a 93 percent survival, the Deepots showed a 97 percent survival and 78 percent for the plants from the Conetainers™. Survival comparisons between the Tree Pots™ and Deepots™ revealed no significant differences. However, the plants from the Conetainers™ revealed a significantly lower survival in comparison to the other two container sizes.

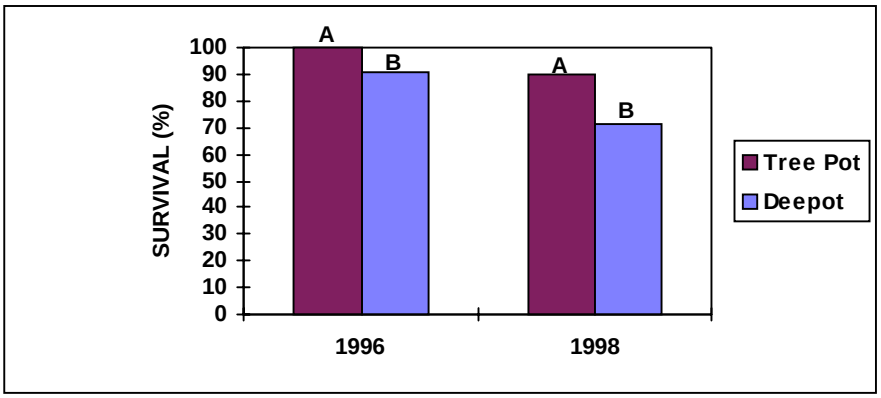


Figure 3 — March 1996 planting, survival comparison with two plant container sizes for brittlebush (*Encelia farinosa*). Percentages with different letters are significantly different at the 0.05 level.

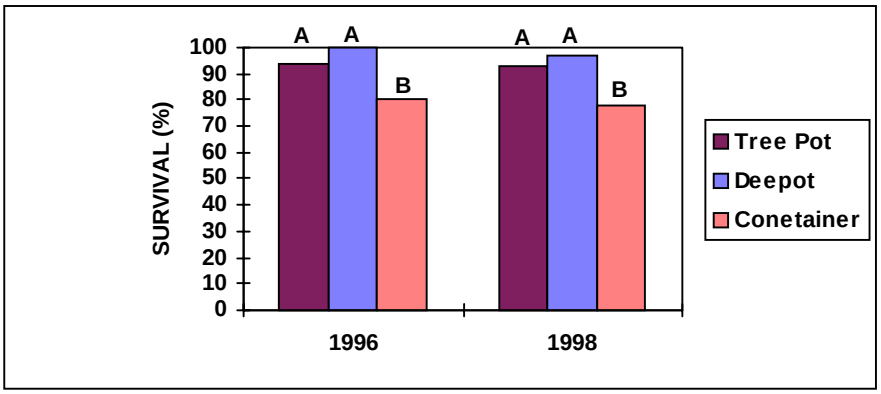


Figure 4— March 1996 planting, survival comparison with three plant container sizes for creosotebush (*Larrea tridentata*). Percentages with different letters are significantly different at the 0.05 level.

Mesquite was propagated only in Tree Pot™ containers. Survival evaluations following six months after transplanting revealed a 78 percent transplant survival. At the end of 1998 the mesquite survival remained at 78 percent. Whitethorn acacia was propagated in Tree Pot™ containers. Survival evaluations following six months after transplanting revealed a 97 percent transplant survival rate. Survival for the whitethorn acacia declined to 91 percent by the end of 1998. Littleleaf palo verde plants propagated in Tree Pot™ containers revealed a 72 percent transplant survival rate six months after transplanting. By the end of 1998 this species exhibited a 70 percent survival (Figure 5).

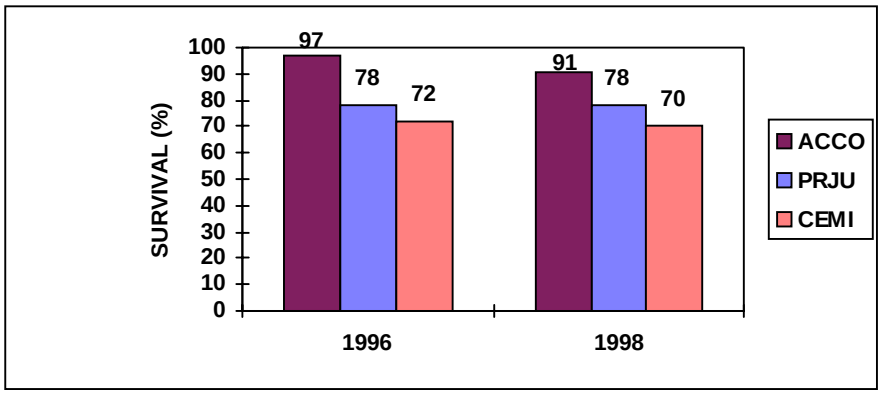


Figure 5 — March 1996 planting, comparison of survival for whitethorn acacia (*Acacia constricta* - ACCO), mesquite (*Prosopis juliflora* - PRJU), littleleaf palo verde (*Cercidium microphyllum* - CEMI) after transplanting from Tree Pot™-sized containers.

Purple threeawn transplants propagated in the Tree Pots™ have also performed well at this site. Survival evaluations following six months after transplanting revealed an 87 percent survival rate. This species displayed a 48 percent survival for the transplanted materials at the end of 1998 (Figure 6). It should be noted that a large number of new seedlings and young plants were observed within the study plot.

Desert marigold and globemallow were propagated in Tree Pot™ containers. Initially both species appeared to react negatively to the transplant process (which had been followed by an extended period with very little to no measurable precipitation). However, during the August 1996 evaluations, these species appeared to be recovering well (Figure 6). Survival percentages 6 months after transplanting showed the desert globemallow to have a 95 percent survival and the desert marigold an 82 percent survival. Despite the hot, dry period during June and July in 1996, most of the plants were performing well in terms of growth and survival. At the end of 1998 the desert globemallow had fallen to a 60 percent survival and the desert marigold survival had declined to zero.

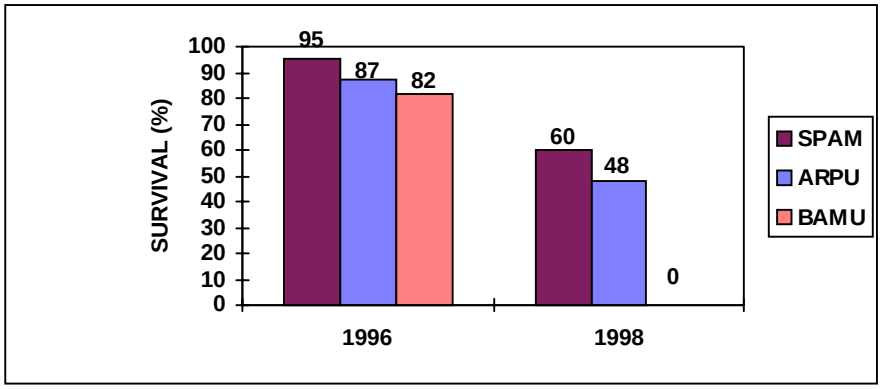


Figure 6 — March 1996 planting, comparison of survival for desert globemallow (*Sphaeralcea ambigua* - SPAM), purple threeawn (*Aristida purpurea* - ARPU), desert marigold (*Baileya multiradiata* - BAMU) after transplanting from Tree Pot™ containers.

The Arizona lupine was the only species not to survive six months past the transplant period. This was primarily due to rabbit grazing shortly after the transplanting.

By the end of 1998, the overall plant survival percentage for this planting had declined from 83 percent to 65 percent. The plants transplanted from the Tree Pot™ containers declined from 90 percent to 68 percent survival as compared to a decline from 73 percent to 56 percent survival for plants transplanted from the Deepot™ containers. These declines in survival can be attributed to the plants being placed too closely together (2-foot spacing between plants) and competition for moisture and nutrients may have caused some plants to die.

From an economic standpoint, it appears to be more cost-effective to propagate plant materials in the Deepot™ containers. The Tree Pot™ containers require more time to modify the containers for propagation, more potting mix and more water to maintain the plants growing in them prior to transplanting.

Other studies by Tucson PMC personnel using different-sized containers for transplant projects have shown that plants grown in Deepots™ attain similar growth rates and size as plants grown in Tree Pot™ containers. Plants propagated in Conetainers™ do not appear to produce sufficient root mass to allow for successful transplanting under arid conditions without supplemental irrigation. Another point to consider is that the plants grown in Tree Pots™ weigh approximately 23 to 25 pounds each versus approximately 3 pounds for plants in a Deepot™ container. The Deepot™ containers are easier to handle and require a much shallower hole, thereby reducing time and labor during transplanting.

Results, 1997 Planting

The 1997 planting was made on the “97 NRCS Oxide Site” at the mine and conducted in two phases: (1) spring planting, made on May 27 and 28, 1997, and (2) summer planting, made on August 26 and 27, 1997. Each species was propagated in Cavity Trays in the Tucson PMC greenhouse. After sufficient growth, seedlings were transplanted into Deepots™. After sufficient growth was achieved in the Deepot™ containers, the plants were moved to the Tucson PMC shadehouse for a 60-day hardening-off period before transplanting. At the evaluation site, plants were transplanted by hand. All containerized plants in both the spring and summer plantings received approximately 1 gallon of water as they were transplanted into the evaluation site. The mine supplied a water truck and a hose for this purpose. The evaluation site was fenced to prevent damage by animals.

By the end of 1997, the creosote bush and purple threeawn exhibited no significant differences in survival between the fertilized and unfertilized treatment areas. Creosotebush demonstrated 52.5 percent survival in the unfertilized plots as compared to a 35 percent in the fertilized plots. By December 1998, the creosotebush had declined slightly to a 50 percent survival in the untreated plots and remained steady at 35 percent in the treated areas (Figure 7).

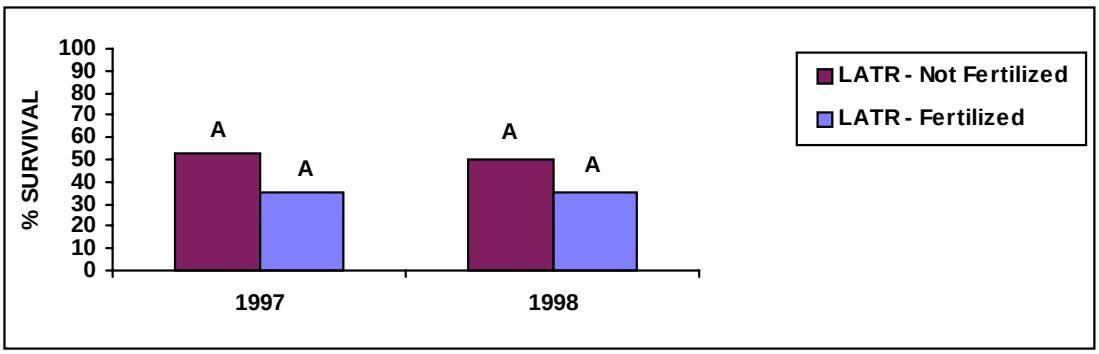


Figure 7 — 1997 NRCS Oxide Site, May planting, survival comparison for creosotebush (*Larrea tridentata* - LATR) in fertilized and unfertilized plots. Percentages with the same letter are not significantly different at the 0.05 level.

In 1997, the purple threeawn exhibited a 27.5 percent survival in the fertilized plots versus 5 percent in the fertilized plots. By the end of 1998, the purple threeawn remained at 27.5 percent in the untreated plots and had declined significantly to 0 percent survival in the fertilized plots (Figure 8).

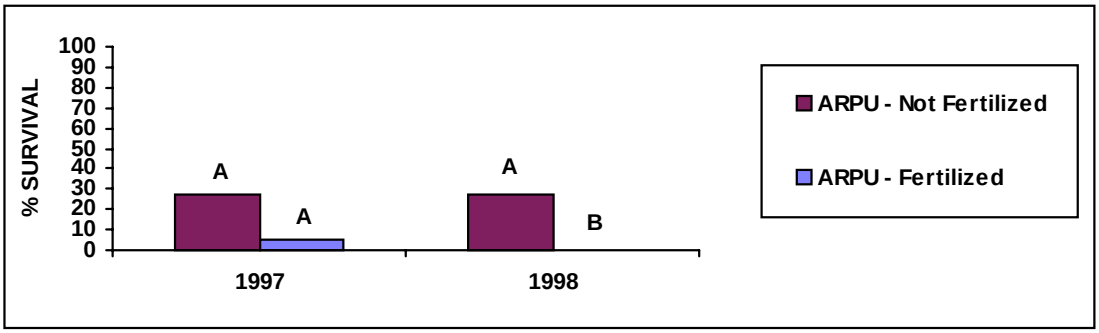


Figure 8 — 1997 NRCS Oxide Site, May planting, survival comparison for purple threeawn (*Aristida purpurea* - ARPU) in fertilized and unfertilized plots. Percentages with the same letter are not significantly different at the 0.05 level.

At the end of 1997, it was apparent that the littleleaf palo verde, fourwing saltbush, and brittlebush did not respond well to the fertilizer applications. Plants in the untreated plots exhibited significantly higher survival percentages than the treated plots. Littleleaf palo verde exhibited a 77.5 percent survival in the untreated plots and 32.5 percent survival in the treated plots. By the end of 1998 the untreated plots had declined to a 70 percent survival and the treated areas had fallen to 2.5 percent (Figure 9). At the end of 1997 the fourwing saltbush had 65 percent survival in the unfertilized plots versus a 12.5 percent survival in the fertilized plots. By December 1998 the fourwing in the untreated and treated plots remained at the same levels (Figure 10). The end of calendar year 1997 showed the brittlebush at 40 percent survival in the unfertilized plots as compared to 2.5 percent survival in the treated plots. By the end of 1998 the survival percentages remained unchanged (Figure 11).

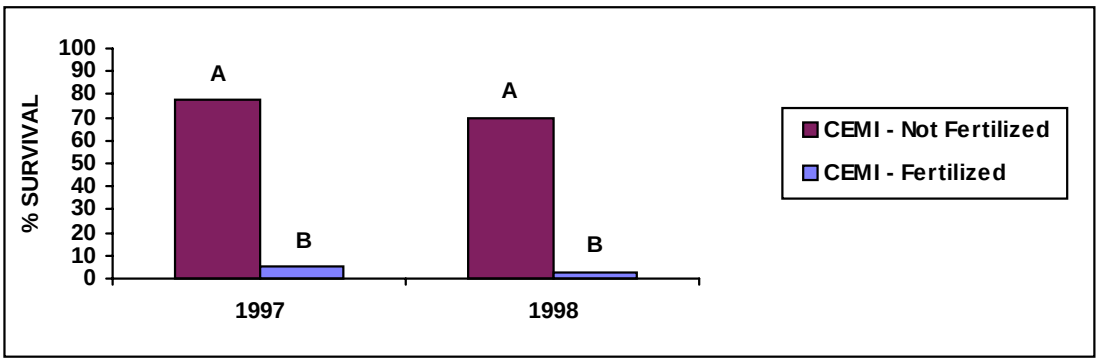


Figure 9 — 1997 NRCS Oxide Site, May planting, survival comparison for littleleaf palo verde (*Cercidium microphyllum* - CEMI) in fertilized and unfertilized plots. Percentages with different letters are significantly different at the 0.05 level.

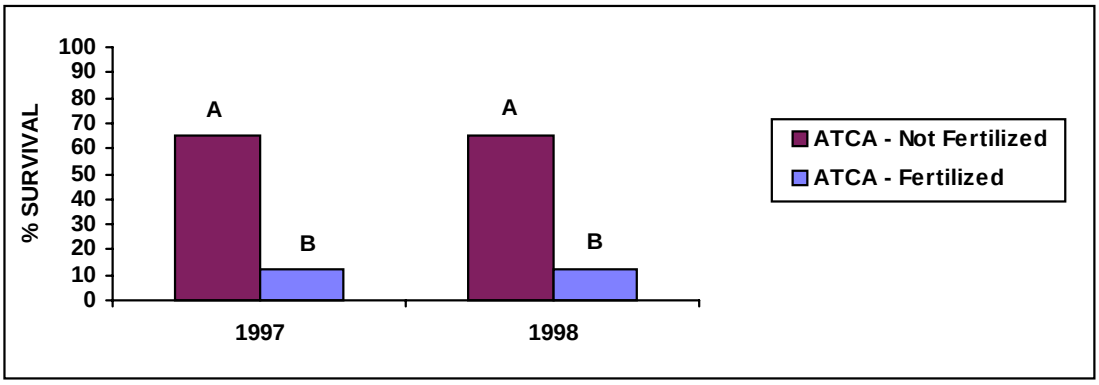


Figure 10 — 1997 NRCS Oxide Site, May planting, survival comparison for fourwing saltbush (*Atriplex canescens* - ATCA) in fertilized and unfertilized plots. Percentages with different letters are significantly different at the 0.05 level.

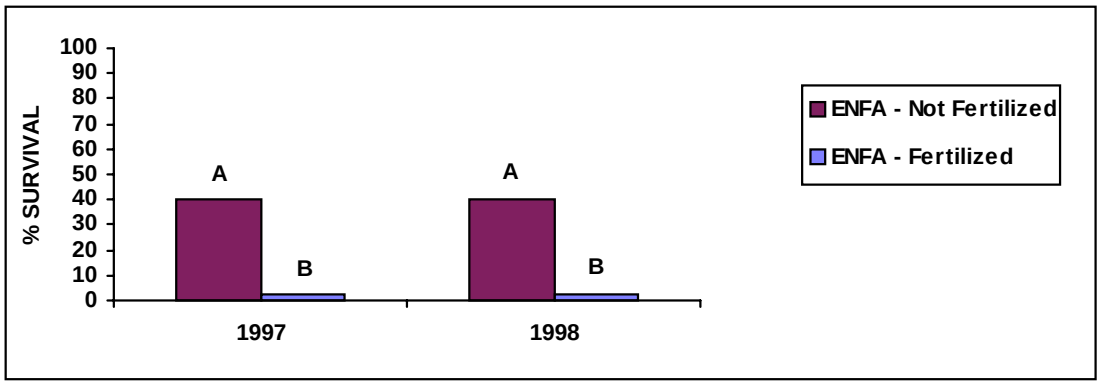


Figure 11 — 1997 NRCS Oxide Site, May planting, survival comparison for brittlebush (*Encelia farinosa* - ENFA) in fertilized and unfertilized plots. Percentages with different letters are significantly different at the 0.05 level.

In comparing the 1997 August planting time with the 1997 May planting time, littleleaf palo verde and fourwing saltbush exhibited no significant differences in survival percentage. Littleleaf palo verde exhibited 77.5 percent survival in the May planting and 85 percent in the August planting by the end of 1997. At the end of 1998, the May planting, had declined to a 70 percent survival and the August planting remained at 85 percent (Figure 12). By the end of 1997, the fourwing saltbush demonstrated a 65 percent survival in the May planting and a 62.5 percent survival in the August planting. At the end of calendar year 1998 the survival in the May planting remained the same and the August planted had declined slightly to 60 percent (Figure 13).

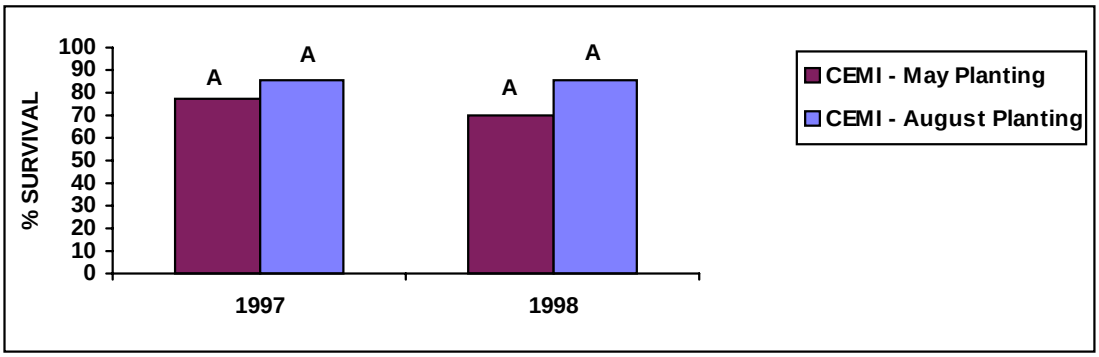


Figure 12 —1997 NRCS Oxide Site planting, survival percentages for littleleaf palo verde (*Cercidium microphyllum* - CEMI) comparing two planting periods (May and August). Percentages with the same letter are not significantly different at the 0.05 level.

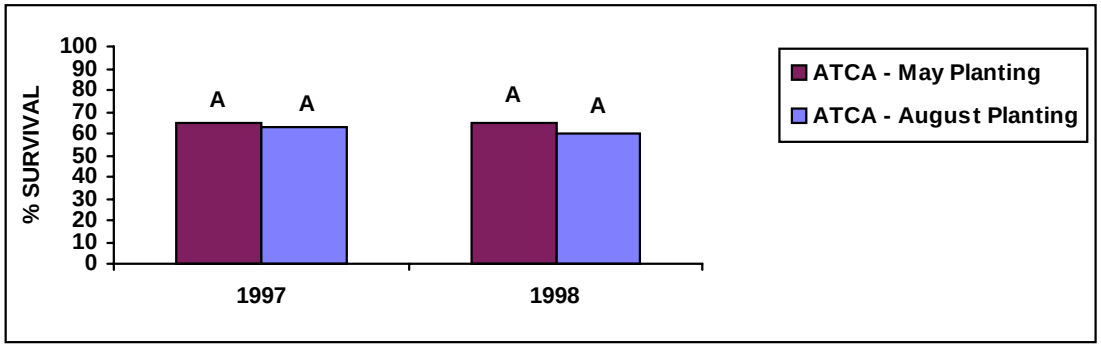


Figure 13 — 1997 NRCS Oxide Site planting, survival percentages for fourwing saltbush (*Atriplex canescens* - ATCA) comparing two planting periods (May and August). Percentages with different letters are significantly different at the 0.05 level.

By the end of the 1997 calendar year, purple threeawn and brittlebush exhibited significantly higher survival for the August planting. Purple threeawn showed an 87.5 percent survival in the August planting as compared to a 27.5 percent survival for the May planting. By the end of calendar year 1998 the purple threeawn showed an 82.5 percent survival for the August planting versus a 27.5 percent for the May planting (Figure 14). In 1997 the brittlebush demonstrated a 100 percent survival for the August planting versus a 40 percent survival for the May planting. By the end of 1998 the brittlebush survival for the August planting had fallen slightly to 95

percent and remained the same at 40 percent for the May planting (Figure 15).

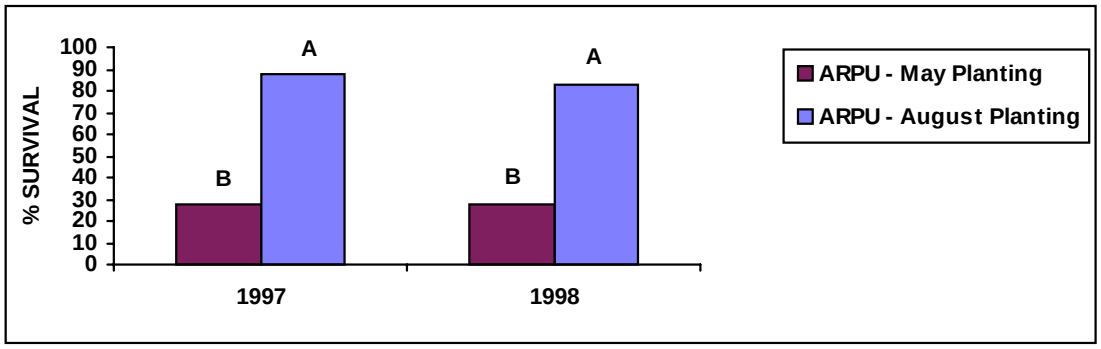


Figure 14 — 1997 NRCS Oxide Site planting, survival percentages for purple threeawn (*Aristida purpurea* - ARPU) comparing two planting periods (May and August). Percentages with different letters are significantly different at the 0.05 level.

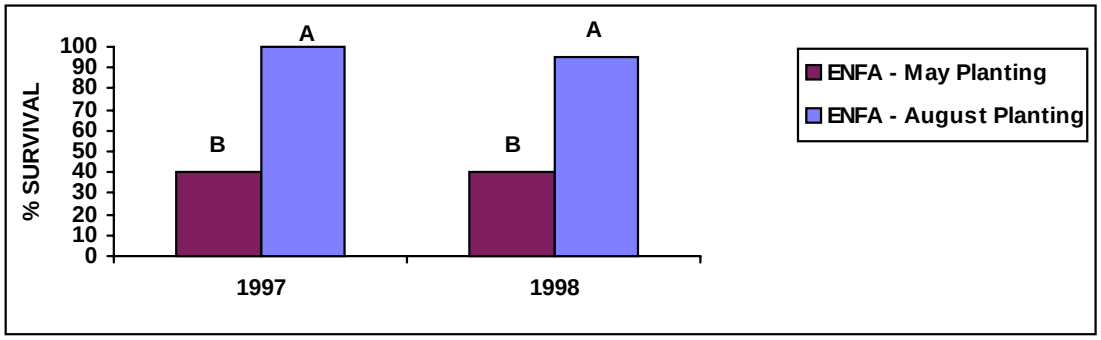


Figure 15 — 1997 NRCS Oxide Site planting, survival percentages for brittlebush (*Encelia farinosa* - ENFA) comparing two planting periods (May and August). Percentages with different letters are significantly different at the 0.05 level.

The August planting period appears more favorable to transplant establishment and survival success. This is most likely due to the higher probability of the plants receiving adequate moisture from summer rains. Transplanting during August appears to allow the plant materials adequate time to become established and acclimated to the site under more favorable conditions (e.g., higher relative humidity, summer precipitation) versus the May planting period that is traditionally followed by a hot, dry period through the month of June. Unless supplemental watering can be provided, it is recommended that transplanting be conducted in late July or early August following the onset of summer rains (Figure 16).

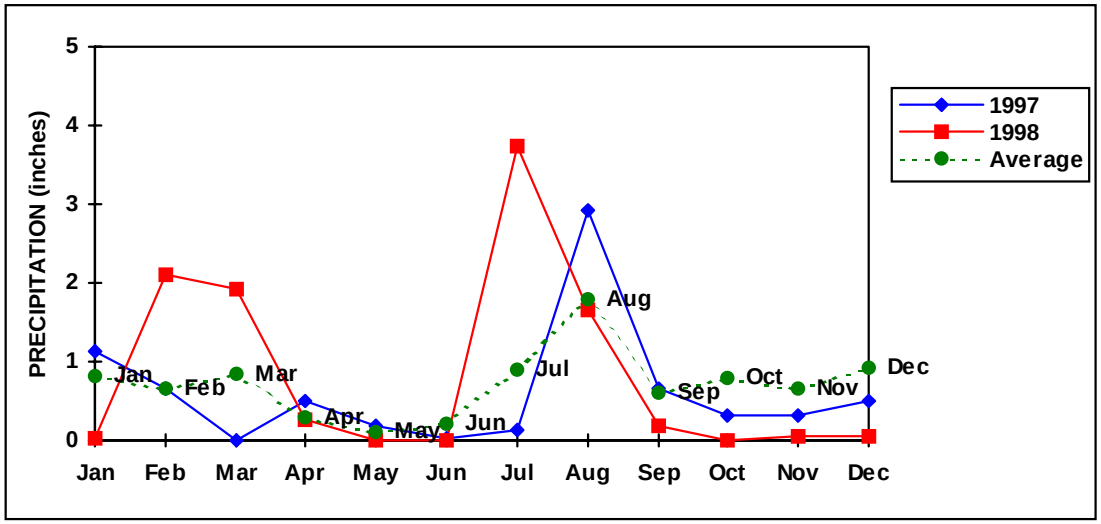


Figure 16 — Cyprus Tohono Mine, monthly precipitation data for 1997 and 1998. Dashed line represents monthly average (1950-80).

Results, 1998 Planting

The "98 NRCS Planting" was done in September 1998 using 1,880 plants. All plants were propagated in Deepots™ at the Tucson PMC greenhouse. On September 9 through 11, 1998, the plants were transplanted into a 90,000 ft^2 evaluation site. As of December 10, 1998, 83 percent of all individuals planted had survived. Whitethorn acacia exhibited the highest survival (100 percent). Mesquite had 99 percent survival followed by ironwood at 97 percent. Purple threeawn, fourwing saltbush and littleleaf palo verde all exhibited a 93 percent survival. Desert globemallow had a 78 percent survival and brittlebush rated at 73 percent. Desert marigold exhibited the lowest survival percentage at 69 percent (Figure 17). Continued monthly monitoring of this planting site through the remainder of fiscal year 1999 should provide adequate data to determine the level of success for this planting.

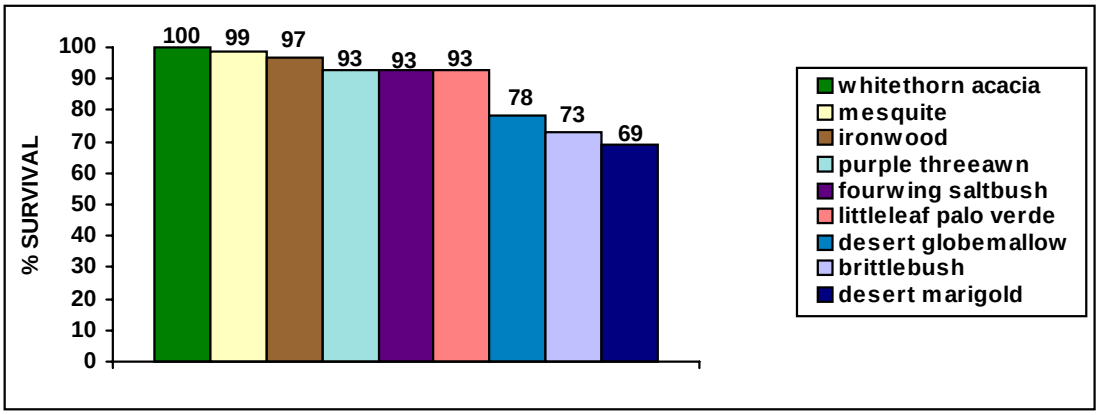


Figure 17 — September 1998 planting, percentage survival for all species planted as of December 10, 1998.

Summary

Successful revegetation of mined lands in the arid southwestern United States requires the development of a sound revegetation plan along with the realization that the challenge of revegetation in the harsh Sonoran desert climate is characterized by low rainfall and wide diurnal temperature fluctuations. In southern Arizona, climate is a serious limiting factor and can create difficulty in the quantification or measurement of what makes a planting successful.

The cooperative agreement between the USDA-NRCS Tucson PMC, the Cyprus Tohono Corporation, and the Tohono O'odham Resource Conservation District was initiated in 1995. During the first year of the agreement Archuleta and Dhruv conducted an extensive literature review in order to develop a comprehensive document outlining methods and procedures that would be applicable to the Cyprus Tohono Mine revegetation project. The focus of the 1995 literature review was on the technical aspects of mineland revegetation.

The first planting at the mine was installed in March of 1996. The objective of this planting was to evaluate transplant growth and survival comparing plants grown in three different container sizes. A total of 1,374 plants using ten native species were propagated at the Tucson PMC and transplanted at the mine site. Survival data after two years revealed that although overall the Tree Pot™ containers showed a significantly higher survival percentage (83 percent), the plants transplanted from the Deepot™ containers also had an acceptable survival percentage (70 percent). It appears that the plants propagated in the Conetainers™ did not produce sufficient root mass to allow for successful transplanting under arid conditions without supplemental irrigation.

Plant materials produced using the Deepot™ containers are more cost-effective than those using the Tree Pot™ containers. The Tree Pot™ containers require more time to prepare for propagation, more potting mix, more water, and more time to produce a product for transplanting. The Deepot™ containers are lighter and easier to handle and also require a much shallower hole when transplanting the plant materials.

Despite the hot, dry summer months of May, June, and early July, most of the plants had performed well in terms of growth and survival. The Arizona lupine was the only species not to survive past the transplant period due to damage by rabbits. The creosote bush appears to have performed most favorably in response to the transplanting process. Despite damage by rabbits, the mesquite, whitethorn acacia and paloverde have also exhibited survigrous growth. The purple threeawn, white bursage, brittlebush, fourwing saltbush, desert marigold and desert globemallow also appear to have performed well.

The second evaluation planting at the mine was installed in May and August of 1997 using 800 plants of five native species (creosote bush, purple threeawn, littleleaf palo verde, fourwing saltbush, and brittlebush). The objective of this planting was to evaluate transplant survival comparing spring and late summer planting periods. In addition, the spring planting comparatively evaluated fertilized and non-fertilized plots.

The fertilized plots showed a significantly lower survival percentage in four of the five species planted. The creosote bush also showed a lower survival percentage in the fertilized plots, however this difference was not significant. At the end of 1998, the survival comparisons between the two planting periods revealed that the survival percentages for littleleaf palo verde and fourwing saltbush did not differ significantly between the two planting periods. The purple threeawn and brittlebush did show significantly higher survival percentages in the August planting period as compared to the planting conducted in May. Creosote bush was not evaluated in this planting.

The August planting period appeared more favorable to transplant establishment and survival success. This may be due to the plants having received adequate moisture from summer rains. Transplanting during August appears to have allowed the plant materials adequate time to become established and acclimated to the site under more favorable conditions (e.g., higher relative humidity, summer precipitation) versus the May planting period that is traditionally followed by a hot, dry period through the month of June. Unless supplemental watering can be provided, it is recommended that transplanting be conducted in late July or early August following the onset of summer rains.

The 1998 planting was installed in September of 1998 using 1,880 plants of ten native species. The primary objective for the 1998 planting is visual mediation and was planned as a large-scale planting using a more natural appearance design versus the block designs used in the past. Evaluation criteria for this planting include survival percentage and growth rates.

The plant materials for this planting were propagated in Deepots™ at the Tucson PMC greenhouse. In September of 1998 the plants were transplanted into a 90,000 ft^2 evaluation site. As of December 10, 1998, 83 percent of all individuals planted had survived. Whitethorn acacia exhibited the highest survival (100 percent). Mesquite had 99 percent survival followed by ironwood at 97 percent. Purple threeawn, fourwing saltbush and littleleaf palo verde all exhibited a 93 percent survival. Desert globemallow had a 78 percent survival and brittlebush rated at 73 percent. Desert marigold exhibited the lowest survival percentage at 69 percent. Continued monthly monitoring of this planting site should provide adequate data to better determine the level of success for the various species in this planting.

To date all of the evaluation plantings conducted at the mine by the Tucson PMC have been located on soils not affected by mine-processed materials (e.g., equipment storage sites and compacted areas). Private contractors have been hired to conduct drill seeding and hydroseeding operations at various locations on the mine property. Ideally, additional evaluation plantings should be conducted on mine processed soils using capping materials and various soil amendments to maintain neutral pH levels. A reimbursable agreement similar to the one that made the evaluations described in this report possible would be desirable.

Tucson PMC personnel could work closely with Cyprus-Tohono Corporation to collect data and monitor drill and hydroseeding projects that are conducted by private contractors at the mine. Long-term monitoring of these sites would provide the type of sound information needed to make critical mineland revegetation decisions. Monitoring and comparison of undisturbed and

revegetated sites may help to better define what constitutes a successful planting in our arid southwestern climate.

References

Bainbridge, D., R. MacAller and M. Fidelibus. 1995. A beginners guide to desert restoration. USDI-NPS, Denver Service Center. 48p.

Bjugstad, A.J. 1979. Bentonite mine spoils and pit reclamation. In: Proceedings from the Mineral Waste Stabilization Liaison Committee. Evelith, Minnesota.

Copeland, O.L. 1973. Mining impacts and resource management. Transactions of the 38th N. American Wildlife and Natural Resources Conference, Mar., Wildl. Manag. Institute, Washington D.C. p.111-120.

Daily Post. Bentonite, the clay of 1,000 uses. Sept. 26, 1972. Belle Fourche, South Dakota. p.5.

Farmer, E.E., and B.Z. Richardson. 1980. Phosphate mine dump stability and revegetation. In: Proceedings from the Symposium on Watershed Management V., II., American Society of Civil Engineers, New York. p.888.

Fuller, W.H. 1963. Reactions of nitrogen fertilizers in calcareous soils. In: Agricultural and Food Chemistry, Vol. 11:188-193.

Monsen, S.B., C.M. McKell, N.C. Frischknecht, R.B. Ferguson. 1979. Plant Materials. In: User Guide to Vegetation. Mining and Reclamation in the West. U.S. Department of Agriculture Forest Service, General Technical Report Int-64, Intermountain Forest and Range Experiment Station. Ogden, Utah. pp.19-23.

Munshower, F.F. 1994. Practical Handbook of Disturbed Land Revegetation. CRC Press, Inc. Boca Raton, Florida. 265p.

Richardson, B.Z., and E.E. Farmer. 1983. Revegetation of phosphate mined lands in the intermountain west. In: Proceedings from the Symposium on Watershed Management V., II., American Society of Civil Engineers, New York. P.373.

St. John, T.V. 1987. Soil disturbance and the mineral nutrition of native plants. In: Proceedings of the 2nd Native Plant Revegetation Symposium. April 15-18, 1987. San Diego, California.

Tripodi, R.A. and P.N. Cheremisinoff. 1980. Coal ash disposal: Solid waste impacts. Technomic Publ., Westport, Connecticut. p.18.

Tucker, T.C. and A.D. Day. 1980. Amendments and fertilizers for use in vegetative reclamation. Proceedings: Vegetative Reclamation of Mine Wastes and Tailings in the Southwest.

Arizona Mining and Mineral Resources Research Institute, University of Arizona, Tucson, Arizona. p7-3.

U.S. Department of Agriculture, SCS. 1973. Technical notes. Guidelines for reclamation of surface mined lands in Arizona. Environment Note No. 2. Phoenix, Arizona.

U.S. Department of the Interior, Bureau of Land Management - California. 1997. Soledad Mountain Project website is www.ca.blm.gov/GoldenQueen/pub-rev6.htm.

Desert Reclamation

Ed S. Kleiner
Comstock Seed

Introduction

An article in the Nature Conservancy Journal contains the following statement: "Nature's winning designs follow an evolutionary path meandering through the trials of life." Beyond poetics, this statement portrays plant-community evolution not as a formulated progression but as a trial. We at Comstock Seed would go a step further and label the process as a struggle that occurs over eons of time whereby the appropriate species competitively sort themselves out into relatively stable communities that we call climax communities. From this perspective, if we observe natural and manmade disturbances over long periods of time, we can observe flora and fauna populations as they struggle to recolonize these areas. We attempt to simplify these recolonizations into distinct steps called serial stages that build on themselves into increasingly more complex and stable systems.

After witnessing a wide variety of reclaimed sites and reclamation programs, and watching how they developed in the face of sporadic natural conditions, we are convinced that reclamation science is truly an art. We can talk about components and integrated programs but we can't control sporadic climatic conditions or ecological events.

Early in the reclamation industry's development, reclamation goals emphasized the establishment of plant communities that had an agronomic value. Erosion control was a goal but we were not necessarily attempting to recreate the native plant communities that were present prior to disturbance. In contrast, contemporary reclamation has shifted more towards the establishment of native communities and less towards agronomic goals. This is partly due to a political shift in public land law towards multiple use as well as a related desire for diverse plant communities. Also, and more importantly, we have gained an appreciation of the ecological perspective mentioned above and the natural limitations imposed by harsh desert habitat conditions. These conditions limit the types of plant communities that will survive and be self-sustaining without our periodic management. Indeed, many of our current projects are older projects that emphasized grass cultivar communities that slowly atrophied over many years. This decline has forced many in the reclamation industry to rethink their goals and place agronomics behind the establishment of plant communities that would survive without long-term maintenance. Thus, we can apply the above quote to the reclamation industry by saying that the winning design is the one that develops into a self-sustaining plant community.

Coupled with this shift in emphasis, the reclamation industry has been growing with the increased mining activity in the Great Basin. This increased reclamation activity has allowed us to witness a wide variety of reclamation programs. Given the ecological complexity of the plant and soil communities that we are trying to recreate, we think it is important to look at these programs as grand experiments and not as guaranteed formulas for success. The serendipitous

influences of nature play too great a role at our reclamation sites to approach these projects with too much certainty.

Last, our emphasis has turned towards soils. Stable plant communities have a living relationship with soil microbial forms that are typically not present in spoil materials or in areas where the topsoil has been removed. We have seen that plant communities that were germinated on these barren surfaces have typically failed over short periods of time. Conversely, successional plant communities and their associated soil microbial populations have evolved together and both must be present for zero maintenance reclamation. Without some evidence of soil preparation we hold little hope that our projects will grow into stable plant communities.

Survey of Reclamation Activities

Even though this program focuses on mine reclamation, I still include this section because it reveals both unique and universal concepts and techniques in reclamation science. The following techniques are typically the final installation step in the reclamation procedure. Prior to seeding, our clients have hopefully built physically and chemically stable subsurface conditions and topdressed these sites with an adequate growth medium. This process varies greatly depending on the nature of the site.

Mines

Our mine operations are primarily open pit where significant amounts of overburden materials are removed from a gold bearing pit. These areas as well as leaching and tailings areas eventually get soil treatments and seeding. Unlike strip mining or pipeline installations, the spoil materials at these sites may sit for long periods of time prior to final reclamation. This presents a challenge to our open pit clients to know the quality of their various fill materials and preserve potential growth media. These soil issues are discussed in the next section and the case studies.

Highways, Cut Slopes

Cut slopes cover a broad group of disturbances including highways, mountain and desert access roads, urban developments, drainage swales, etc. Lake Tahoe's eutrophication problems are intimately related to cut slope erosion. Typically, soil profiles have been sliced through, exposing a mosaic of soil layers from the most productive surface profiles to bedrock. These disturbances are at times too steep for working with surface machinery and even when an application technique is identified, getting soils, seed, and various amendments to stay on the slope can be challenging. The hydromulch and erosion blanket industries are continuously challenged to stabilize such slopes.

The opposite cut slope may require a different seed treatment due to the exposure aspect. We have made different seed blends for opposing cut slopes to compensate for extreme differences in microhabitat. Also, one roadside may be the fill slope containing the loose overburden that was cut out. This material is usually a much better growth medium due to its less compacted state. One cut slope is reviewed in the Horseshoe Bend case study.

Pipelines

The case studies have to do with Comstock Seed's work with the Tuscarora pipeline. Pipelines as a category present unique challenges in that they constitute long linear disturbances traversing variable ecotypes. We usually expect natural colonization to occur quicker than on broad expanses like minesites due to the proximity of undisturbed plant communities adjacent to the corridor. The Tuscarora case study tests this hypothesis. Pipeline construction is usually quick and topsoils are put back down during the same season or soon thereafter. We feel this preserves microbial populations better and should make reclamation an easier process than with long-term disturbances. Last, pipelines usually pass through multiple-land jurisdictions, which makes institutional coordination essential. Rarely does this coordination occur efficiently and in a timely fashion.

Forest Fires

Forest fires have a complexity of their own, at times covering multiple watersheds, plant community types, and political jurisdictions. Due to their size and random locations, at times very remote, aerial applications are frequently used for seeding and little soil preparation is possible. Immediate slope stability is usually a priority for protecting watershed and urban water supplies. Nurse crops are usually used for such purposes. The U.S. Forest Service has multiple mandates and seed blends vary. Also, a hotter fire may kill shrub roots while a cooler fire just burns shrubs to the ground without killing them. This will have an influence on the type of seed blend that we create. Aerial seedings may be combined with transplants and riparian restoration for sensitive areas.

Urban Landscaping, Reclamation

Our urban contractors are asking for many of the same blends as the mining industry. In Reno, drought tolerant landscaping desires, and water conservation mandates from the city and county are resulting in contractors using native seed blends to stabilize cut slopes at housing areas, common areas at golf courses and parks, highway meridians, etc. We think that the experiences that we have had with mining will be useful to the urban sector.

We are excited to see industries in all of the above areas realizing the value of native plants. Whether it be low water consumption, low maintenance, or long-term stability, all goals save our clients resources in the long run.

Soils Considerations: Problems and Long-Term Perspectives

Most projects that we become involved with have not planned ahead to store the original topsoil from the disturbances nor planned to supply an adequate alternative growth medium. Final graded surfaces are typically overburdens or subterranean spoils that are structurally and chemically imbalanced, void of sufficient organic material, and lacking the microbial life necessary to sustain a healthy plant community.

Traditionally, mine reclamation techniques began by enhancing this sterile material with fertilizers and organic amendments if they were readily available and cost effective. Seed blends, typically grass cultivars, would be incorporated into this enriched medium and when favorable climatic conditions occurred, germination would commence and create a grass cover crop. We have seen many projects from mines to ski resorts in which predominantly grass cultivar communities were established and thrived for a few years but then began to atrophy. These older sites are sparsely covered with grass cultivars and minimal intrusion of native shrubs and grasses. If our suspicions are correct, the fertilizer may have acted as a temporary food source to support cultivars with elevated nutrient and precipitation demands. Long-term site stability did not occur in part because of inadequate nutrient cycling related to the absence of microbial activity, or other habitat-species incongruities. For instance, throughout western Nevada there are successful Atriplex communities that do not have sufficient precipitation or soils to support most grass cultivars. If long-term goals include a stable diverse plant canopy at a designed density, these older sites can't be considered success stories. On the other hand, successfully duplicating a complex natural system may take hundreds of years. On occasion, we have been humbled by such minimal growth of any plant material let alone the creation of a complex natural system.

Thus, an understanding of general soils concepts is critical to the design of a reclamation plan. The most important concept is to understand the ecological relationship between plant and soil communities. This relationship is symbiotic and dependent such that neither can exist as a healthy system without the others' well being. Healthy soils are rich in floral and faunal communities largely invisible to the eye yet these communities are essential to the survival of the plant communities above them. Ecological succession of plant communities is easily observable and occurs simultaneously with a mostly invisible succession in soil communities. Undisturbed plant communities have developed soil profiles that vary greatly in depth. The surface profiles contain the smaller microbial life forms that are essential to the survival of plant materials. Their ecological roles are numerous, including the breakdown of complex organic material into usable humus, structural support for the roots, cation exchange, water holding capacity, aeration, pH normalization, etc. One of our miners has a severe problem with arsenic and has recently concluded that the mycorrhizae associated with Great Basin wildrye are tying up the arsenic and making the growth medium more hospitable for later seral stages, primarily sagebrush. Once again, microbial and plant communities are mutually dependent on each other’s well being for their survival and long-term self-sustenance.

This prerequisite of healthy microbial populations challenges us to provide enhanced growth mediums and topsoil qualities to improve a plant community’s chances of establishing nutrient cycling, soil development, and eventual community stability. Unfortunately, few microbial populations are canned on a store shelf for sale. To a certain extent we can amend growing mediums to encourage plant growth but we must also rely on the natural role of successionary plant communities to assist in developing soils.

Soil Considerations: Solutions

So, is there a secret formula to insure successful plant growth and community stability? From the above discussion we think that the formula contains general guidelines somewhat consistent

over a variety of disturbances but, within those guidelines, we will find site-specific solutions. Further, we do not think that when dealing with natural systems, any formula can guarantee success. The best that we can do is set up the optimal microhabitat conditions that could generate success if environmental conditions are favorable during any given growing season. If we complement the microhabitat condition with appropriate species, we think that the chances for long-term success may be optimized.

Also, we have witnessed such a wide variety of soil approaches by our contractors and clients that we are hesitant to prescribe specific solutions. In the case studies we will compare the Horseshoe Bend and Echo Bay projects where the former relied strictly on organic amendments and the later relied partially on chemical fertilizers. Both projects are currently doing quite well.

The following list of general guidelines is by no means complete.

Physical and chemical stability — Prior to our presence at the site, the overburden slopes should have been laid down to prevent long term movement. The literature generally recommends that for coarser and more toxic overburden materials deeper surface profiles need to be laid down for planting. These recommendations range from 1 to 4 feet. One of our clients put down six feet in an effort to isolate toxic materials. We have seen clay materials used as a subsurface fill to help prevent toxic material from leaching to the surface. The Leviathan case study shows what happens when the surface layers are too shallow relative to the toxic and physically unstable layers below.

Growth mediums — Growth mediums include salvaged topsoil, subterranean spoils, and imported materials. These materials are used individually or in combination with various amendments, fertilizers, and specialty products. All potential growth mediums should be tested. Soil testing not only identifies potential growth mediums but also acts as a diagnostic tool for prescribing amendments. These recommendations should be studied with caution as the labs may be accustomed to making prescriptions for growing more conventional agronomic crops instead of natives. You may request the soil lab to make prescriptions based on the targeted plant community.

Topsoil salvage and preservation — Combining research results with our growing body of field experiments, we are coming up with better growth mediums and more successful plant establishment. When topsoils are first scraped off they contain populations of microorganisms. When the host plants are killed, the nutrient cycling is interrupted and time becomes the enemy of mycorrhizal organisms while other microorganisms such as bacteria may retreat into dormant spore forms. We have found that the mortality for mycorrhizal organisms can be a few months or several years. A Caltrans study (Claassen and Zasoski, 1994) reports that 5 months of storage did not affect microbial populations. Munshower (1994) states that in a Yellowstone study good viability lasted for 90 days but if storage extended through the winter most microbial populations died.

Unfortunately, the rate of mortality increases in our colder more moist northern areas.

Also, the shape of the stored soil affects mortality. Deep compacted piles have faster mortality rates than shallow aerated piles. Unfortunately, many of our more mountainous sites have limited storage areas.

We recommend that temporary cover crops be planted on stored topsoil. These cover crops may preserve the life of some microorganisms if the plants are adequate hosts. Most importantly, the cover crops will help to prevent wind and water erosion.

Even without optimal storage and despite the loss of microbial life, surface materials containing organic materials and chemical balance are generally superior to sterile substitutes. We make exception to this generality in the Borax case study.

Other growth mediums — In most cases, we find that even if the surface profile has been stockpiled, there is insufficient material to cover all eventual overburden and other materials must be used. Several of our mines have identified fine textured materials in their pits that they are storing and using in conjunction with the original topsoil. In the Caltrans study (Claassen and Zasoski, 1994), 20 percent original topsoil materials was combined with 80 percent sterile growth medium and still supported biological activity and plant growth. A project in Glacier National Park top dressed a sterile growing medium with 2 inches of salvaged topsoil and then seeded into this material. One of our local contractors uses this technique to inhibit weed growth as well as amend the soils. As mentioned earlier, soil testing will help the technician to avoid toxics, low pH's, heavy metal concentrations, etc. We would recommend that sterile subterranean materials be amended with organic material and even surface soils from the surrounding area. This may add necessary microbial life and essential micronutrients.

Amendments (physical, chemical, biological, and specialty products) — A diagnostic soil test that targets the desired natives that we are seeding will contain recommendations for pH normalizers, micronutrients and macronutrients, and organics. Whenever financially and logistically possible, these recommendations should be taken seriously, but with caution (with caution, because delicate chemical and biological balances within the soil can be easily interrupted by small amounts of chemicals). Also, as we have said, if the recommendations are for agronomic species, the nutrient load can be a detriment to native establishment. The list that follows is of Comstock Seed’s major groups of amendments. Regardless of the final "recipe," remember that a natural system is more than the sum of the parts and that simply putting all the parts together doesn't guarantee plant community establishment.

Physical amendments — Physical amendments can be added if your growth medium is either too coarse or too fine for your target species. For instance, sand may improve aeration if you are planting species that are typically found in coarse alluvial areas. Conversely, finer silts may improve germination of playa species that have evolved in silty conditions. Over several years we have had more successes establishing plant communities on slopes than on flat surfaces due to enhanced drainage. Last, we supply different blends for sloped vs. flat surfaces.

Chemical amendments — Soil recommendations generally emphasize nitrogen, phosphorous, and potassium (NPK) as macronutrients, sulfur, calcium, and magnesium as intermediaries, and a multitude of micronutrients in small quantities. As mentioned above, some contractors prefer to introduce these chemicals in organic forms while others use inorganic forms. The inorganic forms come in quick- and slow-release varieties, and we generally prefer slow-release varieties.

Chemical amendments, primarily lime and gypsum forms can play a significant role in pH moderation and these can be supplied both organically and inorganically. If the growth medium is not chemically stable, periodic treatments using these forms may be necessary, but we tend to avoid this alternative by supplying stable growth mediums.

As mentioned above, the chemical "recipe" for any one site must target the desired plant community and we have replaced a traditional emphasis on chemical nitrogen with organic forms and an emphasis on phosphorous for root development. Many of our native shrubs have deep rooting systems and young plants are genetically tuned to send roots down quick in search of adequate moisture for survival knowing that hot dry summers are on the way. This is quite evident at U.S. Borax where young roots had to penetrate to at least 12 inches to locate 10-percent moisture in the soil. Limited amount of phosphorous can enhance this growth pattern. On the other hand, over application of salt-based fertilizers can be detrimental by harming microbial populations.

Many of our mines have excluded fertilizers and minimized the cultivar grass proportion in the seed blend to reflect reduced nitrogen availability. We have seen at many projects where nitrogen feeding produced excessive vegetative growth relative to root development. This resulted in high rates of mortality. We would much rather stimulate root development with humble first year vegetative development in trade for long-term plant stability. Nitrogen has also stimulated excessive weed growth which inhibited native development.

If, however, your goal is to produce a quick temporary ground cover as an organic amendment or for soil stability, nitrogen dominated fertilizers will help.

Micronutrients are commonly added in both organic and inorganic forms to address specific deficiencies or imbalances. As with NPK recommendations, a soil test will prescribe micronutrients. A complete soil fertility education involving these micronutrients and their subtle balances is beyond the scope of this paper. We will see several approaches in the case studies regarding fertility applications.

We conclude this section with a short list of general recommendations for dryland reclamation:

- Caltrans reported that mycorrhizae infection of roots was greatest with moderate fertilizer applications of 24 lbs N/acre and 35 lbs P/acre (Claassen and Zasoski, 1994). One of the authors stated that he thinks 2250 kg/hectare organic nitrogen is necessary in the soil to sustain a native community through development to the point that nutrient cycles stabilize.

- Munshower (1994) states that if soil organic material exceeds 2-percent additional nitrogen may not be necessary for growing natives. Nitrogen amendments should maintain a C:N ratio between 12:1 and 20:1. If a high carbon amendment such as straw or sawdust is used, additional nitrogen may be required to replace nitrogen being consumed by decomposition.

- Kinsey (1995) states that even though calcium and magnesium are secondary elements, their absolute amounts and biochemical significance are important. Ca and Mg percentages in a base saturation should be about 65 percent and 15 percent respectively. One of our contractors uses poultry manure for its calcium content.

- At one minesite, 2 tons per acre of organic compost plus 10 lbs N/acre has been sufficient to support native blends. 2 tons per acre is only a fraction of a percent organic material in six inches of sterile growth medium!

The variations in the above recommendations reflect different site conditions and target specific plant communities.

Biological amendments — In this area we are interested in organic materials and microbial inoculants. Organic materials will be beneficial to poorer quality growth mediums as a nutrient source, for improving aeration, soil structure, and for water holding capacity. Technically, organic materials include both amendments and mulches. Mulches are applied to the surface and aid in moisture retention and erosion control while amendments are incorporated into the soil for nutrient release and structural support. Since seasonal moisture and microbial action are necessary to breakdown organic materials, we recommend that finer materials be used. As mentioned above, the C:N ratio in the soil is important and many organic amendments can cause detrimental imbalances. Manures, sewage sludge, and grass clippings fall into optimum C:N ratios while straws and sawdust far exceed it. Again, application rates are dependent on the soil analysis and the target species. Several of our clients use two tons/acre as a standard rule.

Inoculums, containing microbial organisms, are commercially available for legumes and trees. We coat and pelletize our legumes with appropriate inoculums. The pelletizing holds the inoculum to the seed and temporarily protects the inoculum from desiccation. Unfortunately, the market is underdeveloped for inoculums for other forbs, grasses, and shrubs. We are interested in the use of locally generated inoculums taken from samplings of local mature plant communities. Acquiring these local inoculums may prove to be unfeasible on a large scale but an attempt should be made to incorporate them into plantings. Again, the Caltrans study (Claassen and Zasoski, 1994) stated that 20 percent of these native soils with inoculums was sufficient with 80-percent sterile growth medium to increase biological activity.

Several mines have already played with the "island" concept by concentrating topsoils and higher rates of amendments in small locations across broad disturbances. Spotty successful vegetative development may assist with colonizing of the remaining areas. Also, the use of colonizing native species will assist with the soil development and microbial colonization. Stay tuned with this scenario. Whatever the means, nutrient cycling requires the presence of both host plants and their associated microbes and inoculums as essential ingredients.

Specialty products — Industry is going beyond the above individual ingredients and creating products that perform a multitude of services. Our jury is out on most of these products until we have seen generally improved projects over time that meet the claims made by manufacturers. Some products may be widely versatile while others have specific limitations. Of course their claims must be weighed against the costs but we eagerly recommend experimenting with them. The Idaho Transportation Department and urban case studies cover a few of these materials.

A final prepared surface has incorporated the amendments into the growth medium and either firmed the surface for a drilling application or left it loose for a broadcast harrow application. Cultipackers that follow the drill or broadcaster will firm the final seed bed and maximize the seed soil contact for most efficient water conservation and eventual transfer of the water from the soil to the seed. Some contractors hydroseed an organic blanket over the final seedbed for erosion control through the winter as well as additional amendment value. The seed section will discuss adding seed to this final blanket as well.

Application: Timing

Because most of our plantings are dryland, the majority of our seedings occur in the fall and winter to capitalize on moisture. Also, many of the shrubs, legumes, and flowers have hard seed coats and winter freeze-thaw cycles help to break the "seed coat dormancy." Last, many seeds have embryonic dormancy and aging helps the seeds to mature. The section on seed will stress these points. Good seed-soil contact is the most important concept in assisting the seed to imbibe moisture and germinate. Winter weather assists in making this bond. We recommend that seeding is timed prior to extended low pressure fronts to increase our odds of successful seed-soil bonding. Spring seedings make up a small percentage of our dryland reclamation efforts. These seedings typically occur as early as the ground is workable. Urban seedings occur more often in the spring because weeds are a more important issue for developers. Further information on germination procedures will be presented later.

Application: Techniques

Our clients are interested in minimizing the number of times that man and or machinery pass over an area during reclamation. The final surfaces that we are typically dealing with are 2:1 to 3:1 slopes with flat or preferably undulating surfaces above. Slopes that are steeper than 3:1 are more difficult to run machinery on the contour and usually require vertical track seeding, hydroseeding, or aerial seeding. For water conservation purposes we recommend working the slopes down to a degree that allows contour track patterns for ultimate water conservation on the slope. At this point, the growth mediums have been applied to the surface and one of the following techniques is used.

Broadcast and Harrow

This method has been used to sow the majority of our seed. The broadcaster has more versatility for working on variable surfaces. Broadcast machines throw seed out in variable widths depending on the size of the machine and the density of the see. They are typically mounted on the front or rear of an all terrain vehicle or a Caterpillar. To minimize the number of passes over the land, Caterpillars may be equipped with rippers and a chain drag. The rippers are playing two roles by reducing compaction, if it is a problem, and by contouring the surface for collecting rainwater, which also reduces erosion. The chain drag, spring harrow, or equivalent is mixing the loose surface materials and the seeds. Chain drags come in a multitude of shapes. Many are

made in-house to be appropriate for specific planting conditions. Most of our blends are optimally planted when buried up to 1/2 inch. A chain drag needs to be heavy enough and shaped to do light blending. If the drag is too light and the soils are compacted or coarse, the chain drag may ride over the ground surface without doing any blending. If the drag is too heavy and the soils are quite loose, the seed can easily be buried too deep. Both conditions occur all too often. With variable conditions over the site, this can create a challenge to the operator. It is important that the operator fine tunes this procedure to obtain surface mixing and optimum planting depths.

The following chart shows a sample of species and their optimum depths. Note the variability.

Species	**Optimal Depth**
Large seeded grasses	3/4"
Small seeded grasses	1/4" to 1/2"
Indian ricegrass	3" to 5"
Winterfat	surface
Sagebrush	surface
Rabbitbrush	surface
Atriplexes	1/2" to 3/4"

Since most seeding is accomplished in a single pass, it is not feasible to place all seeds at their optimal depth. The modern drills addressed in the next section attempt to deal with this problem. However, we still prefer broadcast harrow. If the drag is operating properly, some seed of all species will be planted at their optimum depths. Occasionally, our clients will broadcast the ricegrass while they are ripping to get it deeper in the ground. Also, the surface species are sometimes broadcast separately or hydroseeded following a drill or broadcaster. The final surfaces are either roller packed or left undisturbed.

Frequently, specifications call for doubling seed rates when broadcast techniques are used. In general, we are finding that success or failure of a seeding is far more dependent on weather, soil, and seeding technique. Given germination occurs in the spring, we have had good coverage with seeding rates as low as 7 PLS lbs per acre. Indeed, we have not only had good coverage results with light seeding rates but also poor results with heavy seeding rates. Clients have a tendency to increase seeding rates after poor showings and decrease the rates after good showings. If they are getting seed at the appropriate depth at the right time, weather and soils are the real concerns.

Drill Seeding

Modern drills come in many varieties and are highly specialized for different applications. For most of our applications, we are interested in rangeland drills. These drills have evolved from conventional farm implements. These new machines have larger wheels, independently floating discs, multiple boxes for different sized seeds, built in cultivators, and wheel presses for firming the seedbed after seeding. These modern drills are engineered to plant seed at exact depths as well as perform multiple functions in one pass. The multiple boxes allow for exact proportions of each type of seed to be delivered (on rough terrain like that of mine surfaces, such machinery

is inappropriate). However, a drill is also less likely to bury seed too deep or shallow than a broadcast harrow.

Also, drills are pulled behind tractors while broadcasters are typically attached to the tractor. This makes the broadcaster much more maneuverable on the rough terrain that is typical at most of our mine sites.

Last, drills are expensive relative to the broadcast machines and as mentioned above, under coarse conditions, the drill's precision depth control may be difficult to maintain. We have heard of expensive drill machines being damaged.

Hydroseeding

Hydroseeding has limited use for us. It is most commonly used for lawn installations or for road cuts that are too steep for other machinery. It hasn't been considered an option for some of our more remote sites due to the lack of a localized water source. When used though, it is a convenient way to apply mulch, fertilizers, seed, and tackifiers in one slurry. It is important that this slurry is bonded to the soil surface. Both low temperatures and unstable soils can prevent this bond causing the materials to separate from the soil surface. As mentioned above, hydroseeding has a good role to play when shrub seeds require a surface planting. However, both broadcasters and drills can also leave shrub seed on the surface.

Aerial Seeding

Aerial seeding is usually limited to large projects such as forest or range fire reclamation. There have been many such seedings along the Sierra front over the years and they have had variable success rates. A winter with good snow and a warm wet spring may assure a good germination rate while a dry winter and spring may not yield any germination. If the seed has to wait another year for a more favorable wet spell, it may be lost to predation, wind, etc. Also, aerial seedings usually don't involve surface preparations, which decrease the chances for successful germination.

On the Sierra front, fires can cause serious disruptions to water supply if bare slopes aren't stabilized before winter and spring runoffs. The Verdi fire a few years ago had a tremendous germination of an annual grain that held the ravines through the winter.

One mining client recently did a fall aerial seeding of 150 acres in two hours. The seeding was followed by a cattle treatment to work the seed and organics into the soil surface. Stay tuned.

Cattle

In the last few years we have become involved with projects that are using cattle for soil conditioning prior to or after seeding. The cattle have the ability to assist in fertilizing the soils with manure as well as working the manure, other amendments, and seed into the soil surface. From a seeding standpoint, cattle may be beneficial if the terrain, soil conditions, or lack of

adequate machinery prevent seed from being put down uniformly and at correct depths. We wait patiently for the results of these projects.

Combinations

Many of our projects are using a combination of techniques. The combination of cattle/aerial methods mentioned above is one example. The broadcast/hydroseed combination is another. A popular method with our urban contractors is to drill or broadcast seed into a bed then hydroseed the surface species and a soil stabilizer over the top. As mentioned earlier, any seeds that need to be buried deep can be placed during early ripping operations. I think that the uniqueness and available resources of each site will assist in determining the appropriate seeding technique.

Last, in the following section on seed considerations, seed blends must be designed for the client's seeding machine. This points to coordination of effort throughout the reclamation procedures to make sure that a uniform seed distribution of the optimum blend is achieved.

Seed Considerations

All the sections in this paper including seed considerations are interrelated. This section attempts to list the primary variables in creating a blend. At the end of the section is a group of charts, test copies, and blend samples. Comstock Seed’s blends typically contain a combination of shrubs, grasses, and flowers in varying proportions. The wide variety reflects many criteria, the major ones of which are listed below. After discussing testing and quality, we will go through these criteria in the hope of offering readers a conceptual understanding of decisionmaking for choosing appropriate seed blends for their projects. Seed blends are discussed further in the case studies.

Seed quality, testing, and labeling requirements — Most species of our seed have been tested for quality and all states have minimum quality standards that we have to exceed. Both private and public testing facilities located throughout the United States will test seed for nominal fees. Each state has a time limit period for test date expiration. Nevada's is 18 months while California's is 15 months and Arizona's is a strict 6 months. Since test dates are required on labeling you can check to insure that the species in your blend have current test dates.

Uniform guidelines exist for the testing of traditional agricultural seed crops but testing standards for our native seeds are scant at best. We have included a page showing testing variations that reveal the difficulty in controlling quality. Ultimately, we try to provide these native shrub seeds in a form that will flow through machinery and blend will with other seed. Too little cleaning can leave a trashy mess that can clog machinery or be loaded with weeds. On the other hand, too much cleaning can damage the seed with high mortality rates or shortened shelf life.

The components of a seed test are:

Bulk *vs*. PLS — Seed can either be purchased on a "Bulk" or a "PLS" basis. The bulk weight represents the actual weight that you purchase and the PLS rate represents the pure live seed percentage of that bulk weight. The pure live seed percentage is the product of a seed lot's purity multiplied by its viability or germination rate.

Purities — Purity represents the percentage of pure seed in a seed lot. Normally, purity percentages for conventional grains, grasses, and flowers are relatively high in the 90's. The purities are lowest for our native shrubs, rabbitbrush and sagebrush, where cleaning technology has not been able to reach purities much above 25 percent. On the one hand, we are not concerned that seed be cleaned to its highest purity. If the remaining inert fraction contains minimal weeds and is of a consistency that will flow through our clients' seeders, we consider such impurities as organic amendment. However, if low purities clog seeding machinery or contain high weed counts, we have to set higher standards or alter our planting machinery. Last, as purity goes down, bulk volumes go up as well as shipping and handling expenses.

Weeds — "Weeds of the West" (Whitson, 1996) defines a weed as "a plant that interferes with management objectives for a given area of land at a given point in time." Based on this definition and listed in this volume, many of our native reclamation shrubs, grasses, and flowers are weeds. Some of our reclamation projects consider weeds a natural successionary step prior to perennial development. As long as these weeds do not persist and the perennials do develop, we tolerate them. We also use quick germinating cereal grains to compete with weeds as well as act as organic producers or nurse crops. If the weeds persist or deter the perennials, then the definition becomes more appropriate.

Weed percentages are typically low, in the fractions of a percent, but even small percentages can be large amounts of unwelcome seed. The states have variable tolerances for the amount and type of weeds that are allowed in seed blends. Transporting seed interstate can become a problem if one state’s "other crop" is another state’s "weed."

Each State has a noxious and restricted noxious weed list. Species on these lists are prohibited or allowed in very small amounts. This becomes a concern to the client when seed is quarantined enroute to a job, the entire process is held up, and machinery is idled.

Know your seed company. Whatever the perceptions at a given site, we are only concerned about weeds when they have persisted or the preferred perennial growth has not developed.

Other crop — Any live seed that is neither weed or the species being tested is "other crop." We have seen "other crop" exceed 30 percent, but, typically, it is a fraction of a percent like weeds. We haven't been too concerned about the nature of the other crops except that interstate shipments may result in reclassification of a species from "other crop" to "weed." In many instances, "other crop" is a neutral or favorable species that may compliment a blend.

Inert — Inert represents all that is leftover after the above elements have been identified. The inert may be organic or inorganic. Typically, our inert is organic plant residue and as long as it is fine enough in texture to flow through the seeding machinery, we see it as a favorable amendment.

Viability — Viability measures the percent of the pure seed that contains living material. At the least, we have an enzyme test performed that measures the percentage of seeds containing living tissue.

A germination test can be performed that would determine the number of seeds that germinate in the test and the remainder that show an enzyme activity would be considered as dormant seed. These two factors together should approximate the total viability.

Occasionally, we see "fill" tests performed that reveal the seeds that have material in the seed capsule. These "fill" tests have been used as the viability percentage in many PLS calculations and this represents a dilution in the measurement of quality based on living tissue. We recommend that you require a minimum of a "TZ" test when determining PLS quality.

Other factors — Our other concerns include dormancy and shelf life. Some species such as Indian ricegrass have dormancy percentages in the 90's. This dormancy breaks down over several years. Ricegrass is a favored native grass but it must be seeded with an understanding that its performance will be long term. We occasionally specify increased seeding rates of this species to enhance short term germination.

Most of our species have some shelf life. The hard seed coat shrubs, legumes, and flowers have long shelf lives and can be retested per state law over several years with only minor declines

in viability. The softer seed coat species such as sagebrush, rabbitbrush, winterfat, and kochia have very short lives and should be used by the second growing season after harvest. The Kochia should be used by the spring after the previous fall harvest. Some riparian species do not have shelf life and the seeds need to land directly in water for survival.

DORMANCY

Species	Lot No.	Date	Viablity	Germ	Dorm
Ambrosia dumosa	93	4/94	75.00	2.00	73.00
Oryzopsis hymenoides	C91-150	2/92	93.00	0.00	93.00
Atriplex lentiformis	119A	2-94	68.00	24.00	44.00
Atriplex lentiformis	119A	4-94	87.00	57.00	30.00

DORMANCY OVER TIME

Species	Lot No.	Date	Lab	Viability	Germ	Dorm
Purshia tridentata	91P	11/91	WY	94.00	14.00	80.00
Purshia tridentata	91P	4/94	UT	80.00	75.00	5.00

Species	Lot No.	Date	Lab	TZ	Germ	Dorm
Schismus barbatus	7	6/92	AZ	66.00	-----	-----
Schismus barbatus	7	8/92	UT	89.00	7.00	82.00
Schismus barbatus	7	4/94	UT	-----	0.00	87.00

QUARANTINE NOXIOUS

Species	Lot No.	Date	Lab
Atriplex canescens	196	2-91	WY

Seed identified as Franseria discolor (similar to Ambrosia dumosa)

SHELF LIFE

Species	Lot No.	Date	Germ	Lab
Chrysothamnus nauseousus	313	1-92	90.00	WY
Chrysothamnus nauseousus	313	4-94	0.00	UT

RECLEANING TEST COMPARISON SAME LAB

Species	Lot No.	Lab	Date	Purity	Inert	Crop	Weed	TZ
Sphaeralcea ambigua	33	ID	10-92	93.79	5.32	.25	.64	82.00
Sphaeraclea ambigua	33	ID	11-93	83.27	16.36	.12	.25	89.00

VIABILITY VARIATIONS

Species	Lot No.	Date	Lab	TZ	Purity	Fill by No.	Fill by wgt.
Atriplex polycarpa	43	1-93	UT	51.00	-----	-----	-----
Atriplex polycarpa	43	1-93	AZ	-----	-----	66.00	78.00
Purshia tridentata	23	12-92	UT	37.00	-----	-----	-----
Purshia tridentata	23	12-92	WY	54.00	-----	-----	-----
Deburred							
Ambrosia dumosa	56	7-93	NM	58.00	83.94	-----	----
Burred							
Ambrosia dumosa	56	6-93	AVS	36.00	-----	-----	-----
Ambrosia dumosa	56	5-93	AZ	-	69.56	42.00	56.00
Sarco. vermiculatus	512	11-97	ID	46.00	-----	-----	-----
Sarco. vermiculatus	512	11-97	MT	92.00	-----	-----	-----
Ceratoides lanata	494	10-97	MT	59.00	67.19	-----	-----
Ceratoides lanata	494	11-97	ID	36.00	86.09	-----	-----
Atriplex lentiformis	119A	2-94	WY	68.00	(24.00 germ	44.00 dorm.)	
Atriplex lentiformis	119A	4-94	UT	87.00	(57.00 germ	30.00 dorm.)	

PURITY VARIATIONS

Species	Lot No.	Lab	Date	Purity	Crop	Bulk $/Lb	PLS $
Eriog. umbellatum	91	WY	11-93	82.71	.14	35.00	55.56
Eriog. umbellatum	91	UT	10-93	59.79	.22	35.00	44.30
Ceratoides lanata	61	UT	6-93	82.93	.01	15.00	22.39
Ceratoides lanata	61	NM	9-93	66.55	.17	15.00	27.78
Chryso. nauseosus	416	UT	5-94	10.59	.08	5.00	55.56
Chryso. nauseosus	416	ID	3-94	18.22	.25	5.00	33.33

(prices assume that viability is constant)

WEED & CROP VARIATION

***Atriplex canescens*, Lot No. 99**			
	Utah State Lab	Wyoming State Lab	Wyoming State Lab
Date	11-93	11-93	4-94
Purity	94.14	98.30	98.20
Inert	5.45	1.68	1.76
Weed	.10	.01	.03
	Bromus 24/lb	*Bromus* 24/lb	–
	Salsola 189/lb	*Salsola* 10/lb	*Salsola* 79/lb
Crop	.31	.01	.01
	Atriplex 307/lb	*Chrysothamnus* 5/lb	*Atriplex* 7/lb

***Ambrosia dumosa*, Lot No. 56**		
	NM State, deburred	AZ Seed Lab, burred
Date	7-93	5-93
Purity	83.94	69.56
Inert	15.98	30.43
Weed	07	.01
	Aristida spp.	*Brassica spp.*
	Stinkgrass	*Hymenoclea salsola*
	Downy brome	
	Sonchus oleraceus	
	Aster spp.	
	Boranginaceae spp.	
	Brassica tournefortii	
	Verbesina spp.	

***Sphaeralcea ambigua*, Lot No. 33**		
	ID State Lab	UT State Lab
Date	10-92	10-92
Purity	93.79	89.18
Inert	5.32	10.50
Weed	.64	.17
	Bromus tectorum 151/lb	*Bromus tectorum* 410 /lb
	Plantago ovata	
	Amsinckia sp.	
	Brassica rapa	
	Sonchus oleraceus	
	Alopecurus pratensis	
	Erodium sp.	

Selection Criteria

Each client has a set of criteria shaping the eventual completion and closing of their project. Most are interested in bond release, which occurs incrementally as the bond criteria are satisfied. Success with native plant establishment has been measured by comparing frequency and cover data on the reclaimed sites with equivalent data from undisturbed local plots. Some argue for measurements that include soil microbial development.

We have listed some general criteria used in creating seed blends. These criteria need to be considered individually and in combination to design a blend. You will notice that these criteria at times overlap with the planting techniques and the soil considerations above.

Post reclamation use — Most of our clients are interested in returning their sites to the native plant communities in their respective areas. The relative permanence and stability of native communities is a desired end goal. Occasionally, the end use will be agronomic, specific habitat, riparian, cultural, or other specialized use.

Ecological limitations — As emphasized above, the harsh elements of Great Basin ecology greatly reduce the group of species that will survive on a reclamation site without continual human inputs. For example, if our project is in north central Nevada, the precipitation and elevation is higher and shallow rooted grass cultivars do well compared to western Nevada where many of the cultivar grasses don't persist. Likewise, in southern Nevada, the Mojave Desert conditions limit the grass component to a minor percentage of cover represented in ephemeral communities. Last, ecotypes vary from our basin playas to our alpine zones and the plant species that will survive in these areas differ dramatically. At the end of this section are samples of a few Great Basin/Mojave blends.

Ecological relationships between species in a blend are also of concern. As mentioned earlier, we may include species that are colonizers and represent early seral stages along with seeds of the final desired plant community. These colonizers may be native shrubs or cereal annuals that do not require a developed soil microbial population. Also, each species has specific niche requirements and growth habits that may or may not be compatible with the other species in a desired blend. This point relates to the diversity issue presented in the Echo Bay and Cunningham Hill case studies. All species included in the blend should be able to survive given the site conditions. Some species have aggressive growth habits while others are slow to establish. For instance, we have found that sagebrush germinates best when seeded alone. If our clients wish to grow native shrubs we tend to reduce the amount of highly aggressive grasses that we put in a blend. We are involved in a never-ending debate about the ecological impacts of Crested Wheat and its impact on native shrub establishment. This debate highlights the importance of understanding the habits of the species that we blend together for clients. Many of our clients that have had several years of reclamation efforts have observed their reclaimed areas going through stages of various plant seral stages. This indicates that the soils are developing to support the later seral stages. In many instances, most species in our blends come up simultaneously and we get to watch them sort themselves out over several years. The next consideration also has implications for species interactions.

Seed size — Seed size varies dramatically. The smallest seeds exceed many millions of seeds per pound, while the larger grains and shrub seeds may only have 10,000 seeds per pound. Seed size must be balanced against the other variables mentioned in this section. In many instances, reclamation planners have set an application rate based on pure live seeds per square foot and the blend must total this number.

One of many examples involves flower seeds mixed in grass blends. Flower seeds are generally small and a little seed goes a long way. However, grasses are relatively more aggressive and typically, we have to overwhelm grass seed with flower seed to get good flower displays. In most instances, when flowers in a meadow setting are the goal, we only use very nonaggressive grasses. Generally, bunchgrasses are much less aggressive than sod grasses. We frequently review blend specifications and seed size is often neglected and actual proportions of species in these blends become absurd. The consequences of such imbalances can destroy a project. The following section relates directly to seed size.

Seeding machinery and application methods — These methods were described above. We have occasionally altered the constituents in a blend to accommodate the machine that a client was using for a project. If some of our lighter fluffy native shrub seeds couldn't flow through these older machines we would increase proportions of the heavier species or add a filler to assist in the flow. As mentioned above, some contractors separate the fluffy seeds and hydroseed them over the final seedbed. Most of our contractors are doing single pass seeding and

we have been able to include all the desired species at a consistency that would flow through their machines. Last, when the contractor is using a multibox drill, the seed blend must be broken down by size for the appropriate bin.

Native *vs*. non-native considerations — This is a highly debated issue because philosophical and pragmatic approaches don't always coincide. This issue arises in the Tuscarora, Leviathan, and Horseshoe Bend case studies. The case for natives is made above but non-natives (cultivars and introduced species) also have positive uses. Emergency watershed protection after a fire may require a quick growing nurse crop annual. Temporary cover crops or "nurse crops" are used to prevent wind and water erosion until slower growing species establish or until the temporary condition is changed. These same nurse crops may act as soil builders and early colonizers. However, some critics claim that this cover crop will compete with the slower growing natives for the limited resources available. A fast growing native or annual may be added to a blend to combat weeds. Our blends are usually a mix of both native and nonnative species combined with a small percentage of nurse crop. The literature and our field experience currently hold these nurse crops to 15 percent of a blend when seeding native communities.

Economics — Our seed blends have ranged in cost from $20/acre to $1,800/acre. Much of the native seed used for reclamation projects is not commercially grown and seed supplies are dependent on favorable weather patterns. Inconsistent weather and sporadic native seed production results in price volatility. Our never-ending challenge is to consistently supply our long-term reclamation programs given the market volatility. Increasing amounts of our seed are being commercially grown which is adding stability to supply and prices. Overall, seed is a minor expense relative to the total reclamation budget.

Timing — We mentioned above that most of our seed is planted in the fall and winter to take advantage of natural precipitation patterns. If a client is planting in late spring we have occasionally added an annual cover crop hoping to establish a quick cover crop prior to summer drought. If an early fall planting is attempting to germinate perennials prior to winter, the wheatgrasses germinate much faster than the wild ryes, bluegrasses, and fescues. Cover crops that germinate quickly can alleviate dust problems and hold the soils until the fall rains return. Last, if a contractor is attempting an early fall planting and germination prior to winter, we usually do not seed annual flowers because they die off without producing a seed crop.

Public relations — Perception is as varied as shades of a color. We attempt to create blends that satisfy a wide variety of people. A wildflower may be pretty to one person and satisfy an essential ecological role to another. Weeds may be fine on a mine reclamation project but detrimental, even temporarily, on land that is to be developed. Also, a wildflower may be nice in a turf alternative, but if it invades a turf area it may be perceived as a weed. As urban areas expand towards some of our older projects, the public becomes more demanding about controlling wind

and water erosion, noise, and visual disturbances. Reclamation projects can calm these concerns as well as satisfy erosion problems, etc.

Pilot studies — Many clients start out small with plot studies to learn how to be "farmers" and also to learn about the growth habits and survival characteristics of a wide variety of species. The information gained is used to design reclamation blends.

As a group, we could list selection criteria indefinitely. Each client needs to identify which criteria are significant for his or her site, and then we can design seed blends.

Balanced Options, Seeding Rates

We have included a handout showing a comparison of several blends that have been used in the past. These blends are not meant to be general use recipes. At any given site, they may change each year to reflect the progress and failures of previous years' work. (The last handout shows how a blend changed over a few years at one site.) We also create specialty blends that satisfy specific criteria such as wetland development.

Our seeding rates have varied from 6 PLS lbs/acre to 40 PLS lbs/acre. We can calculate the number of seeds per foot that these blends represent and recommendations have actually varied from 20 to 200+ seeds per square foot. We rarely think that applications rates should exceed 100 seeds per foot except with turf. For emergency erosion control, we have supplied annual grains that were planted at 60 bulk lbs/acre. For our Great Basin minesites the rates average between 15 and 30 PLS lbs per acre. As mentioned earlier, seed size plays a significant role in application rate. Once the seeding rate and species list is determined, we usually blend the seed into even acre bags, which helps the client to better gauge his application.

Each of these blends has been used during one season's planting. The blends have typically varied by year; these examples are not meant to be used as general recipes for a particular ecotype.

Various Arid-Site Seed Blends

Variety	%	Variety	%	Or
Mojave Blend		**Pinion-Juniper Zone**		
Fourwing Saltbush	14.96	Bitterbrush	10.34	CA
Desert Spinach	37.41	Winterfat	8.15	NV
Shadscale	8.31	Fourwing Saltbush	10.01	NV
Creosote	4.68			
Bursage White	5.15	Secar bluebunch wheatgrass	7.43	WA
NV Mormon Tea	1.66	Western Wheatgrass	10.74	WA
Green Mormon Tea	1.16	Sandberg bluegrass	5.52	CA
		Great Basin Wildrye	8.48	NV
Mediterranean Grass	6.28	Indian Ricegrass	4.90	WA
		Needle and Thread Grass	1.25	AZ
Desert Globemallow	1.44			
Plantago	.83	Palmer Penstemon	6.16	NV
Palmer Penstemon	.56	Small Burnet	2.64	OR
		Blue flax	5.40	WA
Annual Rye (nurse crop)	4.43	Cicer Milkvetch	5.52	WY
	97.39	Yellow Sweet Clover	5.06	CN
			91.60	
Cold Desert/Saltbush Zone		**Pinion- Juniper Zone**		
Fourwing Saltbush	16.19	Fourwing Saltbush	10.63	
Shadscale	21.72	Prostrate Kochia	5.34	
Green Mormon Tea	1.12	Rubber Rabbitbrush	1.41	
		Greasewood	6.45	
Rubber Rabbitbrush	.70	Indian Ricegrass	5.91	
		Squirreltail	6.09	
Crested Wheatgrass	6.45	Crested Wheatgrass	6.36	
Siberian Wheatgrass	6.18	Streambank Wheatgrass	6.80	
Indian Ricegrass	3.12	Thickspike Wheatgrass	6.09	
Squirreltail	2.03	Basin Wildrye	6.29	
Rocky Mountain Beeplant	3.09	Ladak Alfalfa	4.52	
		Yellow Sweetclover	4.67	
Ryegrass annual (nurse crop)	18.41			
	85.46	Palmer Penstemon	2.67	
		Small Burnet	7.31	
		Lewis Flax	1.72	
		Bachelor Button	6.29	
		Annual Sunflower	3.25	
			85.35	

Case Studies

These case studies are experience driven. Successive growing seasons may have different programs based on earlier years' results. These observations are included solely for the advancement of our profession with permission of the clients involved. They do not necessarily cover all aspects of a client's reclamation program.

The challenge to diversity — The following two projects have successful revegetation programs in progress and are interested in enhancing shrub diversity.

Echo Bay — We visited Echo Bay in the summer of 1996 and were shown a revegetated slope that to most reclamation engineers would be considered a great success. However, the dominant cover on this slope, and several like it, included wheatgrass cultivars and an occasional saltbush. The management explained that they needed much more diversity of species and more shrubs before these slopes could be considered successfully reclaimed. Several other areas that had been seeded over the past 6 years contained strong thriving communities of Atriplex dominated shrubs. In the fall of 1996, we provided a diverse blend of shrubs, native grasses, and a few forbs. The wheatgrass cultivars were specifically minimized.

The seeding contractor has been and will continue to use a broadcaster mounted on a Caterpillar with a light chain behind. Also, all areas to be seeded have been ripped to 6 inches deep and amended with a subterranean spoil material. Amendments and organics were incorporated prior to seeding and hydroseeded onto the site after seeding. The specific blend of amendments resulted from soil testing of the surface and subterranean materials.

Winter precipitation was excellent and the following spring showed promising results. Most of the species in the blend germinated including a wide variety of the shrubs that do not look like they will be dominated by grasses. If anything, the shrub community may dominate the grasses. By late fall 1997, many of the 18-inch high shrubs had produced seed!

Cunningham Hill — This project is south of Santa Fe, New Mexico, and is visible from the city. The ecosystem in this area is highly influenced by summer precipitation out of the Gulf of Mexico and is located at a cool 7,000 feet in Juniper woodlands. When we visited this mine in the summer of 1996 we could tell that the mine had already been quite successful over the last several years at establishing good stands of warm season grasses. The mine engineers explained that the state required more diversity to fulfill bonding requirements. Also, since the mine was visible from Santa Fe, the grasses were starkly visible and during dormant seasons in the spring and fall, these blond grass slopes were much more obvious. We commenced to design blends that would satisfy the state as well as initiating a harvest

program to bring in many of the local native shrubs and trees. Some of this seed was grown out into container stock and much was directly seeded onto new slopes.

The mine was quite concerned that the highly aggressive grasses would still out compete the native shrubs so we departed from our normal acre bag seeding and created separate blends of the grasses and the shrubs. These separate blends were broadcast seeded onto the contour in alternate rows. We had already seen how successful shrubs were grown on Wyoming coal mines by seeding them pure, especially with sagebrush. The results next summer were quite dramatic. We were most successful with shrub and grass establishment, but we have had mixed results with the tree seeds. Much of the container stock has had predation and we have not as yet had a strong showing from some of the juniper and oak and sumac. From an ecological perspective, this may be predictable since these species represent later seral stages and the soil and habitat conditions may not yet be developed to support arboreal communities. The successes to date have been achieved without fertilizer applications. Topsoil was taken from borrow areas and used as a top dressing on the dumps.

Bullfrog and Colloseum mines update — The Bullfrog and Colloseum mines are located in southern Nevada in a transition zone between the northern Mojave desert and the Great Basin. Indeed, even though the mines are somewhat close in proximity, they are in quite different plant communities. If the mine engineer at these mines was interested in restoring native plant communities and a generic Mojave transition zone blend was specified, quite different results may have occurred.

Transition areas between plant communities are unique in their diversity of species. The common Creosote community of the Mojave is blended with the salt desert-sage shrub communities of the Great Basin. In this respect, the species list for potential reclamation work is broader than if you were centrally situated in either life zone. This transition area is characterized by shrub communities with little native-grass understory, and, as you climb from the lower elevations into the island ranges, the species change dramatically. These two minesites display this variability, and the seed blends that we created reflect it.

Both sites were planted with a broadcaster mounted on the back of a Caterpillar and a chain drag made at the mine was dragged simultaneously with the seeding. Due to the light trashy nature of the seed blend, the agitator in the broadcast bin was modified to enhance the flow of seed.

Bullfrog mine — In the earlier years, plot studies were conducted using various seeding options and fertilizer rates. Early on, the results of these experiments showed that shrubs were responding better than grasses and fertilizers were just stimulating weed growth. Later on, fertilizers were completely eliminated. Some original topsoils were salvaged but many

slopes were planted without the benefit of these soils. Some of the growth mediums that were placed on the overburden were fairly fine-textured materials that could provide structural support. Many of the slopes were too steep for the Caterpillar to work horizontally but instead of changing to vertical, the Caterpillars worked on a diagonal, attempting to reduce surface runoff. The seed blends changed each year to reflect the relative successes of the various species. We found best results with Atriplex canescens and Atriplex polycarpa. Consequently, we adjusted these species down and increased the other species that we wanted to see in higher concentrations. Several of the shrubs including Shadscale, White bursage, and Creosote are slower to germinate and we didn't see much evidence of these until the second growing season. This waiting period could be longer if the aging process reduced the dormancy and the growing season turned out to be dry. The timing and success of germination has been quite variable but we have gained confidence in the planting techniques knowing that weather and timing are unpredictable.

Colloseum mine — We have been fortunate to be able to revisit this minesite and build up an extensive photo survey over several years. Several areas show much variation in the plant communities that have begun to take hold. This is quite startling considering that the same blend has been planted over many of these diverse sites. We have seen this variability in our urban seedings as well where we have planted the same blends at many different sites and have had a wide variety of responses.

The mine had stored topsoil south of the tailings ponds, and this material, as well as a large quantity of overburden, has been used to cap the tailings pond. Water was pumped from the tailings area and used to water seeded areas across the tailings. The plant communities responded favorably to this irrigation.

The Colloseum minesite is a mountainous community consisting mainly of blackbrush and juniper with an extensive variety of transition zone species. Also, this mountainous condition has yielded a wide variety of microsite conditions and the resulting plant communities are quite evident. Prior to our arrival, the reclamation people at Colloseum had built up an extensive collection of seed that was harvested from the local native plant communities over a few years and we combined this with our inventory to create the blends. "Island" plantings were installed across the tailings ponds. At these areas, boulders and related natural debris were stockpiled to attract fauna, and the seed rates were increased relative to the overall surface area. Sloped areas surrounding the tailings flat were hydromulched due to lack of access.

Germination during the first year was light and growth rates of these species were slow. However, the second spring yielded quite a variety of

species that grew much faster. By the third year a wide variety of communities have become established. The tailings area is dominated by Atriplex and Chrysothamnus while the slopes are exhibiting a wide variety of forbs and shrubs with an occasional grass community. Even though many of the slopes are being colonized by different species, diversity within each area is still not sufficiently evident. Several of our other clients are witnessing distinct seral stages of a few species per stage. We consider this favorable, knowing that each stage is helping to increase the soil quality and hopefully giving time for microbial communities to colonize. Of course, any species cover is also assisting in erosion control.

U.S. Borax minesite — This mining operation is located in the western Mojave desert in southern California. The precipitation rarely exceeds 6 inches of annual precipitation with most occurring during the winter months. The plant community is predominately Atriplex, Larrea, Hymenoclea, and Yucca. Due to the low precipitation, herbaceous species are quite ephemeral. As compared to most of our Great Basin gold mines, Borax is a long-term operation with expected life well into the next century. This long time period allows them to develop a long-term reclamation program with extensive plot study work.

The company, having significant land holdings, contacted us several years back, requesting on site seed acquisition for use in their plot studies. The harsh climate and habitat conditions requires well adapted genetic stock and we were in agreement that locally collected shrub and forb seed would be optimal. We vigorously pursued this option and even took our cleaning machinery to their site. On site cleaning has reduced our costs and all screenings have been left at the site to be used as soil amendment.

Their experimental work is located on the 3:1 slopes and flat-top surfaces of overburden dumps. They have purposely experimented with salvaged topsoils and subterranean spoils. Like most of our open pit clients the salvaged topsoils are insufficient to cover all eventual reclamation work and consequently, alternative growth mediums will be essential.

Early seedings were planted with a broadcaster attached to the rear of a Caterpillar. A one-pass operation simultaneously ripped deep contours, broadcast seed, and dragged chain to bury the seed in the furrow bottoms. The 3:1 slopes were optimal for operating big machinery on the contour and the deep ripping enhanced water holding capacity during their infrequent but significant rain events. No fertilizers have been applied to date.

Earlier plots were seeded with a combination of shrubs, grasses, and broadleaf native forbs. Like Bullfrog above, they have had their best early success with the Atriplex shrubs and a minimal showing of the grasses and broadleafs. During the later years Ambrosia and even Creosote have begun to germinate. Paradoxically, the best plots on the flat surfaces have germinated on the subterranean spoils with

only minor germination on the salvaged topsoils. Most later seedings are emphasizing these shrubs, but we still continue to harvest all seed-producing species at the minesite.

Also, they had an unexpected germination of Atriplex lentiformis on other top surfaces that were left in an extremely undulated condition. At many of our mine sites, flat surfaces have proven more difficult to reclaim than sloped surfaces. We speculate that this is partly due to poorer drainage and silting that occurs on these surfaces. We are encouraging other clients to leave their flat surfaces in an undulating condition in hopes of duplicating this successful event.

Even though these germination events have been quite successful, we can't truly gauge success until we have witnessed long-term survival of these plant communities and subsequent succession over many years. U.S. Borax is on the tight track and has lots of time to study and learn from their experiences.

Tuscarora pipeline update — This project was funded primarily by public utilities in Reno. The pipeline brings natural gas from an existing network in Oregon to the Reno area, passing through several counties in two states. This resulted in multiple public jurisdictions and many private landowners being brought into the planning process.

Of primary importance to us, were the several ecotypes that the line passed through and the stipulations by the agencies that the reclamation project attempt to rebuild these different systems. Seed blends were designed to reflect the different ecotypes as well as satisfy private landowner's special requests. We also harvested native seed throughout the corridor and in adjacent areas. The rough products were brought to Reno for cleaning and testing and then shipped to mixing facilities.

During excavation and laying of the pipeline, the engineers made an effort to separate the surface materials and return them to the surface in the shortest amount of time. We suspect that this prompt treatment helped to maintain microbial life and yielded benefits the following spring. Most of the seed was planted with rangeland drills followed by straw mulch and crimping and the cooperation of a late winter.

The various jurisdictions had extensive debates about the nature of the seed blends. Some parties were interested in using fast growing nurse and cultivar species to combat potential weed invasions that many expected to occur. Sections of the pipeline pass through areas infested with medusa head that some feared would aggressively colonize the disturbance corridor, choking out the slower growing natives. These debates continued throughout our involvement. Policy changes during reclamation resulted in changed blends, surplus seed, and less efficient operation, all costs eventually born by the ratepayers. These debates are important but finite decisions need to be made prior to implementation that don't

waste resources yet test various hypotheses without muddying the process. Shrub seed was used sparingly because colonization from the corridor edges was expected fairly rapidly.

Monitoring during the summer of 1996 and 1997 has shown mixed results. Performance categories included vegetation cover, species richness, and woody plant numbers. Early high vegetative cover percentages are partly due to annual native and nonnative species that have carpeted large portions of the corridor. Woody plant cover is well below comparative levels with undisturbed areas adjacent to the pipeline yet 1997 monitoring results show an increase over 1996. Herbaceous cover typically dominates reclaimed areas in the first years following construction. Perennial native grasses have increased during the two summers of monitoring with squirreltail and Sandberg bluegrass performing best in northern areas. Criteria for species richness relative to undisturbed adjacent areas have been met in the majority of transects especially in the northern montane sections. In the southern more xeric areas and in alkaline areas of the Honey Lake basin, results have been marginal and some reseeding continues. Poor structured alkaline silts have resisted germination.

Also, the spring weather patterns have not been cooperative. The 1996 spring was relatively cold and prolonged. This period ended abruptly with hot dry summer weather. During the spring of 1997 we had a record dry spell from the end of February to early April. March is an important period for dryland native germination in the Great Basin.

There has also been a woody plant propogation and transplant program on several sections of the pipeline that is showing good survival rates to date.

Noxious weed infestation has been observed on some areas of the corridor especially adjacent to undisturbed areas that contain these weeds. Lassan and Modoc County Departments of Agriculture have performed spot treatments during both summers since construction.

Grazing and trampling impacts have affected portions of the pipeline. The corridor is an easy travel route for cattle and much of the herbaceous materials are attractive to the cattle.

Generally, the best perennial herbaceous growth has occurred on the corridor in areas where the surrounding undisturbed vegetation is not dominated by annual weeds.

Last, our industry continues to debate the use of straw mulch. We think that the value of crimped straw as a structural amendment and snow catcher performs best in more mesic areas. In xeric areas though, we are concerned that the straw actually draws moisture out of the soil in late spring and inhibits germination.

Since straw decomposition also ties up available nitrogen, these collective problems may exceed the benefits gained.

Candalaria mine update — This mine sits on a volcanic rock heap at 6,000 feet elevation in southern Mineral County, Nevada. The marginal survival of shadscale communities testifies to the harshness of the local ecosystem. Our initial seeding experiments have shown some success. For the first seeding season we created blends that were similar to the local plant community, which is shrub dominated. Even though the local grasses were minor components, we also included them in the original blend.

The first year's blend was broadcast with a light fertilizer application in the late fall. The seeder was mounted on the back of a small Caterpillar dragging a light spring harrow. Seeding continued with a few inches of snow accumulated on the ground. The snow was being disced into the ground with the seed. The first winter provided better than average precipitation followed by a late spring. By late the following summer, we had most favorable growth on sloped surfaces but poor results on flat surfaces. All shrub species that we had seeded not only germinated on the slopes but grew sufficiently to flower and produce a first year seed crop. On the flat surfaces, Greasewood occurred most frequently and we increased this species and other more playa like species in the following year’s blend. Aside from the annuals, the grasses rarely made a significant showing. From these preliminary results, we created two similar blends to reflect development on flat versus sloped surfaces.

We have seen mixed results from the following spring germination. The soils seem easily compacted. In the fall of 1997, the mine did a 150-acre aerial seeding followed by a cattle treatment. We are hoping that this application will help to moderate the soil condition as well as create a more optimal seedbed and nutrient supply. Other mines have used cattle treatments before seeding and we are anxious to compare the results of these projects.

Idaho Transportation Department test plots — The Idaho Transportation Department used one of their cut banks for a series of plot studies to test various reclamation products. This exposed cut slope consisted of decomposing granite and little or no topsoil. We created several seed blends for side-by-side test comparisons using various application methods and amendments. We wished to test the use of nurse crops and included annual barley in sites 71 through 73. Over several years we want to see if the benefits of the nurse crops outweigh their competitive costs in these plots. Sites 71 through 74 were hydroseeded with an organic amendment called Kiwi power which is a humic acid product, 2000 lbs/acre organic compost called "fertile fibers," and 100 lbs/acre cliffhanger tackifier. Site 75 was broadcast seeded and top dressed with 34 yards per acre composted yard waste and soft wood shavings. Site 76 was broadcast seeded and top dressed with 34 yards per acre of composted cattle manure.

Sites 71 through 74 did quite well. The plant density was 20 to 30 per square foot. The nurse crop sites appeared much denser but only had modest increases in coverage. Over the next several years though we hope that the nurse crop and the slow release organic amendments continue to supply NPK to the plant community. Sites 75 and 76 showed much less plant density at 7 to 8 plants per square foot. Site 76, the better of the two, was colonized by sage and rabbitbrush that were not in the seed blend. We think that this is due to the location of the plot in a swale that concentrates drainage and seed transport. Site 76 also had the highest density of weeds, primarily cheat grass, which we think came in with the composted manure. Poor results were exhibited by sand dropseed, bottlebrush, and small burnet. This is opposite of the results with Tuscarora where the bottlebrush did exceptionally well. The best performers included yarrow, Canby's bluegrass, Louisiana sage, and barley. All wheatgrasses were also prevalent.

We need several more years of observation to see the results of the nurse crop comparisons and the survival rates under such poor soil conditions.

Leviathan — This mine has a long history dating back to 1863 and has been mined for copper and sulfur by several mining companies until 1962. In 1980 soil and vegetational surveys yielded little volunteer vegetation and soil pH's ranging from 3.2 to 7.0 averaged 4.2. Soils were predominantly compacted clay loam except the surface was rather loose due to frost heave.

In December of 1995 we supplied two seed blends, one containing a nurse crop wheat grain and one without. The blends were divided into three plots in the pit area and each plot was divided into four sections for comparing seedings with and without fertilizer, lime, and cereal wheat. Lime was applied at 50 lbs per 200 square foot; seed was applied at 50 PLS lbs/acre, and a slow release fertilizer, 22-4-6, was applied at 200 lbs N/acre.

We measured cover during the second summer and found most species came up in all three plots. The missing species included the Atriplex, the Sarcobatus, and the Sporobolus. These species may be inappropriate due to the elevation but under harsh site conditions sometimes we are interested in stimulating any organic production, not just the local plant community.

The most obvious result from the coverage data showed that there was little difference between the fertilizer and the fertilizer plus lime plots. If anything, there was less coverage on the fertilizer plus lime plots. We think that lime is still necessary due to the low pH's but possibly at a lighter rate. All fertilizer and fertlizer plus lime plots showed greater coverage than the control and lime plots. The effect of barley will hopefully be evident over the next few years. The parties involved may consider deeper ripping and deeper lime injections in the years to come. There is evidence of woody plant roots on site turning horizontal when they hit the low pH conditions.

In the end, we are interested in quantifying the amounts of the various amendments that will set up sustainable nutrient cycling and support sustainable plant communities. Without sufficient amendment, the initial plant communities may atrophy over time as we have seen in the past. Conversely, too much amendment is a waste of resources and possibly could create additional "toxicity" that could be detrimental to fungal populations. Without an appropriate growth medium cap on these acid soils, we must be cautious about proclaiming success at this site based on short term plant establishment.

Conclusions

Actual restoration of a disturbed site is an evolutionary phenomenon. Complex soil communities and advanced plant seral stages can't be created overnight, making actual restoration an elusive concept. The best that we can do is set up optimal conditions and plant a variety of species that reflect this evolutionary process.

Due to the variety of techniques in the above case studies, we are hesitant to draw generalized conclusions or to create prescribed formulas for reclamation programs. The approaches to soil conditioning and seeding techniques are as varied as the habitat conditions. The one common thread to all sites is concern for the growing medium and implementation of some program to improve the soil condition prior to seeding. We think that the primary causes for project failure include lack of a soils program, incorrect seed application, and the vagarious nature of climate. Past projects that called for expedience and assured short-term results yielded little in long-term community equilbrium. This equilibrium is now a prerequisite to successful reclamation.

References

For an easy reference for Federal and State weed law, refer to Seed World, an annual publication of Scranton Gillette Communications (telephone: 847-298-6622).

Claassen, V.P., and R.J. Zasoski. The Effects of Topsoil Reapplication on Vegetation Re-establishment: Caltrans Technical Report FHWA-CA-TL-94/18, 1994, 17.

Federal legislation under FLPMA and MUSY.

Kinsey, N. Hands-on Agronomy Louisiana: Acres U.S.A., 1995, p. 87. ISBN 0-911311-39-4.

Munshower, Frank F. Disturbed Land Revegetation: CRC Press Inc, 1994, p. 69. ISBN 1-56670-026-4.

Nature Conservancy; Jan-Feb 1998: p. 12.

Young, James A (Cheryl G. Young). Seeds of Wildland Plants Oregon: Timber Press, 1986, pp. 55-64.

Whitson, Tom D. Weeds of the West Wyoming: Pioneer of Jackson Hole, 1991, p. ix. ISBN 0-941570-13-4.

Native Plants

Bluebunch wheatgrass
Pseudoroegnaria spicata

"Native and Introduced Species in Colorado Reclamation"

Native and Introduced Species in Colorado Reclamation

Larry Routten
Colorado Division of Minerals and Geology

Introduction

Long-term trends in vegetative establishment and succession were reviewed for five parcels of reclaimed land at three surface coal mines in Colorado. Ages of the reclamation range from 11 to 17 years. Trends in establishment of native and introduced life forms, and dominant species, were highlighted.

Acknowledgements

All the field sampling and data collection upon which this paper is based were conducted by mine operators and/or their consultants. The Colorado Division of Minerals and Geology wishes to acknowledge the efforts of Colowyo Coal Company, Slurco Corporation, Greystone Engineering, Flatiron Coal Company, and Warren Keammerer in gathering the data presented in this paper.

Canadian Strip Coal Mine

The Canadian Strip Coal Mine is a small surface mine in the North Park region, near Walden, Colorado. Two sections of the mine were reclaimed. One section, referred to as Sections 1-3, was seeded in 1981. The other section, referred to as Section 4, was seeded in 1987. The mine is situated at an elevation of approximately 8,200 feet and the reclaimed areas are predominantly gently sloping areas with mostly east and northeast aspects. Twelve to sixteen inches of topsoil were replaced over graded mine spoils prior to seeding. A wood chip mulch was applied on revegetated areas during revegetation efforts. Two different seed mixes were used on the areas. The reclaimed areas were grazed in 1996 by 200 cow/calf pairs for 20 days and are subject to use by big game mammals.

Area 4 (11-Year-Old Reclamation)

The following figures illustrate some vegetative trends in Area 4 during the 11 years following revegetation. This area was seeded in 1987 with a seed mix consisting of eight grasses (six native, two introduced), four forbs (three native, one introduced), and three shrubs (all native). Vegetative cover ranged from 32 to 60 percent during the years that monitoring was done. The most heavily seeded species are listed below.

Dominant species in 1987 seed mix	lbs PLS/ acre
Slender wheatgrass (Native)	6.0
Western wheatgrass (Native)	6.0
Thickspike wheatgrass (Native)	3.0
Beardless wheatgrass (Native)	3.0
Pubescent wheatgrass (Introduced)	2.0
Canadian bluegrass (Introduced)	2.0
Green needlegrass (Native)	0.5
Cicer milkvetch (Introduced)	1.0
Penstomen (Native)	0.25
Flax (Native)	0.25

Some trends are apparent in the Figure 1. Introduced forbs are becoming noticeably more dominant in recent years. This is primarily due to the establishment of cicer milkvetch. The relative cover of introduced grasses diminished to nearly zero after 11 years. The fraction of relative cover attributed to introduced grasses decreased noticeably after the area was grazed in 1996. It is also possible that problems with species identification or the seed mix are reflected in the reduction of introduced grasses. Intermediate wheatgrass was not reported in the seed mix, yet it accounted for significant portions of relative cover during early years. The introduced grasses reported in the seed mix never accounted for substantial amounts of relative cover in Area 4. Native forbs appear to be a consistent component of the revegetation after 11 years.

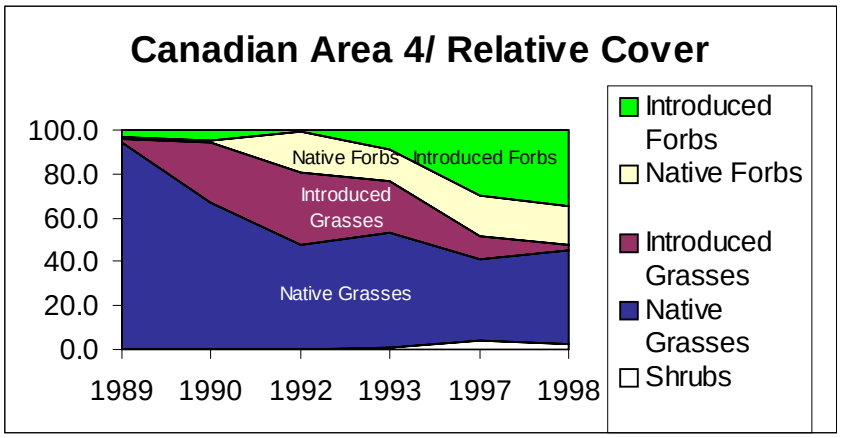


Figure 1 — Relative cover by life form, Area 4 at the Canadian Strip Mine.

Other trends are apparent in Figure 2. The relative cover values for slender, intermediate and thickspike wheatgrass all decreased substantially 5 to 10 years after seeding. Western wheatgrass appears to be establishing as the most dominant grass. Cicer milkvetch began to proliferate 6 years after seeding and is the dominant species 11 years after seeding.

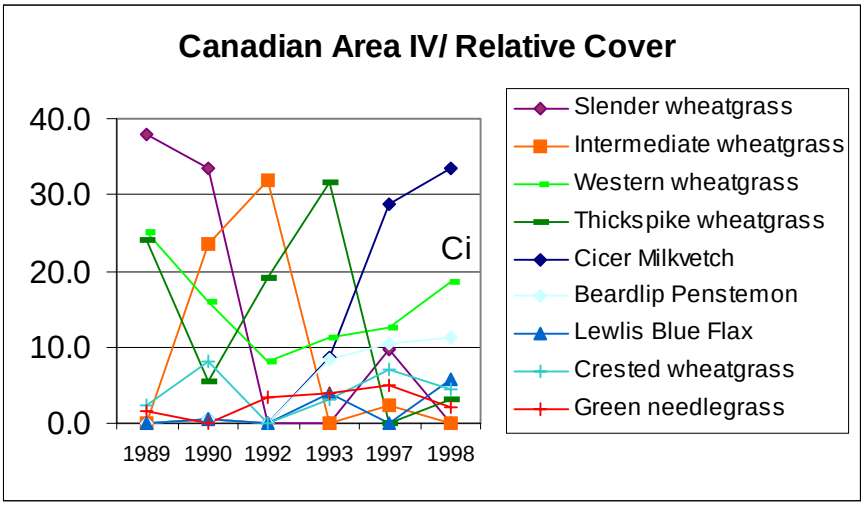


Figure 2 — Relative cover by life form, Area 4 at the Canadian Strip Mine.

Areas 1-3 (17-Year-Old Reclamation)

Figures 3 and 4 illustrate some vegetative trends in Areas 1-3 during the 17 years following revegetation. These areas were seeded in 1979-81 with a seed mix consisting of seven grasses (six native, one introduced), three forbs (all native), and three shrubs (all native). Vegetative cover ranged from 29 to 68 percent during the years when monitoring was done. The most heavily seeded species are listed below.

Dominant species in seed mix for Areas 1-3	lbs PLS/ acre
Beardless wheatgrass (Native)	3.00
Pubescent wheatgrass (Introduced)	2.75
Thickspike wheatgrass (Native)	2.75
Western wheatgrass (Native)	0.80
Slender wheatgrass (Native)	0.55

Some trends are apparent in Figure 3. Native grasses have gradually come to account for nearly all of the grassy component as introduced grasses have nearly disappeared. As with Areas 1-3, the introduced grass component decreased noticeably following grazing in 1996. Native forbs did not account for a substantial amount of relative cover until the reclamation was about 10 years old.

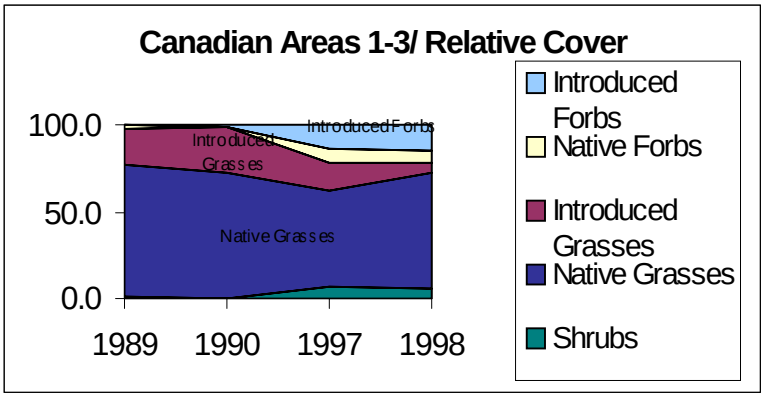


Figure 3 — Relative cover by life form, Areas 1-3 at the Canadian Strip Mine.

Some interesting trends can be seen in Figure 4. Beardless wheatgrass, which was the most heavily seeded grass, is still the dominant grass species 17 years after seeding. Prairie junegrass is becoming a significant grass although it was not seeded. Prairie junegrass is common on the lands adjacent to the mine and accounted for 3 percent of the relative cover of a nearby reference area in 1998. Slender wheatgrass practically disappears, as it did in Area 4, after 8 or 9 years. The relative contribution of cicer milkvetch has increased dramatically in recent years, even though this species was not present ten years after seeding. Cicer milkvetch was seeded into the adjacent Area 4 reclamation in 1987, about 3 years before it began appearing in Areas 1-3.

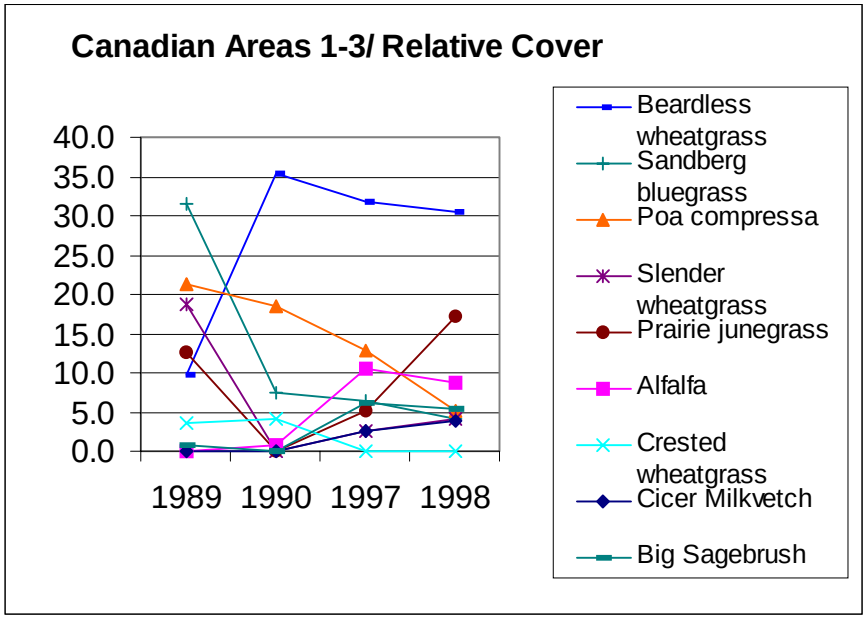


Figure 4 — Relative cover by species; Areas 1-3 at the Canadian Strip Mine.

Bourg Strip Mine

The Bourg Strip Mine is a small surface mine in the North Park region, near Walden, Colorado. The 29-acre portion of the mine discussed in this paper was revegetated in 1984. Therefore, monitoring data presented here represent the first 13 years of growth. An adjacent 80-acre parcel was revegetated with the same seed mix in 1988. The mine is situated at an elevation of approximately 8,100 feet and this portion of the mine consists of predominantly west/northwest facing slopes of 0 to 8 percent. Approximately 15 inches of topsoil was replaced over graded mine spoils prior to reseeding. The area has never been grazed substantially, but it is subject to use by large game mammals.

The Bourg seed mix included few introduced species. The seeding rate was relatively heavy. A summary of the seed mix is:

	Number of PLS/sq. ft.	Number of species
Native Grasses	28.3	4
Introduced Grasses	3.2	1
Native Forbs	39.0	2
Introduced Forbs	1.7	1
Native Shrubs	30.1	5
	102.3	13

Dominant species in seed mix for Bourg Strip Mine	PLS/ square ft.
Achillea lanulosa Yarrrow (Native)	34.0
Artemesia tridentate Big sagebrush (Native)	23.0
Agropyron Smithii Western wheatgrass (Native)	9.6
Stipa viridula Green needlegrass (Native)	8.2
Agropyron riparium Streambank wheatgrass (Native)	6.4
Penstemon strictus Rocky mountain penstemon (Native)	5.0
Oryzopsis hymenoides Indian ricegrass (Native)	4.1
Elymus junceus Russian wildrye (Introduced)	3.2

Figure 5 below reflects the dominance of native shrubs and grasses in the Bourg reclamation while also indicating that the introduced grass component appears to be fairly consistent over

the years. The predominance of shrubs is due almost entirely to the establishment of big sagebrsuh on the site. The apparent lack of native forbs is probably accounted for by timing of monitoring. Monitoring on this, and the other sites in this paper, generally coincides with peak production of grasses. Most native forbs bloom and disappear earlier in the year.

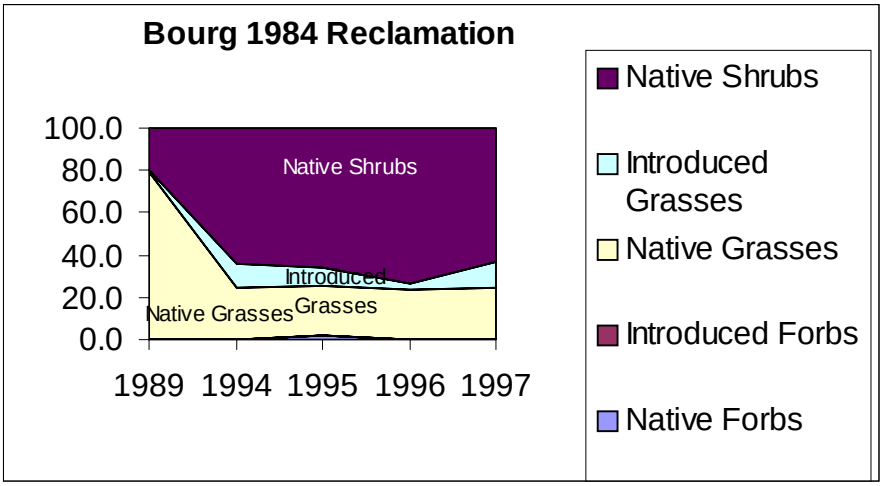


Figure 5 — Relative cover by life form at the Bourg Strip Mine.

Figure 6 indicates that relative cover of big sagebrush increased consistently for about ten years, after which it remained fairly consistent. Over 13,000 stems per acre were established on the site by 1997. Thickspike wheatgrass is the most prevalent grass even though it was not reported to be in the seed mix.

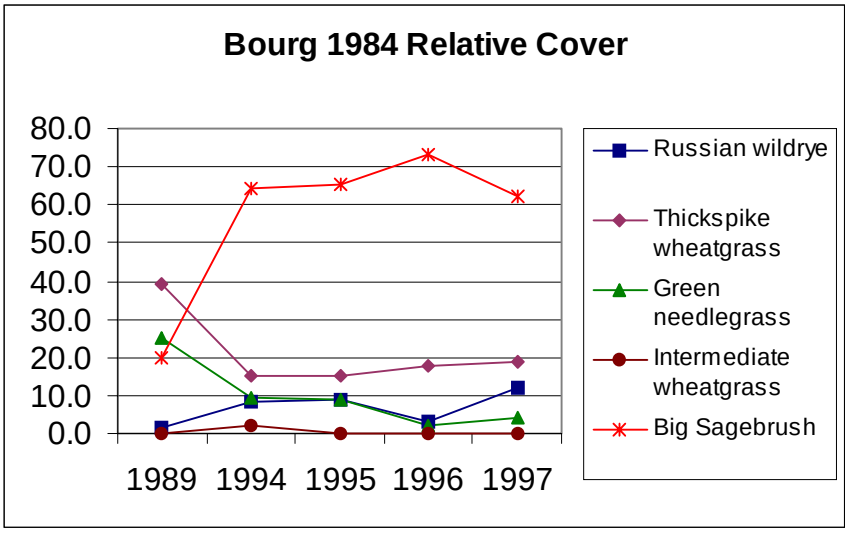


Figure 6 — Relative cover by species at the Bourg Strip Mine.

Colowyo Coal Mine

The Colowyo Coal Mine is a large surface mine in northwest Colorado, south of the town of Craig. Two reclaimed parcels of the mine are discussed in this paper. A 21-acre parcel was reclaimed in 1983 and a nearby 50-acre parcel was reclaimed in 1987. These reclaimed areas are situated at approximately 7,100 feet elevation on northeast facing slopes. The 1983 parcel consists of 5- to 25-percent slopes and the 1987 parcel has 3- to 5-percent slopes. Approximately 16 to 18 inches of topsoil was replaced over graded mine spoils prior to reseeding. Both areas were seeded with the same seed mix. Neither area has been grazed although both are heavily used by large game mammals at times.

The seed mix for these reclaimed areas relied on introduced species to a greater extent than the two mines discussed previously. The seed mix at Colowyo consisted of:

	Number of PLS/sq. ft.	Number of species
Native Grasses	22.7	8
Introduced Grasses	43.4	9
Native Forbs	6.3	6
Introduced Forbs	5.3	3
Native Shrubs	3.5	5
	81.2	31

The most heavily seeded species in this seed mix were:

	PLS/sq. ft.
Poa pratensis Kentucky bluegrass (Introduced)	9.7
Agropyron Dasystachyum Thickspike wheatgrass (Native)	6.1
Festuca ovina Hard fescue (Introduced)	5.2
Agropyron trachycaulum Slender wheatgrass (Native)	4.7
Astragalus cicer Cicer milkvetch (Introduced)	3.9
Stipa viridula Green needlegrass (Native)	4.2
Agropyron intermedium Intermediate wheatgrass (Introduced)	2.9
Dactylus glomerata Orchard grass (Introduced)	2.7
Agropyron sibericum Siberian wheatgrass (Introduced)	2.3

	PLS/sq. ft.
Agropyron Smithii Western wheatgrass (Native)	2.1
Bromus inermis Smooth brome (Introduced)	1.3

1987 Reclamation (11-Year-Old Vegetation)

Looking at Figure 7, it appears that introduced grasses were the dominant life form during the first 8 years. During the next 3 years, native grasses appear to be displacing introduced grasses. Looking at Figure 8, this would appear to be due to the increased establishment of Western and thickspike wheatgrasses concurrent with a marked decrease in the relative cover of intermediate wheatgrass. The relative cover of introduced forbs also decreased substantially after the reclamation became established. This was due to the disappearance of introduced annuals that dominated the area after seeding. Large amounts of pennycress, mustards, and Russian thistle were present in the 1989 data, although they were not included in Figure 8.

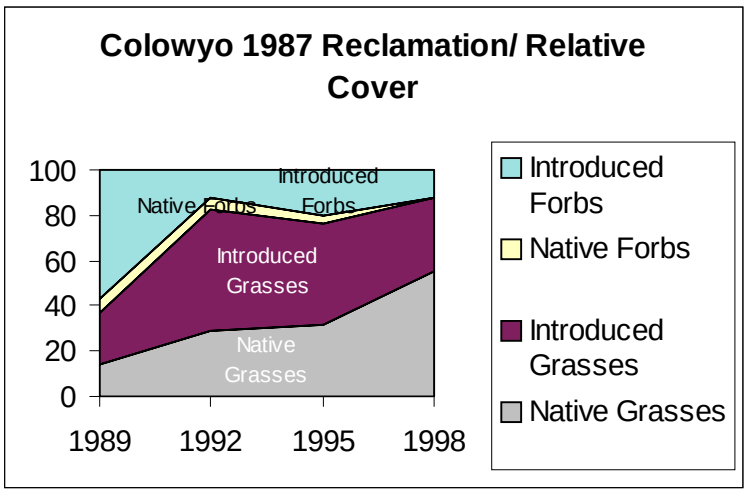


Figure 7 — Relative cover by life form in 1987 Colowyo reclamation.

Figure 8 indicates that intermediate wheatgrass is the dominant grass in this parcel, although there have been wide fluctuations in the amount of relative cover due to this species. There are a large number of wheatgrasses in this reclamation. Therefore, species identification problems may account for some of the fluctuations. As mentioned above, thickspike and Western wheatgrasses have accounted for larger amounts of relative cover in recent years than they did during the early years. It is interesting to note that thickspike wheatgrass is the only one of the five most heavily seeded grasses to account for a significant amount of cover in this parcel.

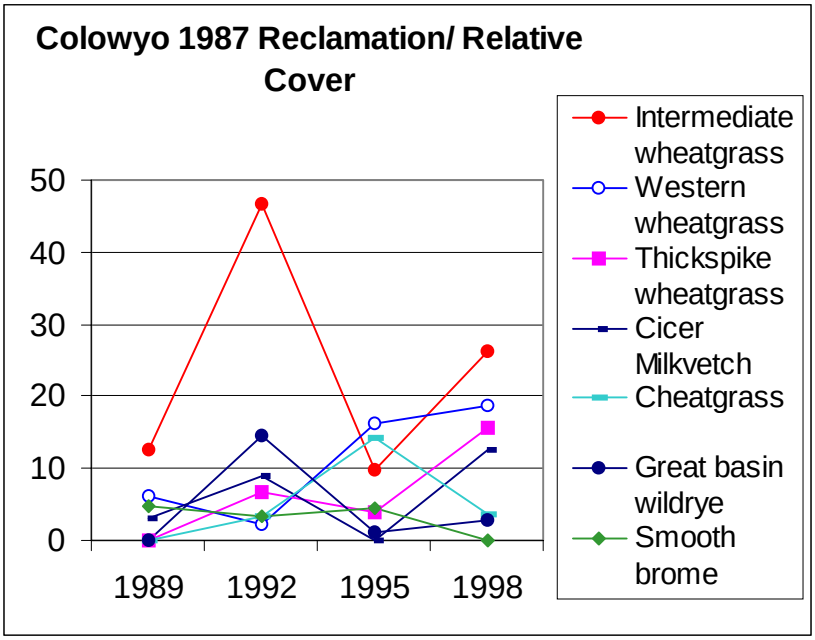


Figure 8 — Relative cover by species in 1987 Colowyo reclamation.

1983 Reclamation (14-Year-Old Vegetation)

Figure 9 indicates that this reclaimed parcel has been dominated by introduced grasses and forbs throughout its history. However, the relative cover of native grasses has increased noticeably during the last 3 years of the period shown. The large increase in relative cover of introduced forbs after 1987 is due primarily to considerable establishment of cicer milkvetch at that time.

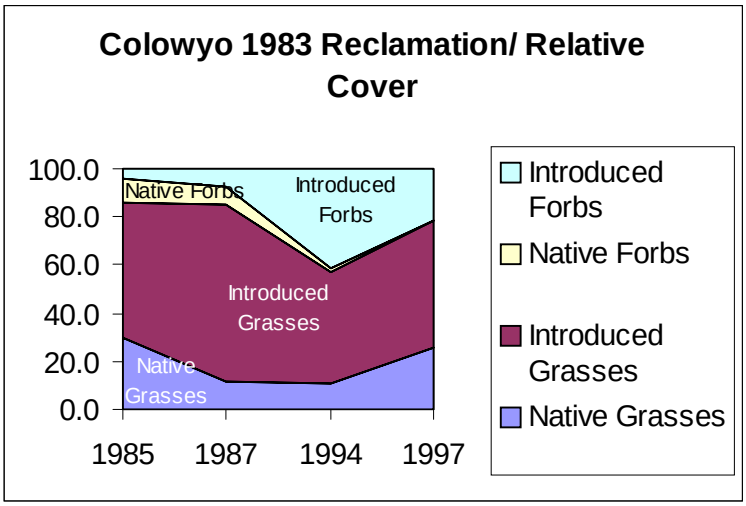


Figure 9 — Relative cover by life form in 1983 Colowyo reclamation.

Figure 10 indicates that the dominant grass in this reclaimed parcel is intermediate wheatgrass, as it was in the 1987 reclaimed Colowyo parcel. In this parcel, other wheatgrasses have only accounted for a small portion of relative cover, and they show no evidence of change. Cicer milkvetch and intermediate wheatgrass account for the majority of cover in this parcel, particularly in the later years. In this parcel, none of the five most heavily seeded grass species are present in significant amounts.

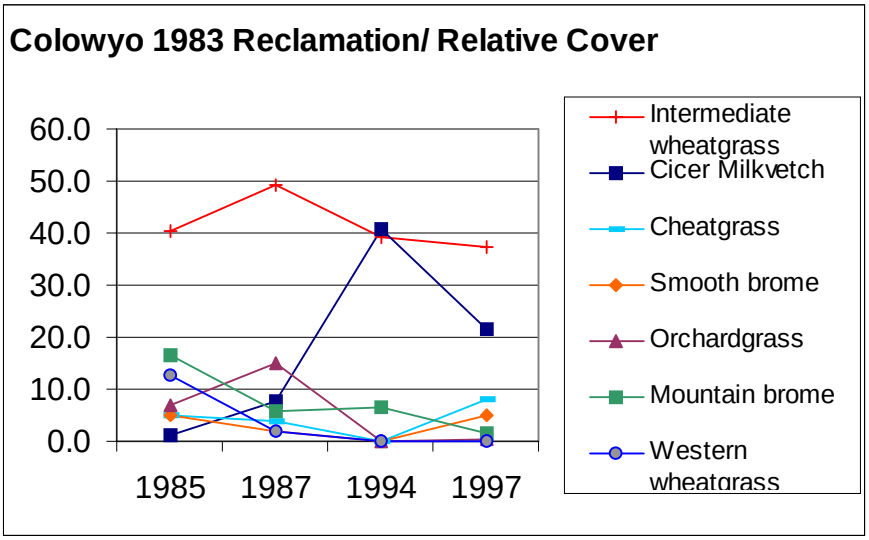


Figure 10 — Relative cover by species in 1983 reclamation at Colowyo.

Conclusions

The reclaimed areas discussed in this paper were selected, in part, because of availability of data in a recently constructed database that the Colorado Division of Minerals and Geology compiled in order to look at trends in vegetation establishment on reclaimed coal mines. Trends at these areas do not necessarily reflect developments at other reclaimed sites, so care should be taken in extrapolating any findings to other sites. However, a few points appear consistently enough in the data reviewed in this paper to merit consideration and/or further investigation.

The use of introduced grass species in reclamation seed mixes appears to result in a long lasting establishment of those species, although they do not appear to displace native grasses once the latter are established. At the one mine where grazing was implemented, native grasses appear to have responded more favorably to grazing than introduced grasses 2 years after a single year of grazing. The use of some aggressive introduced forbs, particularly cicer milkvetch, resulted in communities where cicer milkvetch became a dominant species after several years. In terms of vegetative cover, cicer milkvetch displaced grasses as it became established, 5 to 7 years after

initial seeding. This species also spread into at least one reclaimed area, where it was not seeded, from an adjacent reclaimed parcel where it was seeded.

The data reviewed in this paper indicate that, while species establishment usually corresponds with species selection in seed mixes, there are frequent and significant exceptions. Whether the exceptions seen in these data are due to invasion from nearby areas or to mistaken inclusions in seed mixes is unknown. However, the consistent presence of species that were not seeded, and absence of other species that presumably were seeded, seems to merit further review of the usefulness of including some species in seed mixes and closer attention to the actual content of seed mixes provided for use in reclamation.

Woody Stem Materials

Big sagebrush
Artemesia tridentata

"Direct Seeding Establishment of Wyoming
Big Sagebrush: Research Advances"

Direct Seeding Establishment of Wyoming Big Sagebrush: Research Advances

Gerald E. Schuman, Soil Scientist
High Plains Grasslands Research Station
Agricultural Research Service, U.S. Department of Agriculture

Introduction

Xerophytic shrubs are a significant component of rangelands throughout much of the arid/semiarid West and provide many benefits to the function and utility of rangeland ecosystems (McKell and Goodin, 1973). Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is one of the most widely distributed and adapted shrub species in Wyoming and the region (Beetle and Johnson, 1982). However, its reestablishment on mined lands has generally proven difficult because of low seedling vigor, an inability to compete with herbaceous species, and altered edaphic conditions (Harniss and McDonough, 1976; Young and Evans, 1989; Schuman *et al*., 1998). Reduced levels of arbuscular mycorrhizae (AM) in the disturbed soils have also been postulated as a factor limiting the success of reestablishment of big sagebrush on disturbed lands (Call and McKell, 1982; Stahl *et al*., 1988). AM can improve the host plant's ability to extract nutrients and water from soil (Stahl *et al*., 1988). Indirect evidence has indicated that water availability is one of the key factors involved in big sagebrush seedling establishment success (Jones, 1991). Allen (1984) reported that sagebrush is particularly dependent upon mycorrhizal symbiosis to reach full growth potential. Use of "pioneer" plants to improve soil conditions of disturbed lands for later seral species has also been postulated as a means to enhance reestablishment of big sagebrush (Booth, 1985; Meyer, 1990). It is evident from this brief review of the literature that much additional information was needed to enhance our understanding of big sagebrush seedbed ecology and to develop a seeding technology that would result in successful reestablishment of this species.

Recent Findings

Schuman and Booth (1998), Stahl *et al*. (1998), Schuman *et al*. (1998), and Booth *et al*. (1999) reported on recent research evaluating the effects of historic reclamation practices, soil management, mulching, competition, and AM on big sagebrush establishment.

Schuman and Booth (1998) and Schuman *et al*. (1998) in a study to evaluate the effect of topsoil management (stockpiling *vs*. direct placement), mulching (stubble, surface, stubble + surface, and no mulch), and competition (three grass seeding rates) found that all three variables affected big sagebrush seedling establishment in an interactive manner. Sagebrush seedling densities responded differently to the treatments during the first year (1992) after seeding, and the following spring, than they did in the fall of 1993 and 1994 (tables 1 through 3). The largest increase in sagebrush seedlings were observed between the spring 1993 and fall 1993 due to the wet and cool conditions during that period (table 4).

Table 1–Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1992 (from Schuman *et al*., 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kilogram [kg]PLS/ hectare [ha]$^{-1}$)	0	16	32	0	16	32
Mulch Type	---------- plants/square meter [m^{-2}] ----------					
	Spring 1992					
stubble	5.78	1.11	0.04	0.11	0	0
surface	7.37	0.07	0	0.04	0	0
stubble +surface	1.59	1.56	0.63	0.11	0	0.04
control	0	0	0.04	0	0	0

$LSD_{0.10}$=2.48, within a mulch type with a topsoil management;
$LSD_{0.10}$=2.51 within a topsoil management with a seeding rate;
$LSD_{0.10}$=2.71 within a mulch type within a seeding rate.

	Fall 1992					
stubble	5.15	0.52	0.07	0	0	0.04
surface	6.07	0	0.15	0	0	0
stubble + surface	1.41	1.11	0.37	0.30	0.04	0
control	0	0	0	0	0	0

$LSD_{0.10}$=2.13 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.16 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.30 within a mulch type within a seeding rate.

Table 2.–Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1993 (from Schuman *et al*., 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS ha^{-1})	0	16	32	0	16	32
Mulch Type	plants m^{-2}					
	Spring 1993					
stubble	6.30	2.04	1.81	1.63	0.04	0.15
surface	8.74	0.30	0.89	0.44	0.04	0.93
stubble +surface	4.07	2.48	1.52	1.56	0.33	0.11
control	1.26	0.56	0.22	0.37	0.14	0.04

$LSD_{0.10}$=2.01 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.07 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.73 within a mulch type within a seeding rate.

	Fall 1993					
stubble	9.67	3.93	2.93	5.41	2.11	1.93
surface	13.48	1.00	1.22	2.74	1.81	2.18
stubble + surface	8.04	2.89	1.63	4.59	2.15	1.70
control	7.52	1.37	0.52	1.81	0.52	0.19

$LSD_{0.10}$=2.59 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.89 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.91 within a mulch type within a seeding rate.

Table 3.–Sagebrush seedling density as affected by topsoil management, mulch type, and grass competition, fall 1994 (from Schuman *et al*., 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS ha^{-1})	0	16	32	0	16	32
Mulch Type	---------- plants m^{-2} ----------					
	Spring 1994					
stubble	8.15	9.82	7.11	3.44	2.78	3.26
surface	12.11	4.63	5.33	2.40	3.52	5.07
stubble +surface	9.11	3.78	4.26	3.30	3.85	2.52
control	7.22	5.88	4.56	4.48	2.52	1.70

$LSD_{0.10}$=3.00 within a mulch type within a topsoil management;
$LSD_{0.10}$=3.79 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.99 within a mulch type within a seeding rate

Table 4.–Monthly precipitation and mean monthly temperature, North Antelope Coal Company, Gillette, Wyoming, 1992-94 (from Schuman *et al*., 1998)

Month	1992 Precip. (cm)	°C	1993 Precip. (cm)	°C	1994 Precip. (cm)	°C
Jan	0		-0.6	0	-7.2	0.20-3.3
Feb	0.68	2.2	0.38	-7.7	0.15	-6.1
Mar	3.15	4.4	1.47	2.2	0.41	3.3
Apr	0.76	7.7	6.48	5.5	2.79	6.6
May	2.26	13.2	5.94	12.7	2.87	14.9
Jun	6.43	16.5	14.15	14.3	8.36	18.2
Jul	7.75	17.6	9.70	17.1	4.93	19.8

table 4 continued

Month	1992 Precip. (cm)	°C	1993 Precip. (cm)	°C	1994 Precip. (cm)	°C
Aug	2.95	18.2	10.13	18.2	0.81	20.9
Sep	1.75	15.4	2.29	12.1	1.22	16.0
Oct	0.41	8.8	2.36	6.1	5.49	7.2
Nov	0.89	-0.6	0.36	-2.2	0.58	0
Dec	1.19	-6.6	0.10	-1.7	0.05	-1.7
Total	28.22		53.36		27.86	

1978-95 year average is 32.3 cm.

Big sagebrush seedling densities observed in 1992 on the direct placed topsoil-no competition-mulched treatments (table 1) exceeded the shrub density standard (one shrub/m^{-2}) adopted in Wyoming (Federal Register, 1996). If we use Kriger *et al*. (1987) findings that 32 percent of the big sagebrush established the first year will survive after 11 years we still have adequate seedling densities for the stubble and surface mulch treatments to achieve this standard. This emphasizes the importance of good cultural practices in establishing big sagebrush since 1992 was a below average (87 percent) precipitation year. Direct-placed topsoil resulted in 40 percent more sagebrush seedlings than the stockpiled topsoil treatment, and in 1992 and the spring of 1993, differences were 1-2 orders of magnitude greater for direct-placed topsoil. Soil moisture content of the surface 7.5 cm of direct-placed topsoil was always higher than that observed in the stockpiled topsoil treatment in 1992 (fig. 1). This observed greater soil moisture undoubtedly improved sagebrush germination and establishment on direct-placed topsoil in 1992. Topsoil management benefits were only observed in treatments where no grass was seeded. No differences in sagebrush seedling densities were evident between the 16 and 32 kg PLS ha^{-1} grass seeding rates. However, even the lowest seeding rate is slightly above the maximum used by the industry in their reclamation programs (further discussion of grass seeding rate will be covered later in the paper).

Benefits of topsoil management are clearly evident in the initial year of establishment; however, this study did not clearly delineate some of the benefits expected. Unseeded control plots in an adjacent study did not have any sagebrush seedlings present after 4 years; therefore, direct-placed topsoil did not act as a seedbank for sagebrush nor was natural recruitment occurring.

Even though the AM fungal spore counts were significantly different between the two topsoil management treatments (3,088/gram [g] stockpiled *vs*. 4,500/g direct-placed) no differences in sagebrush seedling infection was observed in the seedlings excavated in June 1993, table 5 (Schuman *et al*., 1998). They believe that the time between topsoil placement (late summer 1990) and June 1993 was more than adequate for reinoculation of the stockpiled topsoil. Loree and Williams (1984) found that native grasses became infected with AM within a year of establishment on long-term stockpiled topsoil indicating inoculum is spread quite readily under

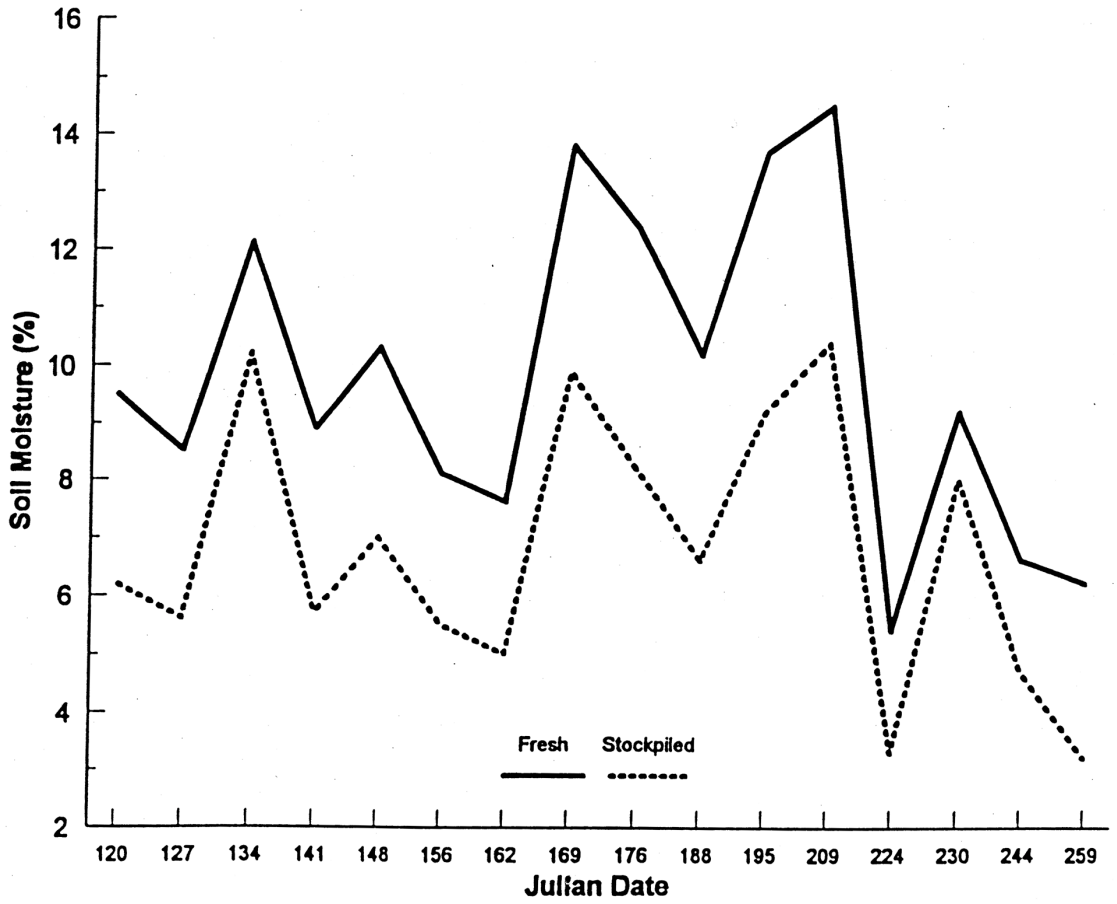


Figure 1 — Soil moisture content in 0-7.5cm topsoil depth as affected by topsoil management, Establishment Study, 1992 (Schuman *et al*., 1998).

natural conditions. However, this finding should not diminish the importance of topsoil management for AM concerns. Stahl *et al*. (1998) found that the sagebrush seedling age groups of 30-150 days old that were mycorrhizal were able to tolerate greater drought stress (moisture tension) before dying than non-mycorrhizal seedlings. Non-mycorrhizal, 45-day-old sagebrush seedlings died when the moisture stress level was -2.8 MPa compared to the mycorrhizal seedlings which tolerated soil moisture tensions of -3.2 MPa before dying (fig. 2). Sagebrush seedling age and mycorrhizae treatment exhibited an interaction, indicating that as sagebrush seedlings age the beneficial influence of AM on soil moisture stress tolerance increases (fig. 3). Their research clearly indicated that those seedlings $\geq$120 days of age that were non-mycorrhizal were much less tolerant of soil moisture stress than younger non-mycorrhizal seedlings. Therefore, sagebrush seedlings become more dependent upon the benefits of mycorrhizae as they age. This phenomena could partially explain the lack of infection differences observed by

Table 5 — Vesicular-AM infection percentage of sagebrush seedlings as affected by topsoil management, mulch type, and grass competition

Treatment	Percentage Infection	Number of Seedlings Evaluated
Topsoil Management		
Fresh	66	66
Stockpiled	76	66
Mulch Type		
Stubble	73	36
Surface	71	36
Surface +Stubble	72	36
Control	67	24
Grass Competition (kg PLS ha^{-1})		
0	73	69
16	68	63
32	--a	--a

[a]Insufficient sagebrush seedlings available for evaluation.

Schuman *et al*. (1998) in seedlings grown on direct-placed vs stockpiled topsoil. Those seedlings growing in stockpiled topsoil failing to form AM early in their development may have not tolerated repeated dry periods experienced in a typical spring-summer period in a semiarid climate. Hence, seedlings sampled a year later may not have been representative of the seedling population that originally germinated and emerged because non-mycorrhizal seedlings may have died early in their development.

The presence of mulch also greatly affected sagebrush seedling establishment in 1992 (Schuman and Booth, 1998; Schuman *et al*., 1998). No seedlings were evident in the first year where mulch was not applied (table 1). Both the stubble and the surface mulch treatments had seedling establishment rates that were greater than or equal to that of the stubble + surface mulch treatment. Soil moisture content of the surface 7.5 cm was greater under all mulch treatments compared to the no-mulch treatment (fig. 4). Schuman *et al*. (1980) demonstrated that stubble mulch enhanced grass seedling establishment through reduced diurnal temperature fluctuations and increased soil moisture.

Grass competition reduced sagebrush seedling densities throughout the duration of the study on direct-placed topsoil treatment where stubble or straw mulch was used (Schuman and Booth, 1998; Schuman *et al*., 1998). They reported grass seedling densities of 0, 196, and 250 grass

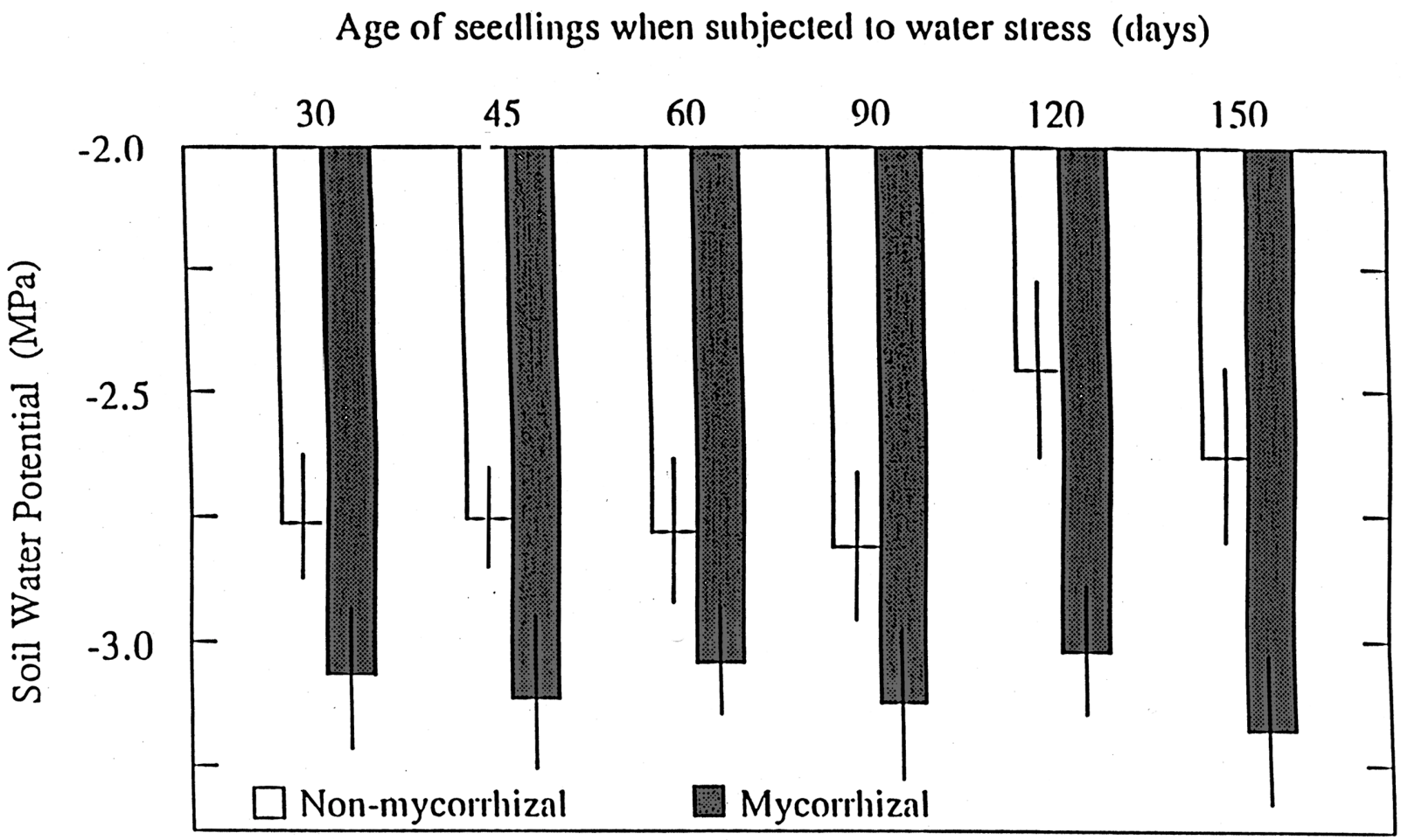


Figure 2 — Average soil water potentials resulting in death of mycorrhizal and non-mycorrhizal sagebrush seedlings. Vertical bars on each column represent 1 standard deviation. Differences between mycorrhizal and non-mycorrhizal treatments were statistically significant at $P \leq 0.01$ for each age group (Stahl *et al.*, 1998).

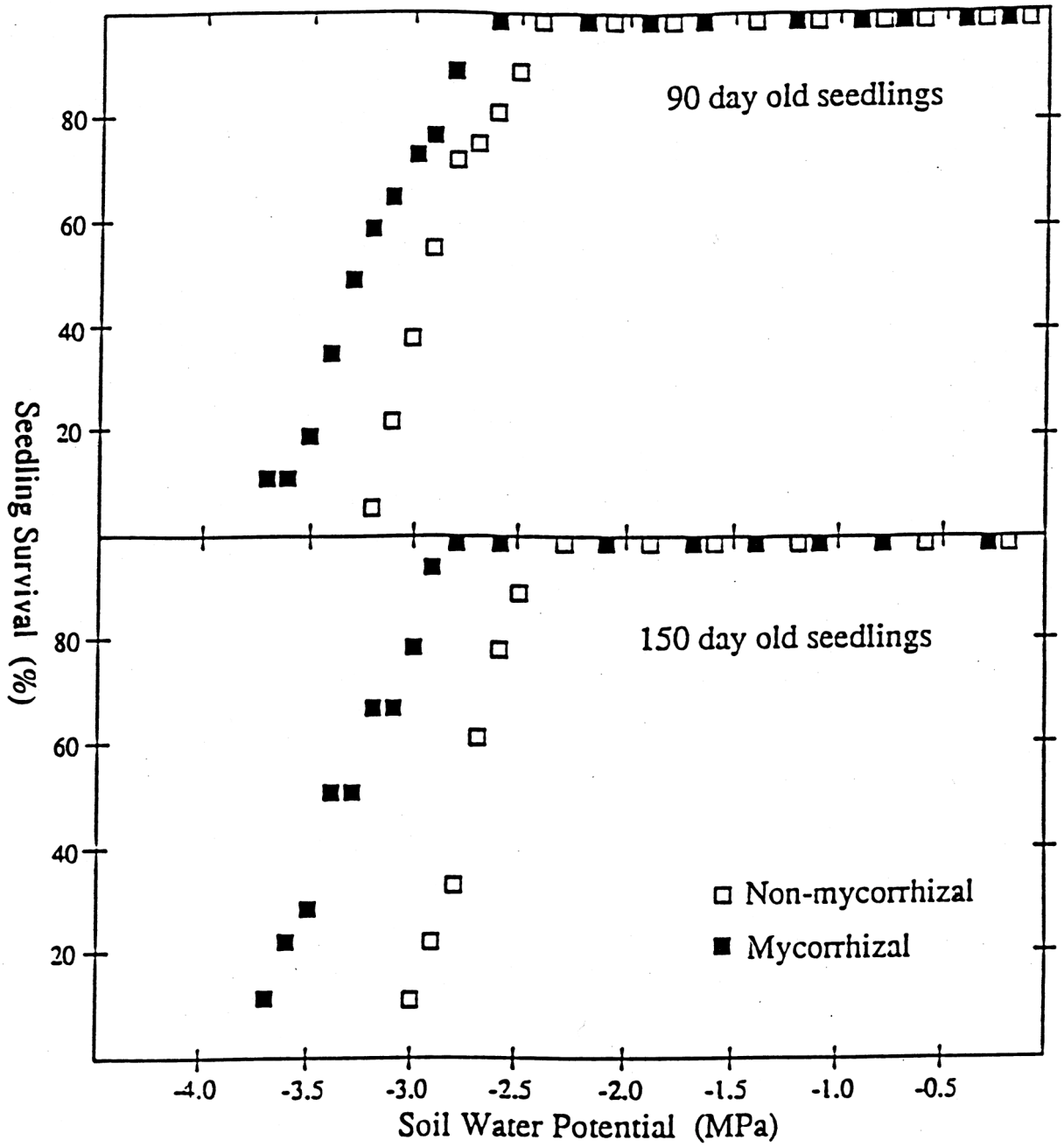


Figure 3 — Survival rates for 90 and 150 day old mycorrhizal and non-mycorrhizal sagebrush seedlings at different levels of soil dryness (Stahl *et al.*, 1998).

seedlings m^{-2} for the 0, 16, and 32 kg PLS ha^{-1} grass seeding rates, respectively. No differences in grass seedling density among topsoil management treatments were observed. They concluded that successful establishment of big sagebrush on mined lands might require seeding in the absence of any grass or perhaps at very low grass seeding rates. These findings have led to

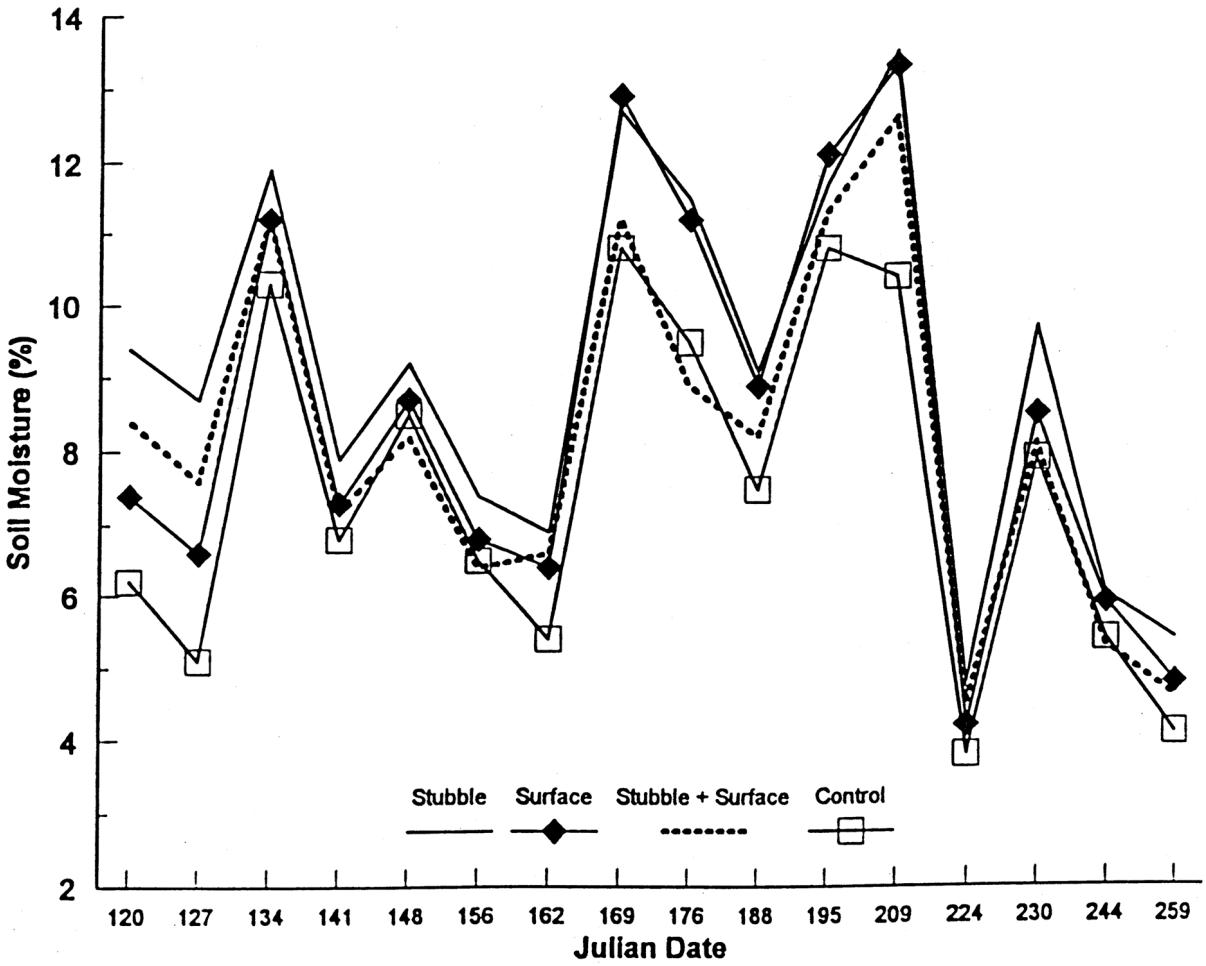


Figure 4 — Soil moisture content as affected by mulch type, Establishment Study, 1992 (Schuman *et al*., 1998).

further research by Fortier *et al*. (2000) evaluating effects of grass competition and big sagebrush seeding rates on sagebrush seedling establishment. Preliminary results have shown a direct relationship between sagebrush seedling density and sagebrush seeding rates. Sagebrush seedling density did not show a response to grass competition on the June 1999 count date but has shown a definite decreasing trend in sagebrush seedling density with increased grass seeding rate on the August 3 and August 30, 1999, counts. Lack of sagebrush seedling density response to grass competition on the June count was attributed to the very high precipitation amounts received at the study site near Gillette, Wyoming, in April-early July 1999. Sagebrush seeding rates being evaluated are 1, 2, and 4 kg PLS ha^{-1} and grass competition seeding rates are 0, 2, 4, 6, 8, 10, and 14 kg PLS ha^{-1} (M. I. Fortier, G. E. Schuman, A. L. Hild, and L. E. Vicklund, personal communication, 2000).

A research study aimed at assessing the role of fourwing saltbush (*Atriplex canescens* ssp. *aptera*) as a "pioneer" plant to enhance the later establishment of big sagebrush and to evaluate

the role of this plant in excluding big sagebrush when seeded at rates in excess of 2.2 kg PLS ha^{-1} was reported by Schuman and Booth (1998). This study also examined two other seeding strategies: delay sagebrush seeding for one year and seeding sagebrush two consecutive years. Grass competition was not evaluated in this study; hence, the only herbaceous plant competition that existed was from plants that became established naturally through the topsoil seedbank or other means of recruitment. The entire study area had a stubble mulch. Unfortunately, this study resulted in no statistically conclusive results; however, some general discussion of the pioneer-exclusion role of fourwing saltbush and other sagebrush seeding strategies can be made. Sagebrush and fourwing saltbush seedling counts were extremely variable which accounted for the lack of any statistical significance in this data set.

In this study, the topsoil management treatment did not exhibit a consistent beneficial response for direct-placed topsoil (table 6). Sagebrush establishment was greater on direct-placed topsoil for the following seeding strategies: delayed sagebrush seeding and the fourwing saltbush pioneer/exclusion seeding strategy. However, sagebrush seedling densities were greater on the stockpiled topsoil treatment where sagebrush was seeded in consecutive years (1992 and 1993).

Table 6 — Mean (+ SD) shrub seedling densities by seeding treatment and topsoil source for the years 1993-96 (Schuman and Booth, 1998)

			Seedling Treatments / Topsoil Source					
	Year	Signif.	ART/STS	ARTR/FTS	F-ARTR/STS	F-ARTR/FTS	ATCA-ARTR/STS	ATCA-ARTR/FTS
			Seedling m^{-2}					
ARTR	1993	(P=0.35)	7.3±7.5	3.4±5.5	3.3±6.7	3.9±7.0	0.8±3.2	2.1±6.4
ATCA-ARTR		(0=0.28)					1.5±2.2	6.3±7.6
ARTR	1994	(P=0.15)	14.0±15.9	7.2±11.3	5.7±5.8	11.9±15.3	3.8±6	7.3±9.6
ATCA-ARTR		(P=0.16)					3.9±3.4	16.8±16.4
ARTR	1995	(P=0.12)	10.8±8.7	4.9±6.8	5.1±4.5	9.1±11.3	3.1±6.2	5.1±6.5
ATCA-ARTR		(P=0.14)					4.3±3.1	12.4±11.8
ARTR	1996	(P=0.10)	9.6±7.7	4.3±5.9	5.1±5.3	7.3±8.8	2.6±5.2	4.1±5.1
ATCA-ARTR		(P=0.12)					7.1±5.7	8.8±6.2
Means across topsoil treatments:			7.0		6.2		8.0	

ARTR = Sagebrush seedlings. The ARTR treatment means that sagebrush was seeded in 1992 and 1993.
F-ARTR = Plot fallowed in 1992 and seeded to sagebrush in 1993.
ATCA-ARTR = Fourwing saltbush seedlings + sagebrush seedlings. The ATCA-ARTR seeding treatment means that fourwing saltbush was seeded in 1992 and sagebrush overseeded in 1993.
STS = Stockpiled topsoil.
FTS = Fresh-Stripped topsoil.

This lack of consistent response to topsoil management in this study is puzzling and inconsistent with the benefits shown by other research. Schuman and Booth (1998) also reported that no conclusive evidence exists that fourwing saltbush excluded or encouraged the establishment of big sagebrush. However, average sagebrush density (table 6) and height was less on this treatment than any other seeding strategy. They did report greater total shrub densities where fourwing saltbush was over-seeded a year later with big sagebrush. Big sagebrush represented 42 percent of the shrub density and the seeding strategy of fourwing saltbush with delayed big sagebrush seeding produced about 10,000 more total shrub seedlings than the other seeding strategies. Gores (1995), Booth *et al*. (1999), and Olson *et al*. (2000) also reported that shrub densities were greater when more than one shrub species is included in the reclamation seed mixture.

Schuman *et al*. (1998) and Schuman and Booth (1998) showed that big sagebrush seed maintains its viability for much longer than thought (Young and Evans, 1989), because new seedlings were noted 3 to 5 years after the initial seeding of big sagebrush in the research they reported. Wyoming big sagebrush has been shown to have some seed dormancy (McDonough and Harniss, 1974; Booth *et al*., 1997); therefore, Schuman *et al*. (1998) and Schuman and Booth (1998) believe that continued germination and establishment of big sagebrush for several years was related to seed dormancy, the continual development of "safe sites" for seed germination and establishment (Harper, 1977) and improved climatic conditions (precipitation and temperature) in subsequent years.

Research has also shown that seeding a mixture of shrub species is desirable and results in a greater overall density, species diversity, and structural diversity than is achieved by a single shrub species (Gores, 1995; Booth *et al*., 1999; and Olson *et al*., 2000). Gores (1995) and Olson *et al*. (2000) also reported that sites seeded to several shrub species resulted in higher diversity indices of reclaimed sites compared to those where only fourwing saltbush was seeded (fig. 5). Greater species and structural diversity greatly enhance wildlife habitat quality.

Conclusions/Summary

Research reviewed in this paper has answered many questions related to establishment of Wyoming big sagebrush on mined lands; however, not all of the issues/concerns have been fully addressed. Current research is assessing the effects of sagebrush seeding rates and multiple levels of grass competition on sagebrush establishment should further aid in defining and developing a big sagebrush establishment technology. I believe that big sagebrush can be successfully established by direct seeding in combination with a level of grass that will result in stabilization and protection of the soil, but one that is less than typically seeded on mined lands.

The fact that big sagebrush has exhibited some seed dormancy and has been shown to retain seed viability for several years after being seeded greatly increases the probability of a good "precipitation and temperature year" occurring while the seed is still viable. This fact alone, may make it desirable to seed big sagebrush at a higher rate than previously recommended to ensure an adequate seed bank for germination and establishment over several years. Even though big sagebrush seed is relatively expensive, this cost would be much lower than having to mobilize

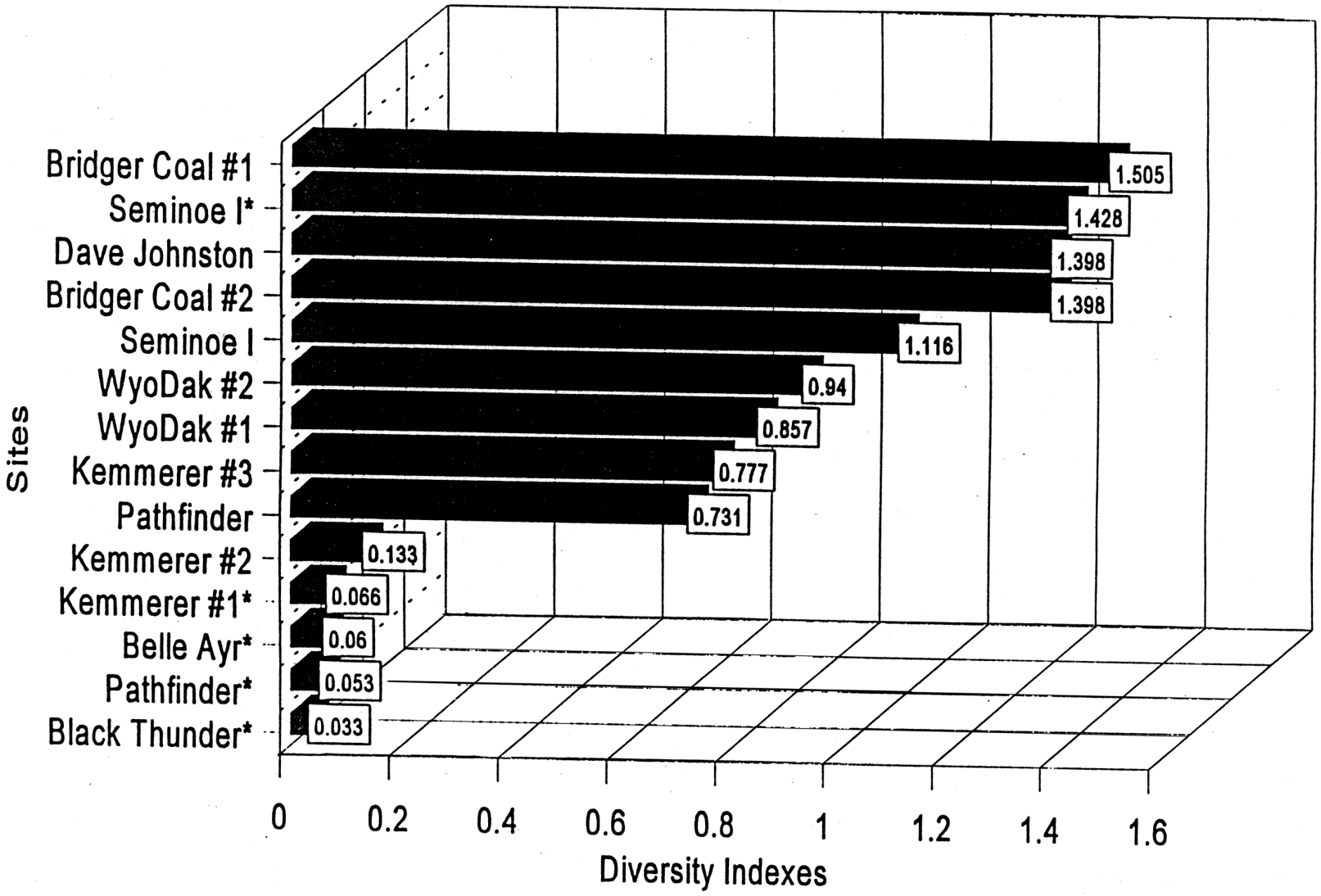


Figure 5 — Diversity indexes for fourwing saltbush/grass (denoted by *) and fourwing saltbush/big sagebrush/grass sites. Refer to Booth *et al*. (1997) for a list of seeding mixture used at each site (Olson *et al*., 2000).

equipment and a contractor a second year to ensure adequate and desired sagebrush densities are achieved.

Evidence also does not seem to support the fact that more easily established shrubs, such as fourwing saltbush, enhance establishment of other shrubs such as big sagebrush and in fact seem to result in slightly lower densities of sagebrush seedlings that are not as tall as those under other seeding strategies evaluated. However, inclusion of multiple shrub species in the seed mixture has been shown to increase total shrub seedling density and greater plant community diversity.

Even though one of the research studies did not show consistent benefits of direct-placed topsoil over stockpiled topsoil, it is highly desirable to use direct-placed topsoil whenever the reclamation process feasibly permits. Research has repeatedly highlighted the many benefits of direct-placed topsoil, such as AM inoculum, better soil physical characteristics, seedbank of native species, healthy microbial populations that ensure good nutrient cycling, and enhanced water infiltration and water storage capacity. Enhanced drought stress tolerance of big sagebrush seedlings when AM associations are present highlights an important factor in improving seedling survival in an arid/semiarid environment where soil moisture levels fluctuate dramatically in the surface few centimeters of the soil.

Mulch has also been shown to be critical to formation of “safe sites” for big sagebrush germination and establishment through microclimate modification. Stubble mulching is a desired practice over the use of straw mulch which is more costly, more labor intensive and has a greater potential to introduce non-desired and noxious weed species into reclaimed lands. Use of a stubble mulch has also been shown to have long-term benefits for water infiltration into the reconstructed soil profile.

Generally, within the last decade a much better understanding of seedbed ecology of big sagebrush has been achieved. Research is leading toward development of a seeding strategy for big sagebrush that should also benefit establishment of other native shrub species as well.

References

Allen, E. B., 1984. Vesicular-arbuscular mycorrhizae and colonizing annuals: Implications for growth, competition and succession. pp. 41-51. In: S. E. Williams and M. F. Allen (eds). VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, Wyoming. Wyoming Agr. Exp. Stn. Rpt. No. SA1261, Laramie.

Beetle, A. A., and K. L. Johnson, 1982, Sagebrush in Wyoming. Wyoming Agr. Exp. Stn. Bull. 779. University of Wyoming, Laramie.

Booth, D.T. 1985. The role of fourwing saltbush in mined land reclamation: A viewpoint. J. Range Manage. 38:562-565

Booth, D.T., Y. Bai, and E.E. Roos. 1997. Preparing sagebrush seed for market: Effects of debearder processing. J. Range Manage. 50:562-565.

Booth, D. T., J. K. Gores, G. E. Schuman, and R. A. Olson, 1999, Shrub densities on pre-1985 reclaimed mine lands in Wyoming. J. Restoration Ecology. 7:1-9.

Call, C. A., and C. M. McKell., 1982, Vesicular-arbuscular mycorrhizae-a natural revegetation strategy for disposed oil shale. Reclamation and Revegetation Res. 1:337-347.

Federal Register, 1996, Office of Surface Mining and Enforcement. 30 CFR Part 950. Wyoming Regulatory Program-final rule; approval of amendment. Vol. 61: (152):40735.

Fortier, M. I., G. E. Schuman, A. L. Hild, and L. E. Vicklund, 2000, Sagebrush establishment on mined lands: Effects of seeding rate and grass competition. Society for Range Management Abstracts, Boise, Idaho (in press).

Gores, J. K., 1995, The evaluation of big sagebrush and fourwing saltbush establishment on pre-1985 Wyoming reclaimed mine sites. M.S. Thesis, University of Wyoming, Laramie.

Harniss, R. O., and W. T. McDonough, 1976, Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29:167-168.

Harper, J. L., 1977, The recruitment of seedling populations. p. 111-147. In: Population Biology of Plants. Academic Press, New York.

Jones, G. P., 1991, Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Ph.D. Dissertation, Dept. of Botany, University of Wyoming, Laramie.

Kriger, J. A., W. A. Berg, J. T. Herron, C. M. Phillips, and R. G. Atkinson, 1987, Shrub establishment in the mountain shrub zone. p. L-3-1 through L-3-6. In: Proc., 4th Biennial Symposium on Surface Mining and Reclamation of the Great Plains and 4th Annual Meeting of the American Society of Surface Mining and Reclamation, March 16-20, 1987, Billings, Montana. Reclamation Research Unit Rpt. 8704, Montana State University, Bozeman.

Loree, M. A. J., and S. E. Williams, 1984, Vesicular-arbuscular mycorrhizae and severe land disturbance . p. 1-14. In: Proc., VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, Wyoming. Wyoming Agric. Exp. Stn. Sci. Rpt. No. SA1261, Laramie.

McDonough, W. T., and R. O. Harniss, 1974, Effects of temperature on germination in three subspecies of big sagebrush. J. Range Manage. 27:204-205.

McKell, C. M., and J. R. Goodin, 1973, United States arid shrublands in perspective. p. 12-18. In: Proc., Third Workshop of U.S./Australia Rangelands Panel, Tucson, Arizona. Society for Range Management, Denver, Colorado.

Meyer, S. E., 1990, Shrubland restoration-an ecologist's perspective. Handout: Workshop on Plant Species and Wildlife Habitat Establishment Successes and Failures. Billings, Montana. Intermountain Research Station, Shrub Sciences Laboratory, USDA, FS, Provo, Utah.

Olson, R. A., J. K. Gores, D. T. Booth, and G. E. Schuman, 2000, Suitability of shrub establishment on Wyoming mined lands reclaimed for wildlife habitat. Western North American Naturalist (in press).

Schuman, G. E., and D.,T. Booth, 1998, Strategies for establishment of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) on Wyoming mined lands. Final Report, Abandoned Coal Mine Land Research Program, Office of Research, University of Wyoming, Laramie and Wyoming Department of Environmental Quality, Abandoned Mine Land Program, Cheyenne, Wyoming.

Schuman, G. E., D. T. Booth, and J. R. Cockrell, 1998, Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51:223-230.

Schuman, G. E., E. M. Taylor, Jr., F. Rauzi, and G. S. Howard, 1980, Standing stubble versus crimped straw mulch for establishing grass cover on mined lands. J. Soil and Water Conservation. 35:25-27.

Stahl, P. D., G. E. Schuman, S. M. Frost, and S. E. Williams, 1998, Interaction of arbuscular mycorrhiza and seedling age on water stress tolerance of *Artemisia tridentata* ssp. *wyomingensis*. Soil Sci. Soc. Am. J. 62: 1309-1313.

Stahl, P. D., S. E. Williams, and M. Christensen, 1988, Efficacy of native vesicular-arbuscular mycorrhizal fungi after severe soil disturbance. New Phytol. 110:347-354.

Young, J. A., and R. Evans, 1989, Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Sci. 37:201-206.

Culturally Significant/
Historical Plants

Pinyon pine
Pinus edulis

"Using the Study of Cultural Landscapes to Develop Postmining Land-Use Plans"

"Small Area Reclamation on the Hopi Reservation and Hopi Uses of Culturally Significant Plants for AML Sites Reclamation"

Using the Study of Cultural Landscapes to Develop Postmining Land-Use Plans

James O'Hara, Coal Program Manager
Mining and Minerals Division
New Mexico Energy, Minerals and Natural Resources Department

Returning mined lands to a productive postmining land use is one of the important accomplishments of the Surface Mining Control and Reclamation Act (SMCRA). While postmining land use plans emphasize the premining agricultural applications, this may not serve the interest of landowners in all cases. We should have much greater flexibility in interpreting postmining land uses and creating plans that fit the needs of landowners.

The best examples I can think of are issues that concern not the productivity of the land, but the cultural values associated with land. The best reference for this may be the term ***Cultural Landscape***, which is a formulation used by geographers and anthropologists. In this context, Cultural Landscape is intended to cover the connection between people and the land, how they live on it, use it, and modify it, as well as the traditions people associate with land. Increasingly over the past decade this concept has found its way into the Section 106 process of the National Historic Preservation Act (National Register Bulletins 30 and 38). Briefly, Section 106 requires Federal agencies, such as the Office of Surface Mining, to consider the effects their projects, such as coal-mine permitting, will have on historic and archaeological properties. The National Register of Historic Places has established criteria by which these sites can be evaluated in terms of national and local significance.

Although a cultural landscape can be applied to any part of the country, it has particular significance in association with Indian lands of the Western United States, where the cultural, religious, and economic uses of the lands are intertwined. In New Mexico, we have several prime examples of connecting a postmining reclamation plan with economic and cultural elements. It has become evident that these are not incompatible with the concept of reclamation created by SMCRA, provided one can recognize the need to take into consideration the Cultural Landscape.

Cultural Landscape: A New Mexico Example

Background

The permit area for the McKinley Mine covers 10,727 acres, comprising all or parts of 25 sections. These sections are located in what is known as the "checkerboard" area of New Mexico, because of the alternating land ownership–State and tribal–from section to section. The "checkerboard" has its origins in the removal and subsequent return of the Navajo Tribe to northwestern New Mexico. Relocation of the Navajo took place in 1863 and 1864, when the tribe was forcibly removed from the Four Corners area to the Bosque Redondo near Ft. Sumner in De Baca County, over 350 miles away in east central New Mexico. Within several years, the

Federal government determined that it could not support the tribe at Bosque Redondo. A treaty was negotiated with the Navajo in 1868, allowing the tribe to return to a reservation that was smaller than their tribal lands had been prior to 1863-64. Consequently, families returned not just to the reservation but to lands they had occupied prior to 1863, which were adjacent to but outside of its boundaries.

In order to recognize a Navajo family's claim to use of the land, the Federal government granted allotments in quarter-section tracts (160 acres). The allotment tracts were located in even numbered sections. The odd number sections in the area of the reservation had been deeded to railroad in 1866, which created the foundations for the "checkerboard". Navajo allotments within the McKinley South permit were approved between 1907 and 1911, based on informal surveys of Navajo families beginning in 1901.

The checkerboard area, encompassing the McKinley South Mine, is a critical element in understanding the Cultural Landscape because it creates a dichotomy of land-use cultures and traditions (those that are "Western" as distinguished from those that are Navajo) from section to section. While all other permit areas in New Mexico, and probably the Western United States, possess a fairly uniform land use (namely, large tracts of land either owned by private individuals or leased largely for the purpose of grazing), the McKinley Mine's 16 contain 48 allotments. Each allotment is owned by an extended Native American family, which can include dozens of people, all of whom have a stake in what will happen to the land after mining.

Given the complexity of land use and the fact that the landscape has become increasingly less important through the years, how does one establish an appropriate post mining land use or uses? New Mexico establishes the following criteria in its performance standards:

> 2073.B. Determining premining use of land –The premining uses of land to which the postmining land use is compared shall be those uses which the land previously supported, if the land had not been previously mined and had been properly managed.
>
> (1) The postmining land use for land that has been previously mined and not reclaimed shall be judged on the basis of a use, which the land was capable of supporting prior to all previous mining, that is compatible with the surrounding areas.
>
> (2) The postmining land use for land that has received improper management shall be judged on the basis of the premining use of surrounding lands that have received proper management.
>
> (3) If the premining use of the land was changed within 5 years of the beginning of mining, the comparison of postmining use to premining use shall include a comparison with the historic use of the land as well as its use immediately preceding mining.

The key elements are how the land was used and managed and putting land use and management in an historic perspective, which are all critical elements in creating a postmining demonstration plan for final bond release. The regulations call for an extensive evaluation of the pre-mining conditions before a postmining land use plan can be approved, but no guidance as to how it can be done. This is a multi-dimensional problem that is not easily answered. The one thing that definitively covers **land use**, **management**, and **history** is the Cultural Landscape. The McKinley Mine affords an excellent example of what can be done to obtain information about the Cultural Landscape.

Identification of Premining Uses

Characterization of the Cultural Landscape was accomplished in a number of actions that are interrelated. Each action happens separately, but the results from each provide new pieces of information essential to creating a postmining land use plan:

- Information provided by the allottees (realty negotiations) –Since leases where negotiated through the children of the original allottees, we have an excellent background on what the landowners said they wanted after mining, but in most cases this will not answer any questions as to why or how it can be accomplished in a postmining land use plan. Many questions surrounding traditional premining uses, such as grazing, residential or agriculture are probably never included in the negotiations. Another event is required to delve into these issues.

- Information provided by the allottees (ethnohistoric research) –Another important aspect of McKinley has been the large amount of information about land use obtained from archaeological and ethnohistoric research. Trained anthropologists and historians conduct ethnohistoric research. They use available historic records combined with interviews with the allottees to gain as much information as possible on how allottees used the land. At McKinley the interviews were carried out after an archaeological inventory so allottees could be taken to identified sites. This made an effective connection between the land and the people who lived there. The oral history of a piece of land and information about land use can not always be identified through an archaeological inventory (i.e., ceremonial sites or plant gathering locations). An ethnohistoric study combined with a physical inventory of sites proved to be most effective at identifying issues associated with the historic landscape.

  A total of 87 people were interviewed in 1978 and 1979. The interviews are critical to addressing the postmining issues outlined in the New Mexico coal regulations. Important issues covered that are relevant to post mining land use were backgrounds on grazing and agriculture. How much livestock did the land support? When was the land grazed? What changes occurred through time? What crops were grown? When were residences used? Who was using the allotments and for what purposes?

Through the time period ending with World War II (WWII), a majority of the allotment families lived on the leased lands and continued to raise sheep and goats and farm the land. The land played an important role in the livelihood of the allottees. After WWII, herding and farming were increasingly supplemented by sale of crafts (rugs and jewelry) and wages. By the 1970's, the leased lands on the McKinley Mine did not provide economic support for the inhabitants. In 1978 it is estimated that livestock on the lease had been reduced by 50 percent from 1940, with only one stockowner keeping more than 100 animals, a figure at one time considered the minimum needed to support a household. Farming was less important than herding with production of corn going mainly to help support the livestock (Kelley, 1982, pp. 185-6). Finally, by 1978, relatively few families still lived on their allotments year round. Several maintained houses used during the summer months, preferring to live closer to jobs in Gallup or Window Rock (Kelley, 1982, p. 193).

Another dimension to the use of the land that is not so easily documented or truly known is the traditional uses of the land, such as plants used for medicinal and religious purposes and areas used for religious practices, and burial sites. These land uses are more foreign in concept to non-Native Americans, but are a significant element to the allottees' cultural landscape. Lease negotiations would never create a forum to discuss these issues, but the ethnohistoric work did. It created an opportunity to plan for the identification of burials and treatment of traditional properties. Without the benefit of the ethnohistoric information these issues could have stopped mining and caused costly delays.

Unlike lease negotiations, the ethnohistoric evaluation provided most of the information about the history of land use and land management. It also created a forum in which allottees could also disclose information about other traditional uses of the landscape such as ceremonial sites and the location of burials.

- Baseline data: soils, vegetation, and archaeological research –Soils baseline surveys were first conducted in 1978 and have been updated as recently as several years ago. In 1979, the Soil Conservation Service declared that there are no prime farm lands in the South Mine.

  Vegetation baseline study conducted in 1978 and 1979 included an inventory of all agricultural land, including condition, crops grown, and acreage under cultivation.

  An archaeological inventory was conducted of the McKinley lease in the late 1970's. In addition to prehistoric archaeological sites historic Navajo sites were also identified and documented. Additional studies were performed after the interviews to document newly identified historic Navajo properties.

The combined techniques used to obtain the baseline data provided a complete picture of the Cultural Landscape and identified not only those elements in use at the time, but evidence of historic land use that are important to establishment of a postmining land use plan.

Premining Land-Use Summary

- Many of the hogans were seasonal residences associated with winter grazing and spring lambing.
- As far back as the 1920, some of the allottees used the lease lands as a year round residences. The annual use of the land could change from generation to generation.
- Traditionally, the leased lands were used for grazing and upland areas were used during the summer.
- The availability of water was a critical factor for the use of allotments for residences, grazing, or agriculture.
- Since WWII, there has been a dramatic decrease in livestock and the number of families who keep herds, and access to upland summer grazing lands has been restricted. Consequently, it is expected that there will be a higher level of year round use on the reclaimed lands.
- Agricultural plots have traditionally been part of the cultural landscape and were being used up until the time Pittsburg & Midway Coal Mining Company (P&M) relocated the allottees of the land.
- Special areas were used to either grow or gather plants for medicinal or ceremonial uses.
- Special areas were used for religious ceremonies.
- A number of unmarked burials were located within the lease area.
- As far back as we have records (1915), it does not appear that the McKinley lease area was over grazed. In fact, since WWII, the rangeland was probably under-utilized.

Postmining Land-Use Plan

The McKinley Mine postmining land-use plan incorporates much of the information obtained through the characterization of the premining Cultural Landscape:

- Grazing –Grazing is the predominant postmining land use planned for the lease area. This is consistent with what we know about the historic use of the McKinley lease. P&M has an approved seed mix which includes both cool and warm seasonals, perennials, and half-shrubs. One of the most limiting factors to grazing, water availability, will be addressed using permanent impoundments.

  Based on the information it is obvious a single allotment was only part of a much broader cultural landscape. Families combined the use of a number of allotments, based on family relationships, to conduct grazing. Grazing was limited by the availability of water and summer grazing lands. The ethnohistoric studies estimated about 1500 sheep, goats, and horses were kept in the McKinley South lease area. By the 1970's, none of the families depended solely on income from grazing for a living and only one third of the households owned livestock and only one owned more than 100 sheep and goats (Kelley 1982, pp. 185). While it is not possible to predict how much the allottees will graze reclaimed lands after bond release, the revegetation plan and postmining land use demonstration will create a resilient and productive rangeland.

- Garden plots –Mining will disturb six garden plots. P&M has committed to replacing the gardens, acre for acre, with appropriate topsoil in similar topographic setting. P&M has also established an experimental garden plot, using drip irrigation, to show that these gardens can be viable.

- Residential uses –All of the allottees living on the mine were relocated to new housing constructed on a section of land owned by P&M, which was later deeded to the Navajo Nation. Some families have requested P&M provide for building or mobile home sites as part of the reclamation of their land. P&M's plans is to grade building sites and roads and, provide a water well according to specifications agreed to with the allottees.

- Traditional uses –This is a broader category of postmining land use identified by allottees as having particular cultural and religious significance to them. The locations of these places have been documented as part of the requirements of Section 106 of the National Historic Preservation Act as Traditional Cultural Properties (TCP). The McKinley permit includes specific provisions to replace or reconstruct TCP.

  McKinley is working with the Navajo Division of Forestry Seed Bank Program to collect and grow plants associated with traditional practices. These plants will be included in the reclamation to ensure their continued presence on the landscape.

Conclusions

An evaluation of the cultural landscape is important to reliably address the planning of postmining land use. The McKinley example may be more complex because of the number of

landowners and their traditional practices, but the same principles can be applied anywhere. This method accomplishes a number of goals that are required under SMCRA regulatory requirements:

- How was the lands historically used? Historic records and interviews created an invaluable picture of seventy-five years of premining land use. Records on land use are readily accessible to the mines and regulatory agencies at the National Resources Conservation Service and local conservation districts, county courthouses and other public places. Ethnohistoric evaluations are invaluable and will save time and money.

- What criteria should be used for a demonstration of the postmining land use plan? This includes issues as basic as stocking rates and the timing (season) of a demonstration. In the McKinley case it is apparent that cattle were rarely kept by the Navajo on these allotments. The demonstration must employ a mix of sheep and goats, or perhaps horses. Based on the history of this landscape, it seems appropriate to use a Navajo herder to conduct the grazing for the demonstration.

- The interview process intimately involves the landowners in determining what the postmining use plan should include. The New Mexico program requires that landowners be notified of the intended postmining land use(s) of their land and that the permit include written acknowledgement they have been appraised of the postmining land-use plan. Since final bond release may not happen for a least a decade after final reseeding, documentation of interviews along with signed acknowledgements may help reduce problems or misunderstandings that may occur years after a permit is put into effect.

References

Kelley, Klara B., Volume Two: *Navajo Ethnohistory of Anasazi and Navajo Land Use in the McKinley Mine Area Near Gallup, New Mexico*. Office of Contract Archaeology, University of New Mexico.

U .S. Department of the Interior, National Park Service, Interagency Resources Division, “Guidelines for Evaluating and Documenting Rural Historic Landscapes,” in National Register Bulletin 30.

U .S. Department of the Interior, National Park Service, Interagency Resources Division, “Guidelines for Evaluating and Documenting Traditional Cultural Properties,” in National Register Bulletin 38.

Small Area Reclamation on the Hopi Reservation and Hopi Uses of Culturally Significant Plants for AML Sites

Ralph Lamson, Gavin Seweyestewa, Max Taylor, and Bob Flowers
Hopi Tribal Office

History of Mining on the Hopi Reservation

Archeologists have found evidence that coal was used at Hopi mesas well before it was in common use in Europe. Coal burning stone stoves and pits for firing pottery, dated to 1300 A.D., are quite common, and some coal use as early as 900 A.D. is documented.

Coal use at Hopi mesas continues today with coal provided by Peabody Western Coal Company's (PWCC's) Black Mesa Mine, located at the northern end of the Hopi reservation.

The PWCC mine started production in the 1960's; before that, coal was obtained from a series of small mines located near the mesas.

- The Bureau of Indian Affairs (BIA) developed these mines.
- The coal was given to tribal members to use for house heating in the winter; however, the main use was for BIA sponsored boarding school boilers.
- A few small pits were developed on coal outcrops with shallow overburden. BIA equipment removed the overburden from the coal outcrop to the face of the mesa. The coal was then retrieved by the villagers for use in their homes.
- Most of the BIA developed mines were small underground mines with one or two openings. These mines were worked by hand with pick and shovel and small carts on rails.

In 1982, the Hopi Tribe entered into a cooperative agreement with the Office of Surface Mining (OSM) to administer an abandoned mine lands (AML)/Title IV program.

- Inventory found 13 sites eligible for reclamation. Most of the sites were located near populated areas. The sites were prioritized according to OSM standards.

In 1983, an environmental assessment was completed for the eligible sites.

In 1985, reclamation of these sites started.

- The Hopi Tribe was granted full Title IV authority in 1988, and reclamation work continued until 1993 when work on all the eligible sites was completed.

General Reclamation Examples

The areas needing reclamation were very small, averaging less than 2 acres each. Most of these areas had conditions–steep slopes, access problems (no roads to the disturbances), and archeological sites located in reclamation areas–that precluded the use of heavy equipment. The majority of the work was therefore accomplished by hand. This had the added benefit of providing employment to tribal members.

Spoil/gob material was disposed of in place.

All of the reclamation sites made extensive use of quarried stone. Examples of these uses are as lining for natural drainage ways, as check dams, as buttresses for installed culverts, as closure material for mine portals and adits, and as substitute for contour terraces.

Topsoil was obtained from nearby borrow areas and seed from the Utah Native Seed Company. (The seed was custom-ordered and contained species of cultural significance to the Hopi Tribe.) The topsoil was raked and the seed spread by hand.

All reseeded areas were mulched.

The areas are at elevations above 6,000 feet, with annual precipitation between 8 and 12 inches, most of it occurring during strong summer thunderstorms. The vegetation can be classified as a Great Basin desert scrub.

Reclamation Examples from the Oraibi Deep Mine

History:

- In the 1950's, the Oraibi deep mine was both developed by the BIA and subsequently abandoned.

- It supplied coal for the boiler in a nearby BIA boarding school.

- It was one of the last reclamation sites, reclamation having been completed in 1990.

- It was one of the costliest sites due to haul road reclamation and demolition/disposal of dangerous mine facilities.

- It is located near the Hopi Civic Center.

- Much of the gob material had been placed in drainages and was being washed into the Little Colorado River watershed.

Reclamation:

- The mine workings were retimbered and spoil/gob material was placed in the mine using wheelbarrows.
- The adit and fan portal as well as several areas in the mine were sealed using quarried stone and cement.
- Quarried stone was also used to line drainages and build check dams and culvert buttresses.
- The natural slopes exceeded 20 percent.

Evaluation:

- The rock-lined drainages have held up well.
- The quarried stone culvert buttress has probably kept the culvert from blowing out.
- Despite using very erodible topsoil material on a steep slope, there were few rills created over the past 9 years.
- The vegetative cover appeared to be about the same as on nearby undisturbed areas.

Reclamation Examples from the Mishongnovi-Shipolovi Pits

History:

- These pits were developed by the BIA to provide house coal to nearby villages.
- They consisted of a series of small shallow pits developed from a coal seam with very little overburden.
- Spoil from the pits provided a very poor plant growth medium.

Reclamation:

- Reclamation was started in 1986 and completed in 1987. The Mishongnovi-Shipolovi pits were one of the first sites to have been reclaimed.
- This site contains several archeological areas that were avoided during construction and reclamation.
- Spoil material was returned to the open pits using wheelbarrows.

- Quarried stone was used to line drainages and to build check dams and culvert buttresses. It was also placed on the topsoiled slope to act as contour terraces.

- The reclaimed slopes were shallow and short in length.

Evaluation:

- The rock-lined drainages and check dams held up well.

- The topsoil material was very erodible but there were only a few shallow rills—the stone used as terraces appeared to help minimize erosion.

- The vegetative cover appeared to be about the same as on nearby undisturbed areas.

Culturally Significant Plants

Topsoiled areas were raked and a custom seed mix was applied by hand. Unfortunately, nobody remembers what that mix contained. Mulch was applied at all sites. The following species were observed on the reclamation sites:

- Grasses (blue grama [*Bouteloua gracilis*] and Indian ricegrass [*Oryzopsis hymenoides*]).

- Forbs (Indian paintbrush [*Castilleja chromosa*], scrambled eggs [*Corydalis aurea*], and scarlet globe mallow [*Sphaeralcea coccinea*]).

- Shrubs (fringed sage [*Artemisia frigida*], rabbit brush [*Chrysothamnus sp.*], fourwing saltbush [*Atriplex canescens*], and cliffrose [*Cowania mexicana*]).

For well over 1,000 years, the gathering and usage of certain native plants has been and continues to be of great importance to the Hopi Tribe.

- Food –Tribal members continue to collect certain plants for food, although plant collection is neither as important nor as necessary as it has been in previous years. Items such as pine nuts from the Pinyon pine are even sold from roadside stands to supplement family income.

- Medicine –Although not as prevalent as in the past, traditional herbal remedies are prepared from certain native plants and used to this day on the reservation.

- Arts and crafts –The Hopi people are very artistic and the use of naturally occurring plant materials is quite common and widespread. Plant materials are used as glazing for pottery, as natural dyes and paints, as basket material, and as carving material for Kachina dolls.

- Cultural/ceremonial purposes–The Hopi people have used plant materials in their ceremonies since the beginning of time. The continued use of these plants in ceremonies is central to the Hopi way of life, making this their most important usage.

Listed, Rare, Threatened, and Endangered Plants

Purple coneflower
Echinacea angustifolia

"The Endangered Species Act of 1973"

The Endangered Species Act of 1973

Joyce Maschinski, Ph.D., Curator of Plants*
The Arboretum at Flagstaff, Flagstaff, Arizona

Section 7 of the Endangered Species Act of 1973 states, in part, that "[e]ach Federal agency shall * * * insure that any action authorized, funded, or carried out by such agency * * * is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with affected States, to be critical, unless such agency has been granted an exemption for such action by the Committee pursuant to subsection h of this section. In fulfilling the requirements each agency shall use the best scientific and commercial data available."

There are (at least) six issues related to rare plants of which all of us should be aware:

- It is important first to identify the plants at your site.
- Review listed and safeguarded species in your State.
- Determine whether the site or land within it has been designated as critical habitat.
- If your site is on Federal land, the Federal agency with which you are dealing must prepare a "biological opinion" about the action proposed for the site.
- If this biological opinion predicts that some harm to a protected species would result from implementing the proposed action, the agency, the U.S. Fish and Wildlife Service, and you must consult to discuss options for implementation that would minimize the effect on the species. This consultation should also clarify restoration expectations.
- Discussions should focus on what can be done to remove jeopardy to the species.

For assistance with any of these issues, please contact the U.S. Fish and Wildlife Service, State Field Office, at www.fws.gov. For information on protected plants in the Southwest Region, contact www.fws.gov.ifw2irm2.irm1.r2.fws.gov. The U.S. Forest Service, the Bureau of Land Management, and the National Park Service all have botanists on staff that can be invaluable resources. The Center for Plant Conservation, Missouri Botanical Garden, P. O. Box 299, St. Louis, Missouri 63166-0299 (telephone: 314-577-9450; www.mobot.org/CPC) is another excellent source for assistance. Finally, for information on botanical-garden affiliates, please consult the "Botanical Garden Affiliate, Plant Conservation Directory."

*This paper constitutes a summary of Dr. Maschinski's presentation at the interactive forum and is based on information contained in overhead slides she used at this presentation; the paper is not the actual text of the presentation itself.

Diversity

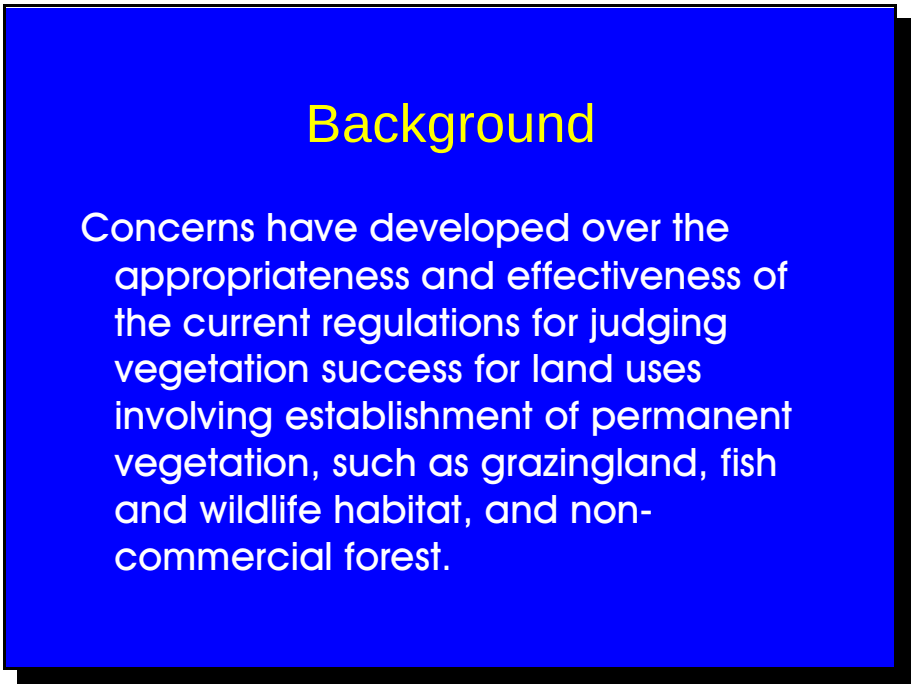
Palmer penstemon
Penstemon palmeri

"OSM's Revegetation Success Public Outreach Initiative: An Assessment of the Need to Revise The Federal Revegetation Success Regulations"
"Building a Foundation for Diversity: Topdressing Variability for Distinct Plant Communities"
"Wyoming's Approach to Species Diversity"
"Applying a Method for Quantifying the Diversity of Montana Wetland Plant Communities to Understanding the Diversity of Plant Communities within Surface Mining Reclamation Units"
"Overview of Statistical Methods for Measuring Diversity"
"Evaluating Biodiversity of Reclaimed Mined Lands"
"A Comparison of Cover Sampling Methods"

OSM's Revegetation Success Public Outreach Initiative: An Assessment of the Need to Revise the Federal Revegetation Success Regulations

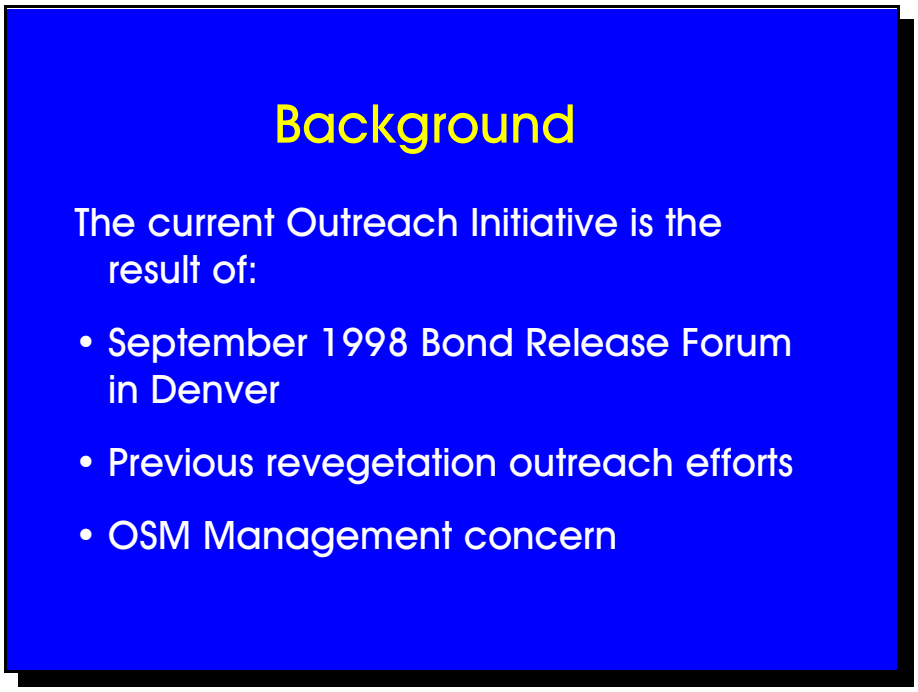
Robert C. Postle, Ecologist
Office of Surface Mining

The following discussion provides a basic review of the results of the Office of Surface Mining's (OSM's) public outreach effort relative to the matter of revegetating surface coal minesites. OSM's Revegetation Team is currently summarizing that effort with an eye to identifying minor revisions to the Federal regulations that will be forwarded to OSM management for possible action. (The Revegetation Team consists of Erv Barchenger and Kim Vories, both of OSM's Mid-Continent Regional Coordinating Center, Milton Allen, of its Appalachian Regional Coordinating Center, Vic Davis, of its Knoxville Field Office, Scott Boyce, of Headquarters, and Robert Postle, of the Western Regional Coordinating Center.)



As part of the outreach initiative, OSM prepared a concept paper, which was mailed to interested parties and made available on OSM's web page and by telefax on demand. The concept paper identified the concern that was driving the outreach initiative, the current statutory and regulatory requirements regarding revegetation, the issues that have been raised on the topic, and questions that the Revegetation Team hoped would facilitate discussion and elicit ideas.

As discussed in the concept paper, for some areas of reclamation (for example, agricultural cropland, hayland, commercial forest land, and so forth), a focus on cover, production, or stocking may be the most appropriate way of determining success. However, concerns have developed over the appropriateness and effectiveness of the current regulations for judging vegetation success for land uses involving establishment of permanent vegetation, such as grazinglands, fish and wildlife habitat, and non-commercial forest.



The concern identified in the concept paper is the culmination of several factors. During the interactive forum "Approaching Bond Release: Applied Statistics for Reclamation and Surface Mining Applications in the Arid and Semi-Arid West", which OSM sponsored in Denver, Colorado, in September of 1998, the conflict within and appropriateness of the current regulations was raised several times. Among other topics, discussions focused on productivity versus diversity and the impact of sample adequacy on reclaimed community complexity.

In addition, previous outreach initiatives had identified problems with the existing regulations. These included the 80/60 rule for tree and shrub establishment, the period for demonstrating revegetation success in areas with less than 26 inches of precipitation, and normal husbandry practice approval requirements.

Based on these events and other information, OSM's Management Council determined that, to better achieve the statutory requirements of the Surface Mining Control and Reclamation Act (SMCRA), it was appropriate for the OSM Revegetation Team to conduct an outreach effort to determine if revision of the Federal revegetation regulations was desirable.

Surface Mining Control and Reclamation Act of 1977

Section 515 (b)(19) requires that the reestablished vegetative cover be diverse, effective, permanent, of the same seasonal variety native to the area, capable of self-regeneration and plant succession, and at least equal in extent of cover to natural vegetation in the area to be mined.

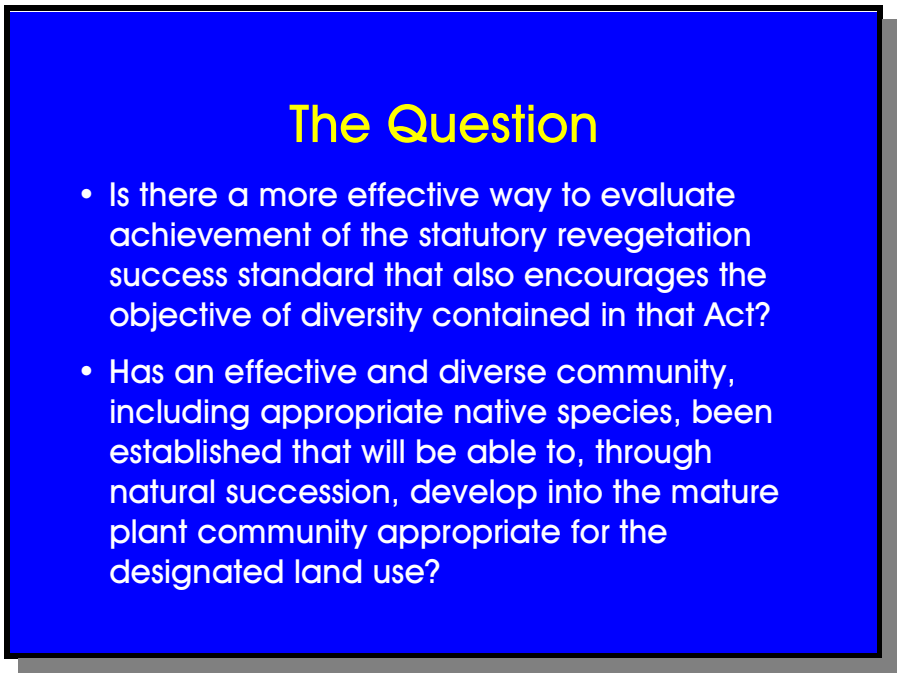
SMCRA, at Section 515 (b)(19), requires that the reestablished vegetative cover be diverse, effective, permanent, of the same seasonal variety native to the area, capable of self-regeneration and plant succession, and at least equal in extent of cover to natural vegetation in the area to be mined, except that introduced species may be used where desirable and necessary to achieve the approved postmining land use. With Section 515 (b)(20), Congress also required that the operator assume responsibility for successful vegetation (as defined above) for either 5 or 10 years (depending on rainfall), after efforts to establish the vegetation had been completed, to assure those efforts were successful.

It appears that Congress recognized the value of vegetative diversity as well as the transitional nature of reestablished vegetative communities that exist after 5 or 10 years. Congress understood that neither mature hardwood forests nor stable climax prairie or desert shrub communities can develop within just a few years. Therefore, Congress established a standard that is based, in part, on cover of a diverse community of native perennial species with the potential for regeneration and plant succession into the plant community ultimately sought. Thus, revegetation efforts must contain the appropriate mix of species to establish a transitional community capable of developing through time into the desired plant community through natural succession.

Federal Regulations

- 30 CFR 816/817.111 paraphrase the statutory standard of 515 (b)(19) with some additions
- 30 CFR 816/817.116 require statistically valid sampling (and statistical analysis with a confidence interval) to determine the adequacy of cover, production, and/or stocking, depending upon the approved postmining land use. Evaluation timeframes are specified.

The existing Federal regulations, intended to implement the statutory performance standard requirements for vegetation, consist of (1) a plan for revegetation at 30 CFR 780.18(b)(5)/784.13(b)(5); (2) the basic vegetation performance standards at 30 CFR 816/817.111, which paraphrase the statutory standard of SMCRA's Section 515 (b)(19) with some additions; (3) the requirements for timing of seeding and mulching and other soil stabilizing practices at 30 CFR 816/817.113 and 114; and (4) standards for judging vegetation success at 30 CFR 816/817.116, which require statistically valid sampling (and statistical analysis with a confidence interval) to determine the adequacy of cover, production, and/or stocking, depending upon the approved postmining land use.



Based on the concerns raised by the concept paper, the question is: is there a more effective way to evaluate achievement of the statutory revegetation success standard that also encourages the objective of diversity contained in SMCRA? That is, has an effective and diverse community, including appropriate native species, been established that will be able to, through natural succession, develop into the mature plant community appropriate for the designated land use? Increased diversity (both community complexity and the number of communities, including niche areas) should result in enhancing fish and wildlife uses, as well as improving the resiliency of the reestablished plant community. In addition, OSM would like to promote a greater use of trees, shrubs, and wetlands during reclamation as a means of improving carbon sequestration.

These basic questions and eight additional questions included in the concept paper were designed to facilitate discussion and, elicit ideas that may have the potential for regulatory or policy change, and explore the regulatory flexibility inherent in SMCRA.

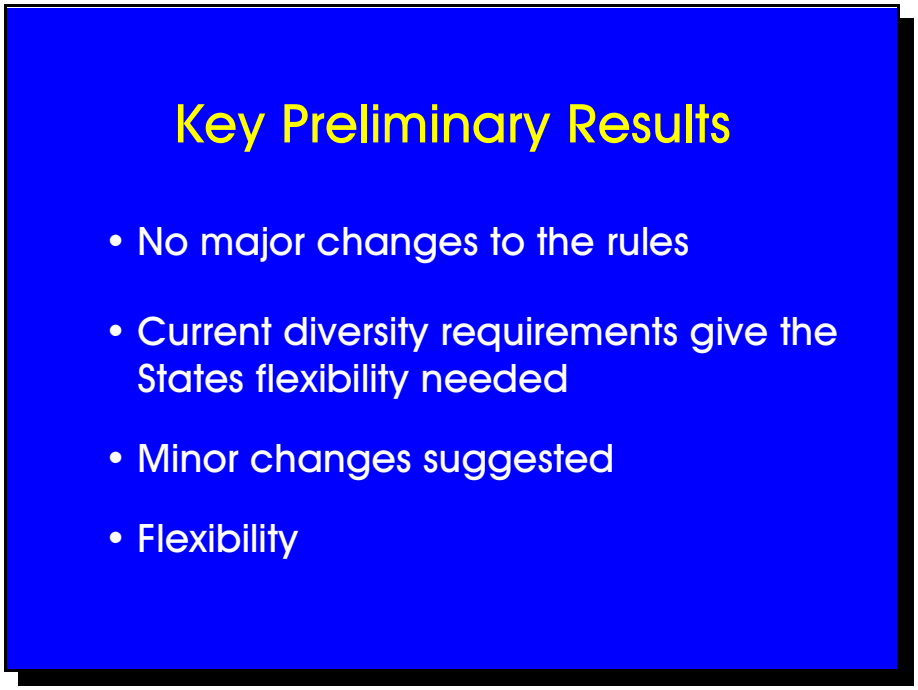
The Outreach Effort

- 10 public meetings held
- Total attendance - 130 people representing States, industry, citizens, OSM, and others
- To date 17 letters and e-mail messages received
- Closing date for comments extended to September 30, 1999

As part of the outreach effort, OSM held eight public meetings—one each in Bismarck, North Dakota, Denver, Colorado, Gillette, Wyoming, Alton, Illinois, Knoxville, Tennessee, Austin, Texas, Farmington, New Mexico, and Price, Utah—, as well as a special request meeting with the Citizens Coal Council in Denver and one with the National Mining Association in St. Louis, Missouri. A total of approximately 130 people attended the public meetings. Specifically, this amounted to about 32 State regulators, 63 industry representatives, and 25 other interested individuals, including individuals from citizen groups, consultants, and other agencies. We feel this represents successful public participation at the outreach meetings.

We have also received, to date, 15 letters or e-mail messages. Of these, five came from State regulatory authorities, five from industry, and five from other interested parties.

Here are the preliminary results.



With few exceptions the overwhelming response was that no major changes in the current revegetation regulations are necessary. The current diversity requirements give the States the flexibility they need to set appropriate standards. Nor were any additional Federal standards desired. As was often stated, if it's not broke, don't try to fix it.

However, several minor changes in the regulation were suggested fairly consistently. These and other concerns will be discussed shortly.

The key word that was repeated over and over at the outreach meetings was flexibility. In fact, it was a key theme of the outreach effort. Flexibility meant many things to different people. It included flexibility in interpretation of the regulations, flexibility in implementation of the regulations and flexibility in approving State program amendments. The consensus seemed to be that if OSM provides the flexibility then the States and industry can attain the goals of establishing a diverse, permanent, effective plant community capable of succession and regeneration.

Commonly Suggested Minor Changes

- Change the timeframe for evaluating revegetation success in the West
- Only 1 year of evaluation for tree and shrub stocking
- Eliminate the 80/60 rule for tree and shrub stocking for non-commercial forest and wildlife habitat land uses
- Allow more flexibility in selecting normal husbandry practices

One of the most commonly suggested changes was to 30 CFR 816.116(c)(3), which requires evaluation of revegetation success during the last two years of the responsibility period in areas with less than 26 inches of precipitation. It was suggested that this rule should be revised to be consistent with the requirements for areas receiving more than 26 inches of precipitation; any two years but the first year. Several alternatives were suggested, but the key point was to allow non-consecutive years to be used, given the climatic variability of the West.

The need to evaluate tree and shrub density for more than 1 year was also questioned. It was suggested that the density values do not change drastically from year to year, so only 1 year's measurement is necessary. Again, consistency with respect to the regulations for the East, which only require 1 year's data, was seen as desirable.

Elimination of the requirement that 80 percent of the trees and shrubs be in place for 60 percent of the responsibility period was raised. It was suggested that this requirement be eliminated for all but commercial forest lands.

For normal husbandry practices, it was suggested that the rules be changed or reinterpreted to allow States more flexibility in selecting appropriate practices. For example, the rules could allow the use of interseeding to improve diversity or of practices designed to control undesirable species.

Commonly Suggested Minor Changes

- Allow planting of trees and shrubs in enhancement features without standards
- Allow creation of wetlands without standards
- Eliminate the uniform topsoil replacement requirement
- Allow more flexibility in backfilling and grading requirements

To improve the use of trees and shrubs it was often suggested that the regulations be revised to allow tree and shrub plantings that would not be subject to density standards. Common examples included shelterbelts, which represent good soil conservation practices, and fish and wildlife enhancement features, which would only have qualitative standards but increase landscape diversity. It was also suggested that to encourage the creation of wetlands, such areas should only be evaluated using qualitative standards.

While not affecting the revegetation success standards, participants suggested that if the goal is to increase diversity on reclaimed lands then the key controlling factors are soils and landforms. It was recommended that uniform topsoil replacement requirement be eliminated as uniform soil depths tend to encourage uniform plant communities. It was also recommended that the backfilling and grading requirements be revised to allow/encourage reconstruction of premine landforms and small depressions. Both these were felt to be key to reestablishing premine landscape diversity resulting in increased plant diversity.

Other Concerns/Ideas Raised

- Maintain/improve FLEXIBILITY
- OSM take the lead in regulatory interpretation
- Use of professional judgement or experienced personnel in evaluating success
- OSM/States failing to enforce existing rules
- Sample adequacy

There were also concerns raised during the outreach that may or may not require regulatory changes or did not represent as common a theme as those previously discussed.

As discussed previously, flexibility was the common undercurrent of the outreach. As part of this it was strongly suggested that OSM take an active, lead role in providing interpretation of the Federal regulations and identifying the levels of flexibility available to the States in developing program amendments. This could include developing policy and defining terms such as diversity.

Another common theme was the role of professional judgment in evaluating revegetation success. It was often stated that both State regulatory authorities and industry have numerous qualified and experienced personnel whose input, along with the quantitative information, should be considered in bond-release evaluations.

However, concern was expressed that OSM and the States are failing to enforce the existing regulatory requirements and are already lowering the standards when operators cannot meet them. It was felt that industry should be held to the established standards.

The issue of sample adequacy was discussed in terms of establishing diverse plant communities. It was suggested that there be additional flexibility in evaluating sample size when the goal is highly diverse plant communities or tree and shrub stocking.

Other Concerns/Ideas Raised

- Consider use of alternative sampling techniques
- Allow flexibility in statistical specificity
- Role of postmining land use in setting standards
- Use of trend analysis in evaluating success

It was suggested that OSM consider the use of alternative techniques for evaluating revegetation success. This included using Revised Universal Soil Loss Equation modeling, remote sensing, and livestock weight gains observations.

There was a desire to allow more flexibility in setting the statistical specificity as, for example, by allowing alternative confidence intervals.

Several participants felt that the postmining land use should have a larger role in setting the success standards. For example, if the goal is livestock production, then the focus of the success standards should be high levels of forage production from desirable species. Conversely, if wildlife habitat is a key goal then the focus may be species diversity.

It was also suggested that trend analysis might have value in evaluating revegetation success. The National Resource Conservation Service's approach discussed in the National Range and Pasture Handbook was identified as one option. Trends were also discussed as a tool for evaluating diversity.

Other Concerns/Ideas Raised

- Use of qualitative with the quantitative
- Length of bond period in the West
- Improve communication - OSM, States, industry, landowners
- Recommended that this type of dialogue continue for this and other disciplines

The use of qualitative information, in conjunction with quantitative information, in making bond release determinations was recommended.

A few participants suggested the bond period in the West should be revised. They recommended that SMCRA be revised to reduce the bond period to 5 years.

The need to improve communication between OSM, the States, industry, and landowners was also discussed. There appears to be an ongoing need to identify additional ways we can all openly discuss and try to resolve the issues and problems we face in reclaiming the land and meeting the requirements of SMCRA and the State counterparts. It was often recommended that this type of outreach effort be continued for this and other disciplines, because it has served to open/improve the lines of communication.

Key Benefits of the Initiative

- An open dialogue between OSM, States, industry and other interested parties
- Recognition that States have flexibility in developing rules and success standards/methods to meet SMCRA requirements

One of the key benefits of this outreach effort has been the open dialogue between OSM, the States, industry and other interested parties. It has been extremely interesting to OSM to hear the concerns and ideas expressed by all the participants at various locations.

The outreach effort has also been important because it provided the team an opportunity to spread the word that the States have the flexibility to develop rules, success standards, and sampling techniques that, while not exactly the same as the Federal regulations, meet the intent of SMCRA and are no less effective than the Federal requirements.

Where do we go from here?

- Revegetation Team reviews comments and prepares report with recommended actions
- Forward report and recommendations to Brent Wahlquist, Regional Director, WRCC
- Present results to the OSM's Management Council
- If rule changes recommended, proceed with informal and formal rulemaking effort

Where do we go from here?

The Revegetation Team is in the process of reviewing and consolidating all the comments. Based on its review of the comments, the team will prepare and forward a report that will recommend certain actions to Brent Wahlquist, the OSM Regional Director in Denver. This could include proposed rulemaking, policy development, etc. Following his assessment of the outreach effort, if a decision is made to go forward, we believe a presentation will be made to OSM's Management Council discussing the results and recommendations. The Management Council will then make the determination of how the Revegetation Team is to proceed. If rule changes are recommended, then the team will begin an informal, followed by a formal, rulemaking effort.

Building a Foundation for Diversity: Topdressing Variability for Distinct Plant Communities

Bruce Buchanan, Buchanan Consultants Ltd.,
Tim Ramsey, San Juan Coal Company,
and Douglas Romig, New Mexico Mining and Minerals Division

Introduction

In the mid-1960's, a reclamation decision was made at Navajo Mine to either save topsoil or use irrigation for the establishment of vegetation. Everyone knew that mine dirt was all the same and that water would make anything grow so, irrigation won. By the early 1970's, the need for topsoil became evident and so a few new terms were added to the mine's vocabulary: topdressing, stockpile, seedbed preparation, and mulch. Irrigation continued at BHP and is still used today at our Navajo and San Juan Mine operations.

The reclamation at the La Plata Mine (LPM) operation is all dry land. Our earliest experiences in mine land reclamation began in 1975. The objective was to protect the soil and produce cover and biomass. The only postmining land use (PMLU) was livestock grazing, and plant diversity was something we measured in inches and pounds.

As we have tried to better understand plant diversity we found, like everyone else, production and diversity are opposites. At Navajo and San Juan Mines pure stands of Alkali Sacaton are the most productive. (For descriptions of individual reclamation plant species, developed in 1994 by the New Mexico Mining and Minerals Division, see appendix C.) They were easy to establish with irrigation, especially on long smooth slopes with uniform applications of topdressing. Shrubs became established in areas where the topsoil was thin or the landscape was concave and water collected. The deep pockets of topsoil might produce stands of Indian Ricegrass or Galleta. But it was easier and generally less expensive to keep things uniform. If we had diversity, it was in the seed mix. Eight grasses, six forbs, two shrubs--and a partridge in a pear tree. At one time we even seeded by the pound: a pound of this with a pound of that. No wonder Alkali Sacaton was successful.

Over the years plant diversity, of sorts, was being created, mostly by doing things that would not be approved. Plant diversity was created especially by our mistakes. Today we see plant diversity associated with variation in some of the following:

- Topsoil depth
- Spoil quality
- Irrigation schedules-timing and amount
- Seed mix
- Seeding rate
- Time of seeding
- Genetic source of seed
- Slope grade and aspect
- Slope shape-convex vs. concave
- Use of amendments
- Application of direct haul topdressing

In 1991, LPM included a program to more carefully document the factors influencing diversity. Attention was directed to two factors; topsoil depth and spoil quality. The objective was to evaluate the effects of topsoil depth and spoil quality on plant response measured by cover, production and diversity. The hypothesis was that plant response would be different for different soil depths.

LPM is located 20 miles north of Farmington, New Mexico. The annual precipitation averages 12 inches (30 cm) per year at an elevation of 6,100 feet. The dominant native plant communities

are a mix of sagebrush grasslands and piñon and juniper forests. The landforms are steeply sloping cuestas dissected by deep valley fills. Soils are typically shallow with occasional deep alluvial fill. The overburden is composed of sandstone, siltstone, and claystone. The rock formation involved is the Kirtland shale.

Double Wedge Study: Study Design and Purpose

In 1991, a study to evaluate topdressing depth and spoil quality was designed by overlapping a topdressing wedge and a spoil wedge, the result being a double wedge plot, with the purpose of monitoring plant response to various combinations of topdressing depth and spoil quality. Previous studies have shown a significant interaction between topdressing depth, spoil quality and plant response. Generally, high plant productivity can be established with thin applications of topsoil if high spoil quality is used as root-zone material. In contrast, deep applications of topdressing are required when low spoil quality is used as the root zone material.

Construction of the plot was completed in August of 1993, and it was seeded September 25, 1993, with a native seed mixture (table 1). The plot is slightly over 2.0 acres in size (300 feet x 300 feet).

Table 1 — Native seed mixture used to seed the La Plata Mine double wedge on September 25, 1993

(Seed was applied at a rate of 17 lbs. pure live seed per acre)

Strata	Common Name	Scientific Name	Variety	Seeds/ft^2
Grasses	Alkali sacaton	Sporobolus aroides	Salado	5
	Blue grama	Bouteloua gracilis	Hachita	4
	Galleta	Hilaria jamesii	Viva	2
	Indian ricegrass	Oryzposis hymenoides	Paloma	4
	Sand dropseed	Sporobolus cryptandrus		2
	Sideoats grama	Bouteloua curtipendula	Niner	4
	Western wheatgrass	Agropyron smithii	Arriba	3
Forbs	Blue flax	Linum lewisii		2
	Coneflower	Ratibida columnaris		2
	Rocky Mtn. penstemon	Penstemon strictus		2
Shrubs	Antelope bitterbrush	Purshia tridentata		4
	Fourwing saltbush	Atriplex canescens		4
	Shadscale	Atriplex confertifolia		4
	Skunkbush sumac	Rhus trilobata		2
	Winterfat	Ceratoides lanata		4
			Total	48

Base spoil, root zone and topdressing samples were collected at 49 equally spaced sample points. Analysis included pH, electrical conductivity (EC), saturation percentage, calcium, magnesium, sodium, and textural class with percent sand, silt and clay.

Vegetation response was determined at 49 equally spaced sample points (same as soil sampling points). Density and cover were determined using four 0.25 m^2 quadrants placed 1 meter from the center of each sample point. Sampling was completed in late summer of 1994, 1995, 1996, and 1997. In August of 1997, the location of all shrubs and perennial forbs was recorded with a global positioning data recorder (GPS).

Study Results: Soils

		pH		EC		SAR	
	Texture	range	mean	range	mean	range	mean
Base spoil	L, SL	4.5-9	6.6	2.46-7.83	6.02	1.4-42	13.2
Root Zone	L	6.8-8	7.6	0.79-5.9	4.17	1.14-4.79	3.18
Topsoil	L, CL, SCL	7.6-8.2	8	0.58-3.22	1	2.08-6.82	4.43

Study Results: Vegetation

Regression analysis was used to develop relationships of the 1997 vegetation cover on density with topdressing depth and root zone thickness. Significant models were developed for five of the twenty-nine species recorded on the wedge plot.

1. Western wheatgrass: density and cover increased with increasing topdressing depth and cover increased with increasing root zone thickness.

2. Indian ricegrass: density and cover increased with increasing root zone thickness and changes were independent of topdressing depth.

3. Rubber rabbitbrush: density decreased with increasing topdressing depth and root zone thickness.

4. Kochia (annual): density and cover decreased with increasing depth of topdressing and root zone thickness.

5. Tumble mustard (annual): density and cover increased with increasing depth of topdressing and changes were independent of root zone thickness.

A frequency procedure was analyzed using chi-square analysis to evaluate the GPS data for shrub and perennial forb distribution. A total of eight shrub and eight perennial forb species were recorded on the wedge plot. Seven species (three shrubs and four forbs) occurred six or less times on the plot and were not in sufficient numbers to be included in the analysis. The following shrub and perennial forbs species were found to be significantly associated with the respective topdressing depth classes.

Species	Depth class (inches)
Winterfat	12-21
Shadscale	6-15
Snakeweed	6-15
Rubber rabbitbrush	3-9
Hoary aster	6-9
Blue flax	6-12
Prairie coneflower	6-12
Penstemon	6-15

Most shrub and perennial forb species were associated with intermediate topdressing depths ranging from 9 to 15 inches. Rabbitbrush preferred the shallow topdressing depth (less than 9 inches) while Winterfat preferred the deep topdressing depths (greater than 12 inches). The intermediate topdressing depths appear to favor greater species diversity. Fewer species were found at depths less than nine inches and at depths greater than fifteen inches than at the intermediate depths.

Reclamation Planning at La Plata

Last year, LPM relinquished their grazing leases on the permit area to comply with the Bureau of Land Management's (BLM's) plans to improve the winter range for deer in this part of New Mexico. The BLM also wanted to enhance upland gamebird populations in the area.

Several opportunities for landscape (gamma) diversity appeared with the change in land use. First, LPM is unique for a surface mine as a result of its complicated geology: steeply dipping coal requires that the pit remain open until all the coal has been removed. This has postponed the reclamation schedule and left the post-mining topography somewhat in question. The original surface topography was characterized by long rocky slopes with southerly aspects. Engineers at LPM are currently developing a new AOC from the drainages up and providing more north-facing slopes. Second, the change from grazing to wildlife PMLU meant that a production standard was no longer required for final bond release. This caveat in the rules allows for the creation of sites that are less productive but provide more opportunities for intra-community diversity. Moreover, as high production across the lease was no longer a goal, the winter habitat needs for deer on a landscape level could also be addressed.

With wildlife habitat now the target, the New Mexico Mining and Minerals Division (MMD) discussed with LPM the reestablishment of three to four distinct plant communities, including a mixed shrub community, sagebrush grassland, and upland grassland communities. The shrub communities would provide the cover and browse for deer. Out-slopes and foot-slopes of regraded spoil dumps were initially identified as potential sites for their establishment. Upland drainages and the flatter portions of hilltops were considered good candidates for the grassland communities. Other wildlife enhancement features have also been contemplated including talus slopes, rock outcrops, and small-area depressions. With help from BLM and New Mexico Game and Fish, a number of plant species were identified as important to meet the wildlife PMLU including wheatgrasses, Indian ricegrass, blue flax, globemallows, saltbushes, sagebrush, oak, and mountain mahogany. In particular, Indian ricegrass and Western wheatgrass were identified as late winter/early spring forage for deer. In addition to Indian ricegrass, blue flax was considered important for upland gamebirds.

It became apparent that the double wedge plot was an excellent resource to answer questions regarding how a diverse post-mining landscape might be created. Clearly certain species

preferred very distinct rooting materials while others appeared to be less discriminating. The double wedge experiment demonstrated that varying topdressing and root-zone depth provides an array of soil environments that quickly manifest themselves into distinct plant communities using a single seed mix. While Western wheatgrass is prevalent throughout the plot, it did exceptionally well in areas with deeper topdressing regardless of the root-zone depth. Indian ricegrass showed no preference for topsoil depth but increased with deeper root zone materials. Blue flax, on the other hand, did well only at intermediate soil depths. Rubber rabbitbrush and winterfat were successful in very divergent conditions, the former preferring shallow portions of the plot and the latter in deep soils and spoils.

It became apparent that the double wedge plot was an excellent resource to answer questions regarding how a diverse post-mining landscape might be created. Clearly certain species preferred very distinct rooting materials while others appeared to be less discriminating. The double wedge experiment demonstrated that varying topdressing and root-zone depth provides an array of soil environments that quickly manifest themselves into distinct plant communities using a single seed mix. While Western wheatgrass is prevalent throughout the plot, it did exceptionally well in areas with deeper topdressing regardless of the root-zone depth. Indian ricegrass showed no preference for topsoil depth but increased with deeper root zone materials. Blue flax, on the other hand, did well only at intermediate soil depths. Rubber rabbitbrush and winterfat were successful in very divergent conditions, the former preferring shallow portions of the plot and the latter in deep soils and spoils.

In conjunction with the double wedge, it was evident that the baseline soils and vegetation data in the permit had important information relating topography and soil depth to native plant communities. It also provided insight into what kind of diversity one could expect at this site given the edaphic and climatic regime. The premine toposequence at LPM illustrates the relationship between genetic soil (A & B horizons) depth and differing plant communities (fig. 1). Piñon-Juniper woodlands are associated with upland lithic soils, sagebrush-grasslands reside in the deeper soils of the alluvial fans and terraces, and sagebrush-greasewood shrublands occur along the deep alluvial drainages. Other soils, especially those on back- and shoulder slopes, are high in coarse fragments that typically armor the soil surface. Standard topsoil replacement methods will likely recreate post-mine soils that have six inches of topsoil over 42 inches of neutral spoil. Perhaps only a handful of species will prefer the reconstructed soils that are built. Furthermore, this reconstructed soil would likely resemble those associated with sagebrush-grasslands, with deep effective root zones and shallow genetic soil materials (figs. 2 and 3). Certainly expectations for greater diversity beyond the inherent richness of the sagebrush-grassland and the reclamation seed mix would be inflated. Incorporating the insights gained from the double wedge and the pre-mine surveys, an idealized final landscape that provides more horizontal diversity can be envisioned (fig. 4). Topsoil depth is only one variable LPM might employ to increase diversity; other qualities that could be manipulated include slope, aspect, soil texture, soil chemistry, fertility, etc.

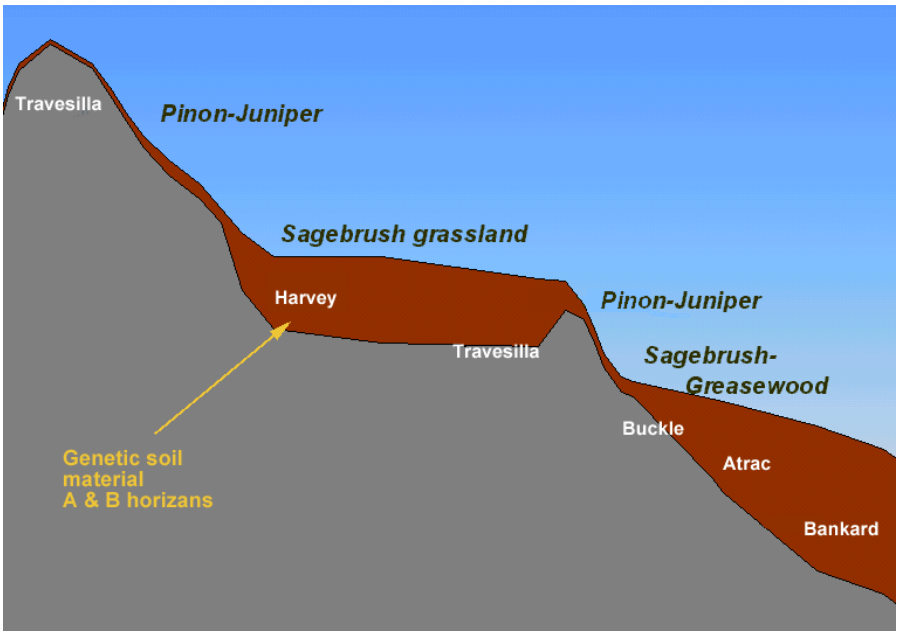


Figure 1— Pre-mine cross section showing soil depths and associated plant communities.

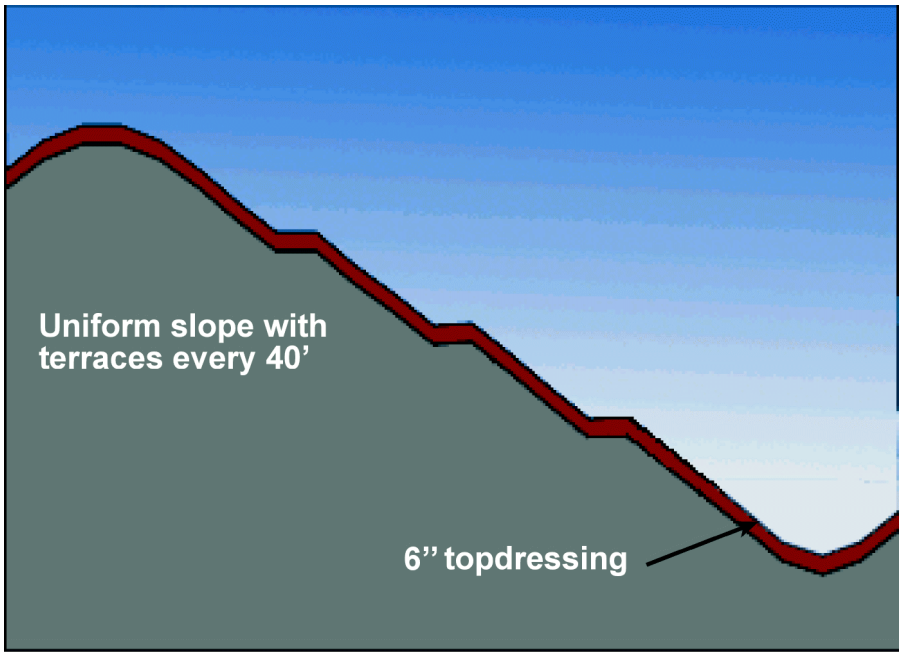


Figure 2 — Approved postmining topography with uniform slopes, soil texture and soil depth.

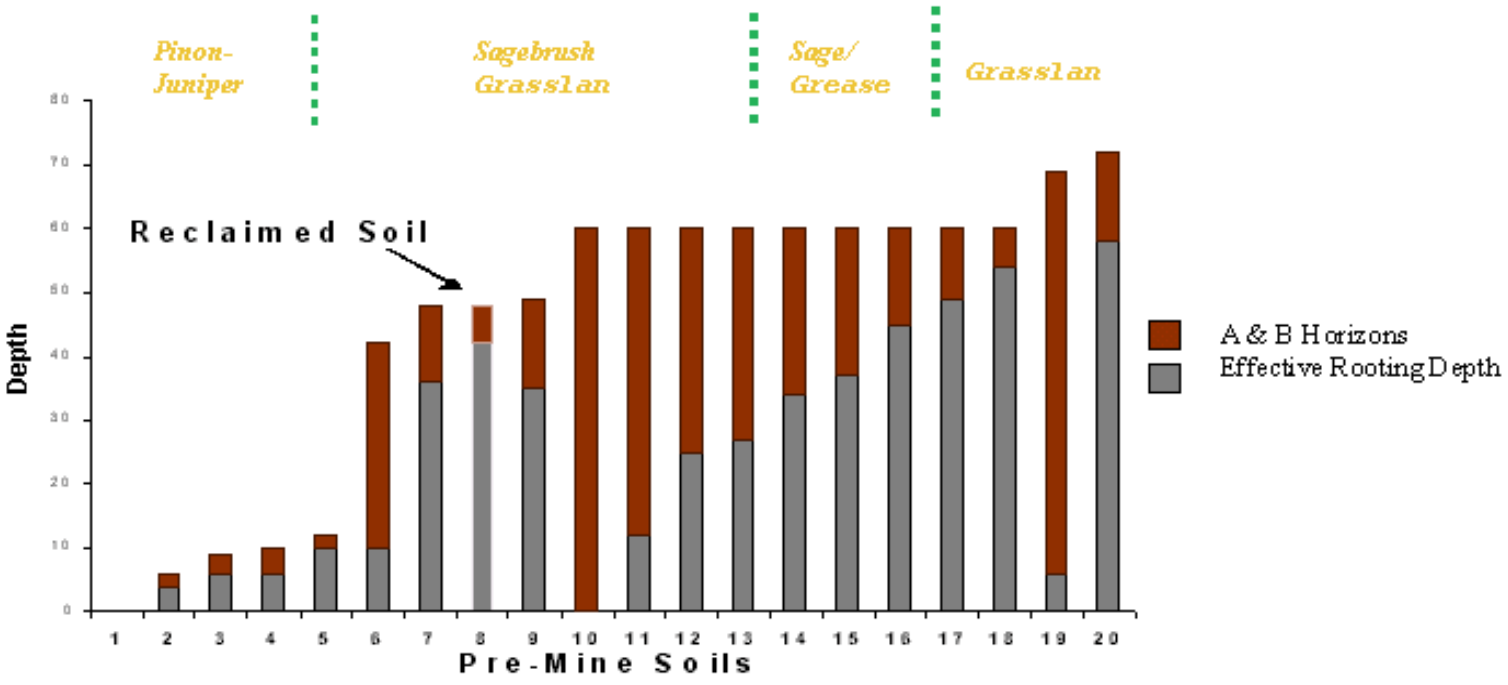


Figure 3— Premine soil depths and associated plant communities.
Reclaimed soil will likely support a sagebrush grassland.

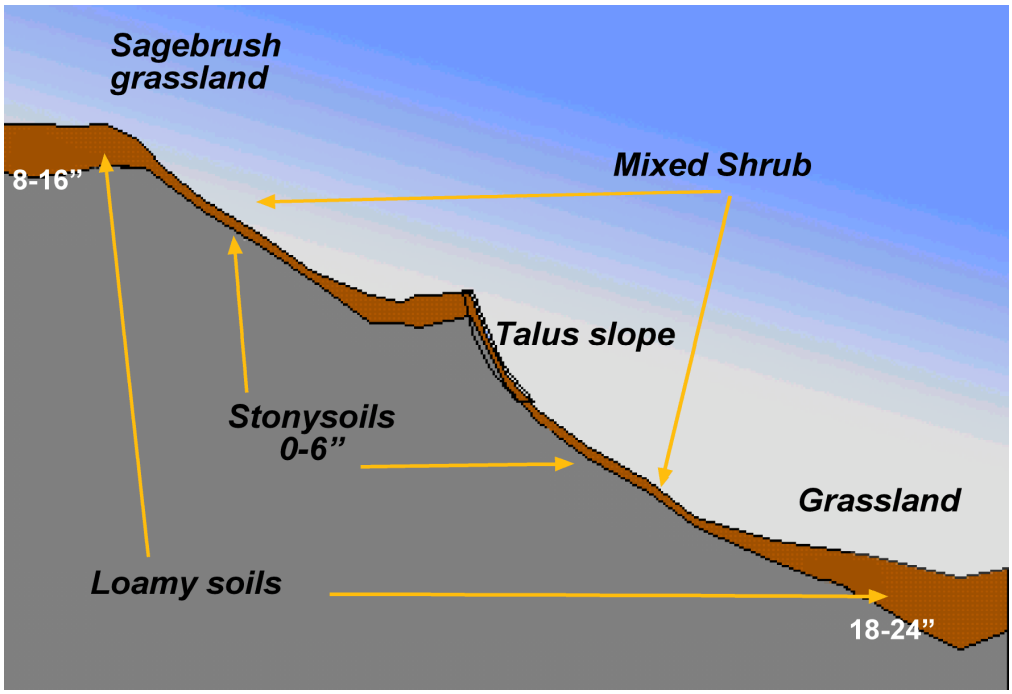


Figure 4 — Idealized postmining topography.

From a regulatory perspective, uniformity is easy to inspect and enforce. With the creation of diverse reclamation, operational and final bond-release standards become more complex. New standards for root-zone reconstruction and topsoil replacement must be practical and allow for flexibility on the ground. Provisions should be made to allow the use of suitable materials instead of topsoil so that a specific root zone for selected species or communities. The largest single hindrance to landscape diversity, however, exists in the rule that requires topdressing to "be redistributed in a manner that achieves an approximate uniform, stable thick consistent with the approved post-mining land use * * *." Fortunately, a wildlife PMLU (in this case) allows for variable topdressing depths because landscape diversity is needed. The use of soil depth to achieve horizontal diversity remains in question for other post-mining land uses. It is ironic that the language for topsoil replacement requires "uniform" redistribution, the complete antithesis of diversity. The term "uniform" is used sparingly in the New Mexico regulations, and, when it is used, it discourages uniformity except for topdressing replacement.

Landscape diversity raises more questions than answers regarding revegetation standards. Should diversity continue to be solely measured at the intra-community (alpha) level? How should landscape diversity be credited or should there be a stand alone standard? Will the different topsoil depths produce discreet plant communities that may require separate cover and diversity standards? Will cover and shrub data need to be stratified with respect to these communities to reduce variance and test against performance to standards?

This type of reclamation also presents challenges to the operator. Building a postmining topography is never easy, and given the variety of landforms one might want to recreate only complicates the issue. Reclamation in the field will require additional supervision of topdressing laydown and the use of multiple seed mixes. Finally, the economic constraints of building a variable landscape ultimately will dictate what is possible.

The perceived need for greater postmine diversity has focused on developing standards and measurement techniques without fully examining what guides reclamation toward uniformity. Early efforts in New Mexico focused on developing appropriate seed mixes that contained as many adapted species that were available. While these mixes were tied to a particular region, they were not tuned to the soils. After drilling the seed, it was then left to chance which species succeeded. Since then, seed mixes have been tweaked and expanded, but it is still largely remains a shotgun approach to achieving diversity. Experience also tells us that standard topsoil replacement methods and suitability criteria homogenize reclaimed soils and generally favor grass establishment to the detriment of plant diversity. Through this lengthy experiment we have identified a number of very successful species that thrive in reclaimed soils and achieved a nominal amount of diversity. The double wedge experiment demonstrates that in the very short time from seeding we can easily increase diversity with different combinations of spoil and soil depths.

Wyoming's Approach to Species Diversity

Richard A. Chancellor, Administrator
Wyoming Department of Environmental Quality,
Land Quality Division

Species diversity is one of those issues that is out there but that one never has time to address, so it is put off until tomorrow. Well, tomorrow has come. Several mines have initiated bond release and other mines are watching to determine if it is worthwhile to go through the process. For the past 2 years, Wyoming Department of Environmental Quality's (DEQ's) Land Quality Division (LQD) has put forth several ideas on how to consistently evaluate reclamation success for species diversity. Some of you may have read, or are aware of, the paper presented by Rich Vincent at the 1998 National Meeting of the American Society for Surface Mining and Reclamation entitled "*Measurement of Quantitative Species Diversity on Reclaimed Coal Mine Lands: A Brief Overview of the Wyoming Regulatory Proposal.*" This was an effort to devise a method that could be applied consistently to a variety of mines.

Attachment 1 to this presentation (immediately following its text) consists of several of the tables from Mr. Vincent's paper. While the proposed method does accomplish what we set out to do, there were concerns. As table 4 of attachment 1 shows, there are numerous categories that must be met to achieve bond release. The more complex a system is and/or the larger number of categories that must be satisfied, the more chance there is for failure.

As OSM has recognized as part of its outreach on bond release, cover and production have been the driving force in vegetation bond release while diversity has been relegated to second-class status. The regulations contain specific measurable standards that address cover and production. The mines in Wyoming have demonstrated that these criteria can be easily satisfied. In almost all cases, lands that have been mined and reclaimed have higher cover and production values following reclamation than they did before mining. This is primarily achieved with the use of wheatgrasses. The downside is these cool season grasses prevent the establishment of warm season grasses and forbs, the two life forms we are most concerned about. Shrubs are addressed separately in the Wyoming LQD rules and regulations that were adopted in the early 1990's.

To understand the issues involved, the meaning of various terms and actual requirements of the regulations must be understood. LQD's rules and regulations (LQD Coal R&R's) contain the following definitions:

> "Approximate original contour" is that surface configuration achieved by backfilling and grading of the mined areas so that the reclaimed land surface closely resembles the general surface configuration of the land prior to mining and blends into and complements the drainage pattern of the surrounding terrain (LQD Coal R&R's, Chapter 1, Section 2(h)).

"Cool-season plant" is a plant species that grows and flowers during the spring. Its growth usually slows or becomes dormant during the hotter, drier portions of the summer, but the species may resume growth in the fall with the advent of cooler temperatures and available soil moisture (LQD Coal R&R's, Appendix A, page A-58).

"Full shrub (full woody shrub)" is a perennial woody plant which differs from a tree by normally being shorter in height and by often having several stems arising near the base (LQD Coal R&R's, Appendix A, page A-58).

"Life form (life-form category)" is a category of (plant) growth morphology which appears to have some adaptive significance. Examples of life forms include trees, full shrubs, sub-shrubs, perennial grasses, annual forbs, succulents, cushion plants, and so forth. (LQD Coal R&R's, Appendix A, page A-58).

"Land use (land-use category)" refers to the specific uses or management-related activities which a given unit of land experiences. Land use is directly supported by, but not directly defined by, the existing plant communities. See definitions of cropland, pastureland, grazingland, forestry, or appropriate discussion in LQD Coal R&R's, Chapter 1, under "land use" (LQD Coal R&R's, Appendix A).

Chapter 1, Section 2 (bc) of the LQD Coal R&R states that:

"Land use" means, "for surface coal mining operations, specific uses or management-related activities, rather than the vegetation or cover of the land. Land uses may be identified in combination when joint or seasonal uses occur * * *."

"Cropland" means "land used for the production of adapted crops for harvest, alone or in a rotation with grasses and legumes, and includes row crops, small grain crops, hay crops, nursery crops, orchard crops, and other similar specialty crops."

"Pastureland" is "land used primarily for the long-term production of adapted, domesticated forage plants to be grazed by livestock or occasionally cut and cured for livestock feed."

"Grazingland" includes "rangelands and forest lands where the indigenous native vegetation is actively managed for grazing, browsing, and occasional hay production, and occasional use by wildlife."

"Fish and wildlife habitat" means "land dedicated wholly or partially to the production, protection or management of species of fish or wildlife."

(Sections 35-11-103 (xxvi) and (xxvii) of the Wyoming Environmental Quality Act W.S. contain the same definitions of grazingland and fish and wildlife habitat.)

The Wyoming Environmental Quality Act 35-11-103(e)(i) states that "reclamation" means "the process of reclaiming an area of land affected by mining to use for grazing, agricultural, recreational, wildlife purposes, or any other purpose of equal or greater value. The process may require contouring, terracing, grading, resoiling, revegetation, compaction and stabilization, settling ponds, water impoundments, diversion ditches, and other water treatment facilities in order to eliminate water diminution to the extent that existing water resources are adversely affected, pollution, soil and wind erosion, or flooding resulting from mining or any other activity to accomplish the reclamation of the land affected to a useful purpose." The LQD Coal R&R further states that:

> "Major species" is a plant species having "a [percent] relative cover value equaling or exceeding two (2) percent" (LQD Coal R&R Appendix A, page A-28).
>
> "Relative cover" is "the expression of any number of cover categories e.g. vegetation + litter/rock + bare ground) in relation to each other, such that the sum of the relative cover values for those categories totals 100 [percent]" (LQD Coal R&R Appendix A, page A-60).
>
> "Shrub mosaic" is "a pattern of shrub patches designed to achieve maximum habitat interspersion and edge effect. The boundary of a mosaic encompasses the areal extent of shrub patches and other vegetation types occupying the area between the patches" (LQD Coal R&R Appendix A, page A-60).
>
> "Shrub patch" refers to "a continuous surface of varying shape and size (no less than 0.05 acres) that is intensively managed to support a high density of shrubs" (LQD Coal R&R Appendix A, page A-60).
>
> "Species composition" means "number, kinds, amount and quality of species" (LQD Coal R&R Appendix A, page A-60).
>
> "Species diversity" means "number of species per unit area" (LQD Coal R&R Appendix A, page A-60).
>
> "Subshrub" is "a perennial plant which is partly woody, usually at the base, but also partly herbaceous. The individual plant generally dies back to the woody tissue after each year's growth" (LQD Coal R&R Appendix A, page A-60).
>
> "Vegetation type" means "a recognizable group of species growing together due to similar requirement and tolerances" (LQD Coal R&R Chapter 1, Section 2[dg]). (Note that appendix A [page A-59] states that "plant community (vegetation type)" is "a relatively homogeneous combination of individual plants existing under common environmental conditions.")

"Warm-season plant" is "a species which produces most or all of its growth during the late spring and summer, subsequently flowering in the late summer or autumn" (LQD Coal R&R Appendix A, page A-61).

In addition, Barbour and others (1980) state that:

"Physiognomy" describes and includes "the external appearance of vegetation, its vertical structure and the life forms of its dominant taxa."

"Succession (plant community succession)" is "a directional, cumulative change, through time, in the plant species which occupy a given area. Seasonal changes in the dominance of plant species due to differences in growth, reproduction and senescence are not considered successional processes."

It is important to note that:

1. The regulations require reclamation and not restoration:

   - It is impractical if not impossible to have the postmine plant communities biologically or ecologically mimic the premine plant communities.

   - At best, the AOC requirements of the regulations result in topography that only approximately resembles the premining contours.

   - The Powder River Basin coal mines are predominately classified as "thin overburden mines" and do not have to achieve AOC.

2. Plant communities, to some extent, are tied to the topography.

3. After consideration of the premining ecology, we (operators and the regulatory authority) **design** postmine topography and **design** postmine plant communities that are purposely different than the premine conditions.

Historically, we have been concerned with *alpha* diversity. The diversity within a plant community (intracommunity). While *alpha* diversity is an import consideration, field observations indicate that large *alpha* diversity has been difficult to achieve. To achieve diversity, we should look more at *beta* diversity (intercommunity). The diversity across the landscape. This approach could ultimately result in a mine permit area consisting of plant communities devoted solely to the production of cool-season perennial grasses, with more diverse communities consisting of warm-season perennial grasses, perennial forbs, shrubs or subshrubs intermingling with the larger expanses of cool-season grasses.

Generally, there are three basic plant communities on the reclaimed landscape: bottomland, upland, and shrubland. Many times the seed mixes for these different communities are very

similar. In order to better achieve maximum beta diversity, the basic seed mixtures intended to establish very different communities will need to be appropriately diversified. Such a change in seed mixture development would produce communities that could more accurately be called and evaluated as cool season perennial grass upland communities, warm-season perennial grass/perennial forb upland communities, shrub/subshrub/perennial forb upland communities, cool-season perennial grass bottomland communities, perennial forb/warm-season grass/full and subshrub bottomland communities, etc.

With one exception, the bond release standard for diversity and composition is not numerically defined in the Wyoming coal permits. Most permits only address the methodology for determining bond release. This results in a "moving" or unknown target, and operators do not know in advance what "numbers" they have to meet to achieve bond release with respect to species diversity. We have proposed a success standard that will numerically define species diversity requirements and can be incorporated into the permits.

In addition, most mine permit reclamation methods assume and require a certain amount of invasion of species to achieve the diversity standard dictated by the permit. There is also the philosophical issue of having bond release depend upon invasion of species that were not part of the approved seed mix. I believe the operators should be responsible only for what is in the permit, however I also realize that natural invasion of nonseeded species is an indicator of successional processes at work and these species can't be totally ignored.

There is a regulatory basis for developing such a success standard for species diversity and species composition. Chapter 4, Section 2.(d)(x) of the LQD Coal R&R states that "[t]he Administrator shall not release the entire bond of any operator until such time as revegetation is completed, if revegetation is the method of reclamation as specified in the operator's approved reclamation plan. Revegetation shall be deemed to be complete when * * * (3) **the species diversity and composition are suitable for the approved postmining land use** [and] (4) the requirements in * * * (3) are met for the last two consecutive years of the bonding period. The Administrator shall specify quantitative methods and procedures for determining whether equal cover and productivity has been established including, where applicable, **procedures for evaluating postmining species diversity and composition.** The following options or an **alternative success standard approved by the Administrator are available"** (emphasis added)."

The "options" here pertain to the land units commonly used on Wyoming coal mines for bond release comparison purposes. These consist of control areas, reference areas, or comparison areas. We have concluded that methods which use such established native, undisturbed land units to establish postmining species diversity and species composition performance standards and evaluation procedures will not directly nor effectively address the intent of Chapter 4, Section 2.(d)(x). Therefore, established control areas, reference areas, or comparison areas will not serve as the standard when evaluating postmining species diversity and composition on lands intended for grazingland/fish and wildlife habitat or pastureland use.

The LQD is proposing that a success standard regarding species diversity will only be necessary for vegetation communities designed to be used as grazingland/fish and wildlife habitat or pastureland. Other land uses for which specific plant communities will be established to support include shrub patches, wetlands and croplands. However, each of these postmining communities already possesses a predetermined standard for species diversity based on the following respective criteria: LQD approved shrub density options (LQD Coal R&R, Chapter 4, Section 2(d)(x)(E)), U.S. Army Corps of Engineers 1987 Wetlands Delineation Manual, and the plant species used in premining croplands.

Thus, this paper outlines our proposal for a Species Diversity Success Standard and its evaluation. The goal in developing these standards is to be consistent, simple, and numerically defined in the permit. This preferred Success Standard and evaluation procedures are firmly rooted in concepts and requirements outlined in Appendix A of the LQD Coal R&R. The LQD emphasizes that one major purpose of reclamation is the creation of postmining topography which supports a variety of land uses (see the definition of "Reclamation" in W.S. § 35-11-404(e)(i)). The topographic diversity in turn should support a number of postmining plant community types. Each postmining plant community type should:

- be diverse and permanent (self-renewing);
- be composed predominately of native species which have documented value (quality) to support the postmining land uses;
- contain introduced, naturalized or non-indigenous plant species only if their suitability to support the approved postmining land use(s) is documented (see LQD Coal R&R, Chapter 4, Section 2.(d)(vi));
- be composed of species of the same seasonal variety (cool-season and warm-season) as those documented in baseline vegetation studies; and
- be composed of most of the life form categories which were documented in baseline vegetation studies.

As mentioned earlier, we acknowledge that the postmining plant communities cannot biologically or ecologically mimic nor do LQD Coal R&R require exact replacement of premining plant communities. We hold that all the available premining qualitative and quantitative baseline vegetation data should be used to design postmining plant communities which have intracommunity and intercommunity diversity, which exhibit the ability to undergo succession and which have a distinct possibility of supporting the defined postmining land use(s).

The Reclamation Plan should contain a specific seed mix (and when appropriate, a transplant mix) for each desired postmining community. The LQD holds that several postmining plant communities are appropriate for most surface coal mines due to each mine's areal extent and the number and variety of premining plant communities. Postmining intercommunity and intracommunity diversity should be supported and enhanced by:

- Designing diverse landforms and features into the approved postmining topography. Landforms and features include aspect, slope/grade variation, rock piles, replacement rimrock or bluffs, roughened surfaces, vertical (spatial) diversity and diversity in hydrologic features. The concept/requirement of "approximate original contour" does impose some limitations (see LQD Coal Standard Operating Procedure No. 3.1).

- Selecting postmining topographic locations which best support each postmining plant community.

- Including as much diversity in each original seed (and transplant mix) as warranted by considering the number and type of premining plant communities, premining community compositions, regional seed availability, documented value (quality) of species and desired biological characteristics (e.g. nitrogen fixation) to support the postmining land uses.

- Seeking more variety between seed mixes, each of whose composition is determined more by the number of seeds planted (per species and total) per unit area rather than being determined by pounds pure live seed per unit area. This consideration could lower the contribution of more aggressive, more easily established cool-season grasses and certain wheatgrass species when dominance by these species is not desirable.

- Ensuring that the best available seeding technology is used in planting each postmining community. This includes consideration of seeding dates, selective seeding of warm-season species, selective seeding of shrub species, minimization of competition within and between communities, advantageous use of landforms and features, and known mine-site-specific considerations.

- Strongly encouraging selective salvage of topsoil and subsoil (as defined in LQD Coal R&R) and direct redistribution of live topsoil whenever possible.

- Selectively considering and approving variable topsoil/subsoil redistribution depths for specific reclamation purposes.

- Selectively considering and approving seed mixes and planting methods which create patches, strips or swaths with specific species and/or life forms (e.g. warm- season grasses, forbs) which are crucial to attaining the postmining species diversity and composition standards.

- Considering desired and useful community structure (physiognomy).

Species composition

The definition of Species Composition in Chapter 1 of the LQD Coal R&R contains several different elements, namely, number and amount of species, kinds of species, and quality of species.

This paper will outline preferred procedures for establishing a Success Standard for each element (individually or in conjunction with other elements) of the definition. As much as possible, each Success Standard will be framed on the basis of each approved postmining community type within the context of the defined land use categories which those community types support.

Number and amount of species

The LQD prefers to evaluate these quantitative elements by establishing a Success Standard incorporating the following characteristics for each postmining community type:

- a specified number of life form categories,
- a specified number of species in each life form category,
- a minimum percentage relative cover value in each life form category, and
- the number of postmine life form categories and the postmine number of species within each life form category will be established by:
    - considering the number of life form categories identified in the baseline inventory for premining plant community types which had similar ecological and biological characteristics and similar environmental characteristics (e.g.., slope, aspect, topographic regime) as the particular postmining plant community type that is planned for "replacing" the premining type.
    - considering the number of plant species identified in the baseline inventory which equal or exceed 2% relative cover, i.e. each major species. These major species should be included in the postmining seed mixes and in this species composition Success Standard, as long as these major species are available from regional commercial seed suppliers.
    - carefully considering the postmining land use(s) which the particular postmining plant community type intends to support.
    - carefully considering the species in each life form category (both major and non major) which have demonstrated value in support of the postmining land use(s).

- carefully considering the species in each life form category which are normally available from regional commercial seed suppliers. The species seeded should have sound potential for persistence and be self-renewing under the prevailing environmental conditions.

Kinds of species

This element of the species composition definition will be addressed during construction of the seed mix for each postmining community and in the derivation of Table 1 presented below.

The approved Reclamation Plan should document that the procedures used to develop and support the "number and amount of species" within the Success Standard included consideration of the "kinds of species."

There will be no independent Success Standard nor independent evaluation of the "kinds of species" criterion. This element will be integrated into the development of the seed mixtures to be applied and the numbers provided in the LQD approved Success Standard Table.

Quality of species

This element within the definition of species composition will be addressed during construction of the seed mix for each postmining community and in the derivation of Table 1 of this proposal. Quality will be addressed by identifying and including those species which have documented value in supporting the postmining land uses and were present in the premining community, including:

- the ability to provide quality forage for domestic grazing animals and wildlife species,
- the ability to provide quality browse for wildlife species, and
- the ability to contribute structural qualities to wildlife habitat.

The LQD suggests that the following sources may/should be used to verify that all major species and the majority of species in each seed mix have documented quality and value. The permittee may add other species (or life forms) which contribute to the "quality of species:"

- range site classification and supporting information from the NRCS;
- range analysis handbook from the USFS;
- available publications from the Wyoming Game and Fish Department; or
- other selective publications.

A specific section of the approved Reclamation Plan should explain how the permittee incorporated these "quality of species" considerations into the approved seed mixes and into the construction of Table 1 presented below. At the time of bond release it will be necessary for the permittee to describe how the species that have established in the postmining community meet the intended "quality of species" considerations set forth during the development of the seed mixture and construction of Table 1 presented below.

Table 1 — Postmining species composition quantitative alternative success standard for the postmining plant community type intended to support pastureland (if defined) or grazingland/fish and wildlife habitat land uses

(NOTE: Individual forb species seldom attain major species status in baseline data. The presence and contribution of forb life forms are important to the evaluation of species composition. The postmining standard will consist only of a minimum percentage relative cover per life form category.)

COLUMN 1 Life Form Category	COLUMN 2 Number of Species Within Life Form Category With a % Relative Cover >2% (Major Species)	COLUMN 3 Minimum % Relative Cover Per Life Form Category
1. cool-season perennial grass		
2. warm-season perennial grass		
3. perennial forb	SEE NOTE BELOW	
4. annual and biennial forb	SEE NOTE BELOW	
5. subshrub		
6. full woody shrub		
7. other		

Species diversity

The LQD Coal R&R definition of "species diversity" implies a density measurement. This definition is straightforward, but no other citations provide direction on the measurement or evaluation of this criterion.

The LQD has never required nor suggested that any species density data be collected during baseline vegetation studies. In most cases, useful measurements of species diversity defined as a density function cannot be extracted from existing baseline data sets.

Historically, the LQD has suggested that some diversity index or similarity index might be used to evaluate the species diversity criterion. Most parties now agree that the use of any index is impractical. Vincent (1998) and Tierney and Wade (1998) chronicle other historical approaches to the evaluation of postmining species diversity and the pitfalls or flaws of some of those approaches. This proposed Success Standard and procedures for evaluation of species diversity does not advocate the use of any species diversity index. Instead, the procedures used to evaluate species composition will also address the concept of species diversity.

The LQD proposes that this Alternative Success Standard be summarized in a specific table in the Reclamation Plan. Table 1 is a suggested format for one table per postmining plant community type.

What must be considered when developing this table?

The permittee and LQD staff are encouraged to use the following considerations when developing the summary table for each postmining plant community. In all cases, the permit text should fully explain reasons for the table's content.

Column 1 –The performance standard for restoring the seasonal variety must be included in this consideration, as well as, the life forms that were present premine and those that will support the intended composition of the postmining community.

Column 2 –The "Number of Species * * * Major Species" column should contain a single number for each life form category. The number entered should be calculated from the number of premining major species which are included in the approved seed mix plus other approved seed mix species which are expected to achieve the status of a major species in the postmining community.

Column 3 –The minimum percentage relative cover per life form category will be established by summing the percentage relative cover values for all premining major species which are included in the community-specific seed mix. Add to this initial sum the increment of percentage relative cover which is expected from other species in the approved seed mix. This second increment is a professional judgement based upon the known and desired responses of other species in the approved seed mix. The professional judgement should be based upon premining information on those species, available interim vegetation monitoring data and available literature on species growth and persistence.

How will species diversity success be evaluated?

Column 1 –The operator would consolidate and tabulate data on the presence of postmining life form categories as generated from the cover sampling regime. The evaluation will be used to assess whether the total number of life form categories presented in Table 1 for a particular plant community are present. If all prescribed life forms are present and no others were encountered during quantitative sampling, the LQD would approve this portion of the Table.

However, if additional life forms are encountered during sampling that were not prescribed in the Table, whether this is or is not satisfactory will require review by the LQD. An example of this is where there were not to be any annual grass species present, but they are encountered in sampling. Is the presence of this life form acceptable for bond release?

Column 2 –The operator would calculate percentage relative cover on a per species basis during the cover sampling program and show that the minimum number of species with a relative cover > 2 percent was achieved. Certain undesirable species which would be excluded from the tabulation of numbers of major species in respective life form categories. The permittee may present the number of undesirable species and their relative cover values, but not receive credit for them. The LQD's evaluation would conclude yes or no for each postmining plant community depending on whether or not the minimum number of major species was established for each life form category.

Column 3 –The permittee would tabulate percentage relative cover in each life form category for all sampled species except those considered undesirable by the LQD. The LQD's evaluation would conclude yes or no for each postmining plant community depending on whether or not the minimum percentage relative cover value was established for each life form category.

This proposal was presented to the operators at several meetings this year. To get a better understanding of the proposal, two operators followed the proposal and developed a table for several of their post mine vegetation communities and compared the values to the vegetation monitoring information. Attachment 2 is a summary of the data and standards developed for one of the mines. One mine's revegetation monitoring data indicates they are moving toward meeting the diversity standard they developed. The other mine's data indicates that they may not meet the diversity standard. This exercise identified several problems or concerns.

A major problem is how to determine the values to apply to Columns 2 and 3 of the Success Standard Table. These values will be negotiated between the operator and the regulatory authority and will be assessed based on the premining vegetation communities, the designated postmining land uses, and what is technically feasible. Different operators may be able to negotiate a better "deal" than another operator. One of our goals was to improve consistency in evaluating species diversity. This proposal does not satisfy that goal because of the subjectivity that is still inherent in developing the values in Columns 2 and 3.

The operators have expressed two concerns. One is the requirement of only considering major species in the postmine communities. The LQD also acknowledges that this tabular approach does not take into account the rare or infrequently encountered species (seeded and naturally invading) within a reclaimed community that do not appear in quantitative sampling, but are important to the health of the community and are a barometer of successional processes. The other concern is what the impact of reducing the cool-season components, to avoid competition with warm-season and perennial forb species, will have on the cover and production bond release

criteria. More thought needs to be given to this proposal with regards to both of these concerns. It is important to note that the data presented in attachment 2 represent reclamation that was not specifically designed under this proposal. Reclamation designed under this proposal and utilizing *beta* diversity may have different results.

We have challenged the operators to develop a proposal that will meet our goals and address their concerns. They have accepted the challenge and will present a proposal later this year.

ATTACHMENT 1

Table 2 — Number of major species (>2 percent relative cover) by life form from 1988 baseline data

PREMINE VEGETATION TYPES						
LIFE FORM	Grassland	Big Sagebrush	Silver Sagebrush	Rough Breaks	Riparian Bottomland	Tame Pasture
Cool -season Grass	3	5	4	3	3	4
Warm-season Grass	3	1	0	2	2	0
Grass-likes	2	1	1	1	6	0
Perennial Forbs	0	0	0	2	1	0
SubShrubs	1	0	0	1	0	0
Shrubs	0	1	1	2	0	0

Table 3 — Percentage relative cover by life form from 1988 baseline data

PREMINE VEGETATION TYPES						
LIFE FORM	Grassland	Big Sagebrush	Silver Sagebrush	Rough Breaks	Riparian Bottomland	Tame Pasture
Cool-season Grass	47.3%	28.8%	20.2%	36.2%	27.0%	91.6%
Warm-season Grass	20.2%	3.5%	3.4%	15.6%	15.0%	2.1%
Grass-likes	13.0%	4.0%	24.4%	2.8%	49.6%	0%
Perennial Forbs	8.4%	4.3%	2.7%	15.6%	7.8%	2.1%
SubShrubs	6.9%	1.6%	0.7%	15.6%	T	2.9%
Shrubs	1.9%	55.3%	46.2%	13.9%	T	0.4%
Annual Forbs/Grass	1.9%	2.1%	2.2%	0.4%	0.5%	0.5%

Table 4 — Evaluation criteria for assessing species composition and diversity in revegetated areas

REVEGETATION TYPE												
LIFE FORM	Upland Grassland		Shrub Grassland		Tame Pasture		Streamside Bottomland		Mesic Bottomland		Closed Basin Bottomland	
	RC[1]	S[2]	RC	S	RC	S	RC	S	RC	S[3]	RC	S
Cool-season Grass	45-75	4	30-70	3	60-95	2	30-70	4	30-60	4	55-85	3
Warm-season Grass	10-30	1	2-15	0-1	0-5	0	2-20	1	10-50	1	2-20	1
Perennial Forbs	5-30	1	2-25	1	5-50	1	5-30	1	10-40	2	5-30	1
Annual Forbs/Grass	0-20	0	0-20	0	0-20	0	0-20	0	0-20	0	0-20	0
SubShrubs	1-15	0	0-10	0	0-5	0	0-10	0	0-10	0	2-25	1
Shrubs	2-20	0	5-60	1	0-5	0	0-20	0	0-20	0	0-20	0

[1]RC Relative cover.
[2] S Minimum number of species with ≥ 1 percent absolute cover.
[3] Developed from data collected in 1980 within the permit area.

Attachment 2

Comparison of Baseline (Breaks) to Postmining Shrub Grassland Reclamation

	NA/RC Complex Baseline Upland Grassland		Rochelle - Shrub-Grass Seed Mixture		Reclamation Area R9103 (Shrub-Grassland)			
					1995		1998	
	% Veg. Cover	% Rel. Cover	# / Acre PLS	% of Mixture	% Cover	% Rel. Cover	% Cover	% Rel. Cover
Agropyron cristatum	0.4						3.3	5.7
Agropyron dasystachyum	2.9	6.0	2.0	13%	0.8	1.2		
Agropyron smithii	3.4	6.8	1.0	6%	6.8	10.1	9.3	17.2
Agropyron spicatum	2.4	4.8						
Agropyron spicatum Inermi								
Agropyron trachycaulum							5.3	9.2
Carex filifolia	3.0	6.3					0.7	1.1
Koeleria macrantha	1.7	3.4			1.6	2.4	2.0	3.4
Oryzopsis hymenoides							0.7	1.1
Poa sandbergii			1.0	6%				
Stipa comata	1.2	2.5					2.7	4.6
Stipa viridula	0.7		1.0	6%	10.8	16.1	25.3	43.7
Bouteloua curtipendula							0.7	1.1
Bouteloua gracilis	3.8	7.8	1.0	6%	1.2	1.8	0.7	1.1
Calamovilfa longifolia	1.4	2.9	1.0	6%				
Schizachyrium scoparium			1.0	6%				
Spartina pectinata	0.1	8.1						
Bromus japonicu	1.9	4.4			12.4	19.0	0.7	1.1
Bromus tectorum	1.2	2.4			2.4	3.6		
Festuca octoflora								
Annual - Biennial Forbs	2.2	4.5			19.6	31.0	0.7	1.1
Linum lewisii			1.0	6%				
Hedysarum boreale			1.0	6%				
Onobrychis viciaefolia					1.6	2.4		
Penstemon strictus			0.5	3%				
Phlox hoodii	1.5	2.9						
Ratibida columnifera					0.4	06		
Sphaeralcea coccinea			0.5	3%			0.7	1.1
Vicia americana	0.1							
Arenaria hookeri	1.0	2.1						
Other Perennial Forbs	5.9	12.2			2.0	3.0		
Atriplex canescens	0.1		1.0	6%				
Gutierrezia sarothrae	1.7	3.4						
Artemisia cana					1.6	2.6	2.7	4.6
Artemisia frigida					0.4	0.6	0.7	1.1
Artemisia tridentata	4.1	8.5	1.5	10%	1.2	2.4		
Ceratoides iananta			1.0	6%	1.2	2.4	0.7	1.1
Chrysothamnus nauseousus	1.5	3.0	1.0	6%				
Column Total	42.2	92.0	15.5	100%	64.0	99.2	56.9	98.3

Comparison of Baseline (Upland Grassland) to Postmining Grassland Reclamation

	NA/RC Complex Baseline Upland Grassland		Rochelle - Grassland Seed Mixture		Reclamation Area R9101 (Grassland)			
					1995		1998	
	% Veg. Cover	% Rel. Cover	# / Acre PLS	% of Mixture	% Cover	% Rel. Cover	% Cover	% Rel. Cover
Agropyron cristatum	2.0	3.1			0.2	0.3	0.4	0.9
Agropyron dasystachyum	3.0	4.6			2.2	3.1	0.8	1.9
Agropyron smithii	3.8	6.0	3.0	23%	15.6	22.1	7.6	17.9
Agropyron spicatum	1.2	1.9						
Agropyron spicatum Inermi			3.0	23%	9.2	12.8	2.4	5.7
Agropyron trachycaulum					1.0	1.4	2.8	6.6
Carex filifolia	3.8	6.0						
Koeleria macrantha	1.4	2.2	0.5	4%	3.0	4.2	0.8	1.9
Oryzopsis hymenoides								
Poa canbyi	0.5	0.8	1.0	8%				
Stipa comata	4.7	7.5			1.4	2.0	0.8	1.9
Stipa viridula			1.0	8%	12.6	17.6	18.4	43.4
Bouteloua curtipendula	0.1	0.1					0.4	0.9
Bouteloua gracilis	7.9	12.7	1.5	12%	1.6	2.2	1.2	2.8
Calamovilfa longifolia	0.3	0.5						
Schizachyrium scoparium								
Spartina pectinata								
Bromus japonicu	4.6	7.3			9.0	12.8	1.6	3.8
Bromus tectorum	6.2	9.8			0.6	0.8	0.4	0.9
Festuca octoflora	6.7	10.9			0.2	0.3	0.4	0.9
Annual - Biennial Forbs	1.4	2.3			10.8	15.6		
Linum lewisii								
Hedysarum boreale								
Onobrychis viciaefolia								
Penstemon strictus	0.2	0.2						
Phlox hoodii	0.3	0.5						
Ratibida columnifera	0.1	0.1	0.5	4%			1.2	2.8
Sphaeralcea coccinea	1.1	1.7	0.5	4%	2.6	3.6	0.8	1.9
Vicia americana	0.3	0.5	1.5	12%	0.2	0.6		
Arenaria hookeri								
Other Perennial Forbs	1.2	2.0					1.2	2.8
Atriplex canescens								
Gutierrezia sarothrae	0.1	0.1						
Artemisia cana	0.1	0.1						
Artemisia frigida	1.1	1.7						
Artemisia tridentata	0.7	1.3	0.5	4%	0.4	0.6		
Ceratoides Iananta								
Chrysothamnus nauseousus								
Column Total	52.8	83.9	13.0	100%	70.6	100.0	41.2	97.0

Breaks Grassland - Sample Table of Diversity Criteria

	Number of Species Within Life Form Category with a Relative Cover >2%		Minimum % Relative Cover Per Life Form Category	
Catagory	Pre-mine	Post-mine	Pre-mine	Post-mine
Cool Season Perennial Grass	6	3	34.6	20.0
Warm Season Perrenial Grass	3	1	14.1	2.0
Perrenial Forf	1	Note 1	15.3	5.0
Annual & Biennial Forb	1	Note 1	4.5	2.0
Sub-Shrub	1	0	5.9	1.0
Full Woody Shrub	2	1	13.7	2.0
Other (lower plants)	1	0	11.9	-0-

Note 1 = Postmining Standard applied to Minimum % Relative Cover

Upland Grassland - Sample Table of Diversity Criteria

	Number of Species Within Life Form Category with a Relative Cover >2%		Minimum % Relative Cover Per Life Form Category	
Life Form Category	Premine	Postmine	Premine	Postmine
Cool Season Perennial Grass	6	3	33.9	20.0
Warm Season Perennial Grass	2	1	17.8	2.0
Perennial Forb	0	Note 1	5.0	2.0
Annual & Biennial Forb	0	Note 1	2.3	2.0
Sub-Shrub	0	0	2.1	-0-
Full Woody Shrub	0	0	1.5	-0-
Other (lower plants)	2	0	37.4	-0-

Note 1 = Postmining Standard applied to Minimum % Relative Cover

Applying a Method for Quantifying the Diversity of Montana Wetland Plant Communities to Understanding the Diversity of Plant Communities within Surface Mining Reclamation Units

Tom Parker, Director of Consulting
Bitterroot Restoration, Inc.

Introduction

Given the continuing challenges associated with diversity and managing reclamation lands, it is important to continue to examine the nature of ecological diversity and propose practical ways to discuss, quantify, and determine whether we have achieved diversity. Bitterroot Restoration, Inc., has developed a sketch of the concept of diversity, which follows in this paper along with a brief illustration of why we should abandon diversity indices. Also following is a proposed conceptual approach to diversity aimed at regulators and mine managers that is based on comparing reclamation units to widely used vegetation classifications.

The Diversity Concept

Diversity, a term commonly used in ecology, is a combination of richness and evenness. Richness is the number of species (or other units) counted in a sampled plot, while evenness is the relative abundance of those species sampled within the plot (Magurran, 1988). Since diversity combines richness and evenness in its strict ecological definition, people developing diversity indices have tried to reflect both aspects in one index.

Peet (1974) recognized three conceptual approaches to diversity: species richness; heterogeneity; and equitability. Species richness is an estimate of the number of species present in an area. By using "species richness" instead of "species number," allowance is made for sampling limitations since a researcher may fail to record one or more species that is present. As a concept, species richness represents the number of species without actually being the true number. Peet (1974) remarks, "Direct species counts, while lacking theoretical elegance, provide one of the simplest, most practical, and most objective measures of species richness." In other words, the best way to find out how many species are out there is to count them. Describing heterogeneity, Peet recognized that two samples with the same number of species have different diversities if the species' relative abundances are different between the two samples. Thus, heterogeneity combines richness and evenness. Given two collections that are equally rich, Peet would say that the collection whose species are more evenly distributed in terms of their relative abundance is more diverse. Equitability ignores richness and focuses solely on how evenly distributed species are in terms of their relative abundance. By using the terms richness, heterogeneity, and equitability, Peet was really describing richness, diversity, and evenness. Ecologists have tended to use the latter three terms, but they often parenthetically mix in the former.

Based on spatial scales, ecologists have defined different levels of diversity (Whittaker, 1965; Magurran, 1988). These are point diversity, alpha diversity, beta diversity, gamma diversity and

epsilon diversity. Point diversity is the diversity of a sample taken from within a sampled plot. Alpha diversity is the diversity that describes a habitat class, and this is arrived at by averaging point diversity from within several plots that represent a particular habitat class (Hurlbert, 1971). Beta diversity describes the change in diversity between adjacent habitats and along environmental gradients. Similarity indices are one method to quantify beta diversity, and a common application is comparing reclaimed areas to reference sites. Gamma diversity describes the diversity of a group of alpha diversities across a landscape. Finally, epsilon diversity describes regional diversity, or the diversity of gamma diversities (Magurran, 1988).

Confusion About the Meaning and Usefulness of Diversity

Hurlbert (1971) criticized the concept of diversity as it was being applied to ecology by his contemporaries, calling it a "non-concept." He insisted that diversity's definition be restricted to "the number of species present (species richness or species abundance) and the evenness with which the individuals are distributed among these species (species evenness or species equitability)." Hurlbert believed that in order to be meaningful, diversity must contain both of these components, and cannot denote richness or evenness and exclude the other. Hurlbert traces diversity indices' creation to a gut feeling among ecologists that number of species and their relative abundances could be combined into a single, useful measure. In addition to insisting that diversity's definition be limited to richness and evenness, Hurlbert cautioned biologists against using mathematical diversity measures to interpret natural systems.

McIntosh (1967) notes that diversity has been said to "increase in a successional sequence to a maximum at climax, to enhance community stability, and to relate to community productivity, integration, evolution, niche structure, and competition. * * *. Measurements of community properties such as diversity, stability, or productivity are enlightening only when the entity in which they are made is meaningful." Various vegetation classification systems use habitat types (and community types) as these entities. Daubenmire (1968) defines habitat types as "all the area (sum of discrete units) that now supports, or within recent time has supported, and presumably is still capable of supporting, one plant association * * *." When developing a habitat type, one assumes that different plant associations capture a reasonable amount of the abiotic variation on a landscape.

Interpreting McIntosh's advice in light of managing vegetation on reclamation units, any measurement of diversity can have greater value if the entity being measured has greater meaning. We can extend greater meaning to denote more widely accepted meaning. Because one goal of reclamation is to come as close as we can to replacing natural diversity, we must look to where ecologists have developed a common language for describing this natural diversity. Often, the most widely accepted system is a formal vegetation classification. Perhaps we can increase the meaning of our discussions about diversity by comparing reclaimed areas not only to local reference sites, but also to formal vegetation classification systems developed by state Natural Heritage Programs, universities, and other institutions. It would, however, be important to closely examine sampling methods used to develop these classifications.

Pielou (1966) pointed out that different types of collections require different methods for determining their diversity. Plant communities fall into her type "E" class of collections,

because they must be "examined in situ" and they have a patchy spatial pattern. Random sampling will overlook species and underestimate the number of species present in an area. For a classification developed by the University of Montana (Hansen and others, 1995), researchers sampled within patches—for example, patches of shrubs or sedge meadows. By avoiding edges and slight topographic irregularities, they reduced the amount of variation in their samples that might have come from different environmental conditions. This method was important in riparian areas where hydrologic considerations influence plant species distribution at a very fine scale. Shrub communities found on western surface mines typically exhibit patchiness which may be driven by snow deposition patterns, subsurface geologic features, or many other potential factors.

Evaluation of Some Diversity Indices

Peet (1974) says that "[d]iversity, in essence, has always been defined by the indices used to measure it, and this has not fostered the sort of uniformity which allows the clear statement of ideas and hypotheses. Progress in ecology, as in all science, depends upon precise and unambiguous definition of terms and concepts."

In his often-cited synthesis paper on species diversity measurement, Peet attempts to "define in a precise but still generalized manner, what is or should be meant by the many terms surrounding the concept-cluster diversity." Peet succeeded somewhat in standardizing diversity index definitions and applications. He did this in a "generalized" manner, but failed to achieve the precision of definition he sought. As Hurlbert suggested, diversity measures, in order to have precise meaning, must be understood in terms of a real ecological system and the particular species relationships in that system.

Diversity indices are often discussed in the literature and compared to ideal data sets with a large number of species. The Q-statistic, which is based on the inter-quartile slope of the species abundance distribution, was proposed by Lamont and others (1978), and recommended by several researchers as more useful that the traditional Simpson and Shannon indices (Kempton and Wedderburn, 1978; Magurran, 1988):

$$Q = \frac{1/2S}{\log_e R2 - \log_e R1} \qquad (1)$$

where S is the total number of species in a sample and where R2 and R1 are the upper and lower quartiles respectively in a ranked list of species' canopy covers.

However, since many plant communities often contain very few species (sometimes as few as one), calculation of diversity statistics that depend on an abundance distribution without definite quartiles is difficult and probably meaningless. Tokeshi (1993) brings up this point and proposes a synthesis of several community structure models. His approach may be more useful, and would be worth testing on plant communities with larger species lists. However, because many plant communities often contain relatively few species, we have chosen to focus on Shannon's index and Simpson's index because they take into account relative abundance for all species that are present.

Hill (1973) proposed that Shannon's index and Simpson's index unify the concepts of richness and evenness into one concept—diversity. Routledge (1979), calling them Hill's family of indices, claims that they are the only admissible indices. Routledge lists several criteria for an admissible diversity index. First, the index "ought to be a function of the proportional abundances of the species." Proportional abundance is the proportion of the total canopy cover of all species in a plot that each species represents. Total canopy cover can be greater than 100 percent, because species overlap each other in vertical layers, so canopy cover alone is not necessarily "proportional abundance." The index must also be able to extend across taxonomic hierarchies. For example, the index would somehow recognize that a plant family with fewer genera and species represented in a sample contributes more to diversity that does a plant family with more genera and species. Pielou (1975) describes a method to evaluate taxonomic hierarchical diversity based on Shannon's index. Few studies have considered taxonomic hierarchy, however; most use species as the sole unit of taxonomic differentiation. We have restricted our inquiry to species diversity, since most classifications are based on species. Still, we do not discount the potential for using families and genera, or perhaps other categories that may be important to a particular investigation. Species richness, Shannon's index, and Simpson' index are defined as follows:

Species Richness

Species richness is the number of species counted in a sample.

Shannon's Index

$$\text{Shannon's index } (H') = -\sum_{i=1}^{S} pi \ln(pi) \qquad (2)$$

where **S** = number of species and
where **pi** = proportional abundance of species (cover of species / total cover of all species in sample).

Simpson's Index

$$\text{Simpson's index } (D) = \sum_{i=1}^{S} pi2 \qquad (3)$$

where **S** = number of species and
where **pi** = proportional abundance of species (cover of species / total cover of all species in sample).

Since D decreases as diversity increases, Simpson's index is usually expressed as 1/D or 1-D (Magurran, 1988). It is interesting to note that Hurlbert (1971) used 1/D when he illustrated that Simpson's index does not necessarily increase with Shannon's index. That example was the basis for his argument that diversity indices are often contradictory. Although he did not publish his raw data, I suspect that using 1-D would invalidate that argument.

Both Simpson's and Shannon's indices increase with the number of species (richness) and how evenly those species are spread throughout a stand (evenness). Because of this, they potentially offer more information than species richness alone. Shannon's index tends to be affected more by rare species (diversity's richness component), while Simpson's index tends to be more affected by changes in the abundance of the most dominant species (Peet, 1974).

Simpson's index (D), according to Peet (1974), measures the probability that two individuals selected at random from a sample will belong to the same species. Again, subtracting D from one causes Simpson's index to increase as richness and evenness increase. Hurlbert's (1971) probability of interspecific encounter (PIE), which is 1/D, is a form of Simpson's index. The reciprocal of D can be interpreted as "the number of equally common species required to produce the same heterogeneity as observed in the sample" (Peet, 1974). According to Peet (1974), Simpson's index, as a Type II index, is most sensitive to changes in the importance of the most abundant species. Formally, with Simpson's index, the second derivative's absolute value decreases or remains constant as species abundance approaches zero.

Shannon's index (H') has been referred to in the literature alternately as the "information theory index," "Shannon-Weaver," and "Shannon-Wiener." Each of these names refers to the same index. Shannon's index relates diversity to the amount of uncertainty associated with a randomly selected individual drawn from a population. Peet (1974) labels Shannon's index a Type I heterogeneity index because it is most sensitive to changes in the rarest species. Formally, the second derivative's absolute value increases as species abundance approaches zero. For example, Peet says that "[t]he effect of a change of 0.01 importance for a pair of species with initial importances of 0.01 and 0.5 will be greater for the rarer species." Conversely, a change in the more abundant species would cause a greater change in Simpson's index.

Much of the debate centers around defining the statistical properties of these indices literally in terms of probabilities of species encountering each other. Hurlbert (1971) seems somewhat favorable toward this view, as it agrees with his insistence on defining diversity in terms of its biological meaning. His probabilities of interspecific encounter (PIE), a conceptual model that he quantifies using a form of Simpson's index, could imply a certain level of ecological complexity, where high PIE drives ecological interactions which yield, according to Hurlbert, ecological stability. Particularly in the case of plant communities, a PIE-driven concept of diversity is limiting, since the plants themselves cannot freely encounter each other in the same way that animals can. In the case of plant communities, diversity indices are probably more useful for explaining community structure than ecological processes.

Hill (1973) summarized previous authors' views as "diversity is essentially a structural concept" and cannot be separated from theories of community organization. He points out that "[d]iversities are mere numbers and should be distinguished from the theories which they support." Diversity is a measurable parameter whose observed values can be correlated to "stability, maturity, productivity, evolutionary time, predation pressure, and spatial heterogeneity." His point seems to be that diversity measures can be explained by these different phenomena, but that the measures are independent of these theories. Based on this idea, it makes the most sense to proceed as follows: (1) understand an ecological system by reviewing literature and observing the system; (2) investigate how diversity indices respond based on this

knowledge; and (3) use this information to interpret values of diversity indices that come from this particular system.

Diversity Interpretation for Surface Mining Reclamation

When diversity indices are examined closely, the notion of an index being interpretable becomes questionable. One method for examining the meaning of a diversity index is to plot diversity indices calculated for sampled vegetation units against species richness. Species richness is a concept we can visualize because it represents the number of species on a site. Figure 1 represents 33 sampled units where species richness and diversity (Shannon's index) were calculated for each unit and plotted against each other to illustrate their relationship. To demonstrate the difficulty of interpreting a diversity index, select the point along the x-axis where Shannon's index equals approximately 2.0. Of the vegetation units sampled that were determined to have a Shannon's diversity equal to approximately 2.0, the species richness varied from approximately 10 species up to 25 species. Therefore, a diversity of 2.0 can represent either 10 species with a very even distribution on the site or 25 species with an uneven distribution on the site. By itself, a diversity index is difficult to interpret and certainly does not provide a basis for making management decisions—and especially does not provide a basis for regulating reclamation practices.

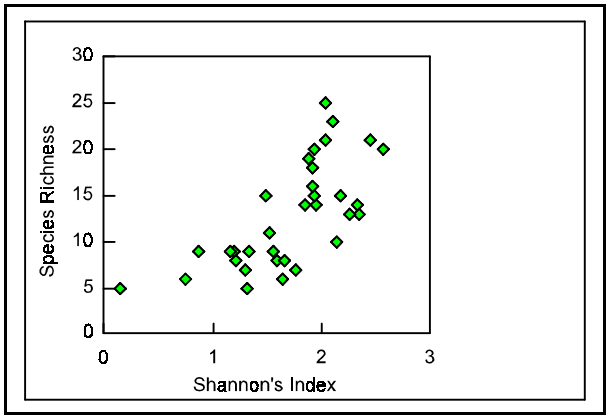


Figure 1 — Plot of species richness *vs*. Shannon's index.

At this point, we can return to the original reason we were concerned about diversity in the first place. To state the goal simply, we desire to replace what was on the landscape prior to disturbance. In order to know what was there before, we can establish reference sites—or, as we proposed earlier, we can look to an existing formal classification of vegetation associations and decide which habitat type most closely fits the vegetation we are working toward replacing through the reclamation process. Rather than using diversity indices, which serve only to quantify alpha diversity and are, practically speaking, merely mathematical curiosities when applied to natural systems; we should instead use the concept of similarity, or beta diversity.

In order to accomplish this from a practical point of view, we need to: (1) choose classification systems that are appropriate for particular regions; (2) locate and organize data from which classifications were developed; (3) select a method for quantifying similarity between a reclaimed area and the habitat type to which it is being compared; (4) decide upon an acceptable level of similarity given the inherent variation in natural systems; and (5) develop tools to manage this information.

Up to this point, we have provided a broad sketch of a portion of the literature dedicated to the concept of diversity, and followed that sketch by illustrating an inherent problem associated with interpreting a diversity index. We have proposed abandoning the use of diversity indices as a tool for evaluating mined land reclamation, and instead using similarity indices. While similarity indices are currently being used to compare reclamation land to reference areas, we further propose enhancing the strength of our comparisons by using established classification systems to denote the entities we aspire to reconstruct. Computerized tools allow us to make a large number of comparisons very quickly. Rather than comparing a reclaimed area to a handfull of sites, we can compare it to hundreds of sites and share the data among several mines in the same ecological zone.

Such a tool is currently being developed for a somewhat different purpose. In Montana, 2,702 areas were sampled to develop a riparian vegetation classification (Hansen and others, 1995). As neighboring states and provinces develop their own classification systems, it is possible to determine whether they have habitat types similar to those found in Montana by comparing sampled vegetation plots, for example in Idaho, to the Montana data set. Each sampled plot is systematically compared to the entire data set (or an intuitively selected subset) and the result is a similarity matrix. The idea is relatively simple—vegetation associations do not follow state or administrative boundaries. Similarity values among sampled vegetation units range from zero to one. The threshold, or the point where one can definitively state that a sampled unit is similar to an existing habitat type, cannot be determined empirically. In the case of vegetation classification, the threshold is an ecological decision. For the mining industry, it will need to be an ecological decision first, tempered by the realities of restoring plant associations on disturbed soils.

As ecological restoration practitioners, we know that restoring diversity is often constrained by: lack of mycorrhizae; nutrient imbalances; absence of microclimates; presence of exotic species; lack of an appropriate time frame when plant communities naturally develop in stages; and many other factors. Selecting an appropriate numerical threshold for determining adequate similarity to natural plant communities will require factoring in many of these constraints. As restoration science continues to develop, hopefully the constraints will become fewer.

In order to successfully achieve diversity objectives, we must first agree on a workable definition of diversity and select appropriate ways to denote and quantify diversity. Otherwise, we will be forever mired in a stalemate.

References

Daubenmire, 1968. Plant communities: Harper and Row, New York, 300 p.

Hansen, Paul, Robert Pfister, Keith Boggs, Brad Cook, John Joy, and Dan Hinckley, 1995. Classification and management of Montana's riparian and wetland sites: Montana Riparian And Wetland Association, Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, Montana, 646 p.

Hill, M. O., 1973. Diversity and evenness: A unifying notation and its consequences: Ecology 54(2): 427-431.

Hurlbert, Stuart H., 1971. The nonconcept of species diversity: A critique and alternative parameters: Ecology 52(4): 577-586.

Kempton, R. A., and R. W. M. Wedderburn, 1978. A comparison of three measures of species diversity: Biometrics 34: 25-37.

Lamont, Byron B., Susan Downes, and John E. D. Fox, 1978. The Q-statistic and the diversity of floras: Nature 275: 252-253.

Magurran, Anne E., 1988. Ecological diversity and its measurement: Princeton University Press, New Jersey. 179 p.

McIntosh, Robert P., 1967. An index of diversity and the relation of certain concepts to diversity: Ecology 48 (3): 393-404.

Peet, Robert K., 1974. The measurement of species diversity: Ann. Rev. Ecol. System. 5: 285-307.

Pielou, E. C., 1966. The measurement of diversity in different types of biological collections: J. Theor. Biol. 13: 131-144.

Pielou, E. C., 1975. Ecological diversity: John Wiley and Sons, New York. 165 p.

Routledge, R. D., 1979. Diversity indices: which ones are admissible?: J. Theor. Biol. 76: 503-515.

Tokeshi, M., 1993. Species abundance patterns and community structure: Advances in Ecological Research 24:111-186.

Whittaker, R. H., 1965. Dominance and diversity in land plant communities: Science 147: 250-259.

Overview of Statistical Methods for Measuring Diversity

originally **a PowerPoint Presentation**

by

Roger Prodgers a
and John Kern Ph.D.

Evaluating Biodiversity of Reclaimed Mined Lands

Gary L. Wade. Ph.D.
Northeastern Research Station, U. S. Forest Service

Introduction

Federal and state regulations do not mention the term "biodiversity." The less inclusive term "diversity" is used sparingly and largely left undefined. However, biodiversity of reclaimed land is important and worth consideration especially when planning and permitting the reclamation of lands to be mined. This paper is an introduction to biological diversity in all of its forms that may be important to the surface-mine reclamationist, or regulator; hence the use of the term biodiversity.

The objective of this paper is to present a thought model for the concept of biodiversity that provides a framework for biodiversity discussion and evaluation.

What is Biodiversity?

There are many definitions of biodiversity. I define biodiversity as the variety and number of living organisms, their organizations and functions, and the environments that support them.

Since we are concerned with surface mining and reclamation and bond release, the question that immediately comes to mind is: "What is the relationship of *bio*diversity to diversity?"

Biodiversity is the sum of several biological diversities attached to species, a site or a region.

Why Is Diversity/Biodiversity Important on Reclaimed Mines?

Why should we be concerned with diversity/biodiversity on mined and reclaimed lands? There are several reasons:

- Diversity is required by regulation.
- Greater diversity increases stability of a reconstructed ecosystem.
- Greater diversity increases ability of an ecosystem to recover from disturbance.
- Diversity is valued and desired by social stakeholders.
- Diversity is a political issue.
- Diversity is an ethical issue.

- Diversity is an economic issue.

Greater numbers of species in each identifiable functional group on a reclaimed mine provide more redundancy in the new post-mine ecosystem. This allows the ecosystem to recover faster and more effectively from perturbations such as fire, flood or abnormally high rainfall, drought, nongrazing (or intensive grazing), pathogens specific to one or several species, and impacts from introduced exotic and/or weed species. A wide number of physical habitats on a mine ensures refugia for species eliminated from other habitats by climate extremes or other disturbances. These refugia may later become sources of species that move into other areas after serious disturbances. Animals, including many insects, rely on a variety of plant species, communities, and habitats for food, cover, breeding or nesting areas, refugia, and alternative hosts. Animals enhance ecosystems by pollinating plants, maintaining nutrient cycles and successional processes, acting as seed vectors and creating soil seed banks, controlling pest populations and increasing the heterogeneity of environments. All of these factors contribute to ecosystem stability (ability to resist disturbance) and recovery following a significant disturbance.

Difficulties with the Term "Biodiversity"

Having defined biodiversity and its virtues, I must address two problems related to the term "biodiversity" (though not with diversity itself):

- Biodiversity is a popular buzzword with *many* interpretations. Individuals and agencies discussing diversity frequently talk past one another. Therefore, a thought model is a helpful guide for discussing or evaluating the kinds of diversity that apply in any given situation.

- There are too few methods for qualitative and quantitative evaluation of biodiversity, though measurement techniques for some types of diversity are well established. The scope of this paper is too narrow to cover this problem, but the thought model presented here can aid in the choices and development of meaningful measures.

A Framework for Consideration of Biodiversity

The following model for biodiversity evaluation is intended to help reclamation planners and regulators determine:

- Kinds of diversity that are important or relevant.

- Criteria for biodiversity goal-setting, management, and evaluation.

- Values that underlie these criteria.

Any discussion of biodiversity should proceed within a conceptual framework that defines:

- Kinds of diversity that are at stake or of interest.

- Scales at which they are relevant or to be evaluated.

- Social stakes and stakeholders.

These factors can and should be integrated using the “thought model” in figures 1 and 2.

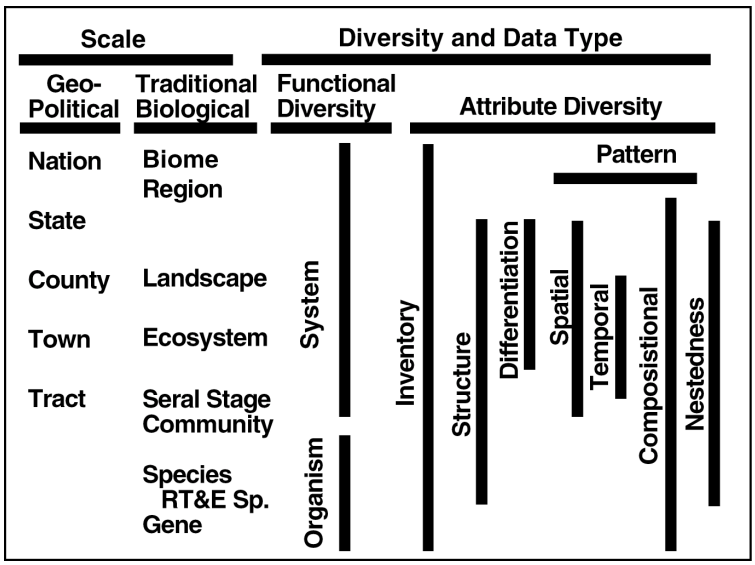


Figure 1— The relationship of the different types of diversity to scale. Vertical lines indicate at which levels of scale particular types of diversity are valid

is a basic consideration. The concept of biodiversity includes eight kinds of diversity, each of which is related to scale. Any meaningful units of scale can be used, either categorical or continuous.

Functional diversity refers to the function of a gene or species as well as to the function of communities, habitats, and ecosystems. We consider functional diversity in reclamation when we include factors such as warm and cool season grasses, annual and perennial plants, nitrogen-fixers, nurse species, wildlife food, and shrubs for habitat structure and cover.

Functional diversity above the species level can include:

- On-site and off-site effects, and could include cumulative effects.

- Organizational stability and resilience as functional attributes.

- Water storage and yield quantity, quality, and timing.

- Permanent and transient habitat for wildlife and other species of interest.

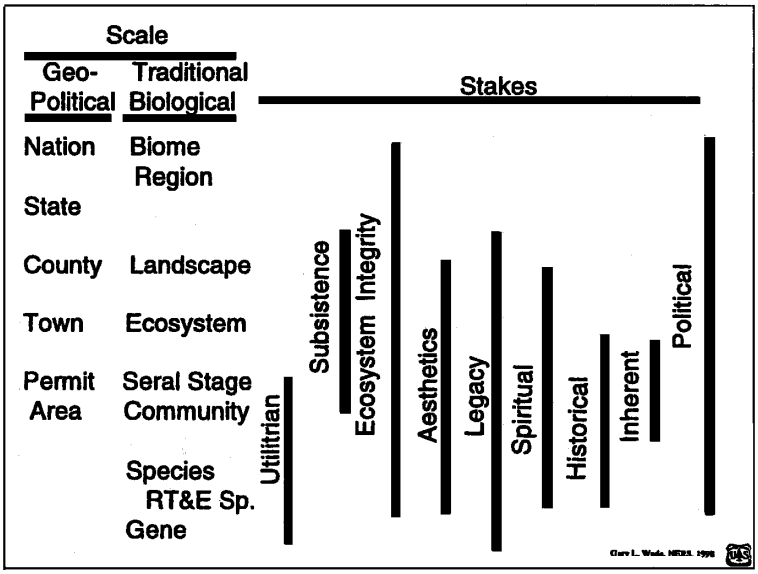


Figure 2 —Social stakes and the scales at which they are applicable.

- Economic function and other human uses.

- Agricultural productivity, grazing, wildlife, forest products, and public recreational use.

- Aesthetic relationships as well as cultural, spiritual, and legacy attributes.

Inventory diversity covers the numbers of species, rare species, community or habitat types, or ecosystems, and the quantity of each, including evenness of distribution. There are many indices of this type of diversity, some of which combine species richness and evenness of distribution (Magurran, 1988). Inventory diversity at the habitat-community level and higher is often termed alpha and gamma diversity.

Structural diversity refers to the kinds of structure contributed by ecological units such as trees and shrubs *vs*. grasses. Structural diversity can be considered at the species level or at the level of habitats and communities (forest *vs*. grasslands). Structural diversity also can include differences among land forms up to the landscape level. Magurran (1988) reviews some methods of quantifying structural diversity.

Differentiation diversity refers to the amount of difference among ecological units. Sowing different species mixes in wet and dry areas results in differentiation diversity among those two habitat types. Beta diversity measures are sometimes applied to indicate the amount of differentiation (Magurran, 1988).

Pattern diversity is that which repeats itself or reveals a pattern across space or through time. There are four potentially useful pattern types:

- Spatial diversity = the pattern of units (species, communities, land forms) repeated across space.

- Temporal diversity = the pattern of units repeated through time, such as particular species or communities that are characteristic of particular successional stages in community or ecosystem development.

- Compositional diversity = the pattern of taxa presence and numbers of each repeated across space. This would be exemplified by repeated variation among plant and animal communities encountered as one crosses a landscape with different habitats.

- Nestedness = the pattern of association of ecological units. Aspects of nestedness include the distribution of normally associated species (such as consumers and specific hosts), the characteristic subgroup of species in a region that occupy a particular habitat, and the association of particular environments one within the other.

While all of these types of diversity are not defined as necessary considerations for mined-land reclamation and bond release, this model is useful for guiding considerations by reclamation planners and regulators.

Social Stakes and Stakeholders

There are a number of social stakes to consider in reclamation planning and perhaps bond release (fig. 2). Different groups of people (stakeholders) have an interest in the following stakes:

- Utilitarian = products removed from an ecological unit.
- Subsistence = “making a living” within the ecological unit.
- Ecosystem integrity = ecosystem stability or health, ability to recover from disturbance, and ability to perform the usual functions of the ecosystem in the greater landscape.
- Aesthetic = the aesthetic value of an ecological unit.
- Legacy = an ecological unit (species to landscape) should be preserved or recreated for posterity.
- Spiritual = the spiritual value of, or contained within, an ecological unit.
- Inherent value = according to the philosophies of some individuals, a species or community has an inherent right to exist.,
- Political = environmental quality, including that of reclaimed land, is a political issue.

Figure 2 shows which social stakes and their stakeholders may have an interest at each combination of diversity type and level of scale shown in figure 1. Scale is the integrating factor for types of diversity and social stakes.

Summary

The concept of biodiversity includes multiple types of diversity evaluated across a range of applicable scales with consideration of social stakes and stakeholders.

The approach to biodiversity evaluation and management presented here can be used to evaluate reclamation plans and post-reclamation results.

References

Magurran, A. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ.

Wade, G. L.; Tritton, L. M. 1997. Evaluating biodiversity of mineral lands. p. 36-343 *In:* Brandt, Jon E. (ed.). Proceedings, 1997 annual meeting of the American Society for Surface Mining and Reclamation, May 10-15, 1997, Austin, TX. American Society for Surface Mining and Reclamation, Princeton, WV.

A Comparison of Cover Sampling Methods

originally **a PowerPoint Presentation**

by

Richard Bonine

Soil, Overburden, and Growth Media

☞ Nutrient management

Nutrient Management

Indian ricegrass
Oryzopsis hymenoides

"Establishing Desirable Vegetation in the Southwest"

Establishing Desirable Vegetation in the Southwest

David R. Dreesen, Gregory A. Fenchel, and Joseph G. Fraser
Los Lunas Plant Materials Center, U.S. Department of Agriculture, and
Agricultural Science Center at Los Lunas, New Mexico State University

The Los Lunas Plant Materials Center is part of a coordinated national plant-materials program established by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). Selection and improvement of plants for conservation purposes and development of methods for plant establishment in the arid southwest are our main program objectives.

Our mining industry partners are Pittsburg/Midway, Raton, New Mexico, Molycorp Mine, Questa, New Mexico, BHP Western U.S. Mining, Farmington, New Mexico, and Lee Ranch Mine, Grants, New Mexico. Their support has accelerated our ability to release new plant materials and to develop more effective methods of propagating and establishing plants for reclamation purposes.

Selecting Plant Materials for Successful Plantings

The NRCS Plant Materials Program has released over 250 cultivars, which can be used in reclamation and restoration projects. Selection of plant materials should be based on the potential adaptation to site extremes such as temperature, precipitation and soils. Latitude should also be considered because of its effect on day length which controls time of flowering. NRCS cultivars are useful if they match site extremes because they have a documented performance record and origin, and are commercially available.

In addition to purchasing cultivars, the custom collection of plant materials at or near a mine site for establishing seed production fields or growing transplants is becoming more common. These plant materials are initially more expensive but because they are indigenous to the site, they generally provide for more effective restoration. We encourage cooperators to use local plant materials for at least part of their reclamation program.

We assist in establishing seed production fields of local ecotypes particularly if there is a potential for a release with commercial value. We are currently in the process of releasing a narrow leaf penstemon (*Penstemon angustifolia*) which was originally collected on a mine site in northwest New Mexico. The flower has a large purple corolla and is adapted to only 7 inches of annual precipitation. This release has generated a lot of local interest in the Albuquerque, New Mexico area by landscapers who use xeric plants (Albuquerque Journal, 1999). Several commercial growers have agreed to produce seed of this cultivar.

Types of Plant Materials

The Los Lunas Center has been developing plant materials that can be planted in deep soil moisture provided by a shallow water table or water harvesting. The goal is to limit or avoid

traditional irrigation treatments generally required for establishment of vegetation in the arid southwest.

Many species can be established using 10- to 15-foot dormant pole cuttings. Studies have included accession trials of *Populus fremontii* and *Salix gooddingii*, *Populus fremontii* pole cuttings in soil lysimeters to determine proper planting depth, a greenhouse study to determine sodium tolerance of cottonwood cuttings, field trials of dormant cuttings of other common riparian species, and use of microirrigation systems to establish *Populus fremontii* seedlings on remote sites (Fraser *et al*., 1998).

Five *Populus fremontii* and three *Salix gooddingii* accessions collected in the Rio Grande Valley were selected as superior after 10 years of evaluation by the Plant Materials Center and now are being grown commercially. Other species determined to establish from dormant pole cuttings include *Baccharis glutinosa*, *Amorpha fruticosa*, and *Forestiera neomexicana*.

Volunteer *Populus fremontii* seedlings were successfully established using microirrigation systems on flood plain sites which are no longer flooded (Dreesen *et al*., 1998). Some seedlings were 3 meters tall by the end of the second growing season. After 3 years of irrigation, sapling roots were established in the capillary fringe above a 6-foot watertable.

Those species or ecotypes that are less likely to establish by pole cuttings may be prerooted by a horticulture practice known as mound layering (Dreesen and Harrington, 1998). During the spring, soil is mounded over the mainstems of a 3 to 4 year old vigorous shrub. In the absence of light, the stems grow roots into the mound. These rooted stems are harvested in late winter and field planted into deep soil moisture. This technique works well for *Rhus trilobata*, *Chilopsis linearis*, *Platanus wrightii*, and *Alnus oblongifolia*.

We have been successful in establishing containerized plants without irrigation using 30-inch deep containers constructed from 4-inch diameter PVC pipe containing 3-year-old shrubs grown in containers. This technique has been successful for plantings in deep soil moisture near a pond or stream or in natural water harvesting areas such as the base of a slope.

Plant Material Establishment in Soils with High Sodium

A study to evaluate five topsoil depth treatments over mine spoil for sustaining maximum plant species richness, density, cover and yield in northwest New Mexico was evaluated for 9 years (Fenchel, 1991). Precipitation at the site averages 7 inches per year. The topsoil treatments were 0, 10, 20, 30, and 40 centimeters. The spoil material and topsoil less than 20 centimeters thick had sodium absorption ratio values that averaged above 14. Consequently, only plant species tolerant to alkaline soils persisted (*Sporobolus airoides*, *Hilaria jamesii*, *Atriplex canescens*, and *Atriplex confertifolia*).

Shrub (*Atriplex canescens* and *Atriplex confertifolia*) density was greatest on bare spoil. As topsoil depth increased shrub density declined. As topsoil depth increased *Hilaria jamesii* density increased. The density of *Sporobolus airoides* increased up to 20 centimeters of topsoil

then declined as topsoil depth increased. These results suggest that varying topsoil depth may enhance species diversity. Lastly, forage yield in 1990 was not significantly different on the 10 to 40 centimeters topsoil plots.

Plant Material Establishment on Acid Soils

Our studies on the reclamation of acid overburden have been conducted at the Molycorp, Inc., Questa Molybdenum Mine, which is a hard rock mine located at high elevation in northern New Mexico. The overburden piles span an elevation range from 8,000 to 9,800 feet, the predominant aspect of the piles is south to southwest, and many of the slopes are at the angle of repose. Precipitation at the site varies from 14 inches at 8,000 feet to approximately 25inches at the highest elevations. The overburden is comprised of neutral waste rock containing aplite (granitic rock) and the more acidic waste rock made up of mixed volanics and andesites. The acid overburden material was excavated from naturally occurring altered scar areas covering the ore body. The more acidic rocks range in paste pH from less than 2.5 to 5.1 with most in the 3.0 to 4.8 range. High soluble salt content from mineral oxidation and dissolution may also be present. Other natural scars and their debris flows in the vicinity of the mine have provided areas to collect plant materials adapted to this extreme soil chemistry.

Numerous plant species and ecotype trials have been conducted over the past 6 years at this mine. Our results and those of collaborators have shown that the establishment of a wide variety of native grasses, shrubs, and trees on the neutral overburden is feasible. Acceptable survival (average 80 percent) has been achieved using 10 cubic inch seedling containers. The logistics of planting on angle of repose slopes has been the primary difficulty with the reclamation of slopes. The primary constraints to rapid growth are (1) the compaction of the top of the piles by heavy equipment, (2) the low fertility of the overburden (particularly nitrogen content), (3) the periods of low precipitation during the growing season (May through June and late September through early October) and (4) the short growing season (80 to 90 days).

Our studies have shown establishment and growth of some plant species on acid overburden materials with pH values less than 4.0 is possible. The better performing species represented by ecotypes collected at the mine site include *Rosa woodsii*, *Prunus virginiana*, *Festuca* species, *Blepharoneuron tricholepsis*, and *Muhlenbergia montana*. Commercially available species and cultivars that performed best in the acid overburden trials include *Robinia neomexicana*, *Amorpha canescens*, *Thermopsis montana*, *Pascopyrum smithii*, *Poa interior*, *Festuca arizonica*, *Elymus trachycaulus*, and *Deschampsia cespitosa*. In addition, *Pinus flexilis* as well as *Pinus aristata* are among the best performing species in the acid overburden and will be dominant components in reclaiming this site to forest land (personal communication, Anne Wagner and John Harrington). Other conifers that have potential include *Pinus strobiformis*, *Pinus ponderosa*, *Picea pungens Picea engelmannii*. Non-natives with potential include *Pinus nigra* as well as *Pinus sylvestris*.

Equipment

Electric hammer drills (8 amps) have been used successfully to plant dormant cuttings of *Salix exidua* to a 3-foot depth in frozen soil. They have also been used successfully to plant 10 cubic inch containers in extremely rocky soils (heavy cobble and gravel class). In both situations the holes were augured in seconds.

A mechanical tree planter pulled by a D 5 bulldozer with a riper attached has been used successfully at a mining location in northeast New Mexico to plant up to 500 sixteen cubic inch containers per hour. The site receives 16 to 18 inches of annual moisture with 50 percent occurring in July through September. Soils are chemically neutral and generally are fine textured. The soil surface has about a 10-percent sandstone boulder cover.

A hand-held gasoline powered auger has been successfully used to plant wetland plants in wet heavy clay soils. The spinning bit sheds the clay ribbons that are cut by the auger. Normally this soil would cake on commonly used hand tools such as shovels and dibble bars.

The stinger probe planter was built specifically for planting pole cuttings into riprap on riverbanks or shoreline (USDA Natural Resources Conservation Service, 1994). It is constructed by welding a long steel bar (7-foot or longer and 4 inches in diameter or greater) to a support frame. The support frame attaches to the backhoe arm, using the same pins as the bucket, after the bucket is removed. The upper hydraulic ram of the backhoe arm moves the bar forward and backward so holes can be punched in the riprap. Once the stinger reaches the soil under the rock riprap, it is pushed in deep enough to make a hole that allows the placement of a cutting into permanently moist soil.

References

Dreesen, D. R., Fenchel, G. A., Fraser, J. G., 1998. *Establishment of Rio Grande Cottonwood Seedlings Using Micro-Irrigation of Xeric Flood Plain Sites*. Proceedings of RMRS-P-7, Ogden, Utah: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Dreesen, D. R., Harrington, J. T., 1998. *Vegetation Propagation of Aspen, Narrowleaf Cottonwood, and Riparian Trees and Shrubs*. National Proceedings of Forest and Conservation Nursery Associations, Gen. Tech. Report SRS-25, Ashville, NC: U. S. Department of Agriculture, Forest Service Southern Research Station, pp 129.137.

Fenchel, G. A., 1991. *Effects of Topsoil Dressing Depth over Mine Spoil on Establishment of Vegetation at San Juan Mine. BHP-Utah San Juan Mine Ten-Year Interim Report,* 1981 – 1990.

Fraser, J. G., Fenchel, G. A., Dreesen, D. R., 1998. *Plant Development for Riparian Areas in the Southwest United States*. Proceedings of the Society for Range Management Symposium in Guadalajara, Mexico.

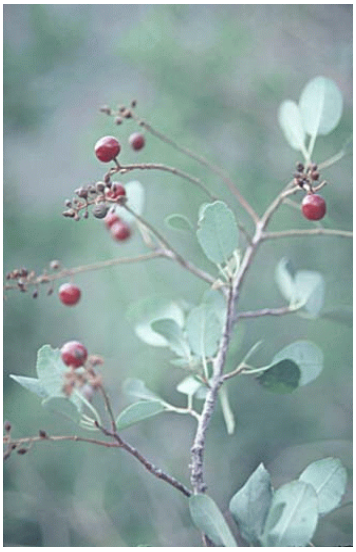
Larranga, Rena, June 17, 1999. *Penstemon a Beautiful Member of Arid Landscape*, Albuquerque Journal South.

USDA Natural Resources Conservation Service, 1994. *The Stinger*, Technical Notes Plant Materials No. 6.

Microclimate, Site Engineering, and Other Management Techniques

- ☞ **Weed control**
- ☞ **Range management**
- ☞ **Water management**
- ☞ **Erosion control**

Weed Control



Chokecherry
Prunus virginiana

"OSM Noxious Weed Guides for the State of Washington and Tribal Lands: Sources of Technical Information Available to Plant Scientists"
"Update on Reclamation Grazing at Jacobs Ranch Mine"

OSM Noxious Weed Guides for the State of Washington and Tribal Lands: Sources of Technical Information Available to Plant Scientists

Rebecca Siegle, Soil Scientist
Office of Surface Mining

Noxious weeds are a concern in mining because disturbed areas are highly susceptible to invasions by these aggressive, non-native plants. Executive Order 13112, issued February 3, 1999, and the Federal regulations at 30 CFR 816.111(b)(5) are two pieces of legislation directing the Office of Surface Mining's (OSM's) involvement in the area of noxious weeds. Executive Order 13112 mandates that Federal agencies will take measures to prevent, control, and monitor the spread of noxious weeds. The Federal regulations require that reestablished plant species meet requirements of applicable State and Federal seed, poisonous and noxious plant, and introduced species laws or regulations. To address both the Federal regulations and the Executive Order, OSM produced noxious weed guides for State of Washington and Indian lands, for which OSM is the regulatory authority in the West.

The guides are intended to be used for identifying weeds and include photos and descriptions of the plants. The guides also serve to provide mines with the noxious weed list of the area. In using the guides, the emphasis is on early detection as a means for more effective control. They are not an aid in weed control. Control can best be addressed by local noxious weed specialists since each species requires unique methods of control that may depend on regional environmental conditions. Also, the level of control expected for each species may vary by area. See appendix D to these proceedings for a list of noxious weed contacts in coal mining regions of the West.

In preparing the guide, the county lists for State of Washington mines and the Bureau of Indian Affairs Navajo area list for Indian lands mines were used. All States in the West where coal mining occurs have an official state noxious weed list, with the exception of New Mexico. At this time, a candidate-species list is in place in New Mexico that includes proposed species for an official list. Plant species that are included on noxious weed lists are mandated for some level of control. All western coal mining States have weed coordinators and county weed supervisors. Some counties have weed lists that differ slightly from the state list. There may be different emphasis on control of certain weeds at the county level, due to differing climates throughout the state and depending on the direction the weed is spreading. Therefore it is best to contact county noxious weed agencies for the local weed list.

Photos and descriptions were not provided for all of the weeds on the State of Washington county and Navajo area lists in these guides, but only for the highest priority species. Some noxious weed lists use a priority rating. For example, State of Washington and Indian lands both have A, B, and C classifications for noxious weeds. The ratings are as follows:

A — These are the highest priority species. Distribution is limited in the State or area; therefore, eradication is still feasible.

B — Distribution of these species is limited to portions of the State or area. Where these species are not yet widespread, control is a high priority. If the species is widespread, control is decided on a local level, with containment a top priority.

C — These species are widespread throughout the State or area. Long-term suppression and control are decided locally.

Montana also uses a priority rating using category 1, 2, and 3 system and New Mexico's proposed list is A, B, C classified.

The majority of information and photos used to produce the noxious weed guides were collected on the Internet. A list of web pages that are valuable sources of information on noxious weeds is included with the list of regional noxious weed contacts in appendix D. (For copies of the noxious weed guides produced by OSM, see appendices E and F to these proceedings.)

Update on Reclamation Grazing at Jacobs Ranch Mine

Roy Liedtke, Environmental Specialist
Jacobs Ranch Mine, Kennecott Energy Company
Gillette, Wyoming

Jacobs Ranch Mine Background

- Construction began at the Jacobs Ranch Mine (JRM) in 1975. Both the first coal shipments from the mine and the first reclamation took place in 1978. Currently, JRM is shipping approximately 29 million tons of coal per year.

- JRM has disturbed approximately 5,700 acres to date. About 3,500 (or 60 percent) of these acres have been reclaimed.

Grazing Background

- Cattle started grazing on JRM reclaimed areas in 1985.

- Through 1997, grazing at JRM was season-long and generally planned to fit the requirements of a local rancher.

Reclamation Technologies

- In 1998, the mine entered into an agreement with Reclamation Technologies (Miles Keogh and Donnie Whitten), the goals of which were to (1) obtain bond release; (2) realize a profit, for both JRM and Reclamation Technologies, from reclamation at the minesite; (3) provide high-quality wildlife habitat through biological diversity; and (4) improve the health of the land.

- The terms of the JRM/Reclamation Technologies agreement were as follows:

  - JRM was to provide land, some permanent fencing, and water (amounting to three wells) at central locations.

  - Reclamation Technologies was to provide cattle, temporary electric fencing, and all labor. They were also to be responsible to get the water to the cattle.

  - The cattle (yearling steers) would be owned by a third party.

  - Reclamation Technologies was to get paid per pound of gain, and JRM was to get a percentage of that per-pound-of-gain payment.

- Upon bond release, Reclamation Technologies would get 100 percent of payment for pounds of gain for a predetermined number of years. (Note that this was viewed as a critical part of the agreement–the agreement had to be structured in a win-win manner.)

- The JRM/Reclamation Technologies agreement was intended to foster a high intensity, short-duration, holistic approach to grazing management. The assumption behind the agreement was that overgrazing is not a result of the number of animals grazing an area but rather of the amount of time a plant is exposed to grazing.

1998 Grazing

- Reclamation Technologies grazed 650 head of yearling steers on 3,200 acres for 4 months.

- They started the summer with 500 head, but added 150 head after 3 days. (We view the fact that they knew 3 days into the summer that we were understocked as one of the advantages of having a good grazing plan.)

- The reclamation was split into 21 pastures. The average pasture size was 150 acres.

- Most pastures were grazed twice during the summer. Cattle averaged 3 days in each pasture per rotation.

- At one point, all 650 head were in a 15-acre pasture for an 18-hour period.

- Steers gained 2.2 pounds/day.

1999 Grazing

- In 1999, Reclamation Technologies began to graze more reclaimed areas, as well as a U.S. Forest Service (USFS) Thunder Basin National Grasslands lease adjoining these.

- They grazed 1,000 head of yearling steers (Reclamation Technologies had wanted to graze 1,250 head, because they were also grazing reclaimed Black Thunder Mine lands adjoining JRM; however, market conditions prevented their obtaining this number of steers).

- We had a wet year and hardly grazed the USFS land. We could probably have handled twice as many steers.

- The majority of areas look ungrazed. Grass has grown back enough to go to seed in most areas.

- We kept pasture sizes slightly larger, because we were grazing more animals.

- Larger pasture sizes can be beneficial during very wet weather, helping the cattle to avoid beating up areas too badly (too much hoof impact can be detrimental).

- Steers gained from 1.5 to a little over 2.0 pounds/day. A number of people–residing everywhere from Montana to Oregon–owned the steers we were grazing, and this complicated matters slightly. Also, the end of the summer was extremely hot and dry, and that reduced gains.

- Gains were also reduced by the fact that some older JRM areas were grazed for the first time this year (we needed to knock down some old vegetation and incorporate it into the soil).

- We improved watering systems, corrals, etc. in 1999.

2000 Grazing

- JRM plans to add 200 to 300 acres of reclaimed land to its grazing program.

- There is a ***possibility*** that JRM could lease additional undisturbed land to Reclamation Technologies.

- Additional land would provide enough grass for a total of 2,000 or more steers.

- A larger number of steer grazing more land has several advantages:

    - It creates more impact in a shorter period of time (we are trying to impact these areas: impact is required to provide the hoof action needed to break up the capping of the soils and knock down standing dead material and incorporate it into the surface).

    - It allows larger pastures and/or a shorter grazing period.

    - It is a configuration that more closely replicates the herds of buffalo from centuries ago, which were instrumental in evolving the Wyoming grasslands.

    - It may result in fewer disruptions to the mining operation (moving across haul roads, etc.).

Management Tool

- Cattle are a reclamation management tool, and JRM tries to use them for everything.

- For example, we graze stubble mulch rather than mow it.

- We graze for weed control (the Wyoming Department of Environmental Quality stopped us from grazing the second year after seeding; however, we have gathered vegetative data and are optimistic that with discussion and education we can reach an agreement with the Department allowing us to use grazing as a method of weed control).

- Hoof action from grazing reduces capping/crusting of soils. JRM has a lot of high clay content soils. The capping process starts after the first good rainfall following seeding.

- We graze to improve wildlife habitat. Areas where big game are routinely observed at the minesite are the newly reclaimed areas (fresh growth of plants) and areas that have been grazed and regrowth has started (fresh growth of plants).

- Grazing steers on a steep slope when it is quite wet tends to control its erosion. Each hoof print is several inches deep. Runoff is completely contained for the next several precipitation events by the prints, allowing vegetation to become established.

- Placing straw bales in gullies prior to grazing tends to repair erosion. In early spring when grass is very lush, the cattle crave dry matter (straw). The steers very effectively incorporate straw into the soil, breaking down the sides of gullies. The end result is smoothed-over gullies with considerable organic matter in the soil (good infiltration) and a quick growing stand of vegetation (grain crop from straw).

Summary

- The health of JRM land is improving:

  - We have new seedlings on old stands of reclamation.

  - We have increased litter and organic material, and less standing dead material, on the ground surface.

- JRM and Reclamation Technologies are making a profit.

- Successful reclamation must continue to focus on the postmining land use:

  - We can meet all kinds of numerical standards, yet if we do not support the postmining land use, we have failed.

- If the postmining land use is grazing, or any kind of agriculture, then the postmining land **user** will most likely be a family trying to make a living off the land.

- The real postmining land use is supporting families and communities. Our decisions should always keep that in mind.

Range Management

Winterfat
Ceratoides lanata

"National Range and Pasture Handbook (1999 edition)"

National Range and Pasture Handbook
(1999 Edition)

Steve Barker
Natural Resources Conservation Service, Arizona

Grazing Land Resources

- **Private grazing lands** are non-Federal grazing lands, constituting forty seven percent of the private lands in the United States.

- There are about 634 million acres of non-Federal grazing lands in the United States.

- Four hundred million acres are rangeland.

Ecological Sites and Forage Suitability Groups

- Landscapes are divided into basic units for study, evaluation and management.

- On rangeland and forest land, these units are called **ecological sites**.

- On forage cropland and pastureland, they are called **forage suitability groups**.

- Ecological sites and forage suitability groups alike are categorized on the basis of their soils, topography, landscape position, climate, hydrology, plants, herbivory, and fire potential.

- Both ecological sites and forage suitability groups are recognized and described on the basis of characteristics that differentiate them from other sites in their ability to produce and support a plant community.

- **Rangeland** is a distinctive kind of land on which the historic climax vegetation was predominantly grasses, grass-like plants, forbs, or shrubs.

- **Forest land** is a kind of land on which the historic climax vegetation was predominantly trees.

- In **native** and **naturalized pasture**, forest land and naturalized open areas are used primarily for the production of forage for grazing by livestock and wildlife. Trees are managed for understory production.

Ecological Sites

- The **historic climax plant community** is the native plant community that developed on a site as a result of the natural environmental factors. It is not a precise assemblage of species for which the proportions are the same from place to place, or from year to year.

- The **state** of an ecological site is defined by the historic climax plant community and other stable plant communities that exist on that site.

- A **transition** is the process that causes an ecological site to shift from one state to another.

- Transitions to other "states" can be caused by **transition pathways** such as grazing, fire, climate, insects, diseases, erosion, introduced species, and/or other reasons.

Forage Suitability Groups

- Forage suitability groups have similar potentials and limitations for forage production. They support similar forage species, they require similar management, and they have comparable productivity.

- Pastureland is grazing land permanently producing introduced or domesticated native forage. It receives varying degrees of periodic cultural treatment to enhance forage quality and yields.

- Cropland and hayland are lands used for the production of cultivated crops, including forage crops, harvested primarily by human labor and equipment. Cropland and hayland may also be occasionally grazed.

Inventory and Monitoring

- Inventory and monitoring are the two methods of determining production, composition, and utilization of vegetation.

- These methods evaluate and rate ecological sites to determine trend, similarity index, rangeland health, and forage value ratings.

- Inventory and monitoring methods other than those currently in use by the Natural Resources Conservation Service (NRCS) are contained in Interagency Technical References: Sampling Vegetative Attributes (1996) and Utilization Studies and Residual Measurements (1996).

- All production and composition data collected by NRCS are based on weight measurements.

- Production is determined by measuring the annual above ground growth.

- Data represent <u>all</u> species that have measurable production.

- **Total annual production** is the total above-ground production of all plant species in a plant community during a single year, except for stem diameter increase in woody species; it is expressed as air dry weight in pounds per acre, or kilograms per hectare.

- The methods of evaluating ecological sites are trend, similarity index, management index, and rangeland health. (Note that the term **management index** has not yet been included in the handbook, but was recommended at the national training to differentiate similarity to desired plant communities from similarity to historic climax plant communities.)

- Trend is the direction of change of the plant community (for example, "toward," "not apparent," and "away from"). A **rangeland trend** is toward or away from historic climax. A **planned trend** is toward or away from a desired plant community.

- **Apparent trend** is a point-in-time determination.

- **Measured trend** measures trend indicators over time.

- A **similarity index** compares the present plant community to the historic climax plant community; it represents the percentage of the historic climax plant community that is currently on the site.

- A **management index** (see note, above) compares the present plant community to the desired plant community (a described "state" in the ecological site description); it represents the percentage of the desired plant community that is currently on the site.

- **Rangeland health** is the degree to which the integrity of the soil, the vegetation, the water, and the air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained.

- Range-health attributes are rills, water-flow patterns, pedestals, bare ground, gullies, wind erosion, cryptobiotic crusts, soil surface, infiltration and runoff, plant mortality, functional plant groups, litter distribution, litter amount, plant stress, production, invasive plants, and recruitment or reproduction.

- Rangeland health measures a departure from ecological site potential based on a preponderance of evidence. It evaluates soil and site stability, watershed and hydrological cycle, and soil and plant community integrity.

- **Forage value ratings** are based on the relative palatability of the forage plants, the relative length of the period they are available, and their relative abundance.

- Forage value ratings are “preferred plants,” “desired,” “undesirable,” “toxic,” and “non-consumed.”

Management

- A **key area** is a relatively small area in a grazing unit used to represent the grazing unit as a whole. It provides a significant amount of forage, is easily grazed, and consists of a single ecological site.

- **Key species** are palatable, perennial species, provide more than 15 percent of forage in the key area, and are useable in evaluating progress towards plan objectives.

- **Prescribed grazing** generally identifies a system in which two or more grazing units are grazed, deferred, or rested to meet plan objectives.

- The grazing management principles are the same for pastureland and grazed cropland. The intensity of management is usually higher, and knowledge of agronomic practices is needed.

- There are various methods for calculating initial stocking rates, as well as adjustments for determining efficiency, slope, and water distribution.

- Producers need to be aware of the nutritional profile of livestock through the year, and of the animal unit equivalent changes.

- NRCS considers 26 pounds oven dry weight, or 30 pounds air dry weight, of forage per day to be the standard forage demand for a 1,000 pound cow (called one animal unit). Thus, an **animal unit equivalent** equals 2.6 percent of an animal’s body weight.

Wildlife

- The development of a wildlife habitat management plan is an intregal part of NRCS assistance.

- Wildlife habitat interpretations are included in ecological site descriptions for rangeland, grazed forest, and native or naturalized pasture.

Enterprises

- Grazing lands provide a wide variety of products, pleasures, and benefits.

- Grazing is usually compatible with other uses.

- Grazing is not always the most economical use of land.

- The handbook identifies other potential uses.

Economics

- NRCS uses economic evaluations as a tool in evaluating alternative conservation practices and systems.

Planning

- NRCS can help clients understand basic ecological principles, the effects of their management on complex ecosystems, and their responsibility for environmental protection and sustainable land use.

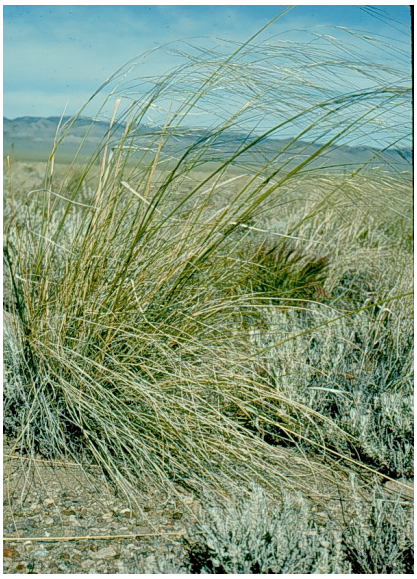
- Clients make the decisions, and clients apply the management and conservation practices.

- NRCS assists by providing resource information, planning assistance, practice design, and monitoring to document improvements in resource conditions.

(Editor's note: Readers may download, in its entirety, the 472-page, September 1997 document National Range and Pasture Handbook from the web site:

http://www.ftw.nrcs.usda.gov/pdf/NRPH.PDF.

Water Management



Needle-and-thread
Stipa comata

"Extreme Surface Roughening: A Technique for Establishing Natives on Arid Lands and Slope"

"Initial Evaluation of Shrub Transplanting Programs for Highway Slopes"

Extreme Surface Roughening:
A Technique for Establishing Natives on Arid Lands and Slopes

originally **a PowerPoint Presentation**

by

Susan White

Initial Evaluation of Shrub Transplanting Programs for Highway Slopes

presented by Debbra Stokes-Haglund

(Note to readers: This paper was first published in October 1997 as a University of Idaho National Center for Advanced Transportation Technology [NCATT] and Idaho Transportation Department [ITD] Cooperative Transportation Research Program [Research Brief No. ESC-03]. Its authors were Stanley Miller of NCATT [principal investigator for the "Integrated Erosion Control Methods for Highway Construction and Slope Maintenance" project] and Charles Rountree of ITD [ITD representative for this project].)

The primary goal is to evaluate options in shrub transplanting programs used for erosion control on highway slopes, including: survivability of various low-growing, non-woody species, comparisons of various chemical and organic treatments, and the effectiveness of DriWater™ (containerized water bound in solid form, which slowly liquefies to provide drip irrigation to transplants).

Beginning in July of 1996, several shrub-transplanting test sites were established in southwestern and northern Idaho, primarily on cutslopes along US 95. The test plots were set-up to allow at least one repeat for many of the proposed treatments, which included local topsoil, MiracleGro™ fertilizer, Quattro Kiwi Power and Fertil-Fibers, Plant Health Care™ mycorrhizal inoculant, and combinations of some of these. Follow-up inventories and evaluations of the test plots used a plant-health rating scheme based on 1=healthy as shown by new growth, 2=some signs of stress, 3=significant signs of stress, 4 =apparently dead.

Results and observations to date are summarized below:

1. Survival rates for shrubs planted with DriWater™ in summer 1996 were 78.5 percent for southwestern Idaho and 91.7 percent for northern Idaho with an overall rating of 155/179, or 86.6 percent.

2. In southwestern Idaho, plants treated with Kiwi Power had lower survival rates than those treated with MiracleGro™; in northern Idaho, there was no apparent difference between the two treatments.

3 . The addition of topsoil did not seem to provide any significant enhancement, whereas adding Fertil-Fibers consistently provided high ratings for the transplants that also received DriWater™.

4. Best performing species were silver and big sage in southwestern Idaho, woods rose in northern Idaho; generally, the 1-gallon size transplants did better than the smaller 10 cu. inch transplants, regardless of plant type.

5. No clear advantages were apparent for the mycorrhizal inoculant treatment, though its plants generally scored well.

6. Survival rates for spring 1997 plantings in northern Idaho were 84 percent for DriWater™ plants, 65 percent for non-DriWater™ plants.

Table 1 — Results of shrub transplanting on roadway slopes in southwestern Idaho

Species	**MiracleGro™ + Topsoil**	**K.Power + Topsoil**	**K.Power Only**	**MiracleGro™ + Mycorr**	**K.Power + Mycorr**
Horseshoe Bend Grade (SH 55 mile point 60.6): planted July 1996; each received 1 quart of DriWater™; field checked May 1997. Total = 26					
prairie sedge	1, 2	4, 4	1, 4		
winterfat	1, 1	1, 1	1, 1		
silver sage	1, 1	1, 1			
big sage	1, 1	1, 1			
Western clematis			2, 4	1, 1	1, 1
North of Weiser, Idaho (US 95 mile point 89.6 and 91.5): planted July 1996; each received 1 quart of DriWater™; field checked May 1997. Total = 46					
prairie sedge	1, 1, 1, 1	4, 2, 4, 1	1, 4		
winterfat	2, 2	1, 1	2, 2		
bitterbrush	2, 1	1, 4	4		
silver sage	1, 1, 1, 1	1, 1, 1, 1	1, 1, 1, 1		
rabbitbrush	1, 1	4, 4	4, 4		
Western clematis			1, 1	1, 1	4, 4

Notes: Very little rainfall occurred from July through early September 1996.
Overall performance: 47 plants received a rating of 1, 8 plants a rating of 2, and 15 plants a rating of 4; 55 of 70 plants [78.5 percent] survived.)
Field inspections in September through October of 1997 indicated similar "scores," with silver sage and big sage doing especially well.

Table 2 — Results of shrub transplanting on roadway slopes in northern Idaho

Species	**MiracleGro™ + Topsoil**	**K.Power + Topsoil**	**K.Power Only**	**MiracleGro™ + Mycorr**	**MiracleGro™ Only**
North of Genesee, Idaho (US 95 mile point 332.5): planted July 1996; each received 1 quart of DriWater™; field checked May 1997. Total = 24 [* = planted November 1996; no DriWater™]					
snowberry	1, 1	1, 1	1, 1		
woods rose	1, 1	1, 1	1, 1		*1, 1, 1, 1,1, 1, 1
crp. Oregon grape	1, 1	1, 1	1, 1		
Western clematis	1, 4	1, 1	2, 1		
North of Moscow, Idaho (US 95 mile point 346.8 and 347.8): planted July 1996; each received 1 quart of DriWater™; field checked May 1997. Total = 17 [** = this site was destroyed bymud slides in January of 1997; tabulated "scores" are from a November 1996 site visit. B = buried by mud debris]					
snowberry**	4	3	4		
woods rose**	3	2	2		
crp. Oregon grape**	1	1	3		
Western clematis**	3	4	4		
Western clematis	4, 4	B, 3	4, 1		
North of Viola, Idaho (US 95 mile point 354.6): planted July 1996; each received 1 quartof DriWater™; field checked May 1997. Total = 18 [* = planted November 1996; no DriWater™]					
snowberry	1, 1	4, 1	1, 1		*1, 1, 1
woods rose	1, 1	1, 1	1, 1		
crp. Oregon grape	1, 2	1, 1	2, 2		
Mineral Mountain Rest Area (US 95 mile point 370.6): planted July 1996; each received 1 quart of DriWater™; field checked May 1997. Total = 17 [* = tabulated "score"is from a November 1996 site visit, before plant was buried by mud debris]					
snowberry	*1, 2	1, 1	1, 1	1, 1	
woods rose	1, 1	1, 1	*1, 1	1, 1	
crp. Oregon grape	*1, *1	*1, *1	2, 1	*1, *1	

Table — continued

Species	MiracleGro™ + Topsoil	K.Power + Topsoil	K.Power Only	MiracleGro™ + Mycorr	MiracleGro™ Only
West of Sandpoint, Idaho (US 2 mile point 16.0): planted September 1996; each received 1 quartof DriWater™; field checked May 1997. Total = 26 [B = buried by mud debris]					
snowberry	1, 1	1, 1		1, 1	
woods rose	1, 1	1, 1	1, 1	1, 1	1, 1
crp. Oregon grape	1, 1	1, 1	1, 1	1, 1	1, 1
Western clematis	B	B	B		

Notes: Very little rainfall occurred from July through September 1996.
Overall performance: 85 plants received a rating of 1, 10 plants a rating of 2, 5 plants a rating of 3, and 9 plants a rating of 4; 100 of 109 plants [91.7 percent] survived.)
Field inspections in September through October of 1997 indicated similar "scores," with woods rose doing especially well.

Table 3 — Results of spring 1997 shrub transplanting in Northern Idaho

Species	MiracleGro™ Only	MiracleGro™ +K Power	Fert. Fibers + K. Power	Fert. Fibers + Mycorr	Fert. Fibers Only	None
North of Genesee, Idaho (US 95 mile point 332.5): planted April 1997; field checked August 1997. Total =70						
woods rose (DriWater™)	1, 1	1, 1	4, 3	2, 3	3, 3, 1,1, 1, 1, 3	1, 2
woods rose (no DriWater™)	1, 4	1, 1	3, 2	1, 1	3, 3, 1, 4, 1, 2, 4	4, 2, 4, 1
Oregon grape (DriWater™)	1	2	4	2	4	3
Oregon grape (no DriWater™)	2	2	4	4	4	2
gold currant (DriWater™)	1	2	4	2	4, 1, 3, 2, 2, 2	3
gold currant (no DriWater™)	2	2	4	4	4, 1, 2, 1, 4, 4	3

Table — continued

Species	**MiracleGro™ Only**	**MiracleGro™ +K Power**	**Fert. Fibers + K. Power**	**Fert. Fibers + Mycorr**	**Fert. Fibers Only**	**None**
West of Sandpoint, Idaho (US 2 mile point 16.0): planted May 1997; field checked August 1997. Total =47 [P = damaged by predator]						
woods rose (DriWater™)	1, 4, 1	2, 1, 1	1, P, 1	1, 1, 1	1, 1, 4	1, 1, 2
woods rose (no DriWater™)	4, 4, 3	3, 2, 2	1, 4, 3	2, 1, 1	3, 4, 4	2, 2, 2
Oregon grape (DriWater™)	4	2	2	3	3	4
Oregon grape (no DriWater™)	4	3	4	3	4	3

Notes: Above average rainfall occurred from April through June 1997.

Overall performance for plants with which DriWater™ was not used: 14 plants received a rating of 1, 15 plants a rating of 2, 10 plants a rating of 3, and 21 plants a rating of 4; 39 of 60 plants [65.0 percent] survived.)

Overall performance for DriWater™ plants: 25 plants received a rating of 1, 13 plants a rating of 2, 10 plants a rating of 3, and 9 plants a rating of 4; 48 of 57 plants [84.2 percent] survived.)

A statistical, two-sample hypothesis test comparing these two proportions clearly indicates that these proportions are significantly different from each other (the calculated value of the Z-statistic is very large: 29.4).

Erosion Control

Western wheatgrass
Pascopyrum smithii

"The Future of Erosion Control on Mine Projects: NPDES and ASTM D-18.25"

"Considerations for Arid and Semi-Arid Designs"

"Terrace Design Using RUSLE and SEDCAD 4"

"Non-parametric Vegetation Evaluation for Bond Release"

"Breeding and Selection of Superior Plants for Use in Reclamation"

The Future of Erosion Control on Mine Projects: NPDES and ASTM D-18.25

Dwight A. Cabalka, P.E./C.P.E.S.C.

Introduction

In 1987, Congress added Section 402(p) to the Clean Water Act which required implementation of a comprehensive approach for addressing storm-water discharges. This section requires national pollutant discharge elimination system (NPDES) permits for storm-water discharges associated with industrial activity and municipal separate storm sewer systems serving "urbanized areas" with populations greater than 100,000. The Environmental Protection Agency (EPA) issued final regulations for these "Phase I" sources on November 16, 1990.

Included in the Code of Federal Regulations (CFR), volume 40, Protection of Environment, are regulatory powers regarding erosion and sediment control. First published as a part of the Clean Water Act of 1992, Sections 122 through 125 of this volume describe provisions of NPDES. These 193 pages provide landmark legislation currently being applied to construction sites of all types, not only within the U.S. but increasingly by environmentally conscious countries, owners, developers, designers, and contractors throughout the world. Given the typical magnitude of disturbance often associated with site projects and improvements, a major focus of this legislation is the controlling storm-water discharges from highways, landfills, and mines.

NPDES Overview

The NPDES program establishes a permitting process for construction projects, defines "total suspended soils" as a pollutant, and also mandates the use of best management practices (BMP's), as appropriate for site-specific needs. As defined in regulations at 40 CFR, BMP means "schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of 'waters of the United States.' BMP's also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage."

To assure compliance with the intent of the Clean Water Act, NPDES requires the development of storm-water pollution prevention plans (SWPPP's). These plans define the BMP's to be used on any given project, both as temporary measures that are part of the construction process and as final treatments to stabilize sites and prevent further erosion. Obviously, the dynamic nature of construction activities require constant monitoring to assure that the planned BMP's remain functional or that additional measures be implemented, as necessary.

Currently, revisions to the Clean Water Act, covering the NPDES program, have been proposed. According to documents posted on the EPA web site at www.epa.gov/owmitnet/sw2.htm, the proposed NPDES Storm Water Phase II Rule includes expansion of the existing national

program to more municipalities and construction sites. Urbanized areas with populations greater than 50,000 (reduced from 100,000) and construction sites with greater than 1 acre of disturbed land (reduced from 5 acres) will be affected by these changes. It is estimated that 110,000 more construction sites will be covered by this program. With the proposed expansion of NPDES, even more attention will be focused on erosion and sediment control activities.

These changes to the NPDES program will increase the total number of permit areas greatly - from approximately 1,200 to approximately 6,700. The planned publication date for the NPDES Storm Water Phase II is October 29, 1999. (Editor's note: The actual publication date was December 8, 1999.)

Current Standards and NPDES Enforcement

The problem, however, is there are no industry-wide standards that define the material characteristics, performance capabilities, installation requirements or application guidelines for BMP's. Over the years, a variety of testing programs, both laboratory and field, have been conducted to investigate the materials, installation, and performance attributes of BMP's (see "References," below). Most of these programs have been relatively short-term, one-time tests that have lacked consistency and uniformity with other such tests. Only one program has been conducted on an ongoing basis. Unfortunately, it was not developed as an industry consensus protocol and contains a number of significant technical and statistical flaws (Sutherland, 1998).

As a result, manufacturers are left facing inconsistent material requirements. Contractors are subjected to arbitrary evaluations of installation quality and designers can not be assured of the suitability of a BMP for a given application. Owners wonder whether their projects meet the intent of NDPES. And regulators are faced with many "gray areas" in terms of enforcement.

These uncertainties in the application of erosion and sediment control BMP's can create significant areas of concern when the enforcement clauses of the NPDES program are taken into consideration. Adminstration of the NPDES program and enforcement actions are the responsibility of the State. The enforcement provisions of the NPDES program are found in regulations at 40 CFR 122.41 (subpart C, Permit Conditions). These enforcement provisions are significant and substantial to individuals, corporations, and government entities and are summarized, as follows:

Persons

Negligent violation:

First infraction:
Fine of $2,500 to $25,000 per day of violation;
Imprisonment up to 1 year; or

Second or subsequent infractions:
Fine up to $50,000 per day of violation;
Imprisonment up to 2 years; or

Persons–*continued*

Knowing violation, criminal:

First infraction:
Fine of $5,000 to $50,000 per day of violation;
Imprisonment up to 3 years; or

Second or subsequent infractions:
Fine up to $100,000 per day of violation;
Imprisonment up to 6 years; or

Knowing violation, imminent danger of death or serious bodily injury:

First infraction:
Fine up to $250,000 per day of violation;
Imprisonment up to 6 years; or

Second or subsequent infractions:
Fine up to $500,000 per day of violation;
Imprisonment up to 15 years; or

Organizations

Knowing violation, imminent danger of death or serious bodily injury:

First infraction:
Fine up to $1,000,000 per day of violation; or

Second or subsequent infractions:
Fine up to $2,000,000 per day of violation.

Both fines and imprisonment penalties can be enacted for the same offense. In addition, "administrative penalties" of up to $10,000 per violation can be assessed, up to a maximum of $25,000 for Class I infractions, as defined by the Clean Water Act. For Class II infractions, administrative penalties of up to $10,000 per day can be assessed, up to a maximum of $125,000.

Given the NPDES requirements, a variety of uncertainties and the enforcement liabilities, it seems obvious that erosion and sediment control standards are needed. And as the regulatory philosophy moves from a BMP-based program to a storm-water quality-based program, the need for standards will be increased. American Society of Testing and Materials (ASTM) Subcommittee D-18.25 may be the answer to these needs.

ASTM Standards Development

In June 1996, the ASTM established a new subcommittee, D-18.25, "Erosion and Sediment Control Technology." This committee was the result of a joint effort between the International Erosion Control Association (IECA) and ASTM for the purpose of developing standards for all manner of erosion and sediment control BMP's. IECA had begun the standards development process for these BMP's in about 1990, but, due to the lack of a structured approval procedure and liability risks associated with document publication, had been unable to develop and publish the desired standards.

Recognizing these obstacles, IECA approached ASTM to determine if a committee could be established for this purpose. After a period of investigation and review, it was decided that Committee D-18, "Soil and Rock," would be the best location for such new group. In addition, since many erosion and sediment control BMP's use or have similarities to conventional geosynthetics (e.g., geotextiles, geomembranes, drainage nets, geogrids, etc.), it was also determined that liaison and involvement with D-35, "Geosynthetics," could bring valuable expertise to this effort.

The use of ASTM's standards development procedures was found to be particularly desirable, since it is based on a consensus building process that demands involvement of both users and producers. To build consensus standards, it is required that any and all negative ballots to a given standard be resolved as either (1) "agree" (in which case the proposed standard is revised and reballoted), (2) "withdrawn" (in which case the voter agrees to withdraw his or her negative), or (3) "nonpersuasive" (in which case the comment is overridden by a majority of the voting members). Dictatorial standards simply can not be published.

In addition, committee D-18 mandates that each subcommittee have a balance of voting members between "users" and "producers." If the committee membership exceeds 50 percent producers, then producer voting privileges are withdrawn until the balance is restored.

D-18.25 Activities

The first working meeting of D-18.25 was held in New Orleans, Louisiana, in January 1997, with approximately 70 participants. At this meeting, it was agreed that "[i]t shall be the responsibility of Subcommittee D-18.25 to develop and maintain standards for all manner of erosion and sediment control best management practices (BMP's), including material characteristics, installation requirements, performance capabilities and application guidelines."

Initially, eight sections were established, but that has already been expanded to ten to accommodate the needs of the committee. The addition of an eleventh section, "Large Armor Units," is currently being considered. The ten existing sections are:

.01 Mulches and tackifiers

.02 Erosion control blankets (ECB's)

.03 Turf reinforcement mattings (TRM's)

.04 Articulating concrete block revetments (ACB's)

.05 Gabions

.06 Geocellular confinement materials (GCS's)

.07 Fabric-formed concrete systems (FFCS's)

.08 Sediment control

.09 Terminology

.10 Soil bioengineering

At present, approximately 150 experts are actively participating in D-18.25, including government officials, owners, designers, contractors, manufacturers, test labs, colleges/ universities and industry associations. D-18.25 meets twice a year during the D-18/D-35 committee-week meetings, once in January and once in June. In addition, "outside" meetings have been held at the IECA annual conference in February. Between meetings, written correspondence, teleconferences, faxes and e-mails, provide the means for communication to further this standards development effort. Approximately 30 standards are currently under development, ranging from informal drafts to main-committee ballot. Of course, the approval schedule for these documents can not be predicted, but steps to seize the initial momentum of this group and expedite publication are being taken. This is particularly important, given the all-volunteer effort of this ASTM activity.

Three standards have been approved for publication, as follows (not official titles):

Performance Capability of Erosion Control Blankets in Protecting Hillslopes from Rainfall-Induced Erosion;

Performance Capability of Erosion Control Blankets in Protecting Channels from Stormwater-Induced Erosion; and

Flow-Ability of Grout for Fabric-Formed Concrete Systems

Standards Application

In the construction industry, one needn't look too far to see the impact of ASTM standards. Anyone involved with the construction of civil or earthwork-related projects becomes quickly aware of how valuable and respected ASTM standards are to many day-to-day work activities. A few of the most fundamental and well-recognized ASTM test standards include:

- Steel tensile strength
- Aggregate gradation
- Soil density (Proctor density)
- Concrete compressive strength
- Geotextile tensile strength

While all the previously referenced documents are for materials characteristics, ASTM is not limited to this type of standard. Therefore, D-18.25 is seeking to develop not only materials standards, but also installation, performance, and applications documents. It is anticipated that each type of document should play a key role in how construction projects are planned and built. Whether these documents are used for periodic tests of material or installation quality as part of an ongoing project, or whether they are used for planning and design efforts prior to construction, they should provide sorely needed guidance.

As with existing ASTM standards, new erosion and sediment control standards are likely to be referenced by owners and designers in their SWPPP's. These standards may also be referenced, as tools for erosion and sediment-control professionals, by the EPA itself, State program administrators, or project owners.

Finally, the groundbreaking NPDES program is affecting the way that erosion and sediment control are viewed worldwide. In some cases, these EPA regulations are being directly referenced by foreign counties as the program to be adhered to within their jurisdiction. In other cases, these U.S. regulations have formed the basis for parallel regulations published by the foreign country. And is some cases, although not mandated, environmentally conscious owners, designers, and constructors have chosen to "export" the NPDES program to meet political and social objectives. Whatever the reason, the impacts of NPDES are being felt around the globe. This is an especially important consideration for the mining industry, which is increasingly developing mines outside of the U. S.

In that same context, cooperative relationships between ASTM and overseas standards organizations may very well have a similar impact. It is quite possible that, as new standards are published by ASTM, they will be adopted verbatim or serve as a basis for use in other foreign standards.

Conclusions

The NPDES established in 1992 as part of the Clean Water Act has greatly increased the awareness of erosion and sediment control activities on disturbed lands, including infrastructure construction sites. To allow consistent application of erosion and sediment control Best Management Practices, evaluation of constructed BMP quality, and enforcement of the NPDES regulations, it is necessary to develop industry-wide standards. ASTM standards which are

developed through a unique consensus process provide the best vehicle for erosion and sediment control standards.

ASTM Subcommittee D-18.25, "Erosion and Sediment Control Technology," is actively developing standards on a variety of BMP's, including material characteristics, installation requirements, performance capabilities and application guidelines. It is anticipated that these standards will be used for planning and design efforts, as well as construction Quality Control/Quality Assurance programs.

Author's Notes

The final status of the proposed EPA "Storm Water Phase II Rule" was not available as of the presentation date for this paper (September 23, 1999).

Anyone interested in participating in ASTM Subcommittee D-18.25 is encouraged to contact Robert Morgan, Staff Manager, Committee D-18, ASTM, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959. Mr. Morgan's telephone number is 610-832-9732. His telefax number is 610-832-9555; his e-mail address is rmorgan@astm.org.

References

Cabalka, D.A. and Clopper, P.E., 1997,"Design, Construction and Operation of a State-of-the-Art Erosion Technology Test Laboratory," Proceedings of the International Erosion Control Association, v. 28, pp. 341-350.

Cabalka, D.A., Clopper, P.E., and Johnson, A.G., 1998, "Research, Development and Implementation of Test Protocols for Channel Erosion Research Facilities (CERF's)," Proceedings of the International Erosion Control Association, v. 29, pp. 238-48.

Cabalka, D.A., Clopper, P.E., Johnson, A.G., and Vielleux, M.T., 1998,"Research, Development and Implementation of Test Protocols for Rainfall Erosion Facilities (REF's)," Proceedings of the International Erosion Control Association, v. 29, pp. 249-63.

Chen, Y.H., and Cotton, G.K., 1986, "Design of Roadside Channels with Flexible Linings," Hydraulic Engineering Circular No. 15, Report No. FHWA-IP-86-5, Washington, D.C.

Construction Industry Research and Information Association (London, England), 1987, "Design of Reinforced Grass Linings." Construction Industry Research & Information Association (CIRIA).

Clopper, P.E. and Chen, Y.H., 1988, "Minimizing Embankment Damage During Overtopping Flow," FHWA Report No. FHWA-RD-88-181, Washington, D.C.: Federal Highway Administration.

U.S. EPA, 1995, “Storm Water Discharges Potentially Addressed by Phase II of the National Pollutant Discharge Elimination System Storm Water Program - Report to Congress. Office of Water. EPA 833-K-94-002.

Gunn, R. and Kinzer, G.D., 1949, “The Terminal Velocity of Fall for Water Droplets in Stagnant Air,” Journal of Meteorology, v. 6, pp. 243-8.

Kosco, J., 1999, “Expanding the Coverage of the NPDES Storm Water Program: The Proposed Phase II Rule”, U.S. Environmental Protection Agency, Office of Water.

Laws, J.O., 1941, “Measurements of the Fall-Velocity of Water-drops and Raindrops,” Transactions of the American Geophysical Union, V. 22, pp. 709-21.

McWhorter, J.C., Carpenter, T.G., and Clark, R.N., 1968, “Erosion Control Criteria for Drainage Channels,” Conducted for the Mississippi State Highway Department in cooperation with the U.S. Federal Highway Administration, by the Agricultural and Biological Engineering Department, Mississippi State University, State College, Mississippi.

Sutherland, R.A., 1998, “A Critical Assessment of the Research Conducted at the Hydraulics and Erosion Control Laboratory - A Focus on Rolled Erosion Control Systems Applied to Hillslopes”, Geotextiles & Geomembranes, Elsevier Science, London, England.

Sutherland, R.A., and Ziegler, A.D., 1996, “Geotextile Effectiveness in Reducing Interrill Runoff and Sediment Flux,” Proceedings of the International Erosion Control Association, v. 27, pp. 394-405.

Texas Department of Transportation, 1993, “Procedures and Evaluation Criteria for Flexible Erosion Control Blankets, Flexible Channel Lining Materials, and Hydraulically Applied Projects,” Texas Department of Transportation in cooperation with the Texas Transportation Institute, Environmental Management Program, Austin, Texas.

Thibodeaux, K.G.,1985, “Performance of Flexible Channel Linings,” U.S. Federal Highway Administration Report No. FHWA/RD-86/114, Washington, D.C.

U.S. Congress, 1995, “Protection of the Environment”, 40 CFR Parts 87 to 149, Washington, D.C.

U.S. Department of Agriculture, 1978, “Predicting Rainfall Erosion Losses,” Agriculture Handbook No. 537, Washington, D.C.

U.S. Department of Agriculture, 1997, “Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation,” Agriculture Handbook No. 703, Washington, D.C.

63 FR 1536-1643, January 9, 1998 (Proposed Storm Water Phase II Rule).

Biographical Sketch

Dwight Cabalka is employed by American Excelsior Company, Earth Science Division, Arlington, Texas, and is the Manager of Technical Services.

Mr. Cabalka has a Bachelor of Science degree in Civil Engineering from Iowa State University, a Masters degree in Business Administration from the University of Colorado, is a registered Professional Engineer and a Certified Professional in Erosion and Sediment Control, and has approximately 18 years of construction industry experience, including project management of erosion control testing activities.

He is the Chairman of ASTM Subcommittee D-18.25, "Sediment and Erosion Control Technology," and one of only two appointed industry advisors on American Association of State Highway Transportation Official's National Transportation Product Evaluation Program Erosion Control Panel.

Mr. Cabalka served as external reviewer of "Guidelines for the Use of the Revised Universal Soil Loss Equation on Mined Lands, Construction Sites, and Reclaimed Lands" which was published recently by the Office of Surface Mining.

He is also active on the International Erosion Control Association Committee-on-Standards and the Erosion Control Technology Council, is the author of numerous technical papers and articles on erosion and sediment control, and is a recognized speaker on these subjects.

Considerations for Arid and Semi-Arid Designs

William Agnew
Granite Seed Company

Introduction

The amount of worldwide erosion is staggering. Cumulative research suggests that excessive sediment in our waterways is the planet's most prevalent contaminant. Sediment accounts for more than two-thirds of all pollutants entering United States waterways. Estimates indicate up to $13 billion per year are spent in the United States to directly mitigate the offsite impacts of erosion and sediment.

Recently a number of laws have been mandated in the United States to combat excessive erosion. Legislation ranges from local erosion and sediment-control ordinances to numerous State and Federal agricultural, waste-containment, and surface-mining acts, to the broadly encompassing U.S. Environmental Protection Agency's (EPA's) 1972 Clean Water Act and the Department of Agriculture's Farm Bill.

In October 1992, the Clean Water Act began requiring projects that disturb more than 2 hectares (5 acres) of land to obtain a National Pollutant Discharge Elimination System (NPDES) permit to help identify and quantify release of pollutants into watersheds.

Landfills, surface mines, oil and gas projects, commercial real estate developments, and public agencies such as Departments of Transportation (DOT's) and county and municipal entities are expected to develop erosion- and sediment-control plans or face stiff Federal fines. These actions are only the tip of the iceberg as more and more government agencies and entities adopt similar programs.

What is Erosion Control?

To control erosion is to curb or reduce (not completely stop) the gradual or sudden wearing away of soils. We have all seen extreme examples of excessive erosion such as gullied hill slopes or stream channels choked with debris, but often erosion goes unchecked on flat to moderately sloping terrain. Soil loss is a continually occurring process in natural ecosystems as well as on successfully reclaimed sites.

The goal of any revegetation or erosion-control project should be to stabilize soils and manage erosion in an economical manner (Theisen, 1988; Agnew and Humphries, 1991). In this era of shrinking budgets, decisionmakers are hard-pressed to reclaim disturbed sites at minimum costs. Given site conditions such as slope angles, climate, runoff, soil profile and ultimate land use, a specifier must select with confidence a technique he/she feels will perform up to expectations at the lowest cost.

During the past 25 years the erosion control industry has experienced rapid growth and is becoming more sophisticated. Materials developed for erosion and sediment control are becoming increasingly effective. Improved design and installation guidelines are directing the use of these products toward more specific and cost-effective applications. The industry has evolved from seed drills, straw blowers, hydroseeders, excelsior, jute, concrete channel liners, and the riprap of the 1960's into a diverse hierarchy of techniques and materials.

Types of Erosion and Sediment Control Materials

Biaxially Oriented Process Nets – Biaxially oriented process nets are typically manufactured from polypropylene or polyethylene resins. These nets are extremely versatile in that composition, strength, elongation, aperture size and shape, color, and ultraviolet stability can easily be designed into the product for site-specific requirements. Because they do not absorb moisture, these nets do not shrink and swell like paper nets and jute blankets. Biaxially oriented nets have proven to be so adaptable they are being used to create more complex products and are even used alone to anchor loose fiber mulches such as straw, hay, and wood chips. The lightweight nettings placed over mulches come in rolls which are 3 to 4 ½ meters in width, weigh only about 55 kilograms, and will cover 0.4 hectares (1 acre) or more. Installation of these products is less labor-intensive than traditional netting products.

Erosion Control Blankets – Biaxially oriented nettings or woven meshes of varying characteristics are placed on one or both sides of finely tuned erosion control blankets adapted to anticipated site conditions. These 1- to 2-meter wide biodegradable fiber erosion control blankets are composed of straw, excelsior, cotton, coconut, polypropylene, or blends. Nettings or meshes may contain ultraviolet (UV) stabilizers for controlled degradation or long-chain interrupters to accelerate photodegradation. Colors vary from clear, tan, or green to black. Methods of holding the fibers in place range from glues and glue strips to more superior parallel lock stitching with cotton, polyester, or polyolefin threads. Applications for the wide variety of blankets range from protection of gradual to steep slopes to low or moderately flowing channels. The top of the line blankets may provide temporary resistance to short-duration flow velocities of up to nearly 3 meters per second.

Perhaps most advantageous to the environment, these meshes and nettings may ultimately become biodegradable. As photodegradation progresses, the plastic chains break into shorter and shorter segments down to a plastic "sand" which becomes part of the soil. These short segments become biologically degradable and are attacked by soil microorganisms and converted to carbon dioxide and water (Guillet, 1974). It is unfortunate that emotional, uninformed anti-plastic stigmas sometimes preclude the use of these extremely cost-effective temporary materials in lieu of costly exotic fibers or hard-armor solutions.

Open Weave Geotextile Erosion Control Meshes – Open weave polypropylene geotextiles can provide performance comparable to that of natural fiber erosion-control blankets. These photobiodegradable, natural-looking, high-strength polypropylene meshes protect the soil surface from water and wind erosion while accelerating vegetative development. Four meter-wide, lightweight rolls facilitate installation on slopes and channels. Erosion control meshes may be used alone, with dry mulches or as a stabilizing underlay for sod reinforcement. They also show promise as an open-weave geotextile facing for fostering vegetation on geosynthetically reinforced steepened slopes or bioengineering installations where establishment of woody plant species is desired. Displaying rapid photobiodegradation in one direction, these meshes allow woody vegetation to freely sprout and emerge through the installation with little potential of girdling.

Temporary *vs*. Permanent – At this point, an important distinction must be presented regarding the intended use of erosion-and sediment-control materials. For many installations, vegetation alone will provide adequate long-term erosion protection. However, getting vegetation established requires a variety of techniques. Materials of a temporary nature which facilitate vegetative establishment, then degrade, are called temporary erosion and revegetation materials.

These temporary materials consist of degradable natural and/or synthetic components that provide temporary erosion control and aid in the growth of vegetation. In only a few instances are temporary products totally organic. Vital geosynthetic components include nettings, stitchings, and adhesives. These short-term materials degrade, leaving only vegetation for long-term low to medium flow resistance.

Temporary techniques include straw, hay and hydraulic mulches; tackifiers and soil stabilizers; hydraulic mulch geofibers; and erosion-control nets, meshes, blankets, and fiber-roving systems.

Site conditions requiring the higher performance of reinforced vegetation or revetment systems will require permanent erosion and revegetation materials. Permanent materials may be subdivided into *Biotechnical composites*™, when vegetation is reinforced, or hard-armor systems when nonvegetated inert materials are installed.

Biotechnical composites™ are composed of nondegradable materials which furnish temporary erosion protection, accelerate vegetative growth, and ultimately become entangled with living 'plant tissue to extend the performance limits of vegetation.

Reinforced vegetation provides permanent medium- to high-flow resistance when biotechnical composites are protected from sunlight by shading from vegetation and soil cover.

Examples of biotechnical composites include UV-stabilized, fiber-roving systems; erosion-control revegetation mats; turf-reinforcement mats; permanent erosion-reinforcement matrices; soil and sports turf geofibers; vegetated geocellular containment systems; and vegetated concrete block systems.

Hard-armor systems generally employ inert materials used to provide high to maximum flow resistance where conditions exceed performance limits of reinforced vegetation systems. Hard-armor systems are used to provide permanent erosion protection of areas subject to high flows, wave action, and/or scour attack. Examples include geocellular containment systems, fabric-formed revetments, concrete-block systems, gabions, riprap, composites, and hybrids.

Bonded Fiber Matrix Systems – Bonded fiber matrices are hydraulically applied systems that conform to the soil surface and are used on steep-slope applications. Once dry, the matrix forms a blanket of continuous 100-percent coverage which adheres to the soil. The resulting blanket is water insoluble, which means it can be re-wetted repeatedly and will hold soil and seed without washing away.

Bonded fiber matrices are fully biodegradable and are composed of wood fibers, organic tackifiers, and mineral bonding agents or may have a wood-fiber gypsum component. As vegetation takes hold, bonded fiber-matrix systems slowly decompose.

The use of bonded fiber matrices is expanding rapidly. The expansion is primarily due to excellent product performance combined with reduced site preparation, enhanced safety considerations, and reduced installation costs compared to traditional natural blankets.

Fiber Roving Systems – Fiber roving systems are another geosynthetic concept providing moderate erosion protection (Agnew and Theisen, 1994). Developed in the late 1960's, rovings are applied in a continuous strand for protection of drainage swales and slopes.

Fiberglass roving is a material formed from fibers drawn from molten glass and gathered into strands to form a single ribbon. Polypropylene roving is formed from continuous strands of fibrillated yarns wound onto cylindrical packages such that the material can be fed continuously from the outside of the package. Use of fiberglass roving has been declining and is being displaced by more versatile "environmentally friendly" polypropylene roving.

Erosion-control roving is unusual because of the flexibility of application, allowing for any width or thickness of material to be applied (Agnew, 1991). Other erosion-control materials, such as blankets or mats, require the user to apply the width or thickness of material supplied. Fiber rovings may be viewed as an "in situ" erosion-control geosynthetic with reduced labor and material costs over

traditional blanket materials. The continuous-strand concept provides ease of installation with minimal waste factors from overlap.

Using compressed air, roving is rapidly applied through a nozzle over the seeded surface and then anchored in place using emulsified asphalt or other natural or synthetic soil stabilizers. Photobiodegradable polypropylene roving may be used for temporary applications or when UV stabilizers are added for extended use situations.

The use of fiber-roving systems is rapidly expanding. Key markets include highways, surface mines, and landfills. The future in fiber-roving systems lies in the development of a one-step application apparatus which will further accelerate installation efficiency. The concept of developing an onsite mat or blanket is certainly appealing and extremely cost-effective.

Geosynthetic Mattings for Turf Reinforcement – Turf reinforcement is a method or system by which the natural ability of plants to protect soil from erosion is enhanced through the use of geosynthetic materials. A flexible three-dimensional matrix retains seeds and soil, stimulates seed germination, accelerates seedling development, and, most importantly, synergistically meshes with developing plant roots and shoots. In laboratory and field analyses, biotechnically reinforced systems have resisted flow rates in excess of 4 meters per second for durations of up to two days, **providing twice the erosion protection of unreinforced vegetation** (Carroll et. al., 1991). Such performance has resulted in the widespread practice of turf reinforcement as an alternative to concrete, riprap, and other armor systems in the protection of open channels, drainage ditches, detention basins, and steepened slopes.

Permanent geosynthetic mattings are composed of durable synthetic materials stabilized against ultraviolet degradation and inert to chemicals normally encountered in a natural soil environment. These mattings consist of a lofty web of mechanically or melt-bonded polymer nettings, monofilaments, or fibers that are entangled to form a strong and dimensionally stable matrix. Polymers include polypropylene, polyethylene, nylon, and polyvinyl chloride.

Geosynthetic mattings generally fall into three categories: permanent erosion reinforcement matrices, turf reinforcement mats, and erosion-control revegetation mats. Having a very high coefficient of friction with soil, reinforcement matrices complement vegetation and provide long-term performance in channels and on slopes under the most adverse conditions. Three-dimensional permanent erosion reinforcement matrices provide unparalleled strength and dimensional stability. Due to their tremendous strength properties, reinforcement matrices may be used as a form which is filled with concrete or grout to create an inexpensive hard-armor system.

High strength turf reinforcement mats provide sufficient thickness and void space to permit soil filling/retention and the development of vegetation within the matrix. Like reinforcement matrices, turf reinforcement mats are installed first, then seeded and filled with soil. Seeded prior to installation , erosion-control revegetation mats are dense, lower profile mats designed to provide long-term ground cover and erosion protection. Erosion-control revegetation mats **provide** superior temporary erosion protection.

By their nature, permanent erosion reinforcement matrices and turf reinforcement mats can be expected to provide more vegetation entanglement and long-term performance than erosion-control revegetation mats.

Geosynthetic mattings currently occupy one of the fastest growing niches of the erosion- and sediment-control industry.

Geocellular Containment Systems – Geocellular Containment Systems work in a unique fashion in that strength or stabilization by confinement is achieved by a series of three-dimensional cells up to 20 centimeters deep. When expanded into position, the polyethylene or polyester cells have the appearance of a large honeycomb, one of nature's most efficient structures. The cells are then backfilled with soil, sand or gravel depending upon application. For vegetation, the soil-backfilled cells are seeded, fertilized, and covered with a variety of either temporary or permanent erosion-control mulches that provide surface protection while the cells greatly reduce the chances of subsurface failure and act as a deeper rooted biotechnical composite. Shallow lateral root development is precluded by the nearly impermeable geocell walls. As such, vegetated geocellular systems are limited to flow velocities of 2 to 3 meters because of the tendency of the cells to sustain scouring under high-flow velocities or shear conditions (Chen and Anderson, 1986).

Similar to reinforcement matrices and for higher flow conditions, geocellular containment systems may act as an easy-to-install form, which is filled with concrete or grout to create a hard-armor system. Typically a geotextile will be placed beneath the expanded web to provide separation and/or filtration. Erosion-control applications for geocellular containment systems are many, including steep slope revegetation, channel liners, shoreline revetments, retaining walls, boat ramps, and low-flow stream crossings.

Fabric-Formed Revetments – Fabric-forming systems are mattresses typically constructed of water permeable, double layer woven geotextiles which are positioned on the area to be protected and filled with a pumpable fine-aggregate concrete (structural grout). The two layers of geotextile are joined at discrete points to create a form which when filled with grout will conform to most subsoil conditions. Thickness and geometry are determined by internal spacer threads woven into the upper and lower sheets of fabric. In many cases the mattresses may be installed for less cost

than conventional armor systems since all construction is conducted in place with no heavy equipment or skilled labor required (Richardson and Koerner, 1990).

Fabric-formed revetments are generally available in three styles: filter point, uniform section, and articulating block mats. Filter point mats are formed with a double-layer woven fabric, joined together by interwoven filter points that relieve hydrostatic pressure. Uniform section mats are formed with a double-layer woven fabric, joined together by spacer cards on closely spaced centers. Relief of hydrostatic uplift pressure may be provided by inserting plastic weep tubes through the mat at specified centers. Articulating block mats are formed with a double-layer woven fabric, joined together into a matrix of rectangular compartments each separated by a narrow perimeter of interwoven fabric. High-strength cables may be threaded between the two layers of fabric to interconnect the concrete filled compartments (blocks) and provide for block articulation. Hydrostatic pressure relief is achieved by slits cut between adjacent blocks and/or inserting plastic weep tubes. A filtration geotextile is recommended beneath all fabric-formed revetments.

Installation of fabric-formed revetments consists of four basic steps:

1. Site Preparation

2. Geotextile and Panel Placement/Field Assembly

3. Structural Grout Pumping

4. Inspection of Field Seams, Zipper Connectors, and Lap Joints

Concrete Block Systems – Concrete block systems consist of prefabricated concrete panels, of various geometries, which may be attached to and laid upon a woven monofilament or nonwoven geotextile. Bending and torsion are accommodated by having the concrete blocks articulated with joints, weaving patterns, or connection devices. Concrete block systems may be subdivided into three groups: non-tied interlocking blocks, cable-tied blocks, and in-situ concrete (Hewlett et al., 1987).

Concrete block revetments incorporate cellular concrete blocks, either open or closed, and are underlain with a properly designed filtration geotextile. The blocks are held on the slope by anchors placed at the top of the slope and/or by friction between the slope and the blocks. The blocks can be assembled into fabricated mats either at the factory or onsite. Sections of prefabbed concrete blocks may be placed by using a special spreader bar, which may lower costs on large projects, or the blocks may be hand-placed with or without the cable subsequently installed.

Articulating concrete block revetment systems combine the favorable aspects of lightweight blankets and meshes–such as porosity, flexibility, vegetation

encouragement, wildlife habitat enhancement, and ease of installation–with the nonerodibility, self weight, and high tractive force resistance of rigid linings. These specially designed interlocking precast concrete grids are a proven cost-effective, aesthetic, and functional alternative to dumped stone riprap, gabions, structural concrete, and other heavy-duty, durable channel protection systems. Additionally, these systems offer enhanced flow efficiencies, nurturing of vegetative cover, and safe access (Koutsourais and Sprauge, 1992).

Gabions – Gabions are compartmented rectangular containers made of galvanized steel hexagonal wire mesh or rectangular plastic mesh and filled with hand-sized stone. Cells of equal capacity are formed by factory-inserted plastic or wire netting diaphragms or partitions, which add strength to the container and help maintain its shape during the placement of stone. In highly corrosive conditions, a polyvinyl chloride coating is used over the galvanized wire.

Advantages of gabions over rigid structures include flexibility, durability, strength, permeability, and economy. The growth of native plants is promoted as gabions collect sediment in the stone fill. A high percentage of installations are underlain by woven monofilament and nonwoven geotextiles to reduce hydrostatic pressure, facilitate sediment capture, and prevent wash-out from behind the structure.

Riprap – Riprap consists of stone dumped in place on a filter blanket or prepared slope to form a well- graded mass with a minimum of voids. Stone used for riprap is hard, dense, durable, angular in shape; resistant to weathering and to water action; and free from overburden, spoil, shale, and organic material. The riprap material is generally placed on a gravel bedding layer and/or a woven monofilament or nonwoven geotextile fabric.

Performance of Erosion-Control Materials

Several test procedures have been proposed to quantify performance of erosion-control materials. Initial concern for vegetated systems is temporary erosion protection prior to and during seed germination and seedling development. Typically, this level of performance is measured by the material's ability to minimize soil loss when subjected to various flow rates and/or rainfall amounts. Temporary erosion protection is important but the long-term goal of any vegetated erosion-control matrix is to provide permanent erosion resistance via permanent vegetation and/or subsequent root reinforcement. The more rapidly vegetation becomes established the more rapidly long-term erosion control may be accomplished. Thus, the material's ability to facilitate vegetative establishment is equally important. Too much emphasis on an erosion-control product's temporary protection may inhibit the growth of newly emerging seedlings.

Perhaps the most critical parameter in an engineering design is flow resistance before, during, and long after vegetative establishment. Some erosion-control materials may be washed away before the vegetation takes hold, while others may temporarily exhibit excellent flow resistance

only to lose their effectiveness as they degrade or decompose over time. When designing grassed slopes and waterways, a specifier must take into account immediate and long-term flow resistance based upon longevity of the material.

Two basic design concepts are used to evaluate and define a channel configuration that will perform within accepted limits of stability. These methods are defined as the permissible velocity approach and the permissible tractive force (shear stress) approach. Under the permissible velocity approach, the channel is assumed stable if the adopted velocity is lower than the maximum permissible velocity. The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between flowing water and the materials forming the channel boundary (Chen and Cotton, 1988).

The permissible velocity approach uses Manning's Equation, where with given depth of flow D, the mean velocity may be calculated as:

$$V = 1.49\ R^{2/3}\ S^{1/2}\ /n$$

where V = average velocity in the cross section;
n = Manning's roughness coefficient;
R= hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter P; and
S = friction slope of the channel, approximated by the average bed slope for uniform flow conditions.

The tractive force approach uses a simplified shear stress analysis which is equal to:

$$\dot{o} = \Upsilon DS$$

where $\dot{o}$ = tractive force;
Υ = unit weight of water;
D = maximum depth of flow; and
S = average bed slope or energy slope.

Design criteria based on flow velocity may be limited because maximum velocities vary widely with channel length (L), shape (R), and roughness coefficients (n). In reality, it is the force developed by the flow, not the flow velocity itself, that challenges the performance of erosion-control systems. Tractive forces caused by flowing water over the ground surface create shear stresses, which can be used as a design parameter independent of channel shape and roughness. Moreover, the higher stresses developed in channel bends or other changes in stream channel geometry can be quantified by simplified shear stress calculations, providing a higher level of design confidence than otherwise possible (Chen and Cotton, 1988).

Critical shear stress determinations are meant to be used with velocity calculations for prescreening of channel lining designs. Manning's Equation remains the primary hydraulic research and design tool. However, as everyday practice has determined, a simplified screening

criteria such as maximum shear stress is necessary to ensure properly engineered design of channel lining erosion-control systems. Figure 1 combines cumulative research for several erosion-control materials and attempts to group categories of erosion-control materials into their cost-effective design niches (Theisen, 1992).

Maximum permissible velocities for vegetative techniques are illustrated under vegetated and nonvegetated conditions. Thus a designer will have performance guidelines from the time a material is installed to when it becomes fully vegetated. As additional data become available from field and laboratory analysis, perhaps a design-guide chart utilizing maximum permissible shear stress may be developed. The reader must be cautioned: velocity and tractive force are not directly proportional. Under certain conditions, a decrease in velocity may increase depth of flow, thereby increasing shear stress.

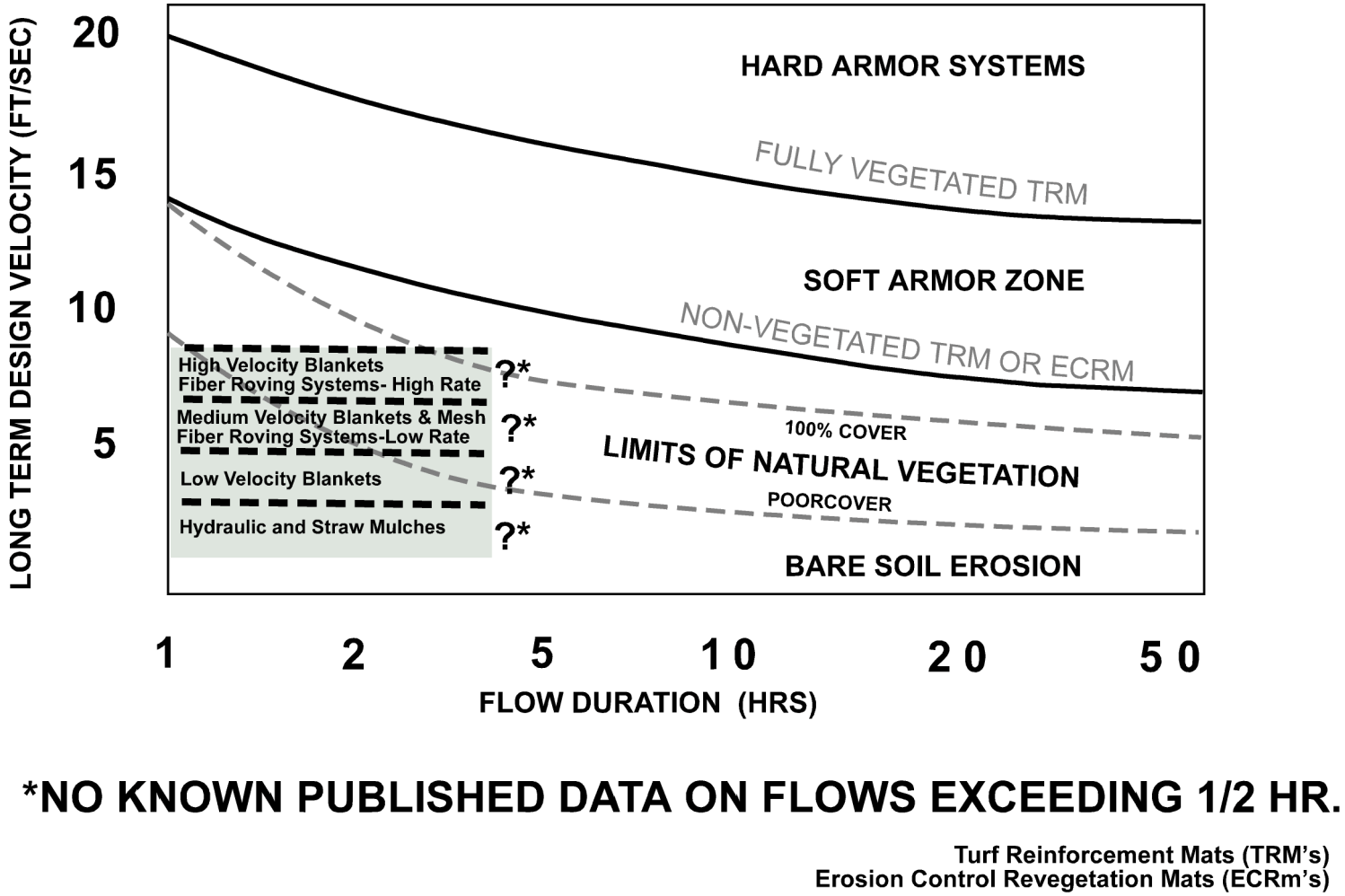
Flow Duration

Of key importance is the significance of duration of flow. Note from figure 1 that allowable flow velocities decrease with flow duration. This is a critical point. Manufacturers of organic, natural, and synthetic erosion-control products often express the erosion resistance of their materials in terms of maximum allowable flow velocity or permissible shear stress. Though unstated, these flow limits are typically for very short durations (minutes rather than hours). They do not reflect the potential for severe erosion damage that results from moderate flow events over a period of several hours. Ironically, many manufacturers, designers, and users do not consider duration of flow when evaluating and selecting erosion-control measures (Theisen and Carroll, 1990).

Typically, a major precipitation event will produce significant flow velocities with durations lasting hours or days, not minutes. The 2-day design duration was selected because, in grass waterways, high velocity flow events should be no longer than about 2 days duration, following which grass recovery and subsoil drainage should be able to take place (Hewlett et. al., 1982). As figure 1 illustrates, duration of flow will reduce the erosion resistance of a grassed surface. It is critical that design of grassed waterways take this into account.

Long-term flow values for the various temporary erosion-control mulches, blankets, meshes, and rovings have not been reported and are not reflected on figure 1 . Short-term performance of fully vegetated surfaces is impressive at nearly 4 meters/second. However, as duration of flow progresses, long-term performance drops off sharply from 2 meters/second (6 feet/second) with 100-percent vegetative cover to only 1 meter/second (3 feet/second) with poor cover.

The "soft-armor zone" begins just above the limits of natural vegetation. Performance data for reinforcing mats range from unvegetated turf reinforcement mats and erosion-control revegetation mats (which exceed performance of natural vegetation) to the upper curve, which delineates maximum recommended design velocities obtained from field and laboratory evaluation of vegetated turf reinforcement mats (Carroll et. al., 1991; Hewlett et. al., 1987; Theisen and Carroll, 1990; Western Canada Hydraulic Laboratories, 1979; Hoffman and Adamsky, 1982; Theisen, 1992). Fully vegetated, geosynthetic mattings may withstand short-term (½-hour) flow velocities of 6 meters/second and flow rates of in excess of 4 meters/second



***NO KNOWN PUBLISHED DATA ON FLOWS EXCEEDING 1/2 HR.**

Turf Reinforcement Mats (TRM's)
Erosion Control Revegetation Mats (ECRm's)

Figure 1 — Recommended Maximum Design Velocities for various erosion control materials.

for durations of up to 2 days. The development of permanent erosion-reinforcement matrices has created a new level of erosion-control performance–geobotanical reinforcement zone–and has elevated flow velocities to 7.6 meters/second (25 ft/sec) for short-term (½-hour) flow durations when fully vegetated.

The upper end of figure 1 demarks the niche for hard-armor materials. Figure 1 is not intended to establish performance limits for these materials, but rather to define the upper limits of "soft armor" (reinforced vegetation). Performance for hard-armor materials will be considerably higher and upper limits are beyond the scope of this paper.

Sediment Control

Going hand-in-hand with aggressive erosion-control measures (including the use of cost-effective conservation practices; Agnew and Humphries, 1991) should be a well-conceived sediment-control plan. Erosion-control measures are an offensive strategy to attack potential sedimentation while sediment-control practices are a stop-gap defensive strategy. In erosion- and sediment-control planning, the old sport's axiom that a strong offense is the best defense is certainly apropos. Vegetation is clearly the finest sediment-control product on the planet!

Geosynthetic silt fences have become a standard construction practice over much of the United States, replacing straw and hay bales, brush layers, and rock check dams. Silt fences are generally installed at the beginning of the construction project and usually consist of woven slit tape geotextiles mounted on prefabricated fence.

A well-designed silt fence must initially screen silt and sand particles from runoff. A soil filter is formed adjacent to the silt fence and reduces the ability of water to flow through the fence. This leads to the creation of a pond behind the fence which serves as a sedimentation basin to collect suspended soils from runoff water. To meet such needs, the geotextile must have properly sized openings to form the soil filter, and the storage capacity of the fence must be adequate to contain the volume of water and sediment anticipated during a major storm (Richardson and Koerner, 1990).

Examples of sediment-control techniques include vegetation, straw and hay bales, brush layers, silt fences, porous sediment control structures, rock check dams, sediment traps, basins, and ponds.

Conclusion

Ideas for geosynthetic erosion- and sediment-control materials abound. It is certain that new ideas have been omitted from this article or are being developed at the time of this publication and that not all existing new ideas are addressed in the article. Odds are high that geosynthetics will work their way down the ladder into more traditional applications such as hydraulic mulches and degradable erosion-control blankets.

Additional research on the effectiveness of the myriad erosion- and sediment-control materials is critical. Questions must be answered regarding resistance to extended flow durations and long-term performance for all materials. Systems must be developed for standardizing product descriptions, sanctioning uniform test and evaluation procedures, and creating a market reporting system to ensure broad acceptance of erosion- and sediment-control products in appropriate applications.

Organizations such as the International Erosion Control Association (IECA), Erosion Control Technology Council (ECTC), American Society for the Testing of Materials (ASTM), Industrial Fabrics Association International (IFAI), and the Geosynthetic Research Institute (GRI) must continue to lead the way to ensure a strong erosion-control industry and development of future research in erosion- and sediment-control applications.

References

Agnew, William. 1991 Erosion Control Product Selection. Geotechnical Fabrics Report Vol. 9, No. 3, April, St. Paul, Minnesota, pp. 24-27.

Agnew, William and H. Bruce Humphries. 1991. A Systems Approach of Permanent Drainage Stabilization on Reclaimed Lands. Proceedings of the XXII Annual Conference of the International Erosion Control Association, Orlando, Florida.

Agnew, William and Marc S. Theisen. 1994. Built-In-Place Matrices, a Cost Effective Concept of Erosion Control. Proceedings of the XXV Annual Conference of the International Erosion Control Association, Reno, Nevada.

Brown, L. R. and E. C. Wolf. 1984. Soil Erosion: Quiet Crisis in the World Economy. Worldwatch Paper No. 60. Worldwatch Institute, Washington, D.C.

Carroll, Jr., Robert G., Jeff Rodencal, and Marc S. Theisen. 1991. Evaluation of Turf Reinforcement Mats and Erosion Control and Revegetation Mats under High Velocity Flows. Proceedings of the XXII Annual Conference of the International Erosion Control Association. Orlando, Florida.

Chen, Y. H., and B. A. Anderson. 1986. Development of a Methodology for Estimating Embankment Damage Due to Flood Overtopping. USDOT Federal Highway Administration and USDA Forest Service, report No. DTFH61-82-C00104, Fort Collins, Colorado.

Chen, Y. H., and G. K. Cotton. 1988. Design of Roadside Channels with Flexible Linings. Federal Highway Administration report HEC-15/FHWA-lP-87-7, McLean, Virginia.

Guillet, James E. 1974. Plastics, Energy and Ecology - A Harmonious Triad. Plastics Engineering, Vol. 30, No.8, pp. 48-56.

Hewlett, H. W. M., L. A. Boorman, and M. E. Bramley. 1987. Design of Reinforced Grass Waterways. Construction Industry Research and Information Association, Report 116, London, England.

Jagielski, Kevin. 1992. Market Profile–North American Erosion Control. Data Textile, Vol. 3, No. 5, February, St. Paul, Minnesota, pp. 1, 10-11.

Hoffman, Gary L., and Robert Adamsky. 1982. Nylon Erosion Control Mat. Presented at the Transportation Research Board sixty-first annual meeting, Washington, D.C.

Koutsourais, Michael, and Joel Sprauge. 1992. An Inside Look at Articulating Concrete Block Revetments . Proceeding of the XXIII Annual Conference of the International Erosion Control Association, Reno, Nevada.

Northcutt, Ben. 1992. The Erosion Control Industry - A Look At It's Past, Present and Future . Proceedings: High Altitude Revegetation Workshop No. 10, Ft. Collins, Colorado.

Richardson, Gregory N. and Robert M. Koerner, Ed. 1990. A Design Primer: Geotextiles and Related Materials. Industrial Fabrics Association International, St. Paul, Minnesota.

Theisen, Marc S. 1988. Cost-Effective Techniques for Successful Erosion Control. Proceedings: High Altitude Revegetation Workshop No. 8, Ft. Collins, Colorado.

Theisen, Marc S. 1992. Evaluation of Biotechnical Composites Under High Velocity and Shear Conditions, Proceedings of the XXIII Annual Conference of the International Erosion Control Association, Reno, Nevada.

Theisen, Marc S. and Robert G. Carroll. 1990. Turf Reinforcement - The "Soft Armor" Alternative. Proceedings of the XXI Annual Conference of the International Erosion Control Association, Washington, D.C.

Thiesen, Marc S. and William Agnew. 1995. Practical Applications of Geosynthetics in Erosion Control. Proceedings: Rocky Mountain Symposium on Environmental Issues in Oil and Gas Operations. Golden, Colorado.

Western Canada Hydraulic Laboratories Limited. 1979. Cove Country Club: Experimental Studies on Permissible Shear Stresses of Bermuda Grass, Port Coquilam, British Columbia, Canada.

Terrace Design Using RUSLE and SEDCAD 4

originally **a PowerPoint Presentation**

by

Richard C. Warner, Ph.D.
and Daniel C. Yoder, Ph.D.

Non-Parametric Vegetation Evaluation for Bond Release

originally **a PowerPoint Presentation**

by

Richard Bonine
Horizon Resource Management
Gallup, New Mexico

Breeding and Selection of Superior Plants for Use in Reclamation

Howard D. Stutz, Ph.D.
Brigham Young University

(Editor's note: Dr. Stutz's presentation consisted of excerpted portions of the research report that he published in October 1998 under the title "Breeding and Selection of Superior Plants for Use in Reclamation." For a summary of this report, *see appendix G.*)

Bond-Release Criteria/
Bond-Release Achievement

☞ Measurement/evaluation

Measurement Evaluation

Prairie coneflower
Ratibida columnifera

"Build It and They Will Come: Successful Bond ReleaseBegins with Postmining Topography"

"Reverse Null Testing for Bond Release in New Mexico"

"Geographic Information Systems: Increased Use and Applications"

"Final Colorado Bond Release Case Studies: The Canadian Strip Mine Bond Release Study"

"Final Colorado Bond Release Case Studies: Red Canyon Mine Phase II and III Bond Release Study"

"Suggested Readings for Western Ethnobotany"

"OSM's Role in Enhancing Bond Release on Indian Lands and in Federal Program States"

"Philosophy and Flexibility in Bond Release"

Build It and They Will Come: Successful Bond Release Begins with Postmining Topography

Chris Yde, Wildlife Biologist
Montana Department of Environmental Quality
Industrial and Energy Minerals Bureau

The Montana Strip and Underground Mine Reclamation Act and the associated Administrative Rules of Montana (ARM) require that all disturbances within active coal mines be reclaimed to the "approximate original contour" (AOC). As defined by ARM 17.24.301(13), AOC means "that surface configuration achieved by backfilling and grading of disturbed areas so that the reclaimed area, including any terracing or access roads, **closely resembles the general surface configuration of the land prior to disturbance and blends into and compliments the drainage pattern of the surrounding terrain, with all highwalls, spoil piles and refuse piles eliminated"** (emphasis added).

Reclamation to AOC is a key element in the restoration of the pre-mine ecological functions in the postmine landscape. Therefore, in order to meet AOC requirements, the proposed postmining topography (PMT) must not just resemble the general premining topography, but must also provide for the protection of the hydrologic balance (ARM 17.24.314), the reestablishment of appropriate drainage systems (ARM 17.24.631), groundwater regime (ARM 17.24.314, 643-644), soils (ARM 17.24.701-703) and vegetation types (ARM 17.24.711), and consideration of wildlife (ARM 17.24.312, 751), grazing (ARM 17.24.762), and other ecological and land use related needs.

It appeared that a straightforward approach had been established that ensured reclamation to a condition that closely approximated the premine situation. However, several rules were adopted that actually conflicted with the AOC requirement, each other, and/or the intent of the law. Examples of these include:

- The requirement that slopes could not exceed 5(h):1(v) unless otherwise approved by the Department.
- The requirement that soil must be redistributed in a manner that achieves approximate uniform thickness.
- The 9-inch rill and gully rule.
- The requirement to elimination of depressions; unless they were approved by the Department or were less than 1 cubic yard in size.

In Montana, as well as much of the West, the premine landscape is often steeper than 5(h):1(v), contains a variety of topographic and erosion features, and is covered by a variety of growth media of varying depths. A diversity of vegetation is supported by this topographic and substrate

diversity. The combination of topographic and vegetative diversity generally supports a diverse wildlife community while providing for livestock grazing.

During the earlier permitting processes, a general conservative approach to the approval of the PMT resulted in a postmine topography lacking many of the premine features. Additionally, the actual reclamation was often directed and performed by individuals encouraging a well-graded, uniform surface. This resulted in a further loss of topographic diversity. During the reclamation process, the 5:1 rule not only encouraged but required that reclamation be dominated by shallower slopes. The application of the 9-inch rill and gully rule and the general concept of absolute erosional stability resulted in additional softening of the reclaimed topography and the removal of features which would have provided niches for the establishment of a variety of vegetative species. The uniform replacement of soil over much of the reclaimed topography resulted in an additional loss of potential to establish vegetative diversity. In many instances, past reclamation has resulted in conversions from diverse native communities to very mundane reclaimed communities with greatly reduced topographic and vegetative diversity.

Since the original permitting of coal mines in Montana, the reclamation process has been constantly evolving. While a large portion of the early reclamation was not to the standards it could have been, much was learned along the way. In general, the evolution of reclamation in Montana was fairly flat-lined for a number of years (approximately 1973 into the early 1990's). As more was learned from reclamation successes and failures and a better understanding of the requirements needed to adequately provide for the two postmine land uses was gained, the application of reclamation concepts and principles began to build. Since the early 1990's, the learning/application curve has steepened significantly, resulting in a diverse post-mine topography more closely approximating the premine conditions. Today, the Department encourages companies to construct a variety of diverse hill slopes instead of uniform slopes resembling highway construction. Construction of reclaimed drainages that more closely resemble those found premine, and in adjacent undisturbed areas, is strongly encouraged. This not only provides an appropriate feature to pass surface runoff, but also appropriate sites for tree and shrub establishment. The reclamation of a variety of habitat features–thin breaks, gumbo knobs, over-steepened and vertical slopes, wetlands, etc.–is a reclamation goal of the Department. Montana also encourages the use of a diversity of growth media and a variety of lay-down depths. When these factors are combined with other advanced reclamation techniques, it is anticipated that a diverse vegetative community will result. To date, the available indicators illustrate that vegetation reestablishment on lands disturbed by coal mines in Montana is approaching, or above, the comparable vegetation within the respective reference areas.

In order to remain progressive and ensure sound reclamation of lands disturbed by coal mining, Montana's coal program has revised many of the ARM's and provided several written guidelines (see attachments) encouraging the coal mining companies to create a diverse postmine topography. Often the change is slow and problems are encountered; however, a programmatic change is taking place and reclamation of lands disturbed by Montana's coal mining operations is resulting in a more holistic approach to reclamation.

It is anticipated that with the appropriate foundation–a diverse postmine topography approximating the original contours and topographic features covered with a diversity of growth media of varying depths–a diverse vegetative community will result. In turn, this will better provide for the two approved postmine land uses: livestock grazing and wildlife habitat.

Montana Department of Environmental Quality and many companies mining coal in the State feel that reclamation should return the disturbed areas to a condition that approximates the premine situation as closely as possible, considering logistics, economics, material availability, etc. This approach should ensure successful bond release in a timely manner and a reduction in the successional timeframe needed until the premine situation is achieved. OSM and the other states are encouraged to do the same.

Attachment 1: Montana Department of Environmental Quality Industrial and Energy Minerals Bureau Coal Program "Approximate Original Contour Guideline"

Definition:

ARM 17.24.301(13) "**Approximate original contour"** means that surface configuration achieved by backfilling and grading of disturbed areas so that the reclaimed area, including any terracing or access roads, **closely resembles the general surface configuration of the land prior to disturbance and blends into and compliments the drainage pattern of the surrounding terrain, with all highwalls, spoil piles and refuse piles eliminated. (Emphasis added)**

Statement of Principle:

"Approximate Original Contour", or AOC, is the requirement that reclamation plans restore as nearly as possible the general pre-mine surface configuration of the disturbed area, and blend with the surrounding terrain. It does not require precise replication of the pre-mine land surface or elevations. The basic AOC evaluation is based upon an overall comparison of the applicant's proposed post-mine topography (PMT) and land use against the pre-mine topography and land use. With the possible exception of specialized alternate reclamation cases (see 1(A) below), prescribed land use goals are met by re-establishing the affected area's pre-mine ecologic function. The pre-mine ecologic function is dependent on the surface topography (slope, aspect), drainage system, groundwater regime, soils and vegetation types, wildlife and other ecologic and land use factors.

Reclamation to AOC is a key element in the restoration of the pre-mine ecologic functions in the post-mine landscape. Therefore, in order to meet AOC requirements, the proposed post-mining topography must not just resemble the general pre-mining topography, but must also provide for the protection of the hydrologic balance (ARM 17.24.314), the re-establishment of appropriate drainage systems (ARM 17.24.631), groundwater regime (ARM 17.24.314, 643-4), soils (ARM 17.24.701-03) and vegetation types (ARM 17.24.711), and consideration of wildlife (ARM 17.24.312, 751), grazing (ARM 17.24.762), and other ecologic and land use related needs.

The most obvious foundation for re-establishing the post-mining ecologic function and land-use would be to restore the area to its exact pre-mine configuration. As this is generally not feasible, the intent of this guideline is to further define what is required for a PMT plan to be considered AOC. This document should provide guidance for the development and evaluation of PMT plans to meet the AOC requirements in future permit application or revision packages.

Criteria for AOC Development and Evaluation:

There are three cardinal requirements of AOC:

I. The post-mine land surface must closely resemble the general surface configuration of the land prior to disturbance. Overall, flat terrain should be reclaimed as flat terrain, rolling terrain as rolling terrain, etc. If specific features are necessary to achieve resemblance to the general pre-mine configuration, they must be replaced. In addition, the primary characteristics of the pre-mine terrain (slope, aspect, drainage density, etc.) need to be retained to the extent possible so that the post-mine landscape can provide for reestablishment of the required ecologic and land use functions, mandated elsewhere in the Act and Rules.

1. Features deemed necessary for achieving "general resemblance" will be determined in consultation with the Department. In addition, some features may be essential to specific ecologic functional requirements in the rules. Features can be shifted, relocated or modified if there are no adverse effects on reclamation goals and standards. The required overall resemblance of the general pre-mine surface configuration must be maintained, and the landscape must blend with and compliment the surrounding terrain.

Alternate reclamation scenarios may, in special and unique cases, limit or eliminate the application of AOC criteria. Such cases *may* be approved *only* in relation to 82.4.232 MCA and ARM 17.24.821-23.

B) The slope and aspect components of AOC will be evaluated quantitatively by the Department when reviewing permit applications or major revisions. This evaluation will include topographic data derived from appropriately spaced pre- and post-mine surface grids. The data will be summarized and compared on the basis of the affected area as a whole.

C) The density of drainages and the drainage pattern in the reclaimed landscape must be similar to that of the pre-mine landscape, as determined on a drainage-basin-by-drainage-basin comparison. If significant changes in drainage density or pattern are proposed, the operator must clearly demonstrate that the proposed changes can meet the requirements of stability, protection of the hydrologic balance, and the restoration of the other post-mine ecologic and land-use functions.

II. The reclaimed land surface must blend into and compliment the drainage pattern of the surrounding terrain. Where applicable, a reclaimed drainage must be connected to the undisturbed up- and down-gradient drainage segments. Reclaimed drainages must blend into surrounding drainages and pass through the reclaimed area at an appropriate grade. All reclaimed drainages must restore similar amounts of runoff to the down-gradient native drainage.

III. Reclamation must eliminate all highwalls, spoil piles and refuse piles. All highwalls must be eliminated by "Reduction, backfilling, or grading ... to the approximate original contour of the land" (82-4-232(1), MCA). In certain cases, such as topographic replacement or wildlife habitat features, vertical or near-vertical rock faces are required in the post-mine landscape as part of standard reclamation practice. This can be accomplished by blasts or other techniques designed to alter the original highwall and produce irregular but stable faces. (See additional guidance under Comment 5, below.)

Lands affected by boxcut spoils and out-of-pit spoils are not exempt from the AOC requirements. Additionally, boxcut spoil disposal is to be specifically handled under ARM 17.24.501(4), and excess spoil resulting from thick overburden must meet the requirements of 17.24.520.

Additional principles that operators should note:

1. AOC is to a degree a subjective, case-by-case determination. While more than one PMT configuration may be capable of meeting the general requirements of AOC, the most acceptable configuration will be the one which most closely resembles the pre-mining topography, and best provides for the post-mine ecologic and land use goals.

2. Applicants should be prepared to submit sufficient information (relative to the above criteria) on the pre-mine landscape and their proposed PMT in a format that will allow the quantitative comparisons, by the Department, described in I(B) and (C) above. Key parameters for this presentation should be worked out in consultation with the Department.

3. The PMT plan must take into account potential impacts to post-mine landowners' *legal* rights, especially where more than one surface owner may be involved. Considerations such as water rights, water distribution, grazing or cropping patterns, or any other factor that may affect the ability of a landowner to maintain a pre-mine land use after reclamation is complete, must be addressed as the PMT plan is developed.

4. Operators should employ the appropriate and opportune use of micro-topographic features such as small depressions, hillocks, rock piles, scoria or gumbo features, rock ledges and outcrops, etc., where it can be shown that these are comparable to the pre-mine landscape, and compatible with or necessary for the achievement of the post-mine land-use goals and standards. If these features are of too small a scale to be shown on the

PMT map, they should be represented as symbols on the map, and/or included in the appropriate narrative sections of the plan. Documentation of the pre-mine landscape should be used to justify this opportune reconstruction option.

5. Important macro-topographic features include over-steepened slopes and vertical faces. Over-steepened slopes are slopes of 3(h):1(v) or greater. These slopes usually have a minimal veneer of soil material or no soil at all, often containing a large percentage of rock fragments, and are important for the re-establishment of a variety of shrub and tree species. Vertical or near-vertical faces - including sandstone outcrops, hoodoo rocks and cliffs, and their associated transition or rubble zones - also provide necessary habitats for a variety of plant and animal species.

   To the extent that these habitats/features were present in the natural pre-mine landscape, replacement of vertical faces or creation of specific habitat features are considered to be essential elements of standard reclamation practice. Incorporation of these features is essential to fully achieve AOC, compliment nearby reclaimed or native ground, and to accomplish postmine ecologic and land use goals. The Department considers these over-steepened and vertical face features to meet AOC when:

   * They replace features that existed pre-mine and were disturbed by mining;

   * They are sculpted or re-shaped to blend with the existing native habitats, as well as the reclaimed habitats;

   * Pre-mine features are replaced on a horizontal linear foot basis, comparable to the pre-mine length; and

   * It is demonstrated that the features can meet the required minimum static safety factor of 1.3.

6. Whenever an applicant desires to employ alternate, rather than standard, reclamation practices, such activities must comply with the requirements of 82-4-232 MCA and ARM 17.24.821-23. If the proposed activities will also change the post-mine land use, or involve alternate revegetation, they must also comply with ARM 17.24.824 and 825, as appropriate. *As in the case of standard reclamation , employment of alternate reclamation practices may justify relocating or even eliminating individual topographic features, but does not necessarily absolve the applicant from addressing the overall requirements of AOC" (See Cardinal Requirement #1.)*

Attachment 2: Montana Department of Environmental Quality Industrial and Energy Minerals Bureau Coal Program "Guideline for Determining Compliance with the Approved Postmine Topography Plan"

I. Introduction

Pursuant to ARM 17.24.313(3)(d), a permittee must submit a postmining topography (PMT) map and a demonstration that the proposed PMT can be achieved. ARM 17.24.313(3)(e) requires a proposal for remediation of grading problems which result in final graded topography not consistent with the approved PMT map. At a minimum, this proposal must contain measures to remedy the problem or inconsistency between the PMT map and the final graded topography. There is no allowance for inconsistency without notification and a remedy. Notification must occur, in writing, within 10 working days after detection.

The Department of Environmental Quality (the Department) recognizes that strict adherence to the PMT map is not always operationally feasible, can be problematic, and in some cases, is not preferred. This point does not negate ARM 17.24.313(3)(d) and (e) as permit application requirements. These requirements secure a commitment to performance standards associated with approximate original contour [ARM 17.24.501A(1)(a)]. The intent of this guideline is to give further enlightenment as to whether an inconsistency with an approved PMT requires a revision to the permit (ARM 17.24.415) or a less extensive form of Departmental notification and consultation.

The following guidelines apply to standard (nonalternate) reclamation with a postmine land use of grazing and wildlife habitat. These guidelines are developed around the establishment of like-function, primary and tributary drainage basins. Please note, the guideline addresses drainage basins as they relate to the PMT plan: drainage channels, pursuant to ARM 17.24.634, are not addressed in these guidelines.

- Primary drainage basins include, but are not limited to, those drainage basins which outlet outside the area disturbed by mining, named drainages, and large drainages as determined by the Department. The primary drainage basin has a defined size and a defined area, depicted on the PMT map, where flows would concentrate. This area of concentration must flow in the same general direction and have a similar grade and bearing as that depicted on the PMT map. The drainage must connect upgradient (when applicable) and outlet in the location depicted on the PMT map.

- Tributary drainage basins are those drainage basins which outlet within the primary drainage. The term tributary drainage basins, as defined in these guidelines, include only those areas where surface water could concentrate and flow. These drainage basins do not need to be established in the exact locations depicted on the PMT map; however, there must be approximately the same cumulative length of tributary drainage (longitudinal profile) as that depicted on the PMT map. The cumulative length will be evaluated within the basis of the primary drainage basin.

-There is a relationship between valley[1] width, depth, length, and aspect and hydrologic/ecologic function. The side slopes of primary and tributary drainage basins must be geomorphically similar, in size and function, to that depicted on the PMT map. The intent of emphasizing similar drainage basin topography is to assure the re-establishment of the hydrologic and ecologic functions provided by the valley floor and side slopes.

II. Determining the Need for a Revision to the Permit

A. Primary Drainage Basins

(1) Landforms which create a drainage divide (ridges or hills) for a primary drainage basin shall be re-established in the general location of that shown on the approved PMT map. A drainage divide is considered to be in the general location of that shown on the approved PMT map if its location does not change the size of any primary drainage basin by more than 10% or any greater amount as determined in consultation with the Department (no minor revision required). Calculation of the percent change includes only that part of the drainage basin disturbed by mining.

(a) Reclaimed upland landforms must provide a similar amount of like-function topography as that approved on the PMT map and must complement the postmine drainage plan.

(b) Reclaimed upland landforms do not have to be constructed to the exact elevation depicted on the approved PMT map [ARM 17.24.501A(1)(a)] but must conform with the requirements and intent of these guidelines.

(2) To be considered consistent with the PMT map (no minor revision required), the area of concentrated flow depicted must:

(a) provide flow in the same general direction and along the same general bearing as that depicted on the PMT map;

(b) outlet at the approved location;

(c) contain similar lengths (longitudinal profile) of similar gradients to that approved and exhibit an overall concave longitudinal profile;

(d) when applicable, connect, upgradient, to a native drainage; and

[1] The term valley, as used in this guideline, includes any elongate depression (Webster's Third New International Dictionary) in the topography from large named drainages to draws, ravines, or dry washes. The term valley floor, as used in this guideline, should not be confused with alluvial valley floor.

(e) provide a smooth transition between graded and native areas and between graded areas with different completion dates [ARM 17.24.501A(2)].

B. Tributary Drainage Basins

(1) The operator must establish, within each individual primary drainage basin area, at least as many tributary drainage basins as committed to on the approved PMT map.

(2) Within the primary drainage basin, the cumulative length of the tributary drainages must be at least 90% of that committed to on the PMT map or as otherwise determined in consultation with the Department.

(3) Each tributary drainage basin must be restored to the geomorphic characteristic of that shown on the PMT map.

(4) The area of concentrated flow, depicted on the PMT map, must exhibit an overall concave longitudinal profile and provide a smooth transition into native and between graded areas with different completion dates [ARM 17.24.501A(2)].

C. Operators may deviate from the approved PMT map, and A and B above, if the alteration more closely resembles the premining topography and does not adversely affect the approved postmine land use, primary drainage size or point of discharge from that approved in the permit. Following consultation with the Department, the PMT map may need to be updated. The need for an update will depend on the magnitude of the deviation. An updated PMT map, in this instance, will not initiate the minor revision process unless the spoil mass balance is changed.

D. All upland topography must have a smooth transition into native and between graded areas with different completion dates [ARM 17.24.501A(2)].

E. Final graded slopes may not be steeper than that allowed by ARM 17.24.501A(1)(a) and 515(1) unless the slope can be shown to exhibit a long term static factor of safety equal to 1.3 and is approved by the Department. Final graded slopes need not be uniform, ARM 17.24.501A(1)(c).

F. Increased topographic diversity should result in better standard (nonalternate) reclamation. The creation of additional features not depicted on the PMT map is encouraged (no minor revision required) within the guidelines of A and B above, if these features do not adversely affect the approved postmine land use or revegetation and wildlife enhancement plans. These features include, but are not limited to, upland tributaries, cairns, knobs, hills capped with rock, and small depressions. Small depressions must comply with ARM 17.24.503.

III. Notification

A. A deviation from the approved PMT map that is not consistent with item II above requires the submittal and approval of a revision to the permit, ARM 17.24.415(1)(a).

(1) The revision to the permit must be approved prior to soil laydown, ARM 17.24.415(2).

(2) Departmental review of the revision application will be directed in accordance with 82-4-221(3), MCA and ARM 17.24.415 (major and minor revisions).

B. A deviation from the approved PMT map that is consistent with item II above does not require submittal and approval of a revision to the permit; however, consultation with the Department is required.

(1) Consultation can take place during mine inspection or through phone conversations, if applicable.

(2) Written documentation is required. Written documentation can be made in the Department's mine inspection report or by the permittee, whichever is applicable. At a minimum, written documentation will include:

(a) a description of the final graded topography or additional feature alteration;

(b) justification/reasoning of why the alteration conforms with II above.

(3) Consultation with the Department and written documentation are crucial to the successful implementation of these guidelines. If, after consultation, it is determined that a divergence from the approved PMT plan is not consistent with II above, the permittee will be notified that a revision to the permit is necessary prior to proceeding with reclamation.

C. All features not consistent with the approved PMT plan must be highlighted in the Annual Report [ARM 17.24.1129(2)(g) and (j)]. This includes features approved through the revision process and through consultation with the Department.

D. Opportunistic practices, within the above constraints and in consultation with the Department, are encouraged.

Attachment 3: Montana Department of Environmental Quality Industrial and Energy Minerals Bureau Coal Program "Guidelines on Erosional Features"

Introduction

The following guidelines are offered as a means of addressing whether or not maintenance work is required or may be imminent for erosional features encountered by field inspectors. In formulating these guidelines, it was first necessary to define some terms so that it would be clear as to what kind of erosional feature was being addressed. Erosional problems commonly found in the field have been placed in one of two categories: 1) those that will require immediate maintenance, placed under the heading of Required Maintenance and, 2) those that may

eventually require maintenance, placed under the heading of Possible Maintenance. Since many erosional features that develop in reclaimed fields are the result of poor planning and/or reclamation procedures, a number of preventative measures have been listed under the heading of Preventative Measures.

Definitions

The following features occur throughout the native and reclaimed landscapes of eastern Montana. Swales and dry washes can be included as part of normal reclamation. Rills and gullies that form after soil laydown may be acceptable as part of reclamation on a case-by-case basis if the features do not conflict with approved post-mine goals.

> Swale – In cross section, a generally broad, shallow feature where runoff may become concentrated. A thalweg and a floodplain are generally not discernable.
>
> Rill – An erosional feature usually less than 12 inches in depth which forms on newly reclaimed or cultivated fields. Rilling is an intermediate stage between sheet erosion and gully erosion. Rills can be removed from agricultural fields using normal tillage operations. In certain areas, as fields become vegetated with the approved permanent seed mix, and the features become less distinct, the rills can form valuable micro-topographic features.
>
> Gully – An erosional feature caused by concentrated but intermittent flow of water usually during and immediately following large runoff events. Gullies are deep enough to interfere with, and not be obliterated by, normal tillage operations. Gullies may contribute to significant redistribution or loss of soil resources and may interfere with the post-mine land use. Gullies are characterized by steep walls and steep head cuts. Gullies usually range from 2 to 30 feet in depth and are unstable.
>
> Dry Wash – A steep-sided feature having a relatively flat bottom (usually greater than 3 feet in width) that is in dynamic equilibrium (there is minimal headcut progression, and usually a mature growth of shrubs and/or trees are present, except in newly constructed dry washes). Readily observed erosion and runoff is usually only due to large precipitation events. A thalweg and a floodplain are generally not discernable. (If a dry wash is to be left in place or constructed, it should have a functional use such as providing a corridor for wildlife or microsites for specific, and desirable, trees and/or shrubs. It should also exhibit geomorphic characteristics of representative native drainage channels.)

Required Maintenance

Location is critical in determining whether or not maintenance work for rills and gullies is necessary. Maintenance will be required if such conditions as the following exist:

- Roads and road embankments are or are becoming impaired to the point that continued safe operations are in question.

- Adverse impacts outside the permit boundary appear imminent or have occurred.
- Post-mine land use has been, is being, or is likely to be adversely affected.
- Soil loss from a soil stockpile is imminent or has occurred.
- A gully or other undesirable erosion feature forms as a result of improper blending.
- Deposition of spoil onto soil, or soil erosion and redeposition onto spoil, is occurring due to excessive and/or widespread gullying.

Many rills and gullies will not fall under the categories listed above, and yet they may still require maintenance work. The determination of whether or not maintenance work is required under conditions other than noted above will need to be made on a case by case basis, and as outlined below under the heading of Possible Maintenance.

Possible Maintenance

To determine whether or not maintenance will likely be required for erosional features not listed under Required Maintenance, the following examples should be considered:

Whenever a soil substitution field is approved, rills and gullies are likely to develop. These rills and gullies may be left in place as long as a situation such as those listed under Required Maintenance does not exist.

- A dry wash that has been inappropriately located or constructed and that results in an unacceptable rates of erosion that conflicts with approved postmine goals.
- Erosion and sediment deposition is occurring and is likely to accelerate in constructed drainage channels. Drainage channels cannot be allowed to degenerate into gullies that interfere with post-mine land use.
- Deposition of spoil onto soil, or soil erosion and redeposition onto spoil, is occurring due to excessive and/or widespread rilling. This should only be viewed as a maintenance item if coverage by spoil, or loss of soil, is severe enough to prevent establishment and/or growth of vegetation, or to interfere with achievement of post-mine land use goals and standards. Severity will be judged on such criteria as the extent of soil loss, contamination, degradation or deterioration, as well as loss of seed through overland flow. Soil is considered to be permanently lost if it cannot be retrieved (e.g., the soil material is deposited in a sediment pond, in a mine pit, or outside the disturbance boundary). Soil is unacceptably degraded, contaminated or deteriorated if establishment and/or growth of vegetation is adversely affected or if the ability of the soil to meet post-mine land use goals and standards is significantly altered.

An entire field may need to be considered when making a decision on whether or not maintenance work is required. For example, the number and density of the rills and/or gullies, as well as the depth to which individual features have eroded, will need to be considered.

Finally, before requiring maintenance, enough time should be allowed for the natural geomorphic process to reach a state of relative equilibrium consistent with the post-mining topography, approved post-mine land use, and with respect to comparable but more mature native or reclaimed sites. Many shallow erosional features will fill with sediment and/or become acceptably stabilized by vegetation given sufficient time. Once a permanent vegetative cover has become established, which often takes one to two years after initial seeding, the level of erosion can be expected to dramatically decline. Field inspectors will decide whether or not to require maintenance work by balancing such things as the location and severity of an erosional feature with the knowledge that a limited amount of erosion is expected and acceptable as newly formed landscapes mature.

Preventative Measures

The following concepts are provided in an effort to reduce the formation of unacceptable rills and gullies:

- The reclamation sequence must be properly planned in terms of blending reclaimed fields with all surrounding fields and include the rough regrading and contouring phases of reclamation. Proper blending of one field to another is a critical factor in preventing the development of rills and gullies.
- The location and type (soil substitution fields, special shrub planting fields, etc.) of fields is a critical factor in whether or not a gully can, and should, be left in place or requires maintenance. Therefore, proper consideration must be given to placement of such fields far in advance of when resoiling and seeding is to occur.
- The newly created feature must complement the vegetation and land use goals.
- It is recommended that swales be constructed (e.g. approximately 300 to 500 feet apart) along ridge lines during the rough regrade phase of reclamation. This should inhibit the formation of excessively large gullies or a high density of rills and/or gullies.
- Reclamation activities (rough regrading, revegetation, etc.) would be best performed in a continuous panel extending from drainage channel to drainage divide. This would help prevent improper blending and encourage the creation of micro-topographic features such as swales.
- Where trees or shrubs are planted on steep slopes, care must be taken to prevent the furrow from exacerbating erosion by concentrating runoff. The furrow should follow the contour of the land. Planting by hand is encouraged and will minimize the concentration of overland flow.

Reverse Null Testing for Bond Release in New Mexico

Dave Clark
New Mexico Department of Energy, Minerals,
and Natural Resources, Mining and Minerals Division

The Salt River Project obtained approval in 1986 to extract test burn coal from a 500-acre permit area northwest of Quemado in Catron County, New Mexico. Mining commenced in January 1987, and coal was shipped to the Salt River Project's Coronado Generating Station for test burning from March through June 1987. The test pit was backfilled and regraded, and the approximately 116 acres of disturbance were topdressed and seeded by November 1987. Additional seeding was conducted on portions of the permit area during 1988, 1989, and in the spring of 1990. The test pit is located on a state land section and has a grazing postmine land use. Controlled grazing of the permit area as a demonstration of the capability of the land to support the postmine land use was conducted in 1999 and will be continued in 2000.

Revegetation data were collected in 1998, the ninth year of the 10-year minimum liability period, to support an application for final bond release. Additional data will be collected in 1999. Dr. E. Linwood Smith of Dames and Moore, Inc. was responsible for study design and field work. Percent cover was estimated by point intercept (100 points on each of 40 randomly located transects). Five randomly located $0.5m^2$ quadrats were clipped along each point intercept transect, and the weights were later combined so that each of 40 production samples was representative of a surface area of $2.5m^2$. The number of shrubs in 120 randomly located 4x50m belt transects was used to estimate shrub density. Relative cover (herbaceous taxa) and relative density (shrub taxa) provided measures of species diversity.

The operator tested the reverse null hypothesis (Erickson, 1992; McDonald and Erickson, 1994) to demonstrate that the revegetation performance standards were met. Briefly, the reverse null hypothesis differs from the classical null hypothesis in the assumption that revegetation parameters are less than the performance standard unless otherwise demonstrated, rather than equivalent to the performance standard unless otherwise demonstrated. This difference in assumptions has the effect of automatically giving the regulatory agency (and the taxpayers) 90 percent confidence that approving bond release is the correct action when the null hypothesis is rejected. The same effect may be achieved when testing the classical null hypothesis only if both alpha and beta error rates are held at 0.10, a constraint that may lead to unreasonably large sample sizes.

The 1998 data demonstrated that the Fence Lake Mine No. 1 reclamation exceeded all approved standards for revegetation with greater than 90-percent statistical confidence. Live herbaceous cover averaged 43 percent (n = 40), compared to a success standard of 20 percent. Mean biomass production was 942 lb/ac (n = 40), compared to a standard of 265 lb/ac. Shrubs had been established at a density of 481 per acre (n = 120), compared to a success standard of 400 per acre. These results, the calculated and tabular *t* values, and the 90 percent confidence intervals for the parameter means are depicted in figures 1a, 2a, and 3a. Calculated *t* values

which are larger than tabular *t* values indicate that the performance standard was met under the reverse null hypothesis. Figures 1b, 1c, 2b, and 2c graphically confirm that the normal

Figure 1a

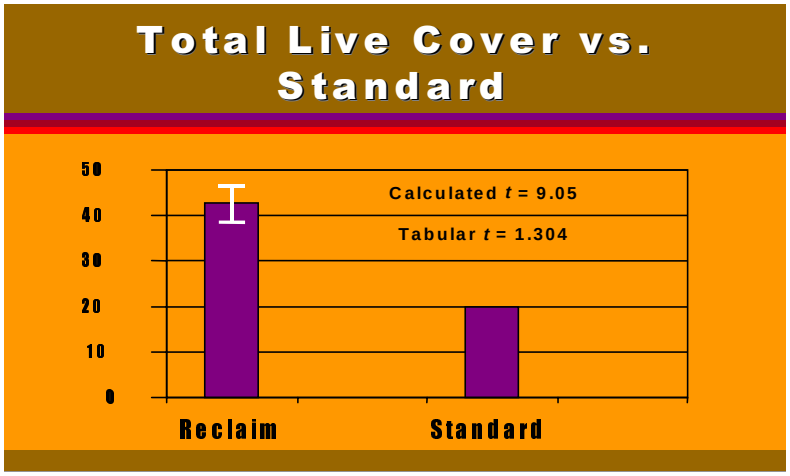


Figure2b

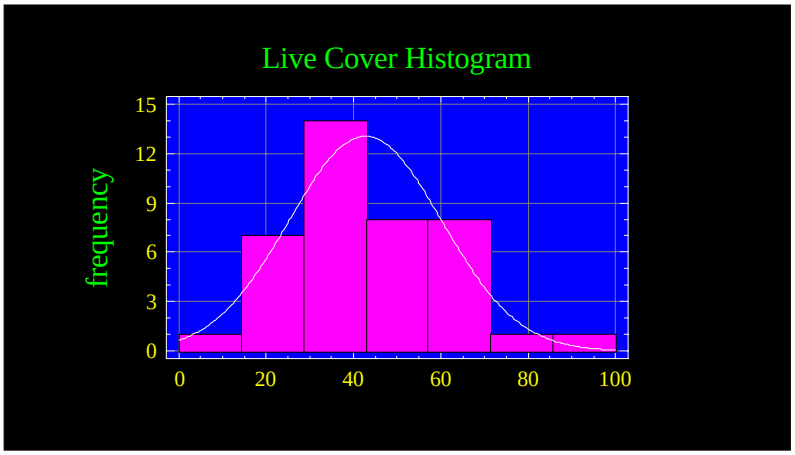


Figure 2c

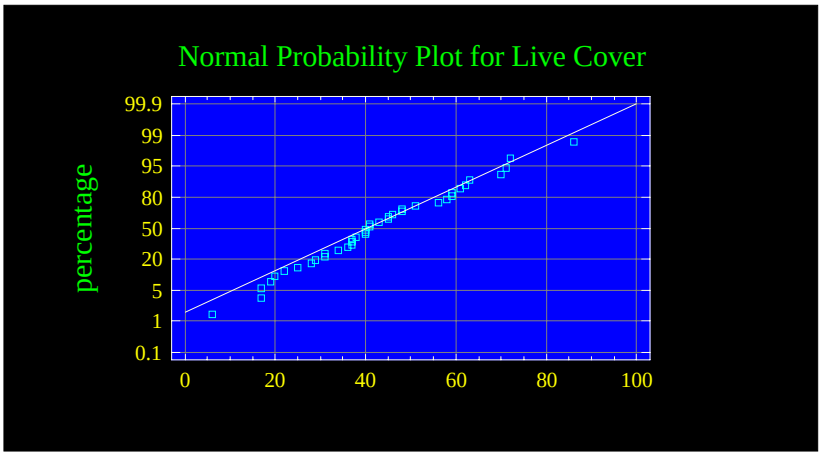


Figure 2a

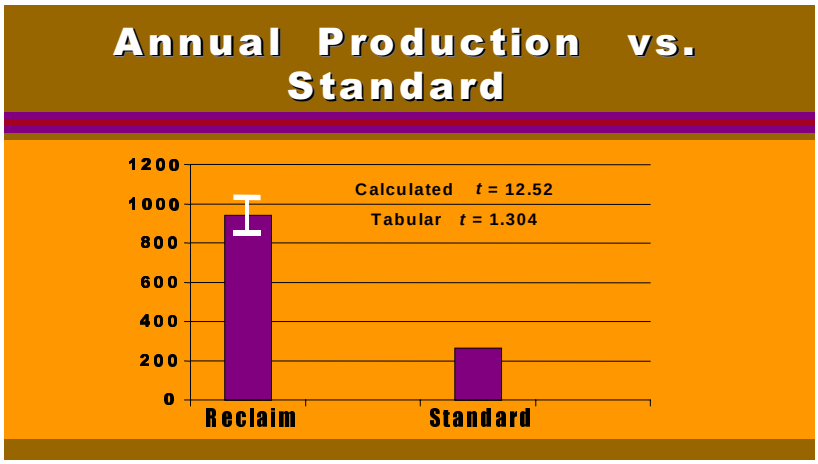


Figure 2b

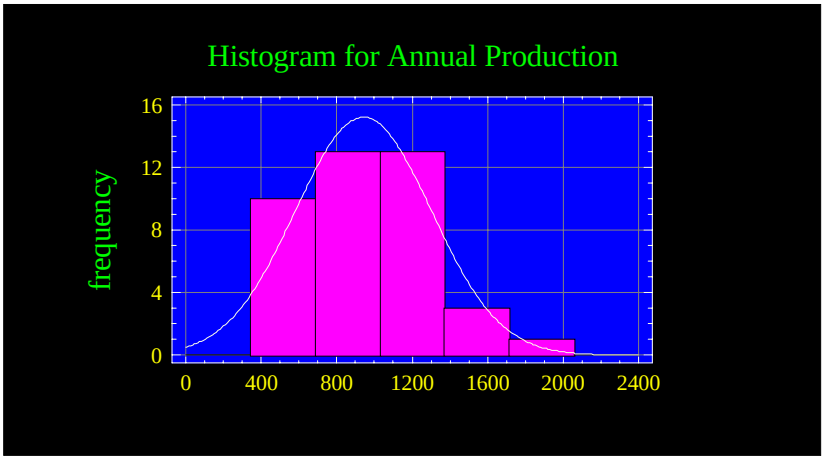


Figure 2c

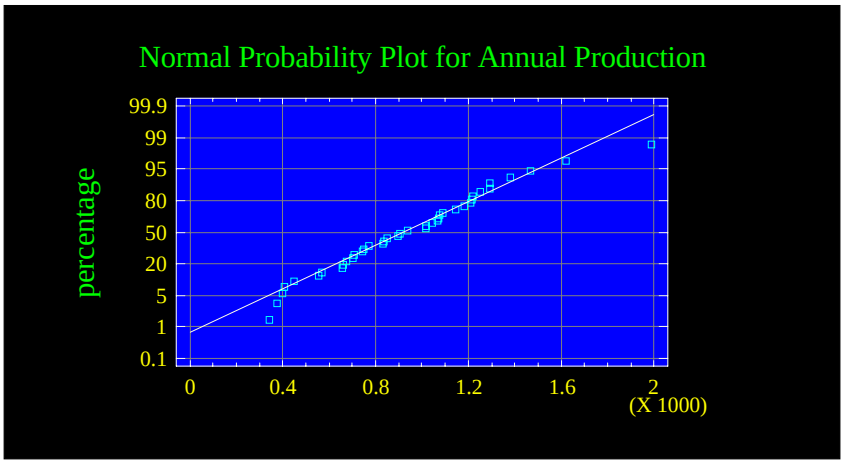
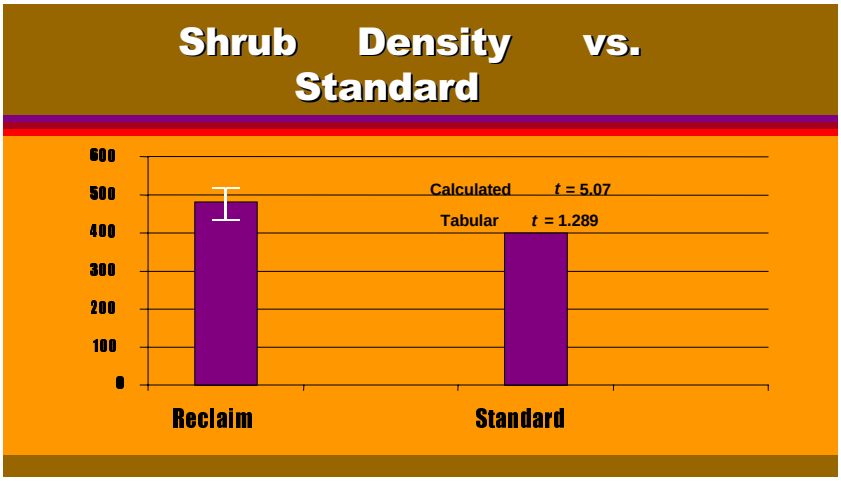


Figure 3a



distribution is an appropriate model for the cover and production data. However, the validity of the normal distribution as a model for the shrub density data was uncertain (figs. 3b and 3c). *Statgraphics*® software (supplied to state regulatory agencies by the federal Office of Surface Mining) also indicated that assuming the data were normally distributed was inappropriate.

The approved species diversity standards (at least three perennial grass species with relative cover between 5 percent and 90 percent, and at least two shrub species with relative densities between 5 percent and 95 percent) were also achieved. Four native perennial grasses and two shrub species met the approved standards for relative cover and relative density.

Due to the indication of nonnormality, the nonparametric one-sample sign test was performed on the shrub density data. Forty of the samples indicated a density less than 360 shrubs/ac (90 percent of the performance standard) and 80 of the samples exceeded that value. The sign test indicated that the reclamation shrub density exceeded 90 percent of the performance standard with greater than 99.9-percent statistical confidence.

As a further check on the procedures recommended in the draft New Mexico *Coal Mine Reclamation Program Vegetation Standards*, a search for an appropriate transformation to normalize the data was conducted. The square root transformation adequately normalized the data (figs. 3d and 3e). A one-sided *t* test performed on the transformed data returned a calculated *t* value of 5.41, which was larger than the *t* value of 5.07 calculated from the untransformed data. This indicates that, when testing the reverse null hypothesis, a *t* test of the nonnormal data was more conservative, from a regulator's perspective, than a *t* test of the normalized data.

Figure 3b

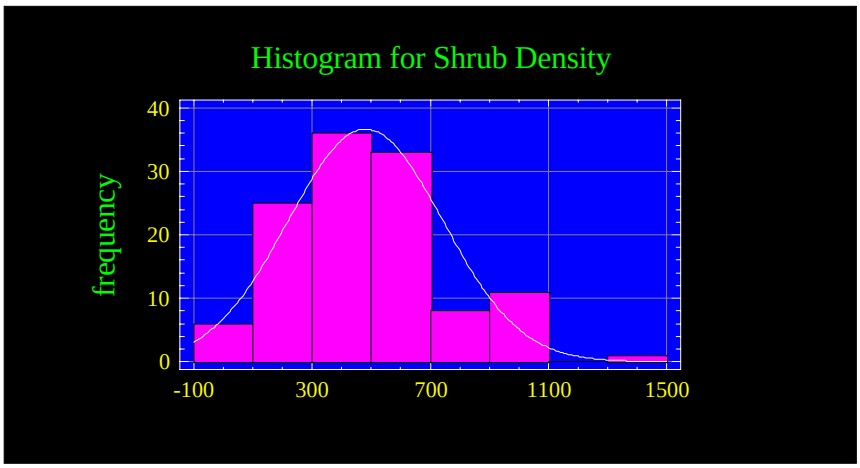


Figure 3c

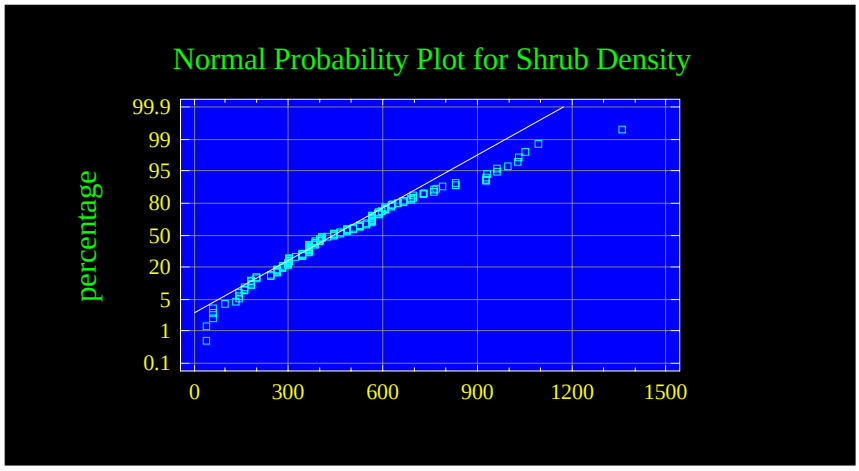


Figure 3d

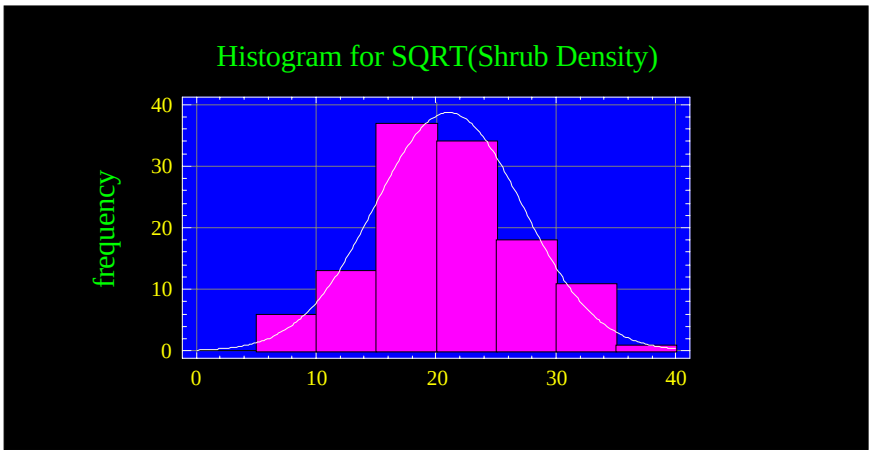
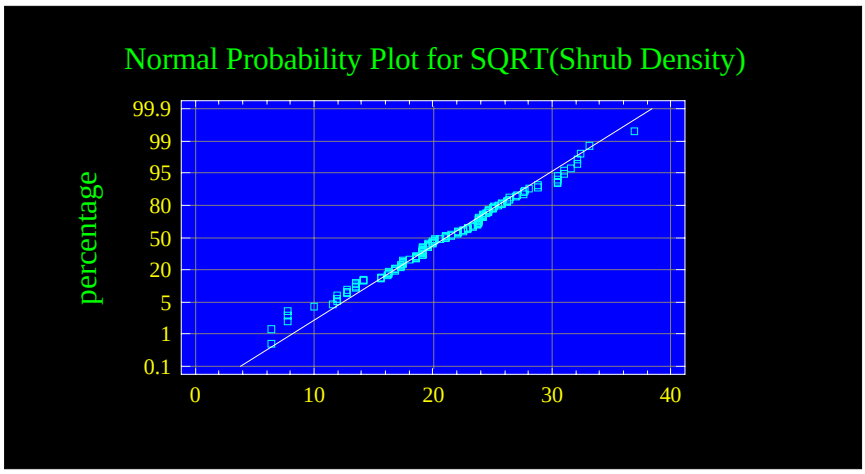


Figure 3e



The implications of these results bear some consideration. The unusually narrow confidence limits for annual production (fig. 2a) appear to stem from the subsampling procedure employed by the vegetation consultant. The $0.5m^2$ clipping plots which are fairly standard for sampling production in the west are probably too small for optimum variance control on desert shrub and grassland sites because of the relatively large interstitial spaces between plants.

In addition to the 40 belts centered on the cover transects, shrub density was measured on a further 80 randomly located belt transects to ensure an adequate sample. Walking a 4m stick down a 50m transect with the sole objective of tallying shrubs doesn't take an unreasonable amount of time, and probably took only slightly longer than using the more typical 1 or 2m-wide belts. The 90 percent confidence limits shown in figure 3a are also uncommonly narrow, and indicative of an adequate sample and a relatively even distribution of shrubs across reclamation.

If the reclaimed shrub density had been a bit lower, but still exceeded the performance standard, the sign test may not have been powerful enough to reject the reverse null hypothesis. Likewise, if a transformation could not be found that would adequately normalize the data, would it have been appropriate to accept the results of the *t* test on the untransformed data, despite the *Statgraphics*® admonition?

I maintain that accepting the results of the test on the untransformed data would be the correct decision. At some point, all of us have probably heard or read a statistician's statement that the assumption of normality is relatively weak and that parametric tests are robust to departures from that assumption. While we have that idea in the back of our minds, few of us feel comfortable about applying it, especially in the regulatory setting. What seems to be called for is a careful consideration of the type and degree of departures from normality, and a recognition that the parametric tests really are robust to such departures, as illustrated above.

The distribution-fitting tests automatically performed by *Statgraphics*® for the shrub density data were the chi-square (p value = 0.09), Shapiro-Wilks quantile comparison (p value = 0.002),

skewness test (z = 2.07), and kurtosis test (z = 0.88). The chi-square *p* value was on the significance bubble, and z values between –2 and +2 for skewness and kurtosis are normal, so the data were just over the positive limit for skewness. Thus, only one of the four tests gave a strong indication of nonnormality. The other three tests indicated that the normal model was a pretty good, but not perfect, fit—about the same impression gained by looking at Figures 3b and 3c. *Statgraphics*® is a powerful and helpful tool, but as regulators, we need to remember that we are the analysts, and not let the software make decisions for us.

One final consideration regarding the Fence Lake Mine No. 1 bond release sampling illustrates a potential difficulty with the regulatory requirement that cover and production must equal or exceed the approved standard during the last two consecutive years of the liability period. Through the third week of July 1999 the site had only received 0.4 inches of annual precipitation, and was still in a state of dormancy. The operator was understandably concerned that there was nothing to measure for a comparison with the approved standards. However, the rains finally began to fall during the last week of July, the vegetation on the minesite began to grow, and an evaluation of 1999 cover and production will be possible.

If the rains had not come in time for growth in 1999, the operator was facing the consequence of collecting additional data during at least two future growing seasons, and maybe more, depending on the weather. The 1998 data could not be used for the two-consecutive-year comparison. A reference area would have permitted comparison no matter what the weather conditions. However, obtaining a sample suitable for statistical evaluation may have been very difficult if the lack of rain had continued, even with the reference area option. It is unlikely that bond release would be granted based upon a comparison of zeros for year ten of the liability period. Likewise, regressions of cover or production on precipitation may be used to develop a predictive equation for dry years, but at least some measurable growth, and some measurable precipitation, would be needed.

Many operators have come to the conclusion that the chances of receiving two consecutive years of normal or above average precipitation are not good. The North Dakota Public Service Commission has recognized the potential effects of drought on bond release evaluation and promulgated a rule change to allow comparisons to be conducted during either (a) the last two consecutive years of the liability period, or (b) three of the last five years, starting no sooner than year eight. While there is no question that the three-of-five option is no less effective than the federal regulations, it does represent additional cost for operators in response to a variable which is beyond their control.

It can be argued that revegetation comparisons conducted during two of the last four years of liability, starting no sooner than year eight, would also be no less effective than the federal rules, without increasing operating costs. A revegetation success demonstration during two of the last four years of the liability period is currently the federal requirement in areas averaging more than 26 inches of annual precipitation, so a precedent has been set in areas which are less subject to climatic variation than the west. As recently expressed by New Mexico operators and consultants (OSM outreach meeting, Farmington, New Mexico, July 1999) revegetation that is capable of meeting the performance standards both before and after a period of drought would provide a better demonstration of resilience, effectiveness, and permanence than revegetation

that could meet the standards during two consecutive (and fortuitous!) years of more or less normal precipitation. The New Mexico Mining and Minerals Division is currently considering the proposal of a rule revision in response to this argument. The likelihood of drought in the west should be recognized and taken into account so that achievable technical standards can be met without undue costs or extensions of the 10-year liability period.

References

Erickson, W. P., 1992. Hypothesis testing under the assumption that a treatment does harm to the environment. MS thesis. Univ. of Wyoming, Laramie.

McDonald, L.L., and W. P. Erickson. Testing for bioequivalence in field studies: Has a disturbed site been adequately reclaimed? *In:* Statistics in Ecology and Environmental Monitoring . Pp. 183-197. D. J. Fletcher and B. F. J. Manly (eds.), Otago Conference Series No. 2, Univ. of Otago Press, Dunedin, New Zealand.

Geographic Informations Systems: Increased Use and Applications

Michael R. Maier

Introduction

Geographic Information Systems (GIS's) are new and powerful tools in dealing with the large amount of information used in the environmental and permitting process. These tools are useful not only in the way they present information but also in how they provide open-pit mining information required by the stringent environmental laws. The cost of building a competent GIS is a quick payback by way of efficiency created in dealing with today's bureaucracy.

To remain compliant with California's environmental regulations many mining operations employed the services of Condor Earth Technologies, a multidiscipline, earth-science engineering company with a history in the mining industry. Condor Earth provides expertise in combining mining, which is geographically rich in data, with a newer science known as GIS. GIS is the method of using a computer to keep track of data in a digital map that associates information by way of graphically choosing map objects. What this offers is a method of keeping track of important data and being able to see the relationships among these data. When looking at geographic data there are many variables. A good GIS will put all the variables, in addition to the options, in front of the user.

What is GIS?

GIS's have been around for years, but the digital revolution has created, and continues to create, many new applications for the technology. Industries and governments now use GIS worldwide in ways unimaginable only a few years ago.

GIS technology is helping people make better decisions in a host of areas, such as agricultural and natural resources management, and environmental control. It is helping businesses streamline customer service operations, coordinate enterprise-wide problem solving, and revolutionize logistical planning. GIS applications have saved millions of dollars through increased productivity and efficiencies.

GIS is the process of utilizing the power of computing to analyze maps or geographic data. The power of the desktop personal computer is making GIS a very common site.

Desktop processing power

By allowing modeling of the world in many small increments, desktop computers are contributing to personal power of a new kind. In most cases people in business have not yet began to discover the true potential of having a small model that can duplicate and calculate the existing situation. Every few seconds, the average desktop computer can process as many calculations as Albert Einstein did in a lifetime. GIS is the only method to take advantage of today's computer power for businesses working in such a geographically dependent industry.

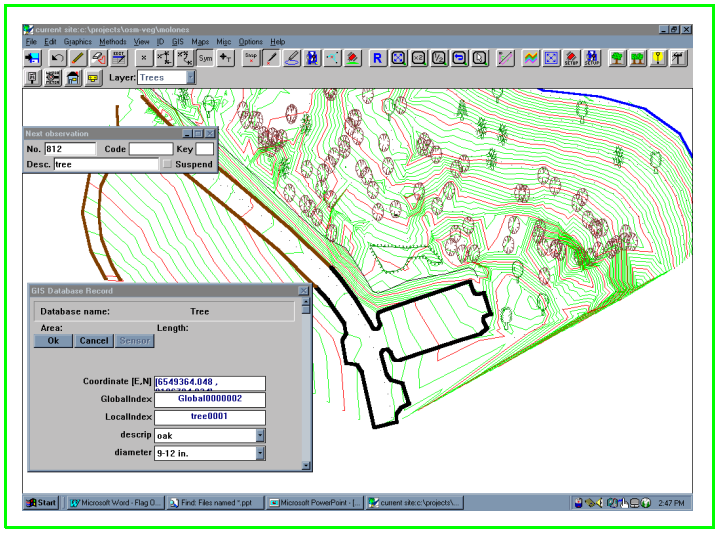
Field Data Collection: Foundation of a good GIS

The most important ingredient for a successful computer model is the data that the model is made from. If the data are inaccurate, they are not merely worthless; in fact, they are expensive, costing money, because they lead to wrong conclusions that have to be revisited. This is why the

creation of a good GIS system is started in the field, by creating forms that prompt the person in the field to collect and contribute uniform and meaningful data.

PenMap

With newer, smaller, and more rugged computers, people can take the system logic of the Windows operating system out into the field. PenMap field data-collection software takes advantage of an evolved operating system. PenMap was developed to interface with many different types of serial data inputs like GPS, reflectorless hand-held laser devices, total stations, bar code scanners, depth sounders to name a few.



PenMap Software

ArcPad

ArcPad is a smaller version of PenMap. ArcPad runs on a palmtop computer with a Windows CE operating system. ArcPad was developed as a less expensive, less capable data-collection unit that still follows the logic of a desktop operating system.

How to build a GIS

The first thing to realise is that you <u>do not</u> need a herd of surveyors to go out in one day and map the user's world. There are many ways of attaining geographic location for your database. Using PenMap or ArcPad makes it very easy to "log" coordinate data of any feature (that is, to assign a location to the feature, on the spot and in real time). What is needed for a good GIS system is a method whereby everybody who has any valuable information about a location is able to contribute his or her data.

Example

As an example of reclamation of a site, let's look at a tree planted in a field. What information is known about this tree? Perhaps we know its supplier, its location, its price, and its type. What other information should we have? How about who planted it, when it was planted, and what the planter thought about the conditions of tree and site alike. This information is some of the best data that gets overlooked many times. The planter's knowledge, added to your database, will become a valuable asset. In any situation, all these data exist, but they are not often found in one place or in one format. It is hard to compile these data to make a fair evaluation of a situation without a computer system. This is how a GIS pays for itself. GIS takes all known information and locates itself by the geographic coordinates.

Conclusion

Field data collection is now the job of every person in the field. This is no longer a surveyor's job. With modern data-collection methods like PenMap and ArcPad we can create methods for every person connected with a project to contribute data to the GIS.

Final Colorado Bond Release Case Studies:
The Canadian Strip Mine Bond Release Study

Sandra Brown
Colorado Division of Minerals and Geology

Introduction

In Colorado, bond releases are becoming a larger part of our workload. Mine operators have started requesting bond release as reclamation is completed. This paper provides a brief summary of coal-mine reclamation in Colorado. Following it are two cases studies of mines that have achieved final bond release. The first of these studies discusses the three-phased bond release of a small surface mine; the second discusses an underground mine that has achieved final bond release.

Summary of Colorado Reclamation

Since the Colorado Surface Coal Mining Reclamation Program was implemented in 1981, 22,700 acres of land have been disturbed; of those, 15,850 acres have been backfilled and graded, 14,268 acres have been topsoiled, and 15,059 acres have been seeded. As figure 1 shows, 67 percent of disturbed lands have been backfilled and graded and 3 percent have been backfilled and graded but are waiting to be topsoiled/seeded. Thirty percent of the lands are associated with the active mining disturbances.

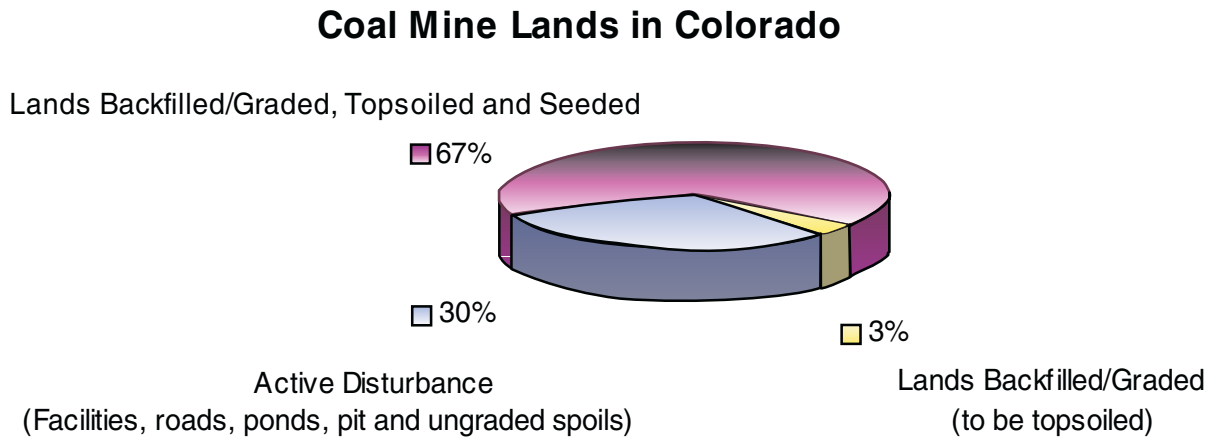


Figure 1 — Summary of reclamation in Colorado

Of these disturbed lands, 12,762 acres (56 percent of disturbed lands) have achieved Phase 1 bond release. Phase II has been approved for 2,136 acres (9 percent of disturbed lands). Final bond release has been granted for 2,449 acres (11 percent of disturbed lands). The discrepancy between the number of acres released for Phase II and Phase III is that some lands that were incorporated into permanent program permits were considered "pre-law." Although, they were included in a permanent program permit, the reclamation was completed prior to the Colorado Surface Coal Mining Law.

Given this summary of reclamation progress in Colorado, I will present a bond release case study. The case study highlights one of the first mines to undergo the three phased bond release process.

Canadian Strip Coal Mine: Bond Release Case Study for a Small Surface Mine

The Canadian Strip Mine is in the North Park Basin in northcentral Colorado. North Park is a high inter-montane basin bounded by the mountains of the Medicine Bow Range to the east and the Rabbit Ears Range to the west and south. The mine is approximately 12 miles east of Walden in Jackson County. The elevation of the mine is about 8,400 feet. The climate is characterized as semi-arid with cool summers, cold winters, low precipitation, and a short growing season. Average annual precipitation is 10 inches, with half occurring as snowfall. All drainage from the mine area flows to Bolton Draw, an ephemeral tributary of the North Platte drainage basin. The average growing season is 40 days. Native vegetation of the mine site was sagebrush grassland. The Bureau of Land Management (BLM) owned part of the surface and leased it for grazing; a private landowner grazed the remaining surface.

Background of Mining Operation

The Canadian Strip Mine was in a historic mining area. The mine was originally permitted in the mid 1970's under Colorado's early reclamation laws. In 1981, Wyoming Fuels Company (WFC), the operator, received a permanent program permit. Twenty three acres had been reclaimed by WFC during 1979 and 1981.

Coal was mined at the Canadian Strip Pit using a truck and shovel. Overburden material was removed and stockpiled prior to coal extraction. Coal was crushed on-site and trucked to a train loadout in Walden.

In June 1982, the operator filed a notice of temporary cessation. The disturbance covered 84 acres and consisted of an open pit, spoil piles, stockpiles, and support facilities. No further mining occurred and operations had ceased prior to completing the anticipated mine plan. Originally, WFC had planned mining, and they had permitted a large area to the south of the existing disturbance. With the early cessation of mining, there was a deficit in overburden, and a revised final reclamation plan was submitted and approved by the Colorado Division of Minerals and Geology (DMG) in 1986.

With the approval of the revised reclamation plan, the worst-case disturbance, which had been contemplated in the original permit, was significantly reduced, and a bond reduction was also approved. The required performance bond was recalculated using the actual disturbance for determining reclamation costs. A reduction in the performance bond was approved during a permit renewal, and the bond was set at $746,450.

During final reclamation in 1988, all facilities at the mine site were removed prior to earthwork. Salvageable materials were sold. Concrete footings, scrap steel, and other suitable non-toxic waste material not sold, were placed in the pit prior to backfilling. The coal pad at the load-out was hauled to the pit and dumped prior to backfilling. The access roads into the mine site were added to the County Road System and designated County Roads for them to maintain.

Final reclamation was completed in 1987. The pit was backfilled using scrapers and dozers. Final grading and topsoiling were completed following backfill operations. Drill seeding and mulching completed the reclamation. The operator used wood chips from a nearby lumber mill for the mulch. During the final phase of reclamation, 55 acres of disturbed areas were reclaimed.

Phase I Bond Release

The Phase I process was fairly smooth. An application for Phase I bond release was submitted December 22, 1987. An inspection was conducted the following spring on May 13, 1988. A follow-up inspection with the Office of Surface Mining (OSM) was conducted. DMG proposed to approve bond release on August 25, 1988. Sixty percent of the bond, or $447,870, was recommended for release. No public comments were received. The proposed decision to approve Phase I bond release became final on December 19, 1988, when OSM concurred with the DMG decision, about 1 year after the application was submitted.

The Phase I release criteria are successful completion of backfilling, regarding, and drainage control in accordance with the approved reclamation plan. DMG used several methods, in addition to the inspection and past inspections, to verify that WFC had successfully achieved these standards.

Approximate original contour, as approved in the reclamation plan, was verified by certified maps provided by the operator, and field and aerial investigations conducted by the DMG. Slopes were regraded to insure stability. All spoil piles, highwalls, and depressions were eliminated. Highwalls were graded to 4:1 slopes. A drainage corridor and sediment pond were formed during the grading of the fill material in the final pit. Drainage control was accomplished for the regraded mine site with three sediment ponds that contained all runoff from the disturbed areas.

High sodium adsorption ration (SAR) values reported in the baseline overburden chemical analysis showed a potential reclamation hazard. WFC was required to prevent sodic problems during reclamation through special handling. During evaluation of the Phase I bond release application, spoil samples of the top 4 feet of material were obtained by the DMG and analyzed by an independent laboratory. The six samples were analyzed for pH, electrical conductivity (EC), and SAR. None of the spoil samples indicated any potential problems for plant growth.

Phase II Bond Release

This bond release application was the most involved as seen by the amount of time needed to process it. The application was submitted on March 1, 1990. A bond release inspection was conducted on September 5, 1990 and DMG issued a proposed decision to approve the application on October 5, 1990. Because this was a federal mine, OSM concurrence was required, but they did not concur with the DMG's decision. Discussions regarding the decision continued and DMG issued a modified decision in August, 1991. WFC contested the DMG's decision and requested a hearing before the Mined Land Reclamation Board. The Board upheld the Division's decision. OSM did concur with the modified decision in April 1992. The primary issue associated with this application was directed at revegetation requirements as discussed below.

A Phase II bond release evaluates the following criteria:

- Topsoil or other material has been redistributed to an approximate uniform, stable thickness consistent with approved postmining land uses;
- The level of suspended solids contributing to streamflow or runoff outside the permit area must be less than or equal to either (1) levels determined by adjacent non-mined areas or (2) pre-mining levels as determined by baseline data; and
- Vegetation has to be established which supports the approved postmining land use and which meets the approved success standard for cover.

For the topsoil evaluation, twenty topsoil depth measurements were taken by DMG. One sample was taken every 5 acres. Sample depths ranged from 6 inches to 18 inches and the average depth was 11.3 inches. The permit required a minimum of 6 inches of topsoil to be redistributed on reclaimed lands. This standard was achieved.

Four composite soil samples were also collected to check for salinity and sodicity hazards. Samples were taken to an independent laboratory for testing. No salinity or sodic hazards were identified.

For the hydrology demonstration, WFC submitted a sediment loss analysis of the sediment generated from a 10-year, 24-hour storm event using SEDCAD and the Revised Universal Soil Loss Equation (RUSLE) sub-routine. The results showed lower sediment generation in the postmining situation (table 1).

A joint DMG/OSM inspection focusing on erosional stability was also conducted. A technique called the Erosion Condition Classification System (described in USDI-BLM Technical Note No. 346) was used to quantify the degree of erosion at the reclaimed mine site. Using this classification system the erosion condition was evaluated based on seven categories: soil movement; litter movement; surface rock fragments; pedestalling; flow patterns, rills and gullies. Each category was rated according to the degree of erosion observed. Overall, the property was rated as having only a “slight” erosional condition (table 2). The field erosion evaluations documented that erosion on the reclaimed areas would not be disruptive to the postmining land use.

Table 1— Canadian Strip Mine, Phase II hydrology demonstration

Hydrology and Sedimentology for a 10-Year, 24-Hour Event
Summary of SEDCAD+ Results

Watershed	Mining Situation	Runoff Volume (ac-ft)	Peak Discharge (cfs)	Sediment (tons)
1	Pre-	2.06	12.61	12.8
1	Post-	1.90	15.26	3.3
2	Pre-	1.08	8.78	5.3
2	Post-	1.04	4.99	4.5
3	Pre-	0.22	2.25	1.1
3	Post-	0.05	0.45	0.1

Table 2 — Canadian Strip Mine, Phase II erosion demonstration

Summary of Erosional Stability Observations

	Identified Factor	Possible Factor	Percentage	Erosion Condition Class
East Facing Slope	N/A	N/A	20-40	Slight
West Facing Slope				
Observer 1	14	71	20	Stable
Observer 2	38	85	44	Moderate
Valley Bottom				
Observer 3	13	71	18	Slight
Observer 4	16	43	37	Slight
Northern Part of Property		12	72	17

There were several issues regarding revegetation starting with the initial sampling efforts. Both the DMG and the operator sampled revegetation in 1989. Three separate areas were sampled: those seeded in 1979, in 1981, and in 1987. Weighted cover and production values were calculated for the 1979 and 1981 areas. There were large discrepancies between the sampling results collected by the DMG and by the operator (table 3). Potential explanations for the disparate results may have been sampling techniques, differences in the definition of litter and abnormally high rainfall in North Park between the sampling times of the DMG and the operator. However, because of the differences, revegetation was resampled in 1990 by both DMG and the operator. Both used the same methodology.

Table 3 — Canadian Strip Mine, Phase II revegetation data

	Division of Minerals & Geology		**Wyoming Fuels**	
Area	Sample Date	Percent Cover	Sample Date	Percent Cover
1989 Data				
79-81 Reclaim	08/21/1989	27.3 percent	09/22/1989	68.4 percent
87 Reclaim	08/21/1989	32 percent	09/22/1989	60 percent
Reference Area			09/22/1989	69.8 percent
1990 Data				
79-81 Reclaim	8/7-8/90	48 percent	8/6-7/90	54 percent
87 Reclaim	8/7-8/90	40 percent	8/6-7/90	44 percent
Reference Area	8/7-8/90	50 percent	8/6-7/90	57 percent

At the time, DMG's policy was that revegetation would be considered successful if the reclaimed area vegetation was 90 percent of the reference area cover with 90 percent statistical confidence. The older areas met the success criterion. The area seeded in 1987 did not meet this criterion, although there was a high degree of stabilizing protection provided to the topsoil resource by the wood chip mulch in combination with the vegetative cover. The Division determined the total cover was acceptable to control erosion.

DMG also evaluated species composition based on the cover data. The species diversity or shrub density standards were not applied, but the DMG realized they would be difficult to achieve. No shrubs were observed in the 1987 reclaimed area. WFC decided to interseed woody plants in the spring of 1991 in order to promote success at the time of final bond release.

DMG issued a proposed decision to approve the Phase II bond release. OSM did not concur with the DMG decision because the vegetative cover was not 90 percent of the reference area cover. Discussions regarding Phase II bond release ensued. DMG decided to modify their decision to exclude the revegetation in the 1987 reclaimed area. The modified decision proposed to release $63,448. Money was retained for revegetating the 55 acres seeded in 1987.

While the Phase II bond release application was being reviewed, the operator (now Slurco Corporation) requested to remove one of the sediment ponds that drained the older reclaimed areas. This was approved and the pond was reclaimed. Retention of the other two ponds as permanent impoundments was approved.

Second Phase II Bond Release

A second Phase II bond release application was submitted on September 7, 1995 for the area seeded in 1987. The review of this application was uneventful and was processed in five months. Vegetation data provided by the operator and verified by the DMG showed that the vegetation cover on the 1987 reclaimed area was greater than 90 percent of the reference area. Permanent retention for Ponds 1 and 2 was approved based on the following factors:

- The landowners requested retention of the ponds;
- Pond retention would enhance the postmining land use of rangeland and wildlife habitat;
- The water quality criteria meets criteria for stock watering ponds;
- Water levels were sufficient to serve as stock ponds;
- Water rights were obtained from the State Engineers Office; and
- The pond designs were in compliance with the regulations for permanent impoundments.

Phase III Bond Release for Loadout

A Phase III Bond Release application for the loadout was submitted on March 20, 1997. An inspection was conducted on May 14, 1997. The bond release criteria for an industrial facility are:

- A request from the landowner to retain an industrial facility;
- A demonstration that the commercial use has commenced; and
- Adequate erosion control.

The loadout was adjacent to the tracks and as landowner, the railroad requested that the site be retained. They used the site to store railroad ties during removal of the North Park line. The site was partially vegetated and graveled, erosion off the site was controlled. Therefore, the site met all bond release criteria. DMG issued a decision to approve the bond release and proposed to release $11,362 which covered the liability of the loadout facility.

Phase III Bond Release

A Phase III Bond Release Application was submitted on August 4, 1998. An inspection was conducted on October 7, 1998. Participants included representatives of Slurco Corporation, OSM, the DMG and the private landowner.

The Phase III bond release criteria are listed below:

- Completion of 10-year liability period;
- Successful completion of reclamation plan;
- Achievement of all revegetation success criteria during the last 2 years of the liability period;
- A demonstration that on-site hydrologic impacts have been minimized and that off-site hydrologic impacts have been prevented; and
- A demonstration that the post mining land use has been achieved.

Revegetation success was demonstrated by the operator during 1997 and 1998, the last 2years of liability period. Data had been collected in 1996 in an effort to apply for final bond release in 1997. Productivity was acceptable. However, the cover results were negatively affected by grazing of the reclaimed area and the success standards were not achieved. Therefore, the 1996 results did not count and Slurco Corporation sampled in 1997 and 1998. During these two years, herbaceous productivity, vegetative cover, species diversity and woody plant density were deemed successful A complete review of the standards was discussed at last year's bond release forum, and therefore I will not go into the details.

A small two-track road was retained to gain access to the ponds and northern part of the reclaimed area. The road had been seeded and was included in the area sampled for revegetation.

The hydrology impacts were analyzed using the surface and ground water monitoring data collection that the operator initiated in 1980. Results were reported each year in their Annual Hydrologic Report. The annual results were compared with the Statement of Probable Hydrologic Consequences from the permit application. Based on the analysis, the DMG made the following findings:

- Impacts to streamflow were negligible. There was no discharge reported for several years. What little flow that may have been lost due to pond retention was counteracted by the increase in available water to livestock and wildlife;
- The predicted salt loading was less than anticipated;
- Impacts to surface water quality were considered negligible;
- A local lowering of the potentiometric surface was predicted in the coal seam, and the adjacent overburden. Lower water levels were observed, but rising water levels recorded from the spoils monitoring well indicated the recovery of the potentiometric surface;

- Spoil water quality was suitable for livestock purposes; and
- No springs or seeps were observed emanating from the mined area.

At the request of the landowner, the remaining spoils monitoring well was retained for his future use. A well permit had been obtained from the State Engineers Office. Water quality was suitable for livestock use.

The approved postmining land use of rangeland and wildlife habitat was demonstrated. The operator successfully grazed the reclaimed lands in 1996 with no adverse impacts observed. Wildlife, specifically, antelope, deer, elk, coyotes, and rabbits were frequently observed utilizing the reclaimed areas. Many duck and bird species were observed on the ponds. An old cabin identified during baseline studies was protected from mining disturbance.

BLM, as one of the landowners, requested the replacement of their original fence configuration. The operator removed old fence and rebuilt the fence along BLM's boundary.

DMG recommended approval of final bond release on November 18, 1998. DMG proposed to release $100,606, the remaining liability at the mine. OSM concurrence was received January 25, 1999. The permit was terminated and the letter of credit was returned.

Conclusion

In conclusion, the Canadian Strip Mine was one of the first Colorado mines to go through the three phased bond release process. Final reclamation occurred in 1987, and the mine was eligible for full bond release 11 years later in 1998. Public involvement was minimal during all phases of bond release. The private landowner and BLM participated in most of the bond release inspections and had a few comments that were addressed.

The revegetation issues that arose during the first Phase II application help set the precedence for future bond release decisions. The Colorado Regulations were revised to specifically say that the Phase II criteria would be based upon establishment of vegetation that supports the postmining land use and meets the approved success standard for cover. One year's worth of statistically valid data must be submitted showing the reclaimed area has at least 90 percent of the cover of the reference area with 90 percent confidence. DMG also developed Bond Release Guidelines in 1995 to further clarify the process and the type of data and procedures that would be requested during each phase of the bond release process. These have been very helpful as we continue to evaluate more and more bond release applications.

Final Colorado Bond Release Case Studies:
Red Canyon Mine Phase II and III Bond Release Study

Dan Mathews
Colorado Division of Minerals and Geology

Introduction

A complete Phase II and III (final) bond release application for the Red Canyon Mine, operated by MINREC, INC., was submitted to the Colorado Division of Minerals and Geology (DMG) and Office of Surface Mining Reclamation and Enforcement (OSM), on November 12, 1998. Eighty-one surface owners of lands in or adjacent to the permit area were notified of the bond release application. A joint OSM/DMG inspection was conducted on December 1, 1998, with the participation of five landowners. During the bond release evaluation, several permit area landowners expressed concern that their land or residences may have been harmed by subsidence caused by Red Canyon Mine operations. Investigation by the Division indicated that mine subsidence was likely not the cause of problems reported by the landowners. Certain concerns were raised by the Division regarding hydrologic projections, but were adequately addressed by the operator. No additional adequacy issues were identified during the review, and the Division issued a proposed decision to approve the bond release on June 17, 1999. No comments or objections were filed. OSM concurrence on the bond release decision was received August 3, 1999, and the remaining performance bond (a $74,000.00 certificate of deposit) was released to the operator. The Division has terminated its jurisdiction over the Red Canyon Mine.

Background on Operation

The reclaimed Red Canyon Mine is located on the southern flank of the Grand Mesa, in west-central Colorado, at an elevation of approximately 6500 feet. The dominant native vegetation type in the mine vicinity is pinyon-juniper woodland, with extensive acreage of improved irrigated pasture associated with perennial streams, which have headwaters higher on the Grand Mesa. Land ownership in the permit area and vicinity is private, with many retirement homes and small “ranchettes”. Annual precipitation in the mine vicinity averages 12 inches per year, with a peak in late summer/early fall.

The small underground mine was initially permitted by Grand Mesa Coal Company, and operated for only a few years in the late 1970’s and early 1980’s. The mine entered into temporary cessation in 1984, and operations never resumed. The mine was permitted to extract both private and federal coal, and so was classed as a federal mine; surface lands were privately owned, with multiple owners. The permit area encompassed approximately 610 acres, of which approximately 150 acres were actually affected by underground workings. Surface disturbance was 26.4 acres.

Two coal seams were approved for mining, but operations were never initiated on the lower seam. Extraction was limited to between 50 and 55 percent, to prevent subsidence damage to alluvial aquifers, stream channels, irrigation structures, and residences. The coal seam averaged six feet thick and dipped 3 to 5 degrees to the northeast beneath the Grand Mesa. Cover ranged from less than 100 feet near the portals to approximately 1,000 feet at the northern permit boundary. Mining extended to the north and west from the portals. Coal was shipped to the nearby town of Delta by truck, where it was loaded for rail shipment. Maximum annual production was 138,000 tons, in 1981.

The surface disturbance area is at the upper end of a southerly oriented draw, with an ephemeral drainage which flows only in response to heavy storm runoff or due to irrigation runoff from agricultural lands north of the property. Mine portals, a ventilation shaft, coal stockpile and associated facilities were located at the upper end of the disturbed area, with the sediment pond located further down the draw. An office trailer was located on a small bench west of the draw.

There was extensive pre-law disturbance throughout the 26.4 acre disturbed area, from small scale surface and underground coal mining activity dating to the early 1900's.

During operations, underground development waste was disposed of in abandoned strip pits on the slope east of the draw. The entire site was reclaimed in the fall of 1988 by MINREC, INC., the current permittee. Reclamation included portal sealing, cleanup of coal residue, facilities removal, backfilling and grading, permanent drainage channel construction, and revegetation. Refuse material was covered with 4 feet of non-toxic cover (spoil material from pre-law strip pits). Due to prior disturbance, topsoil was not available for salvage. Final graded slopes were drill seeded with a mix of native grasses, forbs and shrubs, to accommodate the postmine land use of wildlife habitat. Additional reclamation work was performed in 1997, and included modifications to the permanent drainage channel to direct flows into the pond, ripping and seeding of the remaining segment of the road into the site, and reclamation of certain collection and diversion ditch segments. Remaining monitoring wells were also reclaimed.

Phase I bond release was approved in 1989. Following approval of Phase I release, the sediment pond was approved for retention as a permanent impoundment, and a transmission line and segment of the access road were also approved for retention, at the request of the operator/landowner and the local electric association.

Final Bond Release Technical Findings: Backfilling and Grading

The Division found, as a part of Phase I bond release in 1989, that waste disposal slopes were in accordance with approved design, required 4-foot cover had been provided, and remainder of site met approximate original contour and was in accordance with permit. Permanent drainage channel had been properly constructed and reclaimed area was stable. These findings were affirmed during Phase II/III release.

Final Bond Release Technical Findings: Topsoil Replacement

Due to pre-law disturbance, the best available material on site was used for plant growth medium, with coaly material buried or disposed of in the underground development waste disposal site. The material was largely comprised of spoil from pre-law strip pits. Bond release inspection revealed "no bare areas of significant extent, areas of stunted vegetation, salt crusts or discoloration, or other apparent indications of the presence of chemical or physical soil characteristics inhibiting plant growth."

Final Bond Release Technical Findings: Revegetation

Because of the pre-law disturbance, the only specific success standard specified was vegetation cover. When the mine was permitted, a revegetation standard of 23 percent non-noxious, perennial vegetation cover was established, based on sampling conducted in 1983 within a sagebrush vegetation community in the vicinity of the disturbed area.

Sampling conducted by a consultant to the operator indicated non-noxious perennial cover sample mean of 34.9 percent in 1992, 42 percent in 1997 and 41 percent in 1998. In 1998, dominant species were fourwing saltbush and bluebunch wheatgrass. Western wheatgrass and

basin wildrye also contributed in excess of 3 percent relative cover. Annual species contributed approximately 17 percent relative cover (similar to reference site sampled in 1983). Absolute and relative cover of perennial grasses was much higher than documented for the native sagebrush community. Noxious weed species accounted for 5 percent relative cover in 1997 and 1.7 percent relative cover in 1998 (Russian knapweed, whitetop, and bindweed).

From the September 1997 Division inspection report: "Vegetation growth on the reclaimed areas seeded in 1988 remains green and lush due to the ample late summer precipitation this year. During walk-through of the revegetation, 11 cool season grasses, 3 warm season grasses, 3 shrub species, and 2 perennial forb species were observed. The vegetation has effectively stabilized the site, with essentially no erosion apparent on the reclaimed slopes. There are scattered patches of the noxious species Russian knapweed, whitetop, and field bindweed, but the operator has conducted weed control efforts in compliance with Division guidelines, and the noxious species represent a very minor component of the vegetation biomass."

Although there was no species diversity standard required by the approved permit, a relatively diverse assemblage of native shrubs and grasses supportive of the wildlife habitat post-mining land use has been established on the reclaimed area. Woody plant density was not quantified, but appeared to be on the order of 4000 stems per acre or higher, dominated by fourwing saltbush, with significant numbers of big sagebrush throughout the site.

Final Bond Release Technical Findings: Reestablishment of the Essential Hydrologic Functions of Alluvial Valley Floors (AVF's)

Two perennial streams flow through the permit area, Ward Creek and Williams Creek, and the valleys of both streams were determined to be AVF's, based on geomorphic criteria and the presence of extensive irrigated pasture, hayland and orchards. Both streams were undermined by mine entries. The probable-hydrologic-consequences study (PHC) associated with the mine permit concluded that impacts to stream flow and quality of water used for irrigation on the alluvial valley floors would be insignificant. Hydrologic baseline and subsequent monitoring data collected from stream gages and alluvial wells upstream and downstream of mining operations supported the PHC projections. Fluctuating water levels of Ward and Williams Creek during the period of mining and the liability period showed no evidence of depletions. Alluvial monitoring wells showed no sudden drops in water level which might have indicated mining impact. Postmine total dissolved solids levels and sodium adsorption ratio remained well below projected worst case conditions.

Due to limited coal extraction, subsidence effects to irrigation structures and farming operations were anticipated to be limited to minor cracking , depression, or swelling, and capable of easy remedy. No disruption of irrigation structures or other possible surface effects of subsidence interfering with farming on the AVF's had been observed by or reported to the Division prior to issuance of the final bond release proposed decision. The decision included a finding that the mine had been "operated and reclaimed so as to preserve the essential hydrologic functions of alluvial valley floors within and adjacent to the permit area."

Subsequent to issuance of the decision, one landowner reported "disappearing irrigation water and gaseous emanation" from a pasture adjacent to Williams Creek. Division investigation revealed that areas of concern ranged from ¼ mile to over ½ mile from mine workings. There was no apparent surface cracking or deformation, and methanometer checks revealed no anomalous methane or oxygen levels. Our conclusion was that water distribution problems were likely associated with topography and soil factors unrelated to mining, and the landowner did not file a formal objection to the bond release.

Final Bond Release Technical Findings: Protection of the Hydrologic Balance

As discussed previously with regard to AVF's, water quality data from surface streams and alluvial wells in the permit area showed minimal effects from mining; observed impacts were of a lesser magnitude than worst case projections and well below suspect levels for material damage. No apparent impacts to surface water or ground water were noted during the bond release inspection.

During bond release review, the Division noted that, in recent years water levels had been rising in a coal seam monitoring well down-dip from the workings. The Division was concerned that the rising water levels could be indicative of rising water levels in the abandoned workings. If this were the case, the concern was that there might be postmine drainage from the sealed portals, despite permit projections to the contrary. Further evaluation indicated that the rising water level in the well was likely due to improper completion, allowing inflow from irrigation water in the overlying alluvial aquifer. This determination was based on the high quality of well water, which was similar to alluvial water quality, as opposed to degraded water quality which would be expected if there was inflow from abandoned workings.

Based on the inspection, and review of monitoring data and additional information provided by the operator during the bond release evaluation, the Division determined the mine had been "operated and reclaimed so as to protect the hydrologic balance in the permit and adjacent areas."

Final Bond Release Technical Findings: Erosion and Sediment Deposition

There were no significant erosional features observed on the reclaimed minesite during the bond release inspection. Minor rill erosion, which occurred early in the liability period on a few reclaimed slope locations and within the reclaimed channel had been repaired by the operator at that time. More recent downcutting in two ditch locations resulting from heavy storm flow in 1996, had also been satisfactorily repaired, and had not recurred.

An effective cover of shrubs and grasses was established on the reclaimed slopes. In 1992, the operator successfully demonstrated, by universal soil loss equation comparison, that sediment loss from the reclaimed area would be lower than that from an undisturbed sagebrush community in the permit area. Based on the fact that vegetation cover levels on the reclaimed area increased between 1992 and 1998 (from 34.9 percent to 40.6 percent), and based on the observed absence of erosional features on the reclaimed area, the earlier finding was upheld in the final bond release decision.

Final Bond Release Technical Findings: Reclamation of Diversion and Collection Ditches

Temporary drainage and sediment control ditches were either completely reclaimed or modified to tie into the permanent reclaimed channel in 1997. The lower segment of the permanent channel which had previously bypassed the sediment pond/impoundment, was relocated to empty into the impoundment. Refuse area perimeter ditches and "temporary terrace ditches" on the reclaimed refuse pile were left in place. These ditches were stable and supported well developed vegetation, as did older sections of the permanent drainage channel. The lower segment of the permanent drainage constructed in 1997 had functioned well, with no erosion, and vegetation was rapidly establishing within and adjacent to the channel.

The Division found that the final drainage system as modified in 1997 was in compliance with the approved permit and regulations, and provided for a stable and functional landscape.

Final Bond Release Technical Findings: Construction and Performance of Permanent Impoundments

The existing sediment pond on site functioned effectively throughout the life of the operation and was approved by the Division as a permanent impoundment due to demonstrated compliance with specific regulatory requirements:

- water quality suitable for intended use;
- water level and configuration adequate for intended use; no impediments to access;
- water storage in compliance with State water law; and
- P.E. certification of design and construction in compliance with applicable criteria.

Final Bond Release Technical Findings: Subsidence Impacts

Due to the presence of numerous residences, roads, perennial streams, AVF's, and irrigation systems in the permit area, the potential for surface impacts of subsidence had been a significant concern in the original mine design and permitting. Coal extraction was limited to 55 percent, with 50 percent extraction beneath structures, to prevent subsidence damage. Residences in existence prior to undermining were inventoried, and subsidence survey monuments were installed. Monitoring was conducted between 1982 and 1989, and was suspended based on the fact that monitoring detected a maximum of 0.3 feet of residual vertical subsidence, with none of the protected and monitored structures exhibiting any subsidence.

Upon receiving notice of the bond release application, three landowners contacted the Division with concerns that their property might have been damaged by subsidence. Two of the individuals were concerned with their houses which had been constructed within or adjacent to areas potentially affected by subsidence. Both houses had been constructed in the 1990's, well after mining at Red Canyon had ceased. The landowners were concerned with features such as hairline cracks in drywall, foundation cracks with evidence of seepage, and narrow cracks in concrete slab basement flooring. These houses were inspected during the bond release inspection on December 1, and in a follow-up inspection by the Division's engineering geologist on March 17, 1999. The Division concluded that none of the features observed appeared to have been caused by mine subsidence, but were likely the result of site drainage and construction techniques, and expansive soils.

A third landowner was concerned with a surface crack on an undeveloped portion of his property, adjacent to the mine disturbed area. The location was observed during the bond release inspection, and was subsequently filled in by the mine operator. The crack was located on fill material excavated during pre-law surface mining activity, apparently during the 1960's. The crack was likely associated with settling of the poorly compacted fill material, rather than subsidence associated with the Red Canyon Mine.

Based on review of monitoring records and site inspections, the Division found that no material damage related to Red Canyon Mine subsidence had occurred. Subsequent to issuance of the proposed decision, with this finding, a fourth landowner contacted the Division. The landowner's concerns were with "disappearing irrigation water and gaseous emanation" in his irrigated pasture, described previously under "Final Bond Release Technical Findings: Reestablishment of Essential Hydrologic Functions of Alluvial Valley Floors."

Final Bond Release Technical Findings: Land Use

The approved postmine land use was wildlife habitat, and the reclaimed site is within an area designated as critical mule deer winter range. Due to the abundance of grass and browse, the reclamation provides excellent forage for mule deer, which utilize the site throughout the year. Cottontail rabbits are abundant on the reclaimed area; and rock squirrels and other rodents are also present. A pair of red-tailed hawks has nested successfully on one of the old power poles on site in recent years. The impoundment effectively extends the period of time that water is available on the site, and should further benefit wildlife use of the property.

Summary and Conclusions

Based upon review of the bond release application, consideration of landowner comments, and results of site inspections, the Division determined that the operator had successfully completed all surface coal mining reclamation operations. As a result, the reclamation bond was returned to the operator, and the Division's jurisdiction for the operation has been terminated.

Suggested Readings for Western Ethnobotany

Robyn W. Tierney

The two volumes that follow provide comprehensive and well-documented reviews of the plants that are of special cultural and regional interest today. Many of the species described in these books are well-suited to being planted on reclaimed lands:

> Dunmire, William W ., and Gail D. Tierney. 1995. Wild Plants of the Pueblo Province. Santa Fe: Museum of New Mexico Press, 290 p.
>
> Dunmire, William W., and Gail D. Tierney. 1995. Wild Plants and Native Peoples of the Four Corners. Santa Fe: Museum of New Mexico Press, 313 p.

Although this monograph is now out-of-print, it is available on reserve at the University of New Mexico Library. It contains rich and unique descriptions of cultural uses of plant species not commonly found in the Four Corners region today. However, many of these species are well suited for inclusion in reclamation seed mixes and are now available from seed suppliers:

> Elmore, Francis H. 1944. Ethnobotany of the Navajo. Monograph Series, Vol. 1, No.7. University of New Mexico and the School of American Research.

This volume represents a unique treatment of the cultural uses of plants in the Pacific Northwest. Many of the species discussed here are also found in Alaska:

> Gunther, Erna. 1945. Ethnobotany of Western Washington. First published in University of Washington Publications in Anthropology, Vol. X. No.1.

This is a useful and popular illustrated book that continues to be reprinted every few years. It may be of special interest to the mines in Powder River Basin and Montana since the ranges of many of the species discussed here extend well into those States:

> Harrington, H. D. Edible Native Plants of the Rocky Mountains. 1967. The University of New Mexico Press.

This is a nicely illustrated and well designed book that summarizes some of the less accessible literature (including Elmore's reference above) on the subject:

> Mayes, Vernon 0., and Barbara B. Lacy. 1989. Nanise. Tsaile, Arizona: Navajo Community College.

This book offers a very comprehensive and complete guide to the identification and use of traditional medicinal plants of the West:

> Moore, Michael. 1989. Medicinal Plants of the Desert and Canyon West.

Although not a treatise on ethnobotany, this book provides interesting discussion of the agricultural traditions and uses of native plants of the Tohono O'odham or "Desert People" of Southern Arizona:

Nabhan, Gary Paul. 1982. The Desert Smells Like Rain. San Francisco: North Point Press.

Again, this is another treatment of past and future cultural uses of indigenous plants native to the Sonoran Desert. With some imagination, some of the ideas contained here could be extended to other regional floras and in developing seed mixes that extend the cultural value of reclaimed lands:

Nabhan, Gary Paul. 1987. Gathering the Desert. The University of Arizona Press.

A more thorough treatment of the importance of wild plant conservation:

Nabhan, Gary Paul. 1989. Enduring Seeds. San Francisco: North Point Press.

This is a republication of *Ethnobotany of the Zuni Indians* in the Thirtieth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1908-09, published in 1915 by the United States Government Printing Office, Washington, D.C. The nomenclature and taxonomy contained here may be dated, but this is a detailed and thorough review of the cultural significance of several plant species now regularly used in the region's reclamation seed mixes:

Stevenson, Matilda Coxe. 1993. Ethnobotany of the Zuni Indians. Dover Books.

Although this book is not illustrated, it contains a very good review of the cultural importance and uses of plants common to the Colorado Plateau and the Four Comers regions:

Whiting, Alfred F. 1966. Ethnobotany of the Hopi. Flagstaff: Museum of Northern Arizona.

OSM'S Role in Enhancing Bond Release on Indian Lands and in Federal Programs States

Willis Gainer
Director, Albuquerque Field Office,
Office of Surface Mining

The Office of Surface Mining Reclamation and Enforcement (OSM) is the regulatory authority (RA) for surface coal-mining operations on Indian Lands and for Federal Program States in the western United States. Currently this includes active mining on four reservations (Crow, Hopi, Navajo, and Ute Mountain Ute) and one Federal Program State (Washington). OSM is responsible for regulatory activities for seven mines on Indian Lands and two mines in Washington that currently include more than 25,817 acres of mining-related disturbance on permanent-program lands. In addition, another 4,751 acres of lands have been disturbed under the initial regulatory program.

OSM is concerned about the limited amount of reclaimed land that has been released from liability on these coal mining operations. As a result, OSM is placing an increased emphasis on bond release in an effort to stimulate the timely release of lands, as envisioned under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). OSM will be implementing new initiatives that will encourage mine permittees to apply for bond release. At the same time, OSM will be implementing changes within its inspection and enforcement operations that will hopefully ensure that the bond release process proceeds smoothly and efficiently.

The GPRA Stimulus

The Government Performance and Results Act of 1993 (GPRA) mandates that all Federal agencies measure the results of implementing their programs. GPRA requires agencies to set specific performance goals, measure the results of their performance, and annually report to Congress on their accomplishments. As one of its key performance measures, OSM has selected the number of bond releases (by phases) completed annually on all coal mines across the United States. From a reclamation success standpoint, what could be a better measure of the ultimate success of SMCRA than release of a mine from reclamation liability? Bond release is an official determination by the RA that a mine has successfully met all the reclamation requirements imposed by SMCRA.

So how is OSM "measuring up" under GPRA? The OSM Western Regional Coordinating Center (WRCC) recently compiled data from each mine that it regulates regarding the status of reclamation including the number of acres that have been released under various phases of reclamation. As shown in the following table, there is a lot of "opportunity" to increase the acreage of bond release. OSM's inventory shows that up to 9,687 acres have been backfilled and graded and as such are potentially eligible for Phase I bond release. However, only 1,011 acres have actually been released under Phase I. Of the 9,687 backfilled and graded acres, another 6,508 acres have been revegetated and are potentially eligible for Phase II release; however, no

acres have been released. In addition, OSM believes that another 1,523 acres have been revegetated for more than 10 years (the vegetative liability period) and could be eligible for final, Phase III, release. No permanent-program lands have been released under Phase III in the West, with the exception of one 16-acre mine in Washington State.

Bond-Release Acres
Indian Lands/Federal Programs
Permanent-Program Lands - WRCC

Bond Phase	Potential for Release	Released
I	9,687	1,011
II	6,508	0
III	1,523	0

In addition to the permanent-program lands, eight mines on Indian Lands have reclamation liabilities on initial-program lands that could be subject to “termination of jurisdiction” (the counterpart to bond release on permanent-program lands). On initial-program lands mines, 2,737 acres have been backfilled and graded, and of this amount, 2,397 acres have been revegetated, but no acres have been released.

Initiatives to Encourage Bond Releases

OSM recognizes that in order to improve our performance results, emphasis must be placed on enhancing the process of bond release. OSM is considering several new initiatives that may assist permittees achieve more bond releases. On the other hand, we recognize that bond release request is voluntary and can not be mandated upon industry. However, there may be some steps that can be taken by OSM to support an effective and efficient bond release program for mines on Indian Lands and in Federal Program States.

- Encourage voluntary releases — OSM has initiated discussions with industry representatives in an effort to determine why bond releases are lagging and more importantly, to determine what actions can be taken to assist industry in requesting timely releases. This recent attention by OSM has been positively received by industry and has started the “thought processes” on planning for bond release. Information required under 30 CFR 780.18 (general requirements for reclamation plan) includes a “detailed timetable for the completion of each major step of the reclamation plan”. Through communications with the permittees at mid-term reviews, revisions, renewals, etc., OSM anticipates that the information in this section of the permit can be kept up to date which, in turn could provide a planning mechanism for potential bond releases. OSM also hopes that the increased attention on bond release will stimulate industry action.

- Enhance reporting requirements — OSM's WRCC has enhanced the information required in annual mine reports in an effort to assist with GPRA reporting. By reporting the status of various reclamation activities, OSM, and the permittee, can monitor annual reclamation accomplishments. These reporting requirements include items such as acres disturbed; acres backfilled and graded; acres topsoiled, seeded, and planted; and information on the various stages of bond release. Similar reporting requirements have been required by most western States and OSM has put this reporting requirement into effect this year for mines on Indian Lands and in Federal Program States.

- Completion of bond-release guidance documents — OSM's WRCC recently has developed several guidance documents entitled "Guidance for Initial Program Termination of SMCRA Jurisdiction;" "Administrative Procedures for Termination of Jurisdiction Under the Initial Program on Indian Lands and In Federal Program States;" and "Administrative Procedures for Bond Release and Termination of Jurisdiction Under the Permanent Program on Indian Lands and in Federal Program States." These documents were developed by WRCC's Termination of Jurisdiction Team and can be found on WRCC's web page at http://www.wrcc.osmre.gov/WRguidance.html . In addition, this team has also drafted a guidance document entitled "Permanent Program Phase I Bond Release Guidance" that will soon be released for review and comment. (Editor's note: This document is now available on the WRCC web page just mentioned.) WRCC recognizes that one of the deterrents to achieving more bond releases on mines under its jurisdiction is the lack of specific technical guidance from OSM on how Phase I, II, and II bond releases will be conducted. WRCC will continue its efforts to accelerate the development of technical guidance for bond release and will actively seek input from interested parties as to the type and content of guidance needed.

- Other initiatives — OSM is considering several other initiatives that could enhance bond releases. Among those being evaluated are (1) bond releases initiated by OSM on eligible permanent-program lands; (2) OSM terminating jurisdiction on eligible initial-program lands; and (3) the implementation of a bond release awards program. (Editor's note: As indicated on WRCC's web page, the document "Guidance for Initial Program Termination of SMCRA Jurisdiction" is currently under review and revision.)

OSM believes that it has authority under Section 519 (c) to independently release bonds on eligible lands. In part, this section states that "[t]he regulatory authority may release * * * said bond * * * if the authority is satisfied the reclamation * * * has been accomplished." OSM believes that such agency initiated releases would be most appropriately applied to lands eligible for Phase I bond release and possibly on some lands eligible for Phase II release. In those circumstance where OSM has data and can document that the lands meet approved reclamation requirements, OSM could actually trigger the bond release process by placing the required newspaper notices and sending out the notification letters of its intent to terminate its

jurisdiction. OSM would prefer that permittees initiate the bond release process on their own; however, releases triggered by the agency would help achieve the goals of timely bond releases. An OSM-sponsored bond release recognition/awards program may provide additional incentives for companies to seek timely bond releases. Awards could be issued for accomplishments such as: the most acreage of Phase III released for the year; best wildlife enhancement; highest vegetative productivity; best innovative reclamation techniques; and reclamation excellence (best overall reclamation). Awards could be presented at ceremonies and be followed up with press releases. The awards would recognize the accomplishments of the operators in achieving reclamation success and may also stimulate release of more lands.

The Bond-Release Process

As discussed above, WRCC has developed administrative procedures that outline guidance for processing bond release applications. Although the detailed guidance will not be repeated here, the documents contain information on how to file an application, how applications will be processed, and the time frames for processing a decision.

OSM would like to create an atmosphere in which bond release is not viewed as a stand alone endpoint but rather is viewed as a goal that is carried throughout an operation from the initial development of the coal mining lease and permit through OSM's final termination of jurisdiction on mined lands. The key factors leading to successful reclamation and bond release are developed and approved up front during the permitting process. Plans for postmining topography, land use, drainage patterns, wildlife enhancement, and vegetation are planned and agreed upon with the RA, the landowner, the agencies, and the operator before the permit is issued. Just as important, the reclamation success standards for ground cover, diversity, and productivity are established up front in the permit. The plan is continuously monitored and adjusted during the mining and reclamation phases. The plan for reclamation success ultimately comes to fruition with the bond release process and decision to terminate jurisdiction. The goal of bond release thus becomes an integral part of mining, from beginning to end. If this process is properly developed, bond release decisions will become routine and efficient.

What can OSM do to help foster this atmosphere? OSM believes that its mine inspectors could play an important role in assuring that the bond release process is timely and smooth.

Focus on Inspectors

How does an OSM inspector fit into the bond release process? WRCC has established individual mine teams to oversee the administrative and regulatory process for the active mines on Indian Lands and in Federal Program States. The "reclamation specialist," or inspector, is an integral member of the mine team. The team is involved in the review of permit applications, revisions, midterm reviews, and permit renewals. As a result of being on the mine team, the inspector becomes intimately familiar with all aspects of the permit application package and soon becomes "the expert" on the implementation of the approved permit in the field. The inspector is in the position of being the primary "eyes and ears" for the mine team because of his/her proximity to inspection and enforcement issues in the field.

The inspector also maintains a prominent role because of the mandated monthly mine inspections. The primary purpose of the mine site inspection is to ensure that the mining operation is in compliance with the approved permit and that environmental performance standards are being met. The inspector conducts one complete and two partial inspections per calendar quarter at each active mining operation. This averages one inspection per month. In addition, the inspector usually accompanies other team members on technical site visits throughout the year. Citizen complaint inspections also present other opportunities for site evaluations. Altogether, an inspector on Indian Lands mines usually averages 35 days per year on the ground at a mine site. Putting this into the perspective of a Western surface mine which may have a proposed life of mine of twenty years or more, an OSM inspector may visit (inspect) a mine more than 240 times and spend more than 1,000 days on the ground at the mine during the 20-year period. This is a significant amount of time that presents a tremendous opportunity to "evaluate" the success of reclamation leading toward bond release.

The inspector is OSM's primary field contact for tribes, agencies, and citizens involved in mining issues. The inspector has the opportunity to keep these parties informed of issues, get input from the interested parties, and more importantly, provide them with information about the status of reclamation. Just as important, the inspector is also the primary agency contact with the operator for "on-the-ground" reclamation issues. The inspector communicates with the operator on the status of reclamation plans and provides the operator with "heads-up" on potential issues such as erosion, stability, and drainage control that may impact reclamation success. The inspector is in a position to monitor the progress and success of the reclamation process through the life of mine. The inspector becomes thoroughly familiar with the approved plan as it is implemented on the ground.

Can OSM inspectors become more involved in the bond release evaluation process and actually enhance timely bond releases? To a large extent, the inspectors are already performing a role in bond release by monitoring the permittee's implementation of the approved mining and reclamation plans. At present, OSM inspectors are not taking on-the-ground measurements that would verify and document compliance with the reclamation plan. A proposed new direction by OSM would involve inspectors in regularly documenting successful compliance and completion of approved reclamation plans on Indian Lands and Federal Program mines on a timely, ongoing basis.

Contemporaneous Inspections

The Federal regulations at 30 CFR 816.100 require that reclamation, including backfilling, grading, topsoil replacement, and revegetation, occur as contemporaneously as practicable with mining operations. The approved permit sets forth the plans by which the operator plans to achieve contemporaneous reclamation. Typically, on Indian Lands and Federal Program mines, mining and reclamation have been proceeding according to the approved plans but OSM has not documented (measured) the adequacy of the reclamation and permittees have not initiated bond release requests on eligible lands. For example, a mine has been inspected on a regular basis for conformance with the performance standards and the inspector has a "general feel" for the permittee's implementation of the reclamation plan but no measurements have been taken to

ensure that factors such as postmining contours, slopes, and drainage patterns have been restored as approved. This situation could place both OSM and the operator in a difficult position if OSM were to discover a problem with the postmining contours after the area has been graded, topsoiled, and vegetated. If mining and reclamation proceed in a normal sequence without cross-checks, and reclamation is not evaluated regularly, remedial actions such as additional grading could be required after topsoil replacement and vegetation has already been established. The disruption caused by regrading would most likely result in severe short-term environmental impacts and also would impact the potential for long term reclamation success because of a second removal and replacement of the topsoil. Regular inspections of reclamation as it is performed can help avoid any costly rework that may cause additional environmental harm.

OSM believes that SMCRA envisions bond release to proceed concurrently with mining and reclamation. Section 519 (c) of SMCRA establishes three phases of bond release that are compatible with contemporaneous mining and reclamation (backfilling and grading; topsoiling and revegetation; and final release). The strongest support for contemporaneous bond release is the requirement of Section 518 (b) of SMCRA that specifies that the RA must make a decision on bond release within 60 days from the filing of the request. We believe that this fairly short evaluation period supports the argument that reclamation success is to be evaluated contemporaneously so that by the time the RA gets to the bond release decision, all measurements have been made and the decision is fairly routine, so that it can be finalized within a 60-day period.

In order to get to the point at which bond release decisions become routine and are conducted contemporaneously, planning and coordination by both the operator and the RA will be needed. OSM is considering the implementation of a procedure called “contemporaneous inspections” that would ensure that OSM inspectors evaluate reclamation success as the mining operation proceeds. In simple terms, this means that the inspector would take various measurements and collect data contemporaneously (as the mining progresses) to verify that the reclamation plan is successfully followed. This would ensure that the are no surprises when bond release decisions are made and it will also instill a higher comfort level for both the operator and the RA that reclamation is proceeding as approved. (Editor’s note: This document was finalized and approved by OSM’s Western Region Management Council on September 19, 2000.)

How would contemporaneous inspection principles be applied? A focus on Phase I bond release requirements may best demonstrate the possibilities. As outlined in WRCC’s draft “Permanent Program Phase I Bond Release Guidance,” the primary factors to be evaluated in Phase I investigations are verification of acreage and location; measurement of slopes and contours, replacement of spoil depth; verify drainage control; determine topographical blending; and evaluate stability. If topsoil replacement is included in Phase I, topsoil replacement depths would also be verified. These types of measurements could be done and documented by an inspector during the course of an inspection.

During Phase I evaluations, inspectors could evaluate and document backfilling and grading by measuring slope angles, determining replaced spoil height, and evaluating topographical blending with the surrounding territory. Drainage control could be evaluated by reviewing drainage

patterns to ensure consistency with the approved plan, to ensure positive drainage, to monitor channel stability, and to review the adequacy of small area depressions. Site stability could be evaluated by determining the slope lengths; evaluating terraces, diversions, and similar structures; and monitoring erosion (rills and gullies). If topsoil is included in the Phase I evaluation, the inspector could confirm in writing topsoil replacement depths, sample for soil suitability, and verify the suitability of mitigation material (if applicable). For example, the State of North Dakota has incorporated a backfilling and grading inspection in its approved program. The operator contacts the RA prior to replacement of topsoil and an inspection is conducted to verify that the backfilling and grading has been placed according to the approved plan. OSM believes a similar approach could be applied on Federally permitted mines to enhance the timeliness of bond releases.

Moving Forward

How do we get to the point that phased bond releases become a routine occurrence on Indian Lands and Federal Program mines? The following actions are being considered in order for OSM to move forward with the concept of contemporaneous inspections:

- Catch up on the backlog of unreleased acres — OSM must develop a plan to address how we "catch up" on the backlog of nearly 10,000 acres of initial- and permanent-program lands that may be eligible for some phase of bond release or termination of jurisdiction. OSM must finalize technical guidance for the evaluation of bond release that would include technical guidance for inspectors who will be conducting contemporaneous inspections for bond release verification.

- Shift in inspection workload — OSM inspectors will need to assume a new role to undertake contemporaneous inspections for bond release. Currently inspectors are inspecting mines for compliance with the approved permit and performance standards through their monthly inspections and mine team participation. They are generally aware that the mines are in compliance with their postmining contours, drainage plans, and topsoiling efforts and actively point out potential problem areas to the operators. However, inspectors have not been expected to take any measurements to verify that in fact the mines are meeting their postmining topography, soil depths, and other requirements for phased releases. The concept that is being proposed is that such measurements would become a routine part of an inspection. In order to get to that point, increased emphasis will need to be placed on inspection workload planning and scheduling. A basic assumption is that once OSM catches up with the backlog of unreleased acres, the inspectors would be able to keep current with on-going reclamation to verify conformance with phased releases.

- Industry role/information sharing — As previously mentioned, OSM has begun some initiatives such as enhanced reporting and planning requirements to encourage industry to move forward with phased bond releases of eligible lands. However, in

order for the concept of contemporaneous inspection to work most efficiently, industry will need to willingly share information on reclamation activities. As mine operators complete backfilling and grading, the companies often develop postmining contour maps, cross sections, and even GIS maps that document compliance with the approved reclamation plans. For example, information sharing could assist the OSM inspector's role if the operator were to provide OSM with a map showing regraded backfill contours (and possibly cross sections and slope measurements). The inspector would need only to collect data on a few random samples to verify that the information complies with the approved plan. The guidance that will be developed by OSM under "Catch up on the backlog of unreleased acres," above, will address such issues as the amount of tolerance allowed in replaced contours versus approved contours and when revisions to permits would be triggered if field measurements demonstrate a significant variance. OSM is hopeful that arrangements can be made with the operators to share essential information on reclamation success.

- Enhanced use of technical tools — A goal will be to make the process of contemporaneous inspection as efficient and effective as possible. Inspection activities should blend with mining and reclamation activities on the ground so that they can then be easily correlated with approved permit documents. Measurements of slope angles, slope lengths, backfill height, etc. can now be made quickly and efficiently with equipment such as Global Positioning System (GPS) and laser rangefinders. GPS measurements taken in the field can be downloaded into computers and compared to maps and data in a Geographic Information System (GIS) database. Also, the technology lends itself to assisting OSM (or the operator) in developing a structured process for location and documentation of the reclaimed acreage. Once the information is collected in the field and downloaded into the GIS, it will serve to document what specific areas have been verified, which information can then be easily accessed in the future. Thus, a historical record is created. Again, if the process is to work most efficiently, sharing information and data, particularly GIS information, will be very important. Once a desired level of confidence in the information is achieved, all parties should be looking at the same information, in the same level of detail, and thus achieve a common goal of measuring and achieving reclamation success.

Summary

Recognizing that many OSM-permitted Western mines are lagging behind in expected release of reclaimed lands, OSM has embarked on an effort to stimulate phased bond releases on eligible lands. New initiatives are being planned to provide encouragement and incentive to industry to initiate bond release requests for eligible reclaimed lands in an orderly fashion. OSM will soon be setting plans in motion to conduct bond release evaluations on the backlog of reclaimed, but unreleased, lands on both initial- and permanent-program lands. OSM anticipates that through a new initiative termed "contemporaneous inspections," field inspectors will be able to monitor reclamation as it progresses and collect data to verify that the reclamation is successful. An

important key to ensuring that this process works efficiently will be the cooperation of industry in sharing available information on reclamation efforts. If a high degree of cooperation is achieved, OSM believes that all interested parties will have an increased level of comfort in the bond release process and the common goal of successful reclamation will be achieved in an orderly process as envisioned under SMCRA.

Philosophy and Flexibility in Bond Release

Wanda Burget, Environmental Manager
Peabody Group

This discussion attempts to represent various coal industry comments, specific to Wyoming, regarding the philosophy and flexibility of bond release.

A presentation was given at the last bond-release forum (in September 1998) reporting on the establishment of a Wyoming joint industry-regulatory work group. This group was specifically focused on the development of bond-release criteria. Mining has occurred in Wyoming through a period spanning five evolutions of mine permitting and reclamation laws. In 1997, the Wyoming Department of Environmental Quality, Land Quality Division, proposed four separate sets of bond-release criteria, one to correspond with the period predating the enactment of the Surface Mining Control and Reclamation Act (SMCRA) and three to correspond with the period postdating this enactment. The division designated these sets as categories 1 through 4. A fifth period, or category 5, represents the current law under SMCRA.

The joint work group reached consensus on the criteria for categories 1 through 4. Work on criteria for category 5 is currently on hold, because the joint work group took a recess from meetings this summer. Many industry representatives have expressed the desire to get this process back on track. The development of general criteria has value for the following reasons:

1. We can't play the game effectively and efficiently if we don't know the rules.

2. A level playing field is established for all operators.

3. Data can be formatted and analyzed with the established bond-release criteria in mind–we can plan ahead.

4. The current state of the mining economy requires us to do more with less. A turnkey bond release process will benefit both the operator and the agency.

Without general criteria, the operator must take one of two options:

1. Hit or miss–or, if at first you don't succeed, try, and try again. Taking this tack could involve multiple submittals and countless rounds of comment and response until the application is successful or the operator gives up. Frankly, it's difficult to know why anyone would go through this. It's time-consuming and frustrating for all involved.

2. The second option involves working with the agency to develop site-specific bond-release criteria. It seems that some aspect of this is necessary, even if only general

criteria are developed. However, as the sole process, this is still time-consuming, although preferable to the “hit-and-miss” option.

In closing: industry believes that it is imperative to move forward with the development of general bond-release criteria for lands disturbed under SMCRA or category 5. We’ve come this far; let’s finish the job. Let’s make final bond release a reality in Wyoming.

Workshop Presentations

- ☞ **Infiltration and runoff**
- ☞ **RUSLE**

Infiltration and Runoff

Little bluestem
Schizachyrium scoparium

"Infiltration and Runoff: A General Overview"

Infiltration and Runoff;
A General Overview

Stephan A. Schroeder, Ph.D., CPSS
Environmental Scientist, Reclamation Division
North Dakota Public Service Commission

Introduction

Probably the most important cycle in maintaining plant, animal, and human life is the hydrologic or water cycle. This cycle has been defined as the conversion of ocean water to atmospheric water, to precipitation, to groundwater or to runoff, and back to ocean water. However, it should be pointed out that the hydrologic cycle is not just one cycle but contains many cycles and that parts of the cycle are erratic both in time and space. The study of the hydrologic cycle helps to lead to an understanding of the amounts of water available for plant growth during various parts of the year (Kohnke, 1968). Figure 1 shows the hydrologic cycle within a flow chart and indicates some of the complexity of the cycle.

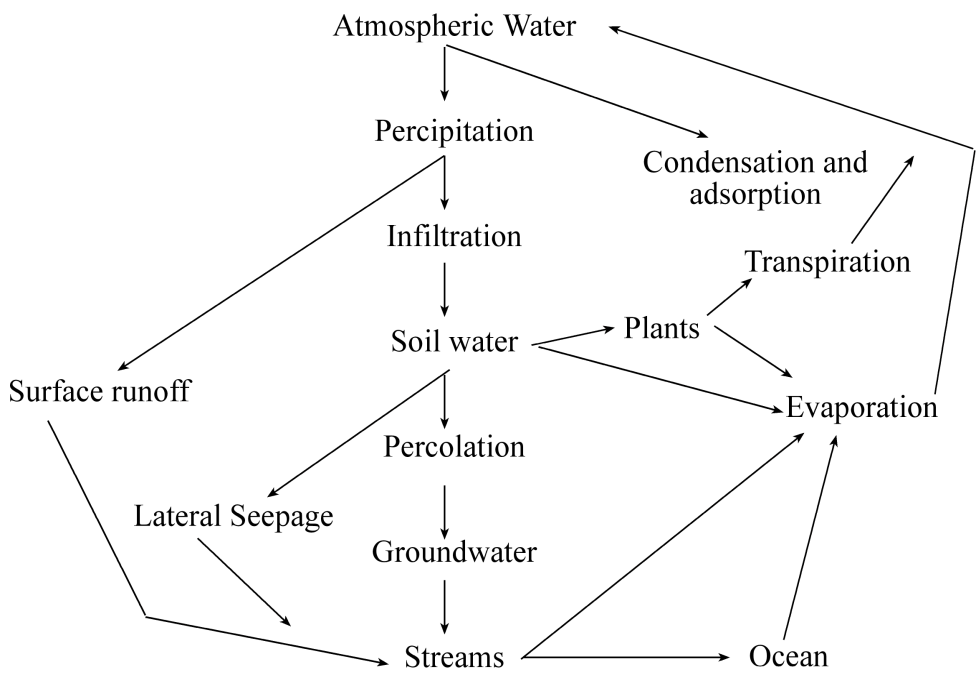


Figure 1 — A schematic of the hydrologic cycle

Surface storage is that part of precipitation that is stored as free water in surface depressions when the infiltration rate is exceeded by the rainfall rate. This depressional storage water can be

lost as runoff once the depression overflows, can ultimately infiltrate into the soil, or can evaporate directly into the atmosphere. This factor can represent a sizable amount of water on relatively flat surfaces and generally decreases as the slope increases (Kohnke, 1968).

Interception is defined as that part of precipitation directly intercepted by plants or other soil covers such as rocks. Some of the intercepted water may eventually reach the ground and either infiltrate or runoff (often called stem flow). The remaining fraction that remains on the vegetation generally evaporates from the vegetative surface back into the atmosphere. The total amount of interception varies according to the type of cover involved.

These two factors, and how they would fit into their respective part of the hydrologic cycle, are shown in figure 2. The addition of these two factors further complicates the relationships within the hydrologic cycle as shown in figure 1.

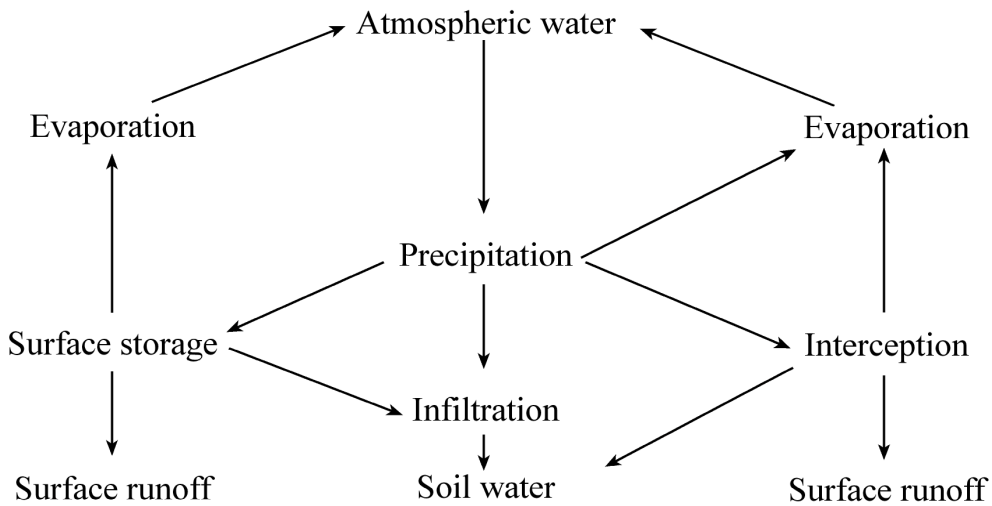


Figure 2 — Surface storage and interception cycles within the hydrologic cycle.

Since the success or failure of reclamation can depend upon the soil water component within the hydrologic cycle, especially in the semiarid/arid west, the use of a soil water equation can also be useful (Kohnke, 1968). This equation may be written as follows:

Water gain	minus	Water loss	=	Water storage (+ or -)	
Precipitation		Runoff		Infiltration	**Eq. 1**
Condensation		Percolation		Interception storage	
Adsorption		Evaporation		Surface storage	
		Transpiration			

For the purposes of this paper, only the infiltration and runoff processes within the hydrologic cycle will be discussed and only in the most basic terms since both processes are extremely complex. There are many other sources that describe these processes in much more detail than presented here (Hillel, 1974; Hudson, 1971; U.S. Department of the Interior, 1977).

Infiltration

Definitions

Infiltration is defined as the passage of water through the surface into the soil and can be considered as the first phase or step of percolation (Kohnke, 1968). Thus a distinction is drawn between infiltration and percolation, the latter being the downward movement of water within the soil profile above the ground water table (or more commonly known as the vadose region). This movement within the vadose region of a soil profile has also been referred to as the permeability or hydraulic conductivity of a soil. These terms will be considered interchangeable within this paper since only downward movement of water will be discussed. The two processes, infiltration and percolation, are closely related since infiltration cannot continue if percolation does not allow the water on the surface to move downward into the profile.

Another term associated with infiltration is infiltration capacity. The infiltration capacity of a soil is the maximum infiltration rate at which water can enter the soil at a particular point under a given set of conditions. As described later in more detail, the infiltration rate of a soil equals the infiltration capacity of a soil only when the supply rate (i.e., the precipitation intensity) equals or exceeds the infiltration capacity. As the soil profile becomes saturated, the infiltration rate will equal that of the saturated percolation or saturated hydraulic conductivity within the soil profile.

The U.S. Soil Conservation Service (1951), which is now known as the Natural Resources Conservation Service, classified both infiltration and percolation rates. These rates are listed in table 1. As can be seen from the listed rates, the ranges for the different classifications differ somewhat between infiltration and percolation (no explanation can be found).

Table 1 — Classification of infiltration and percolation rates

Description term	Infiltration rate	Percolation rate
	inches/hour	
Very rapid	> 10.00	
Rapid	5.00 - 10.00	> 6.30
Moderately rapid	2.50 - 5.00	2.00 - 6.30
Moderate	0.80 - 2.50	0.63 - 2.00
Moderately slow	0.20 - 0.80	0.20 - 0.63
Slow	0.05 - 0.20	0.05 - 0.20
Very slow	< 0.05	< 0.05

Mathematical Functions Describing Infiltration and Percolation

One of the first attempts to describe infiltration on the basis of physical principles was a model proposed by Green and Ampt (1911). Their formula could be written in the following manner:

$$t = \left(I/K_r \right) - \left[f \times \left(H_w - P_w \right) \times \quad In\left[\left(\left(H_w - P_w \right) + \left(I/f \right) \right) / \left(H_w - P_w \right) \right] \right] \qquad \textbf{Eq. 2}$$

where t is the time of accumulated infiltration of amount I, H_w is the depth of ponded water, P_w is the soil-water pressure head just above the wetting front (P_w is negative), K_r is the conductivity or permeability in the wetted zone, and f is the fillable porosity (difference between volumetric water content before and after wetting). This equation was based upon their work in analyzing water flow in uniform diameter, parallel capillary tubes.

Gardner and Widstoe (1921) and later Horton (1940) proposed that the infiltration rate be empirically formulized as the following :

$$f_1 = f_c + \left(f_0 - f_c \right) e^{-bt} \qquad \textbf{Eq. 3}$$

where f_t is the infiltration rate at any time t, f_o is the initial infiltration rate, f_c the final rate (usually assumed to be the saturated hydraulic conductivity), e is the naperian base, B is a characterizing constant, and t is time from the beginning of rainfall. The equation, however, is applicable only when the supply rate is equal to or larger than the infiltration capacity throughout the storm. Some of the difficulties with the Horton equation include that there are no general tables for selecting values for the three parameters, it does not account for spatial variability in nonhomogeneous soils, it makes infiltration rate a function of time, and it does not account for variations in rainfall intensity.

Holtan (1961) proposed advanced an empirical equation based upon the theory that the infiltration rate is proportional to the unfilled water capacity of the soil. His model for infiltration is as follows:

$$f = a F_p^{\,n} + f_c \qquad \textbf{Eq. 4}$$

where f is the infiltration rate, f_c is the final infiltration rate, F_p is the unfilled soil water capacity and a and n are constants. The exponent n has been found to be around 1.4 for many soils. The value of F_p ranges from a maximum of the available water holding capacity of the soil to zero. Values for available water holding capacity for many soils can be found elsewhere (U.S. Department of Agriculture, 1968). The Holtan model for infiltration has a more physical basis and can describe infiltration and the recovery of infiltration capacity during periods of low or no rainfall better than the Horton model (Haan and Barfield, 1978).

An empirical equation similar to Horton's equation was developed by Philip (1957) that proposed that the infiltration rate, i, can be described as follows:

$$i = \left[\left(A t^{-1/2}\right)/ 2\right] + K \qquad \textbf{Eq. 5}$$

where A is a constant and K is the saturated hydraulic conductivity. A generalized graph of this model is shown in figure 3. This equation indicates that as time increases, the first term in the equation becomes smaller until a constant rate is reached as indicated in figure 3.

In 1974, Swartzendruber conducted a detailed analysis of infiltration from constant-intensity rainfall based upon the Green and Ampt approach. He found that the infiltration rate versus time curve could be expressed over certain ranges by two equations in time. The first equation was similar to Philip's equation (equation 5) written as the following:

$$i = a t^{-a} + K \qquad \textbf{Eq. 6}$$

where a and n are constants for a given rainfall intensity (a= ½A and n= ½) in Philip's equation. In comparison with the Green and Ampt curve, the error for an optimized fit was ± 5 percent for R/K (where R is the constant rainfall rate) between 1 and 10, but this error increased to ± 25 percent for larger values. He therefore concluded that as R approached instantaneous surface ponding that the error became greater.

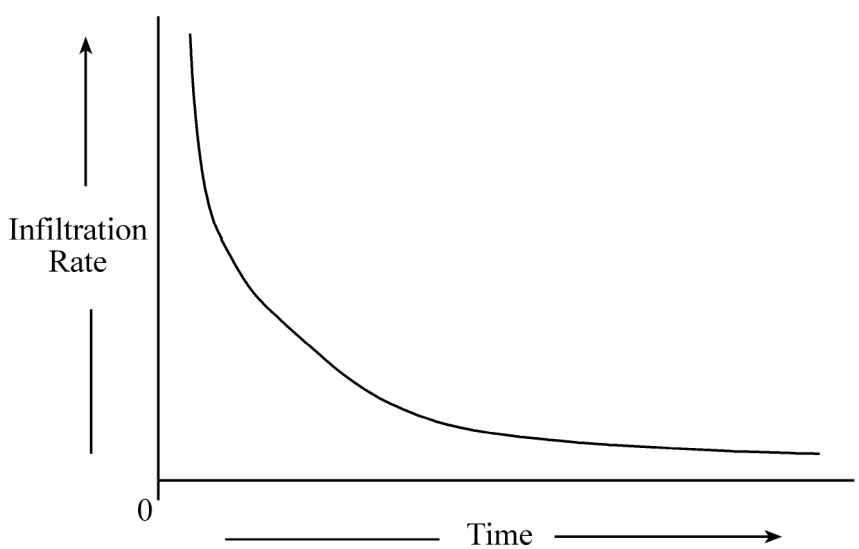


Figure 3 — Graphical representation of Philip's infiltration model.

The second of two equations that Schwartzendruber used was the following:

$$i = B(t - c)^{-1/2} + K \qquad \textbf{Eq. 7}$$

where B and c are constants for a given rainfall intensity. This form of Philip's equation when optimally fit to the Green and Ampt curve showed an error of ± 11 percent for the range of R/K from unity to infinity (surface ponding). Noting with Sulaiman (1976) that i=R at $t=t_0$ (t_0 the time in minutes at which free water first appears on the soil surface) evaluates the B parameter as

$$B = (R - K)(t_0 - c)^{1/2} \qquad \textbf{Eq. 8}$$

which when substituted back into equation 7 yields

$$i = (R - K)[(t0 - c)/(t - c)]^{1/2} + K \qquad \textbf{Eq. 9}$$

Since infiltration rate versus time is the main function of equation 9, the constants c and K can be evaluated using regression/correlation techniques.

In 1969 Philip defined sorptivity as the basic hydraulic property of the soil that relates to capillary forces and the square root of time for one-dimensional infiltration without gravity as

$$I = S\, t^{1/2} \qquad \textbf{Eq. 10}$$

where I is the cumulative intake per unit area (m), t is the time (s), and S is the sorptivity (m $s^{-½}$). Swartzendruber (1987) used this concept to promote a three-parameter infiltration equation that is applicable and exact for all infiltration times and also allows for surface ponding. The simplified equation is

$$I = K_1 t + (S/Ao)\left[1 - \exp\left(-A_0 T^{0.5}\right)\right] \qquad \textbf{Eq. 11}$$

where K_1 is the hydraulic conductivity of the wetted portion of the soil, S is the sorptivity of a soil and A_0 is a coefficient. Sorptivity was first defined by Philip (1969) as a basic hydraulic property that relates to capillary forces and the square root of time for one-dimensional infiltration without gravity by the equation

$$I - S\, t_{1/2} \qquad \textbf{Eq. 12}$$

where I is the cumulative intake per unit area, t is time and S is the sorptivity. This property has been used in various infiltration equations such as this one by Warrick (1992) for use with a disk infiltrometer:

$$I - St^{1/2} + \left[1.1284SD^{0.5}/r_0\right]t + \left(0.0608Sr_0/D^{0.5}\right)\left[\exp\left(-4.01\left(Dt/r_0^{\,2}\right)\right) - 1\right] \qquad \textbf{Eq. 13}$$

where D is the average soil diffusion coefficient between water contents h_i and h_0 and r_0 is the disk radius.

The above discussion is, by no means, a complete historical account of the development of infiltration equations. Many other classical solutions for one-dimensional Darcian flow in a variably saturated rigid porous medium have been built upon the Richards equation that is given by the following:

$$\partial\theta/_{/\partial t} = \nabla[K(h)\nabla - {}^{\partial K}/_{/\partial z} \qquad \textbf{Eq. 14}$$

where θ is the volumetric water content, h is the pressure head, K is the hydraulic conductivity, z is a vertical coordinate (positive downward) and t is time. However, most of these solutions deal more with steady state flow, i.e., hydraulic conductivity, than with the actual infiltration rate with time. Youngs (1995) has reviewed the historical development of infiltration theory including the classical solutions based on the Richards equation.

Factors Affecting the Rate of Infiltration and Hydraulic Conductivity

Baker (1978) showed that some soils show higher variability within the same series under similar conditions than between different soil series. Some of these differences were accounted for by spatial variability in factors such as bulk density, earthworm activity, and geometry and arrangement of pores (discussed later).

Musgrave (1955) listed many of the factors that have been shown to influence infiltration. These included surface conditions, surface cover, pore size and distribution within the soil profile, depth or thickness of the permeable layer (or inversely the depth to a less permeable layer). In addition, the degree of swelling of clay, content of organic matter, degree of aggregation, duration or rain or rainfall application and season of the year also has shown to affect infiltration. These factors have been reiterated in one form or another by many other researchers since the 1940's (Borst and Woodburn, 1942; Moldenahuer, 1970).

One of the major factors affecting infiltration is that of surface sealing. This is due to a thin, compact layer formed on the soil surface due to the kinetic energy of impacting raindrops. This layer has a much lower infiltration rate than the original surface condition did. Some of the earliest work on surface sealing was done by Duley (1940) and Mannering (1967). There have been many other researchers since that time. A surface seal reduces infiltration because fine soil materials are loosened by raindrop impact and washed into the soil plugging up the pores and thereby reducing the number of pores available to allow water to infiltrate.

Formation of surface seals has been shown to be greatly reduced and higher infiltration rates maintained with the use of surface mulches or vegetation (Jones et al., 1969; Harris et al., 1966; and numerous others). The direct effect of these mulches or vegetative cover is to reduce the kinetic energy of the falling raindrops. This in turn reduces the amount of fine soil particles loosened that could ultimately plug the pores and thereby reducing infiltration.

Entrapped air within the soil profile has also been shown to reduce both the infiltration rate and conductivity of a soil (Linden and Dixon, 1976). The volume of entrapped air caused by the downward movement of water or the production of gases by microorganisms present in the soil

(Poulovassilis, 1972) causes the air pressure within the soil profile to increase. This causes a reduction of water movement through the large macropores and forces the water to try to move through the smaller pores (micropores). This creates a more tortuous route with fewer pores conducting water thus resulting in a decrease in both the infiltration rate and conductivity. Typically, conductivity measured in the field is less than that measured in the laboratory due to entrapped air bubbles and the increase in air pressure. These air bubbles entrapped in the soil when it is saturated by downward moving water result in a lower water content in the soil than under fully saturated conditions (Reynolds, 1991). It thus becomes readily apparent that the size distribution of soil pores (macropores vs. micropores), the connectivity of the pores between themselves and to the surface, and the tortuosity of the pathway can greatly influence both the infiltration rate and conductivity.

Dixon and Peterson (1971) and Peterson and Dixon (1971) have described infiltration and conductivity as water movement through channels (macropores or pores larger than 0.002 inches) and capillaries (micropores). If the macropores were open to the surface and tension-free water was present, both the infiltration rate and conductivity of the soil increased. If the openings at the surface become plugged (formation of a surface seal), the water cannot get into the channels and thus infiltration rate and conductivity are decreased. Similarly, the release of air pressure through these channels increases if they are open to the surface, which will keep the infiltration rate and conductivity higher than when the air cannot escape and the air pressure within the soil profile builds. This channel flow concept has also been shown by other researchers to be directly associated with the presence or absence or earthworms whose tunneling in the soil creates “macropores”(Ehlers, 1975). Decaying or growing roots also provide ready avenues for water infiltration into and conductance through the soil profile (Williams and Allamn, 1969).

Other factors that can affect infiltration and conductivity include compaction, organic matter, antecedent soil water, and time of year. Increasing the bulk density of a soil through compaction decreases total pore space with the most of the decrease occurring in the amount of macropores present. As the percentage of macropores decreases, movement of water into and through the soil becomes much more difficult. Increases in organic matter, to a certain point, tend to increase infiltration by protecting soil aggregates from breaking down and thus reducing the plugging of the pores at the surface. Soils that are wet prior to a rainfall event generally will have lower initial infiltration rates and will reach saturated hydraulic conductivity sooner than the same soil under dry conditions since more of the pores are already filled with water. Time of year, of course, is important if a comparison were to be made of a frozen soil in the middle of winter or the same soil in the summer.

While not an exhaustive list, it can readily been seen that many factors can influence infiltration and permeability of soils. In addition, many of these factors discussed above may affect infiltration and permeability not only individually, but several of these factors may be operating at the same time.

Laboratory and Field Measurement Techniques

The field core method described by Klute (1965) is probably the most widely used laboratory technique, although other field core techniques are also used (Childs and Poulovassilis, 1960), for measuring infiltration and hydraulic conductivity. For these measurements, a thin-walled cylinder or can is pressed into the soil to obtain a sample or soil cores may be obtained in metal cylinders that fit into a sampling tube.

Once the sample has been obtained, there are essentially two main methods for measuring infiltration and conductivity (Klute, 1965). The first of these methods is called the constant head method because a constant depth of water is placed upon the top of the sample throughout the measurement time period. This method is best suited to samples with high conductivity. The volume of water that passes through the sample (or the amount of water needed to maintain the constant head) in a known time t is measured until steady state conditions are reached. Samples taken from the beginning until that time will give an estimate of the infiltration rate. The saturated hydraulic conductivity of the soil would be calculated using the following equation once steady state conditions are reached:

$$K = (Q/At)(L/\Delta H) \qquad \textbf{Eq. 15}$$

Q is the measured volume of water over time t, A is the cross sectional area of the core sample, L is the length of the sample, and ΔH is the head of water measured from the top of the water head to the bottom of the sample. The time necessary to reach steady state conditions will vary greatly among soils depending on the reasons given earlier.

The second common method used is the falling-head method used mainly for samples with relatively slow conductivities. Similar to the constant head method, this procedure, however, measures the change in hydraulic head with time. No additional water is added at any time once the measuring begins, thus a fairly large reservoir of water is needed at the beginning in the standpipe. The bottom of the sample is placed within a pan of water that is allowed to overflow with time. Measurement of the time for the hydraulic head to decrease from H_1 to H_2 is recorded. Conductivity is calculated from the following:

$$K = (al/At)\mathrm{In}(H_1/H_2) \qquad \textbf{Eq. 16}$$

where a is the cross sectional of the standpipe within which the hydraulic head is measured from the top of the water level to the level of the water in the pan in which the sample is seated, l is the length of the sample, and t is the time for the hydraulic head to change from H_1 to H_2.

Advantages to the laboratory methods described above include increased accuracy of measurements and no disruptions due to weather since it is done in a laboratory any time after the samples are taken. However, difficulty in obtaining undisturbed cores that represent field conditions severely limits these methods. As briefly mentioned previously, just the difference caused by the release of air pressure within the cores can significantly increase the conductivity measured in the laboratory versus in situ measurements in the field.

To surmount some of these obstacles, numerous field methods have been proposed. These include the auger hole or shallow-well pump-in method (Boersma, 1965), single (Reynolds and Elrick, 1990) and double ring infiltrometers (Swartzendruber and Olson, 1961), and tension infiltometers (Reynolds and Elrick, 1991). Other methods include double tube devices (Fletcher, 1957; and Bouwer, 1961), field monoliths (Stibbe et al., 1970), disc infiltrometers (Smettem and Clothier, 1989) plus sprinkling infiltrometers (Bertrand and Parr, 1961). The differences, generally, between these methods is how the water is applied and how the water measurements are taken. Some, like the single and double ring infiltrometers, use the same principles used in the laboratory for cores but on a much larger scale. Because of the complexity in describing each of these methodologies, the reader is advised to look up the references cited (or others) for more detailed information on each method.

Like laboratory measurements, field measurements of infiltration and conductivity also have advantages and disadvantages. The main advantage is that a larger and, generally, less disturbed soil sample is being used. However, at the same time, more variability in the sample due to its size and the distance between replicates in the field may add to variability of the resultant measurements. Additionally, field methods are more labor intensive, are subject to weather delays and effects (such as natural rainfall and changes in antecedent soil water), and most of the methods require a large water source that is often times not available.

Some Mine-Land Research Examples

Strip-mining and reclamation processes have been shown to have dramatic effects on soil properties that affect infiltration. Compared to undisturbed soils, reclaimed soil bulk densities are generally greater (Bauer et al., 1976). These higher bulk densities have resulted in changes in porosity (both amount and size distribution) and hydraulic conductivity in the reclaimed soils as compared to undisturbed soils (Schroeder, 1987).

Sharma and Carter (1996) used double-ring infiltrometers to show that undisturbed soils had a much greater percentage of soil macropores to conduct water downward than reclaimed mined soils. The median pore soil for undisturbed soils (natural prairie) ranged from 30 to 46μm while the reclaimed soils (hay and pastureland) ranged only from 14 to 21 μm. As a result, the saturated hydraulic conductivity of the undisturbed soils ranged from 4.6 to 10.4 inches/hour while the reclaimed sites had conductivity values ranging only from 0.6 to 0.7 inches/hour.

Hauser and Chichester (1987) showed that very low rainfall infiltration into mine spoil reduced the amount of rainfall stored in the soil profile resulting in a reduction in forage yield and vegetative vigor. Many other researchers have also found similar effects mainly due to the increased bulk density/reduced porosity effects in mine soils. Some research has also demonstrated that deep tillage may alleviate some of these physical problems, which will increase the amount of available soil water for crop growth (Burnett and Hauser, 1967). However, it should also be pointed out that under semi-arid conditions the ability to store additional available water, if not used, does not always lead to increased yields (Schroeder and Vining, 1993). Subsoil bulk densities and soil strength increased with time after tillage and no effect, for the most part, was found for the productivity of the crops grown.

Runoff

Definition

Surface runoff is that portion of precipitation that ultimately makes it way to surface streams through overland flow. It is this movement on the soil surface that can cause soil erosion and nutrient loss that decrease potential productivity levels of soils. In addition, the loss of potential soil water through runoff also reduces the amount of water available for vegetative growth thereby causing a reduction in production.

Runoff generally begins when the precipitation rate exceeds the infiltration rate (or hydraulic conductivity) of a soil and surface storage is mostly satisfied. It should be noted that surface storage within a watershed is made up of depressions of various sizes. As some of the smaller depressions begin contributing to runoff, some of the larger depressions could still be filling (Linsley et al., 1949).

Mathematical estimations

Linsley et al. (1949) proposed an exponential relationship for surface storage as the following:

$$V_d = S_d (1 - e^{-K_d (P-F)}) \qquad \textbf{Eq. 17}$$

where V_d is the volume of water in surface storage, S_d is the total available surface storage, P-F is the total amount of rainfall (P) minus infiltration (F) and any other losses except surface storage, and K_d is a constant. By noting that P-F is near zero when all of the water goes to filling depressions, the value of $dV_d/d(P-F)$ is, for all practical purposes, equal to 1. Thus K_d is equal to $1/S_d$.

If the amount of precipitation lost to interception is minimal or neglected, the rate of water that becomes available for surface runoff, σ, would be the precipitation rate (i) minus the total of the infiltration rate (f) and dV_d/dt (where t is time). Thus the surface runoff supply rate becomes the following:

$$\sigma = (i - f)(1 - e^{-(P-F)/S_d}) \qquad \textbf{Eq. 18}$$

It can then be seen that the ratio of the surface runoff supply rate to the difference in the rainfall and infiltration rates, $\sigma/(i-f)$, becomes the right-hand side of equation 18. This value ranges from 0 at the beginning of the precipitation event when P-F=0, to 1 when P greatly exceeds F. Surface storage, as expected, is of much greater importance on flat surfaces than on steep surfaces. Also, if long duration rainfalls are being examined, the values for surface storage will not significantly affect estimated runoff rates since the early part of the storm will fill this storage before the occurrence of the major runoff producing segments of the storm.

One factor that must be defined in order to develop runoff rates for several numerical methods is called the time of concentration. The time of concentration of a watershed is the time, expressed

in minutes, required for surface water to flow from the most remote (in time of flow and not necessarily the greatest distance) point of area to the watershed outlet. When the duration of a storm equals the time of concentration, all parts of the watershed are contributing to the discharge at the outlet simultaneously. Time of concentration has been estimated from the following equation (Schwab et al., 1971):

$$T_c = 0.0078L^{0.77}S^{-0.385} \qquad \textbf{Eq. 19}$$

where T_c is the time of concentration in minutes, L is the maximum length of flow in feet, and S is the watershed gradient in feet per foot. For example, a watershed with a maximum flow length of 1000 feet at a gradient of 1 percent would have a T_c value of 9 minutes but only 5 minutes if the gradient were 5 percent. A very large length of flow, such as 10,000 feet, would have a T_c of 97 minutes for a 1 % gradient versus 52 minutes for a 5 percent gradient. Equation 19 assumes that the maximum length of flow is also the length of flow that takes the greatest amount of time to reach the watershed outlet. This assumption is fairly safe to use for almost all cases.

Some prediction methods for runoff rate equations also require estimates of the rainfall depths (or intensities) for certain durations and frequencies of occurrence, better know as the return period of a storm. One good source of information of this type is the U.S. Weather Bureau TP 40 publication (Hershfield, 1961). Future rainfall amounts for a certain duration and frequency period can thus be estimated, on a probabilistic basis, based upon historical data. Attempts to develop a depth-duration-frequency relationship for rainfall at any geographical point have been tried (Bernard, 1942). These models, however, have encountered many constants that are difficult to estimate and which show quite a bit of variability throughout the U.S.

One method that uses these concepts to estimate the design runoff rate of a watershed is called the peak runoff rate by the Rational Method. The design runoff rate is defined as

$$Q = CiA \qquad \textbf{Eq. 20}$$

where Q is the design peak runoff rate in cubic feet per second, C is the runoff coefficient, and i is the rainfall intensity in inches per hour for the design return period and for a duration equal to the time of concentration for watershed area A in acres. The runoff coefficient is defined as the ratio of the peak runoff rate to the rainfall intensity and is dimensionless. The mathematics of this method are that for rain at an intensity of one inch per hour on one acre equals approximately one cubic foot per second (43,560 sq ft X 1/12 inch per hour to feet per hour X 1/3,600 hours to seconds = 1.008 cfs). Examples for C from Schwab et al. (1971) are listed in table 2. When more than one land use is included within the watershed (a very common occurrence), the listed C values above are weighted accordingly for the entire watershed.

Table 2 — Runoff coefficient values for C for use in the Rational Method for estimating peak runoff rate

	Soil Texture		
Topography/ Vegetation	**Open Sandy Loam**	**Clay and Silt Loam**	**Tight Clay**
Woodland			
Flat 0-5 % slope	0.10	0.30	0.40
Rolling 5-10% slope	0.25	0.35	0.50
Hilly 10-30 % slope	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82
	30 % of area Impervious	50 % of area Impervious	70 % of area Impervious
Urban Areas			
Flat	0.40	0.55	0.65
Rolling	0.50	0.65	0.80

Another peak runoff rate method is Cook's Method (Schwab et al., 1971). The runoff coefficient in this method is evaluated by assigning numerical values for four runoff-producing characteristics within the watershed. These are relief (or gradient), soil infiltration, vegetative cover and surface storage. Table 3 gives some of the ranges and characteristics used to determine values for each of the four runoff-producing characteristics (from Schwab et al., 1971).

Values are assigned for each portion of the watershed in question and weighted values for each characteristic are calculated. The sum of the four watershed characteristics is obtained and designated ΣW.

It is important to differentiate clearly between this watershed or catchment characteristic (ΣW) and the runoff coefficient (C) of the Rational Method described earlier. The runoff coefficient is a fraction and indicates the fraction of rain that will run off. Thus doubling the runoff coefficient will double the amount of runoff. The catchment characteristic, ΣW, on the other hand, is a number which by reference to further charts or tables can be used to predict runoff. The runoff from a watershed with a catchment value of 80 will not normally be twice that of a watershed with a catchment value of 40.

Table 3 — Range of values used for the runoff-producing characteristics used in Cook's Method

Runoff-Producing Characteristic Values

Characteristic	100 – Extreme	75 – High	50 – Normal	25 – Low
Relief	(33-40) Steep, rugged, ave. slopes above 30 %	(25-32) Hilly, ave. slopes 10-30 %	(17-24) Rolling, ave. slopes of 5-10%	(5-16) Relatively flat, ave. slopes
Soil Infiltration	(17-20) No effective soil cover, rock or thin soil mantle	(12-16) Slow, clay or soil with low infiltration capacity	(7-11) Normal, typical prairie soil, deep loam	(2-6) High, deep sand, takes up water readily
Vegetative Cover	(17-20) No effective plant cover, bare	(12-16) Poor to fair, cultivated crops, less than 10 % under good cover	(7-11) Fair to good, good grassland or woodland, less than 50 % in clean cultivated crops	(2-6) Good to excellent, about 90 % in grassland or good woodland
Surface storage	(17-20) Negligible, no ponds, steep drainageways	(12-16) Low, well defined system of small drainageways, no ponds	(7-11) Normal, considerable depressional storage, typical prairie lands, ponds less than 2 % of drainage area	(2-6) High, surface depressional storage high, large flood-plain storage, large number of ponds or marshes

The peak runoff value, Q, for a specified location and return period is determined from the equation

$$Q = PRF \qquad \textbf{Eq. 21}$$

where P is the peak runoff value determined from a nomograph depicting the drainage area in acres versus the peak runoff rate in cubic feet per second U.S.ing ΣW as the qualifying input variable. (These types of tables and graphs for various regions should be available from the state NRCS offices. It is not possible to print them within this paper's content.) The variable R is a geographical rainfall factor ranging from 0.5 to 1.4 depending upon location. For example, this value is approximately 0.8 for Bismarck, North Dakota, and 0.5 for essentially all of New Mexico. The F variable is the return period factor found in table 4. The product from multiplying the three factors estimates the peak runoff rate.

Table 4 — F factor values for the Cook's Method for estimating peak runoff

Return Period (years)	Factor F
2	0.6
5	0.8
10	1.0
25	1.2
50	1.4

These two methods, while similar, may give very dissimilar results. This illustrates the difficulty, and the judgment, that must be exercised in estimating runoff rates. It may be best to get estimates from both methods for decision purposes.

One of the more common methods used today does not estimate runoff rates but instead estimates the amount of runoff. The method is generally known as the SCS Curve Number Method (U.S. Department of the Interior, 1977). The method uses three variables in estimating runoff, namely the hydrologic soil-cover complex, antecedent moisture, and rainfall.

The hydrologic soil-cover complex is used to describe those two watershed characteristics that influence 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 defined as follows:

Group A. (Low runoff potential) Soils that have high infiltration rates even when thoroughly wetted. Consists chiefly of deep, well- to excessively-drained sands or gravel. High conductivity rates.

Group B. Soils that have moderate infiltration rates when thoroughly wetted. Consists chiefly of deep moderately well to well-drained soils with moderately fine to moderately coarse textures. Moderate rates of conductivity.

Group C. Soils having slow infiltration rates when thoroughly wetted. Consists chiefly of soils with some sort of restricting layer that impedes conductivity downward or soils with moderately fine to fine textures. Slow rates of conductivity.

Group D. (High runoff potential) Soils having very slow infiltration rates when thoroughly wetted. Consists chiefly of clay soils with high swelling potential, high water table, claypan or clay layer near the surface, or shallow soils over nearly impervious materials. Very slow rates of conductivity.

Major soils throughout the U.S. have been previously listed (U.S. Department of the Interior, 1977; Haan and Barfield, 1978). The rating 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 for this variable is based upon the type of land use and treatment, classified on a flood-runoff-producing basis. General land uses included 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) and 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 curve numbers show the relative values of the complexes as direct runoff producers. In other words, as the curve number increases, the potential for a higher amount of direct runoff increases. Table 5 shows a few of these values (for factors AMC-II and I_a=0.2S which are discussed later) using small grains and pastures. This is how one of the three variables used to estimate runoff, namely the hydrologic soil-cover complex, is estimated for use in this method.

Table 5 — Runoff curve numbers for selected hydrologic soil-cover complexes

Land use	**Practice**	**Hydrologic condition for infiltrating**	**Hydrologic soil group**			
			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). Three groupings for AMC are determined by the previous five-day rainfall totals. These three groupings and their respective five-day rainfall totals for the growing season are defined as follows:

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 of less than 1.40 inches.

AMC II: Average condition. Average conditions that have preceded the occurrence of the maximum flood on numerous watersheds. Rainfall totals of 1.40 to 2.10 inches.

AMC III: Highest runoff potential. Watershed soils practically saturated from previous rains. Rainfall total greater than 2.10 inches.

Previous research (Schroeder et al., 1990) has shown that the average condition, AMC II as defined above, was not the true case for a semi-arid climate like that found for North Dakota. That study indicated that for five-day rainfall totals from April 1 to November 1 the AMC I condition was prevalent for 94 percent of the time for the years 1948 through 1986. Thus the validity of using the five-day rainfall total for a semi-arid climate may be questionable because AMC II conditions would tend to overestimate runoff amounts. 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 curve numbers for one AMC to another.

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 the following runoff equation developed by the SCS to determine the ratio of actual to potential runoff:

$$(P - Q)/S = Q/P \qquad \textbf{Eq. 22}$$

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:

$$Q = P^2/(P + S) \qquad \textbf{Eq. 23}$$

Equation 23 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, the use of an initial abstraction term, I_a, is required to account for interception, infiltration, and surface depressional storage. Since I_a cannot, by definition, be greater than P, Equation 22 becomes the following:

$$((P - 1_a) - Q)/S = Q/(P - I_a) \qquad \textbf{Eq. 24}$$

which when solved for Q becomes:

$$Q = ((P - 1_a)^2/(P - I_a + S) \qquad \textbf{Eq. 25}$$

Because S includes I_a, an empirical relationship between the two variables was developed to simplify equation 25. Based upon data collected from various watersheds in different parts of the country, I_a has been estimated as the following:

$$I_a = 0.2S \qquad \textbf{Eq. 26}$$

Schroeder (1994) found that this method for estimating I_a generally overestimated the value from know field data which showed the value to be closer to 13 percent. This may be partially accounted for by difference in the size of the research plots versus using watershed data. When equation 26 is substituted into equation 25 the resultant equation gives the standard form of the SCS runoff estimation equation as:

$$Q = (P - 1.2S)\ 2/(P + 0.85) \qquad \textbf{Eq. 27}$$

Solutions to equation 27 are generally depicted on a graph plotting rainfall (P) and the x axis and direct runoff (Q) on the y axis with delineating curves for various CN values. 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. Use of equation 27 for estimating direct runoff for semi-arid minelands has been shown to be fairly reliable (Schroeder, 1994).

Factors Affecting Runoff

Those factors that have a direct impact on infiltration also influence runoff but in an opposite manner. For instance, as texture becomes finer and infiltration rates decrease, runoff increases (assuming all other factors are equal). The same can be said for any of the factors such as cover, antecedent moisture, porosity, entrapped air and surface seals as discussed in subsection IIC. The reader is invited to re-review that section again to see how those factors that affect infiltration will have an opposite effect on runoff.

Field Measurement Techniques

Most measurements of runoff have involved the use of rainfall simulators of one type or another. Each simulator will have its own weaknesses and strengths and must be judged upon the data to be collected by the user. Simulators are generally divided into two groups. The first group uses some variation of a nozzle to produce rainfall while those in the second group will use some sort of a drop former to produce their rainfall..

The largest amount of rainfall simulation work has probably been accomplished with the rainfall simulator described by Meyer and McCune (1958). This has been used extensively by the U.S. Department of Agriculture, Agricultural Research Service especially to collect data for the Universal Soil Loss Equation (USLE) that will be discussed later. A publication by Bubenzer (1979) lists many of the rainfall simulators and many references for additional information. Advances in simulator designs are slow and, although this is an old article, many of these same simulators are being used today or have been modified for use today (Dunne et al., 1980).

As one might expect, the major drawbacks to the use of a rainfall simulator are the large amounts of water necessary to be applied, the amount and cost of equipment (both application and measuring) needed, the high labor requirements and the general lack of drop-size distributions of natural rainfall. However, simulators are cost-efficient because some control can be exercised

over the operation thus reducing the long-term unit costs as compared to experiments relying on natural rainfall. Rainfall simulators also give a maximum amount of control over when and where data are to be collected, plot conditions at the time of experimentation, and, within some limitations, the rates and amounts of rainfall to be applied. Some simulator designs have also been modified such that additional overland flow can be applied at the upslope end of the plot to simulate longer slope lengths. Plot sizes usually range from a fraction of a square yard to hundreds of square yards depending upon the simulator.

The most common procedure in use with rainfall simulators is to enclose a plot of some predetermined size on three sides to prevent surface water from entering the plot and any runoff from the plot to be channeled downslope. There the water is conveyed to a flume where the rate of runoff is measured and the runoff can be subsampled periodically for sediment concentration. Usually this procedures entails applying the simulated rainfall on a dry surface for a length of time, pausing for awhile, and then reapplying an additional "storm" or two onto the plot. The hydrograph of the runoff is then analyzed to determine the amount of runoff. In addition, the rate of runoff can be estimated at almost any time during the application runs and, assuming all initial abstractions have been met, an infiltration rate can also be estimated.

The publication containing the Bubenzer article (U.S. Department of Agriculture, Agricultural Reviews and Manuals, ARM-W-10/July 1979) is an excellent source of information on many of the currently used simulators. As stated above, design changes for the large field simulators are slow to occur except, possibly, in the type of nozzles or drop formers employed in applying the simulated rainfall.

Some Mineland Research Examples

As might be expected, runoff from spoils increased from dry to wet conditions but only slightly when the surface was initially disturbed versus being crusted (Schroeder, 1987). Runoff CN values calculated from the runoff data also increased from the dry to wet conditions with little difference due to crusting. One aspect of the experiment that was unexpected was that the sodium adsorption ratio also had little to no effect on calculated CN values.

Hofmann et al. (1983) indicated that runoff from simulator studies was lower for initially dry soils (both native and reclaimed) than for wet conditions. However, runoff from wet soils was much greater from the reclaimed soils versus the undisturbed soils. In addition, when the reclaimed soils were heavily grazed or had the surface vegetation burned off, runoff increased 4 to 5 times as much as where the reclaimed soils were ungrazed or only lightly grazed.

Toy (1983) looked at runoff from reclaimed sites at two Wyoming coal mines. At one mine the runoff from the reclaimed site was about the same as the native site for initially dry conditions, but considerably higher from the reclaimed site at the second mine. At both mines the runoff under wet conditions was much greater from the reclaimed sites. As mentioned briefly earlier, Schroeder (1987) found similar results for grassland areas in North Dakota.

In a laboratory-type setting using simulated rainfall, Lang et al. (1984) indicated roughly a 30-percent reduction in runoff from reclaimed topsoils when one ton per acre of mulch was placed upon the surface of the topsoil as compared to bare topsoil. Regardless of the slope gradient, the reclaimed topsoils all had higher runoff rates under wet conditions than the initially dry conditions. Much of this was attributed to the formation of surface seals on the bare soils during the initial rainfall application.

Water Erosion

Definition and Effects

As infiltration rates decrease and runoff rates increase, the possibility of the 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 from one point to another point (removal from the field itself is not a requirement) by surface runoff. Many factors influence erosion such as rainfall rate and duration, infiltration and conductivity rates of the soil, soil texture, organic matter, slope gradient and length, cover and tillage to just name a few.

If the flow of the runoff is concentrated, this removal of the soil can result in the presence of rills and gullies that can affect the farming operations. Additionally, if the sediment leaves the fields, water erosion can cause drainageways to become less efficient or even plugged and results in the loss of nutrients and pesticides applied to the field. These losses can result in high maintenance costs to clean the plugged drainageways, productivity losses and eutrophication of the receiving lakes where the runoff water ends up. Eutrophication is a means of aging of lakes whereby accelerated enrichment of the waters with surface runoff containing nitrogen and phosphorus makes aquatic plants abundant and waters deficient in oxygen.

Scientific planning for soil conservation and water management thus requires a knowledge of the factors affecting infiltration, runoff, and other factors that cause the loss of soil as well as runoff water. This is where such methodology discussed earlier for infiltration and runoff becomes increasingly important. By studying those factors affecting infiltration and runoff, conclusions can be made concerning possible effects on soil erosion.

Estimating 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 using either surface flow characteristics of the runoff or rainfall characteristics in conjunction with factors describing the soil, topography and vegetative cover. These models must not only consider detachment of soil particles but also the transport of the sediment. Detachment must include the kinetic energy of the falling raindrops and the shear capacity of the runoff. Transport must include an analysis of the suspended sediment load as well as bedload. It is not the intent of this paper to go into detail on these interactions.

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 restraints.

Wischmeier and Smith (1965) improved the equation developed by Musgrave with additional data from 48 locations in 26 states. They also proposed the use of nomographs for several of the factors. Because this equation did not contain the inherent geographical restraints of the Musgrave equation, it has become know as USLE and is expressed as the following:

$$A = RKLSCP \qquad \textbf{Eq. 28}$$

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. A very good, detailed accounting of this equation is given by Haan and Barfield (1978).

As mentioned above, however, this equation estimates soil loss from a field assuming no deposition which is known as gross erosion. Between the field and the final point where final deposition occurs the suspended soil will have numerous chances to settle out. This normally reduces the sediment yield reaching the final deposition point and this effect has been defined as the sediment delivery ratio written as the following:

$$D = Y/A \qquad \textbf{Eq. 29}$$

where Y is the sediment yield from a watershed and A is the gross erosion occurring on the watershed. Parameters affecting delivery ratio for a watershed include the length of the flow path as affected by the size of the watershed, the degree of channelization present, size of the eroded material and vegetation in the flow path. Haan and Barfield (1978) show how this delivery ratio can be used with the USLE.

In 1976 Williams developed a data base to propose that sediment yield can be predicted by using a form of the USLE he called the Modified USLE (MUSLE). This equation was written as follows:

$$Y + 95(Qq_p)^{0.56}\ KLSCP \qquad \textbf{Eq. 30}$$

where Y is the sediment yield in tons from a storm, Q is the volume of storm runoff in acre-feet, q_p is the storm peak discharge in cubic feet /minute and KLSCP is the weighted watershed factors from the USLE. This weighting is accomplished by using the following equation:

$$X = \Sigma X_i\ DA_i/DA \qquad \textbf{Eq. 31}$$

where X is the weighted factor (K, LS, C or P), X_i is the value of the factor covering drainage

area DA_i, and DA is the total drainage area of the watershed. Williams found good agreement when this model was tested on watersheds in Texas. However, the model is susceptible to some errors where only some of a watershed is disturbed since the watershed parameters are lumped together (Haan and Barfield, 1978).

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

Because the USLE was devised for agricultural soils, researchers over the years have made many adjustments within the model for mined lands. The definitive manual for a version of RUSLE designed especially for mined lands, construction sites and reclaimed lands became available as RUSLE, Version 1.06, in 1998 (Toy and Foster, 1998). Modification to many of the parameters based upon data from mined lands were made within this version.

Some Mineland Research Examples

In the research cited above for runoff, soil loss also generally increased as runoff increased and was measured at higher rates for reclaimed versus undisturbed soils. Hofmann et al. (1983) found that grazing removal of cover also significantly increased soil loss rates for reclaimed pastures much more than for undisturbed pastures. This research also indicated that live surface cover estimates were a poor measure of how susceptible reclaimed or native pastures may be to runoff or erosion.

As reclaimed soils become wet and runoff increases, the reclaimed soils become much more erodible. Toy (1983) indicated that at one of the mines soil loss was four times greater from the reclaimed site than that of the natural site under wet conditions. However, this trend was not always true for reclaimed grasslands and spoils as found by Schroeder (1987, 1989) where the initial application of rainfall had larger soil loss rates than for wet conditions. While some of this was attributed to a longer rainfall application, much of it was also due to the loose soil materials on the surface at the start of the first rainfall application. Subsequent rainfall applications had to disperse the soil before it could be eroded since all easily transported spoil materials had all ready been eroded. This meant lower soil losses although higher runoff rates.

Increasing slope gradients also generally increase the amount on soil loss. Schroeder (1987, 1989) showed that on both spoils and reclaimed grasslands soil loss increases with slope gradients. Much of this was due to increased runoff amounts and increased surface runoff velocity (thereby increasing the transport capacity and the energy of the surface runoff to disperse additional surface soil particles). This effect of slope gradient on soil loss had also been documented by McIsaac et al. (1987). That research also showed that there was close agreement between the observed slope steepness effects and that predicted by the USLE slope steepness

factor for short slopes with less than 9 percent slope gradient. The USLE tended to overestimate the observed slope steepness for longer and steeper slopes.

With the amount of disturbance involved with mining, it was not unexpected to find that the USLE or RUSLE did not always give reliable soil loss estimations. Nor were users making a smooth transition, even for undisturbed soils, in transferring from the USLE to the RUSLE. In 1997 a working group was created under the auspices of the U.S. Department of the Interior, 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. A very good article on this model is given by Toy and others (1999). While not perfect, since no empirical model yet has that capability, this version of RUSLE is a marked improvement for estimating not only soil loss but also includes the ability to compute sediment-delivery ratios and sediment yields. The changes in the RUSLE model from the version for undisturbed soils were based directly upon research data from disturbed soils.

References

Baker, F.G. 1978. Variability of hydraulic conductivity within and between nine Wisconsin soil series. Water Resources Res. 14(1): 103-108.

Bauer A.G, G.W. Gee, and J.E. Gilley. 1976. Physical, chemical and biological aspects of reclamation of strip-mined lands in western North Dakota. Old West Regional Commission Final Report, North Dakota State Planning Div., Bismarck, North Dakota.

Bernard, M. 1942. Chapter II in Hydrology. Edited by O.E. Meinzer. Dover Publications, New York.

Bertrand, A.R. and J.F. Parr. 1961. Design and operation of the Purdue sprinkling infiltrometer. Purdue Univ. Agr. Exp. Sta. Bul. 723, 16 pp.

Boersma, L. 1965. Field measurement of hydraulic conductivity above a water table. In Methods of Soil Analysis, C.A. Black (ed.), Part 1, Am. Soc. Agron., p. 242-247.

Borst, H.L., and R. Woodburn. 1942. The effect of mulching and methods of cultivation on runoff and erosion from Muskingum silt loam. Ag. Eng. 23: 19-22.

Bouwer, H. A double-tube method for measuring hydraulic conductivity of a soil in situ above a water table. Soil Sci. Soc. Am. Proc. 25: 334-339.

Bubenzer, G.D. 1979. Inventory of rainfall simulators. In Proceedings of the Rainfall Simulator Workshop, USDA, Ag. Reviews and Manuals, ARM-W-10, 185 pp.

Burnett, E. and V.L. Hauser. 1967. Deep tillage and soil-plant-water relationships. Conf. Proc., Tillage for greater crop production, ASAE, St. Joseph, Michigan. p. 47-52.

Childs, E.C., and A. Poulovassillis. 1960. An oscillating permeameter. Soil Sci. 90: 326-328.

Dixon, R.M. and A.E. Peterson. 1971. Water movement in large soil pores: A channel system concept of infiltration. Research Report 74, Univ. of Wisconson, Madison, Wisconsin.

Duley, F.L. 1940. Surface factors affecting the rate of intake of water by soils. Soil Sci. Soc. Am. Proc. 4: 60-64.

Dunne, T., W.E. Dietrich, and M.J. Brunego. 1980. Simple, portable equipment for erosion experiments under artificial rainfall. Ag. Eng. Res. 25: 161-168.

Ehlers, W. 1975. Observations on earhtworm channels and infiltration on tilled and untilled loess soil. Soil Sci. 119(3): 242-249.

Fletcher, P.W. 1957. A device for rapid field measurement of a soil's water transmission rate. Soil Sci. Soc. Am. Proc. 21: 561-562.

Gardner, W.H., and J.A. Widstoe. 1921. Movement of soil moisture. Soil Sci. 11: 215-232.

Green, W.A., and G.A. Ampt. 1911. Studies on soil physics: 1. The flow of air and water through soils. J. Agric. Sci. 145: 317-329.

Haan, C.T., and B.J. Barfield. 1978. Hydrology and Sedimentology of Surface Mined Lands. Office of Continuing Education and Extension, College of Engineering, Univ. of Kentucky, Lexington, Kentucky.

Harris, R.F., C. Chesters, and O.N. Allen. 1966. Dynamics of soil aggregation. In Advances in Agonomy, A.G. Norman (ed.), Academic Press, Inc., New York.

Hauser, V.L., and F.W. Chichester. 1987. Rainfall intake rates on five soil profiles. Trans. ASAE 30(3): 670-675, 682.

Hershfield, D.M. 1961. Rainfall frequency atlas of the United States. Tech. Paper 40, U.S. Dept. of Commerce, Weather Bureau, Washington, D.C.

Hillel, D. 1974. Soil and Water Physical Principles and Processes. Academic Press, New York.

Hofmann, L., R.E. Ries, and J.E. Gilley. 1983. Relationship of runoff and soil loss to ground cover of native and reclaimed grazing land. Agron. J. 75: 599-602.

Holtan, H.N. 1961. A concept for infiltration estimates in watershed engineering. USDA ARS Publication 41-51.

Horton, R.E. 1940. The role of infiltration in the hydrologic cycle. Trans. Am. Geophys. Union 14: 446-460.

Hudson, N. 1971. Soil Conservation. Cornell University Press, Ithaca, New York.

Jones, J.N., J.E. Moody, and J.H. Lillard. 1969. Effects of tillage, no tillage, and mulch on soil water and plant growth. Agron. J. 61: 719-721.

Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil. In Methods of Soil Analysis, C.A. Black (ed.), Part 1, Am. Soc. Agron., p. 210-221.

Kohnke, H. 1968. Soil Physics. McGraw-Hill, Inc.

Lang, K.J., L. Prunty, S.A. Schroeder, and L.A. Disrud. 1984. Interrill erosion as an index of mined land soil erodibility. Trans. ASAE 27(1): 99-104, 109.

Linden, D.R. and R.M. Dixon. 1976. Soil air pressure effects on route and rate of infiltration. Soil Sci. Soc. Am. Proc. 40: 963-965.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1949. Applied Hydrology. McGraw-Hill, New York.

Linsley, R.K., M. Kohler, and J. Paulhus. 1975. Hydrology for Engineers. McGraw-Hill, Inc., New York.

Mannering, J.V. 1967. The relationships of some physical and chemical properties of soils to surface sealing. Ph.D. Thesis, Purdue Univ., W. Lafayette, Indiana.

McIsaac, G.F., J.K. Mitchell, and M.C. Hirschi. 1987. Slope steepness effects on soil loss from disturbed lands. Trans. ASAE 30(4): 1005-1013.

Meyer, L.D., and D.L. McCune. 1958. Rainfall simulator for runoff plots. Ag. Eng. 39(10): 644-648.

Moldenhauer, W.C. 1970. Influence of rainfall energy on soil loss and infiltration rates: II. Effect of clod size distribution. Soil Sci. Soc. Am. Proc. 34(4): 673-677.

Musgrave, G.W. 1947. Quantitative evaluation of factors in water erosion, a first approximation. J Soil and Water Conserv. 2(3): 133-138.

Musgrave, G.W. 1955. How much rain enters the soil. US Dept. Agric.Yearbook, pp. 151-159.

Peterson, A.E. and R.M. Dixon. 1971. Water movement in large soil pores: Vailidity and utility of the channel system concept. Research Report 75, Univ. of Wisconsin, Madison, Wisconsin.

Philip, J.R. 1957. The theory of infiltration: 1. The profile at infinity. Soil Sci. 83: 435-448.

Philip, J.R. 1969. Theory of infiltration. Adv. Hydrosci. 5: 215-305.

Poulovassilis, A. 1972. The changeability of the hydraulic conductivity of saturated soil samples. Soil Sci. 113(2): 81-87.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Ag. Handbook No. 703, U.S.DA-ARS, Southwest Watershed Res. Center, Tucson, Arizona.

Reynolds, W.D., and D.E. Elrick. 1990. Ponded infiltration from a single ring: I. Analysis of steady flow. Soil Sci. Soc. Am. J. 54: 1233-1241.

Reynolds, W.D., and D.E. Elrick. 1991. Determination of hydraulic conductivity using a tension infiltrometer. Soil Sci. Soc. Am. J. 55: 633-639.

Schroeder, S.A. 1987. Runoff from reclaimed grasslands compared to undisturbed grasslands. p. G-81 to G-87. In Fourth Biennial Billings Symp. On Mining and Reclamation in the West, Billings, Montana. 16-20 Mar. 1987. Am. Soc. For Surface Mining and Reclamation, Lexington, Kentucky.

Schroeder, S.A. 1987. Runoff curve number estimations for reshaped fine-textured spoils. Reclam. And Reveg. Res. 6: 129-136.

Schroeder, S.A. 1987. Slope gradient effect on erosion of reshaped spoil. Soil Sci. Soc. Am. J. 51(2): 405-409.

Schroeder, S.A. 1994. Reliability of SCS curve number method on semi-arid, reclaimed minelands. Int. J. of Surface Mining, Mining, Reclam. and Environ. 8: 41-45.

Schroeder, S.A, J.W. Enz, and J.K. Larsen. 1990. Antecedent moisture conditions for North Dakota runoff predictions. North Dakota St. Univ. Farm Res. 48(3): 8-11.

Schroeder, S.A., and K.C. Vining. 1993. Relation of compaction and soil physical parameters to productivity of reclaimed soils. Project GR896381 Final Report. U.S. Dept. of the Int., OSMRE, Western Tech. Center, Denver, Colorado.

Schwab, G.O., R.K. Frevert, K.K. Barnes, and T.W. Edminster. 1971. Elementary Soil and Water Engineering. John Wiley & Sons, Inc., New York.

Sharma, P.P., and F.S. Carter. 1996. Compaction effects on mineland soil quality. p. 430 to 441. In Successes and failures: Applying research results to insure reclamation success. 18-23 May 1996. 13th Annual Mtg. Proc., Am. Soc. For Surf. Mining and Reclam., Knoxville, Tennessee.

Smettem, K.R.J., and B.E. Clothier. 1989. Measuring unsaturated sorptivity and hydraulic conductivity using multiple disc permeameters. J. Soil Sci. 40: 563-568.

Soil Conservation Service. 1951. Soil Survey Manual: Soil Permeability. U.S. Dept. of Agriculture Handbook No. 18. p 167-168.

Stibbe, E., T.J. Thiel, and F.S. Taylor. 1970. Soil hydraulic conductivity measurement by field monoliths. Soil Sci. Soc. Am. Proc. 34: 952-954.

Sulaiman, K.A. 1976. Saturated soil hydraulic conductivity as determined in the field with a small-plot sprinkling infiltrometer. M.S. Thesis, Purdue Univ., W. Lafayette, Indiana.

Swartzendruber, D. 1974. Infiltration of constant-flux rainfall into soil as analyzed by the approach of Green and Ampt. Soil Sci. 117(5): 272-281.

Swartzendruber, D. 1987. A quasi-solution of Richards' equation for the downward infiltration of water into soil. Water Resources Res. 23: 809-817.

Swartzendruber, D. and T.C. Olson. 1961. Sand-model study of buffer effects in the double-ring infiltrometer. Soil Sci. Soc. Am. Proc. 25: 5-8.

Toy, T.J. 1983. Evaluating runoff and erosion from reclaimed hillslopes: Two case studies. p. 43 to 46. In Soils and overburden in reclamation of arid/semiarid mined lands. Symposium Proc., 20-21 January 1983, Casper, Wyoming.

Toy, T.J., and G.R. Foster. 1998. Guidelines for the use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on mined lands, construction sites, and reclaimed lands. The Office of Tech. Transfer, Western Regional Coord. Center, OSMRE, Denver, Colorado.

Toy, T.J., G.R. Foster, and K.G. Renard. 1999. RUSLE for mining, construction and reclamation lands. J. Soil and Water Conserv. 54(2): 462-467.

U.S. Department of Agriculture. 1968. Moisture-tension data for selected soils on experimental watersheds. Report 41-144, Ag. Res. Service, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Interior. 1977. Design of Small Dams. Bureau of Reclamation. U.S. Government Printing Office, Washington, D.C.

Warrick, A.W. 1992. Models for disc infiltrometers. Water Resources Res. 28: 1319-1327.

Whisler, F.D., and H. Bouwer. 1970. Comparison of methods for calculating vertical drainage and infiltration for soils. J. Hydrology 10:1-19.

Williams, R.E. and D.W. Allman. 1969. Factors affecting infiltration and recharge in a loess covered basin. J. Hydrology 8: 265-281.

Wischmeier, W.H., and D.D. Smith. 1965. Rainfall erosion losses from cropland east of the Rocky Mountains. Ag. Handbook No. 282, U.S. Dept. of Ag., Washington, D.C.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses: A guide to conservation planning. Ag. Handbook No. 282, U.S. Dept. Ag., Washington, D.C.

Youngs, E. 1995. The physics of infiltration. Soil Sci. Soc. Am. J. 59:307-313.

RUSLE

Ponderosa pine
Pinus ponderosa

“RUSLE Version 1.06"

RUSLE Version 1.06

originally **a PowerPoint Presentation**

by

Richard C. Warner Ph.D.
and Mike Anderson