PROCEEDINGS:
HIGH ALTITUDE REVEGETATION WORKSHOP NO. 7

Edited by

Mark A. Schuster and Ronald H. Zuck

October 1986

Colorado Water Resources Research Institute

Information Series No. 58

Colorado State University

Proceedings

HIGH ALTITUDE REVEGETATION WORKSHOP
NO. 7

Colorado State University
Fort Collins, Colorado
March 6-7, 1986

Edited by

MARK A. SCHUSTER, GRUBB & ELLIS COMPANY

&

RONALD H. ZUCK, RANGE SCIENCE DEPARTMENT
COLORADO STATE UNIVERSITY

Information Series
Water Resources Research Institute
Colorado State University

Copies available from:

Bulletin Room
Aylesworth Hall
Colorado State University
Fort Collins, Colorado 80523

PREFACE

Our gratitude is extended to the committee members that provided the great effort and many hours of time required to generate, organize and host the High Altitude Revegetation Workshop #7. Their program aligned some of the most interesting and pertinent topics with the exceptional and foremost practitioners and researchers. Certainly, the many fine speakers in the Workshop provided the real measure of program quality and our appreciation is extended to each of them. The Workshop attracted 231 participants representing 20 states (including seven eastern states) and two foreign countries. The geographic distribution and affiliations of the participants is shown below:

Total Participants	231		
Foreign (Canada and Switzerland)	4		
States	227		
Colorado		150	
Plains communities			80
Mountain communities			62
Western valley communities			8
Wyoming		28	
Montana		11	
Utah		8	
California		6	
Others		24	
(Arizona, Arkansas, Indiana, Michigan, Nevada, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, South Dakota, Texas and Washington)			

Government Agencies	85	
Federal		60
State		23
County		2
Industry	38	
University and College	36	
Consultants	28	
Reclamation Contractors	13	
Seed and Plant Materials	11	
Reclamation Products	10	
Other	10	

TABLE OF CONTENTS

Preface.. iii

The High Altitude Revegetation Committee............. viii

SESSION: OPENING
(Chaired by Warren Keammerer, Stoecker-Keammerer and associates, Boulder, Colorado)

Keynote Address: A Systems Approach to the Reclamation of Disturbed Ecosystems.
Mohan K. Wali, State University of New York, Syracuse, New York. (No paper)

SESSION: GENERAL TRENDS
(Chaired by Ben Northcutt, Manage of Reclamation, Mountain West Environments, Inc., Steamboat Springs, Colorado)

The Bad and the Beautiful: Forty Years of Revegetation.
Lew Hammer, Revex, Inc., Louisville, Colorado..........1

Western Revegetation in Perspective: Past Progress, Present Status and future needs.
Edward J. DePuit, Associate Professor, Range Management Department, University of Wyoming, Laramie, Wyoming....6

Mitigating the Visual Impact of Major Construction Projects Through Computer Simulation.
Kurt Culbertson, Design Workshop, Inc., Aspen, Colo...35

SESSION: TECHNICAL
(Chaired by Peter G. Moller, Director of Environmental Technology, Colorado Mountain College, Leadville, Colo.)

Passive Mine Drainage Treatment Using Artificial and Natural Wetlands.
David Holm, Director of Colorado Inactive Mine Reclamation Program, Colorado Mined Land Reclamation Division, Denver, Colorado, and Thomas Elmore, Northwest Council of Governments, Frisco, Colorado.............41

The Identification and Handling of Acid Materials.
David Y Boon, Soil Scientist, Wyoming Department of Environmental Quality, Cheyenne, Wyoming...........49

Selected Environmental and Reclamation Case Studies of the Cotter Corporation.
Tim Smith, Director of Environmental Affairs, Cotter Corporation, Lakewood, Colorado; and Thomas A. Colbert, Vice President, Intermountain Soils, Inc. Denver, Coloado (no paper)

SESSION: CASE STUDIES
(Chaired by Marc S. Thiesen, Erosion Control Specialist, Bowman Construction Supply, Inc., Denver, Colorado)

Revegetation Success at Exxon's Colony Oil Shale Project.
D. Michael Barker, Environmental Engineer, Exxon Company, USA, Grand Junction, Colorado; and Warren Keammerer, Stoecker-Keammerer & Associates, Boulder, Colorado; and Ben Northcutt, Mountain West Environments, Inc., Steamboat Springs, Colorado.....................66

Reconstruction of a Pond, Spring and Creek System for Fish and Wildlife Enhancement.
Dale E. Miller, Hydrologist, Inter-Fluve, Inc., Bozeman, Montana.......................................75

Water Quality Improvement and Erosion Control at Heavenly Valley Ski Area, Lake Tahoe Basin.
Julie Etra, Botanist and William N. Johnson, Watershed Staff Officer, USDA Forest Service, Lake Tahoe Basin Management Unit, California...........................93

SESSION: TECHNICAL
(Chaired by Wendell G. Hassell, Plant Materials Specialist, USDA Soil Conservation Service, Denver, Colorado)

The Erosion Control and Revegetation Mat...Product & Application.
James S. Martin, Mirafi, Inc.........................120

New Developments in Plant Materials for High Elevations.
Jack R. Carlson, Plant Materials Specialist, USDA Soil Conservation Service, Portland, Oregon..........122

Performance of Native and introduced Species Seven Years After Seeding on Alpine Disturbances.
M. Guillaume, Pinedale High School, Pinedale, Wyoming; and W.A. Berg, USDA Southern Great Plains Range Research Station, Woodward, Oklahoma; and M. Guillauame, Pinedale High School, Pinedale, Wyoming; and J.T. Herron, Colorado
Mined Land Reclamation Division, Denver, Colorado....131

Effect of Fertility Treatments and Mulches on Revegetation of Alpine Disturbances.
W.A Berg, USDA Southern Great Plains Range Research Station, Woodward, Oklahoma; and M. Guillaume, Pinedale High School, Pinedale, Wyoming; and J.T.Herron, Colorado Mined Land Reclamation Division, Denver, Colorado....142

SESSION: TECHNICAL
(Chaired by Carl Mackey, Independent Consultant, Lafayette, Colorado)

Monitoring Schemes for Evaluating Reclamation Success.
Warren Keammere, Stoecker-Keammerer and Associates, Boulder, Colorado......................................153

Use of Sewage Sludge for Reclamation of Coal Mine Spoils.
Burns R. Sabey, Karl Topper and Gerard Voos, Colorado State University, Disturbed Lands Laboratory, Fort Collins, Colorado...............................158

Reclamation Art - The Artistic Potential of Mmining Waste.
Paul Klite, Sculptor, Denver, Colorado...............187

Rehabilitation of Alpine Hiking Trails in the National Parks of Canada.
David Walker, Walker & Associates, Edmonton, Alberta; and Gail Harrison, Parks Canada, Calgary, Alberta....204

SESSION: TECHNICAL
(Chaired by Thomas A. Colbert, Vice President, Intermountain Soils, Inc., Denver, Colorado)

Behavior of Alpine Plants and High Altitude Revegetation Research.
Krystyna M. Urbanska, Geobotanical Department, Swiss Federal Institute of Technology, Zurichbergstrasse, Switzerland..214

Secondary Succession Patterns in Disturbed Sagebrush Community in Northwest Colorado.
Edward F. Redente and Mario E. Biondini, Range Scieence Department, Colorado State University, Fort Collins, Colorado....227

Results of Woody Species Test Plots Established on a Mine Exploration Site in Alaska.
Stephen G. Long, Cedar Creek Associates, Inc., Fort Collins, Colorado; and Scott L. Ellis, ERT, Fort Collins, Colorado....245

Constructing Ski Terrain in Colorado in the 1980's.
Jim Gregg, USDA Forest Service, Dillon Ranger District, Dillon, Colorado....259

LIST OF PARTICIPANTS....268

HIGH ALTITUDE REVEGETATION COMMITTEE

Larry F. Brown Chairman	Brown & Associates	Idaho Springs, CO
Wendell G. Hassell Vice Chairman	USDA Soil Conservation Service	Denver, CO
Robin L. Cuany Treasure	Colorado State University	Fort Collins, CO
Gary L. Thor Secretary	Colorado State University	Fort Collins, CO
Patricia Andreas	Homestake Mining Company	Gunnison, CO
Mike Baker	Exon, USA	Grand Junction, CO
Richard Brammer	Union Energy Mining Division	Parachute, CO
Ray W. Brown	USDA Forest Service	East Logan, UT
Rob Clard	Snowmass Skiing Corporation	Aspen, CO
Tom Colbert	Intermountain Soils, Inc.	Denver, CO
John E. Ericson	Consultant	Grand Junction, CO
Julie Etra	USDA Forest Service	South Lake Tahoe,CA
Charles L. Jackson	Amax, Henderson Mine	Emmpire, CO
Warren R. Keammerer	Stoecker-Keammerer & Associates	Boulder, CO
Carl Mackey	Consultant	Lafayette, CO
Peter G. Moller	Colorado Mountain College	Leadvelle, CO
Ben Northcutt	Mountain West Enviroment	Steamboat Springs, CO
Jeffrey L. Pecka	Landscape Architect	Englewood, CO

Mark A. Schuster	Grubb & Ellis Co.	Denver, CO
David Stevens	Rocky Mt. Natl. Park	Estes Park, CO
Marc Theisen	Bowman Construction Supply	Denver, CO
Krystyna Urbanska	Geobotanic Institute	Zurich, Switzerland
Ron Zuck	Colorado State University	Fort Collins, CO

THE BAD AND THE BEAUTIFUL
40 YEARS OF REVEGETATION

Lew Hammer
Revegetation Exchange, Inc.
760 S. 104th
Louisville, CO 80027

1940 - 1950

Northern Minnesota in the early 1940's was considered by many to be a vacation paradise - The Land of 10,000 Lakes - the ideal fishing spot - a wonderland abundant in deer and water foul.

A closer look would expose huge areas of mining scars on the Mesabi Iron Range, large taconite piles on the north shore of Lake Superior, vast acres of useless second growth timber where the lumber industry had clear-cut the Norway Pine and White Pine Forests. Large numbers of starving farm families were trying to make a living on rocky, sandy and eroding soil that couldn't produce 25 bushels of corn per acre.

While working with the United States Forest Service in the Cook National Forest (now known as the Boundry Waters Wildnerness) I was able to participate in tree planting and other programs started by the Civilian Conservation Corps. We were restoring the beauty of this winter wonderland. Since that time large timber companies have purchased these run down farms and woodlands and replanted thousands of acres to beautiful production forests.

1950 - 1960

The United States Air Force and its strategic air command with headquarters in Omaha, Nebraska has several large air bases in the midwest. Jets were the rage and Gen. Curtis Lamay couldn't seem to get enough planes or train enough pilots to keep our strategic air defense in the air. On the ground these jets were scorching the grasses at the edge of runways and parking ramps - the grass would die, the soil would erode, the Air Installations Squadron would haul fill dirt, pour concrete, lay down asphalt and dredge out drainage channels. The end of the next rainy season would see increased run off and erosion and the Air Installations Squadron would start over.

A. I. Squadron Commander Col. Gail Young accepted a plan and within one year all Strategic Command Bases had directives to jet pilots which restricted their jet blasts to specific protected areas thus reducing the damage to existing turf. Proper soil preparation, seeding and fertilizer programs replaced the asphalt and concrete projects and resulted in tremendous cost savings and limited erosion.

I am proud that in these 40 years I have continued to have a part in solving or at least in helping to minimize the negative impact American industry was having on the beauty of our great land.

1960 - 1970

Fortunately for all of us, organized groups of strong individuals recognized that something must be done about our envioronmental problems. Some of us were fortunate enough to be in the right place at the right time and were able to assist in the development of controls and programs and to get involved in the actual projects designed to put the industry on the right track.

Erosion control contractors were hard to find with only Henry Giesman, and Bert Clark established in the business in the Rocky Mountain area. Jim Renolds, Ken Jeronimous, and myself were scrambling to bid on these many projects so as to discourage the out of state contractors and to prevent government agencies from doing their own work. This was a new field. Without a track record the banks did not want to work with us, bonds were very difficult to obtain and experienced help was just not available. General contractors assumed we would do their finish grading, pick the rocks, clean up their construction debris and move on and off the job several times at no additional charge. Project engineers didn't know anything accept what was written in the specifications and they weren't motivated to read that. Pure live seed, hydromulch, 20-20-10, crimping, depth bands and erosion blanket were foreign terms to most of them.

I was very lucky in those years and the harder I worked the luckier I got. I was lucky to have a wife that put up with me being gone all the time and I was lucky to pick up some top rate people such as Gene Eyerly, Rick Randall, Harry Nix and a little later Dick Brammer, Merril Blake and Fred Schlott. To this day contracting and contractors are my real enjoyment but I would like to pass on a few observations which might make them a little luckier.

Hard work can make you luckier but occasionally you need to stand back and view the total picture, to enjoy your family and to see the country which you are beautifying. You need to separate the nuts from the bolts and do a little long term planning. I realize its tough out there in the real world meeting deadlines on the job and at the bank, when the weather doesn't cooperate, the equipment breaks down and your help just doesn't seem to give a hoot. I also am aware that you can't see the total project with your head in a trench and that you can not make sound decisions if you are tired and feel harassed. A good plan helps you make those right decisions, helps you operate more efficiently, gives your bank and bonding company something to hang their hats on and also gives your employees a little direction and a feeling of security. Those of you who know me now know how I always seemed to have time to hunt and fish - I was really planning. I was planning so that I could work more efficiently, so that I could have more time to plan , ie., hunt and fish.

Contractors need all the luck they can get. Who else must bid competitively:

- Against unqualified competition that has no intention of completing the job as designed.

- Subject to many conditions for which he has no control, i.e., other contractors on the job, weather, subsurface rock, etc.

- On a time schedule that is impractical

- For an owner who may not pay

- Supervised by an educated idiot

- Controlled by ambiguous specifications

- Using a plan that doesn't fit the property

- Guaranteeing plants that do not normally grow in the area

Contractors need to make money so that they can do the quality of work that is expected.

Design specialists have a great responsibility to provide plans and specifications which are meaningful to the contractor as well as cost effective for the owner. Believe me when I say that the owner is the big loser when plans and specs come out with a "short fuse". Contractors need time to look at the job, make a material take off and shop for material prices. In order to give his best shot he needs to know his job costs. Two to three weeks does not seem like an unreasonable time to allow for bidding a job. Six to eight weeks from award of the contract to move-in can also be a big factor in getting the better contractors to give their best. Adequate time for contractors to organize their best people and the right equipment can quite often result in high quality, cost effective, completed contracts.

As a contract administrator try to remember that if a contractor is to do a good job he must make money. He must make money on a job that more often than not is in the middle of nowhere, with limited living conditions, no outside communication, no repair service, no fuel and no nothing. Most job sites have a super abundance of rain, wind, equipment break downs, hang-overs and lost sleep. Remember these conditions are not conducive to maintaining a work force of highly trained, God fearing, milk drinking young Americans. Mistakes will be made. Experience points out that the contractor seldom makes over half of them but quite often is expected to be responsible for 100%. Why must the contractor be responsible for all over sights, changing conditions and design deficiencies?

It is gratifying to observe the positive, overall results we are experiencing in this transformation of the bad to the beautiful. I am pleased at what has taken place these past few years with the industry, with academia as well as with governmental agencies. Industry in many instances is going beyond the guidelines set up by controlling agencies. Academia has done a super job of modifying existing curriculum and establishing new courses of study to meet the demands of this new industry. Governmental agencies have trained existing personnel and hired qualified specialists so as to better administer the many environmental programs.

The future of the revegetation industry is very very bright. The momentum is there and if we are to continue to grow with the demands of this dynamic industry we will need to become more effective through better planning and better education.

The high altitude revegetation work shop is a prime example of continuing education through the joint effort of government, academia, suppliers and contractors. I can see a need in the near future to do a great deal of consolidation of the many related seminars, societies, work shops and conventions which presently tax the budgets of time and money we in the industry must commit. Surely by combining some of those efforts we can reach more people and present them with more diversified, quality information.

The bright future of the revegetation industry has a down side. More acres will be seeded at a smaller unit price. This has been a trend over the past 10 or more years. With cost escalating annually, how can the price go down? I don't have all of the answers but indications are that along with technological advancements we will see the following cost cutting cultural practices being advanced.

Seed requirements per acre will be drastically reduced. This can be accomplished by better seed bed preparation, proper seed placement and distribution and more concern regarding soil moisture and soil temperature factors as related to germination and seedling development. On the long haul fewer healthy, mature plants will prove to be far better than a dense population of weaker plants fighting for limited moisture and nutrients.

Green mulch crops grown on the disturbed area will soon replace much of the hay and straw mulches presently dominating the market. Grain crops planted in the spring, mowed in mid to late summer and over-seeded with permanent grass crops in the fall seems to have many cultural as well as definite monetary advantages.

- The equipment required is greatly reduced
- The man power requirement is leveled out and very limited
- The annual weed crop as well as the green mulch crop is mowed prior to seed stage
- No competive species are introduced by incorporating hay or straw
- The remaining stubble plus the vegetative mulch from mowing acts as an ideal media for the fall seeding of desired species.

Soil stabilizers are going to play a large role in this cost reduction program. Proper seed bed preparation and proper seed distribution will always be prime requirements where possible. When budgets are limited or where slope conditions make mulching impractical, seed and soil held in place with stabilizers will produce an acceptable stand once moisture and temperature requirements are met. These products also minimize evaporation of soil moisture thus increasing the water available to the seedlings.

Mulch tackifiers are just starting to come on as a viable supplement to mulches. Tackifiers added to hydromulches not only make them more stable but also greatly improve the performance of the mulching equipment. Tackifier as an overspray for hay and straw presently is being used on steep slopes and on rocky soils where crimping is not practical. Tackifiers retain a higher percentage of mulch on the soil surface where it is needed to prevent wind and water erosion. Tests presently indicate that much smaller quantities of mulch in combination with tackifiers are producing more cost effective results, i.e., more mature, healthy plants per acre.

Low cost, recycled news print and cardboard as a result of advanced technology and increased quality control will soon be making strong inroads on the hydromulch market. Contractors and owners alike greatly appreciate the recycling of our natural resources and this coupled with cost savings and proven results can only lead to greater use and lower over all costs.

We have come a long way in 40 years but "you ain't seen nothin' yet". Special interest groups will continue to require the industry to clean up its act. Research and development along with communications brought about at meetings such as this will continue to promote the development of better products and more efficient methods. Design engineers and contractors will work together to produce more cost effective products. The industry will do more and more acres of revegetation at lower and lower costs per acre.

We are a very fortunate group. If we just continue to do "our thing" we can always feel confident that our efforts have made this world a better, safer, more beautiful place in which to live.

WESTERN REVEGETATION IN PERSPECTIVE: PAST PROGRESS, PRESENT STATUS AND FUTURE NEEDS

Edward J. DePuit
Range Management Department
University of Wyoming
Box 3354, University Station
Laramie, Wyoming 82071

INTRODUCTION

"Disturbance" of some level, pattern and magnitude is common under natural conditions, and plays a major role in the evolution or maintenance of ecosystems (Pickett and White, 1985; Denslow, 1985). It is reasonable to assume that ecosystems in the West have always been subjected to and responded from periodic disturbance. However, the massive influx of modern man in the mid-nineteenth century added variety, frequency, extensiveness and, often, intensity to ecological disturbance in our region. Many such disturbances have proved "drastic" in the sense of completely destroying pre-existing ecosystems (Box, 1978). The environmental consequences of such drastic disturbances are now considered ethically and ecologically unacceptable. Hence, ecosystem reconstruction following disturbance (i.e., reclamation) is a major, often legally mandated concern in the West.

Significance of Revegetation

Plants comprise the basic trophic level of ecosystems, and consequently influence nearly every aspect of ecosystem function either directly or indirectly. The nature of vegetation has direct bearing on the utilitarian value and environmental quality of ecosystems. Therefore, ecosystem reconstruction following a drastic disturbance is strongly dependent upon revegetation. However, it must be recognized that revegetation is only an important part of the overall recovery process, which must be approached from a total ecosystem perspective (Wali, 1975; Billings, 1978; Brisbin, 1982).

Nature, Concepts and Goals of Western Revegetation

Since revegetation of disturbed lands is often initiated using agricultural practices, many people conceptualize it as an "instantaneous" phenomenon--that is, plants are introduced, become established, and revegetation with a permanent, static plant community is rapidly achieved. This perception is invalid on western disturbed lands, where revegetation usually strives to re-establish rangeland or forest plant communities maintained under ambient conditions and low-intensity management. Revegetation in such situations is essentially a process of secondary or, sometimes, primary plant community succession (Moore et al., 1977), and therefore is a dynamic process of change over time. The nature, rate and direction of succession are governed by a complex, interrelated array of allogenic factors (e.g., environmental conditions, nature of disturbance, human inputs, etc.) and the autogenic, plant-regulated processes such factors influence. Revegetation of disturbed lands in the West therefore must be approached and (to the extent possible) manipulated on an ecological basis.

Revegetation in the West is constrained, variably influenced and complicated by the widely divergent environments within which disturbances occur, ranging from arid deserts (Wallace et al., 1980) to alpine tundra (Brown et al., 1978). It is also directly affected by the nature of disturbance, which sometimes may change the direction of succession from that normal to an undisturbed ecosystem (Pickett and White, 1985). Such directional change becomes more likely as the intensity of disturbance increases. Drastic land disturbances, such as surface mining, may permanently alter site conditions and, hence, the type of plant community ultimately achievable through succession.

The dynamic nature of succession indicates that revegetation to a relatively stable plant community will take time. Studies of natural (i.e., non-induced by man) succession on western disturbed lands have often indicated incomplete succession decades after disturbance (e.g., Mackey and DePuit, 1985), while other studies of induced succession have shown that vegetation may remain in a developing state for extended periods of time even when revegetation technology is applied (e.g., Sindelar, 1978).

These directional and temporal aspects of succession on western disturbed lands have major implications for revegetation goals and technology. Most current regulations imply rapid return to stable, predisturbance vegetation conditions as the general goal of revegetation. For reasons discussed above, such a goal may be at best technologically difficult and at worst ecologically impossible to achieve (Sindelar and Murdock, 1985; Harthill and McKell, 1978). More realistic short-term revegetation goals may include (DePuit, 1985; Sindelar and Murdock, 1985; Harthill and McKell, 1978; and others):

1) Achievement of adequate environmental protection (e.g., vegetational soil stabilization, etc.)
2) Re-establishment of facets of ecosystem function influenced by vegetation,
3) Establishment of desired utilitarian values influenced by vegetation, and
4) Establishment of positive trends in succession toward ultimately desired vegetation conditions.

Rapid achievement of these revegetation goals on western disturbed lands is often confounded by the slow rate and, to a point, unpredictable direction of natural succession. The application of ecologically sound revegetation methods can address this problem, both at high elevations (Billings, 1978) and elsewhere (Moore et al., 1977) in the West. The basic functions of initially applied revegetation methods are to accelerate and properly direct succession. Proper site management following plant establishment may further manipulate succession, such that desired trends may develop and be maintained over time. However, it must be realized that there are ecological and technological limits to the degree of successional acceleration and direction possible.

This paper will first briefly review the past development of revegetation theory and technology in the western United States. The point to which this evolution has progressed will then be illustrated by a general discussion of the present status of western revegetation, in both theoretical and technological terms. The final portion of the paper will discuss remaining problems in western revegetation that, hopefully, will be resolved by future progress.

THE PAST:
THEORETICAL AND TECHNOLOGICAL EVOLUTION OF WESTERN REVEGETATION

John Marshall's 1848 gold discovery at Sutter's mill in California had ecologic as well as historic significance. It and subsequent precious metal discoveries in Nevada, Colorado and Montana stimulated massive mineral development and immigration of modern man in the West. Extensive drastic disturbances of western ecosystems by industrial and agricultural activities of man began during this period, and have continued unabated to the present.

Although occasional steps were taken to reduce drastic land disturbance in the mid to late 1800's, the prevalent societal attitude of unbridled environmental exploitation precluded any serious, general effort to either control or mitigate impacts. Mining, for example, was considered the "highest and best" use of public lands by the federal mining law of 1872, a philosophy under which protection of the environment and other land uses was frequently ignored (U.S. Gen. Accounting Office, 1979). Although time and natural revegetation have ameliorated many early environmental impacts, others are still apparent today. For example, effects of extensive deforestation of pinyon-juniper woodlands to support the Nevada mining boom of the 1860's and 70's (Budy and Young, 1979) are still evident on the present distribution and structure of such woodlands (Tausch et al., 1981).

Conservation first emerged as a major societal concern in the early 1900's, as the consequences of past environmental degradation began to be realized. Revegetation had its beginnings as a field of applied science during this period. Early efforts in the West were directed primarily toward renovation of depleted rangelands (Chapline, 1978; Stoddart et al., 1975) and reforestation (Allen and Sharpe, 1960), an emphasis that was maintained during the drought years of the 1930's. Early revegetation technology was largely an outgrowth of conventional agricultural principles and practices, although new or modified approaches were developed as technology evolved. As reviewed by

Vallentine (1980) and others, this evolution has allowed great progress in revegetation of non-drastically disturbed lands over the past 50 years.

Revegetation of drastically disturbed lands became a major concern in the West only recently, despite earlier emphasis in other parts of the U.S. (Bowling, 1978). Although some previous research and application occurred, revegetation technology for drastic disturbances developed markedly during the 1960's and 70's under the stimulus of the first stringent state reclamation laws in the West and a variety of federal laws directly or indirectly affecting reclamation (Imes and Wali, 1978; Bowling, 1978).

Revegetation technology for drastic land disturbances in the West was born of needs to rapidly address serious environmental problems. Consequently, much early revegetation technology was of necessity "borrowed" from existing range reseeding and reforestation technology; was applied and evaluated largely on a site-specific, emperical basis; concentrated primarily on immediate problems, such as soil stabilization and plant establishment; and tended to view revegetation somewhat independently of other aspects of ecosystem reconstruction. Revegetation technology thus initially developed antecedent to revegetation science, and experienced the shortcomings that might be expected from such an inverted developmental sequence. Such shortcomings were soon recognized and addressed by progress in our theoretical understanding of western revegetation. It is now realized, for example, that the severity of drastic land disturbance often necessitates technologies over and above (and sometimes different than) those required for lesser disturbances (Vallentine, 1980); that technologies must address the dynamic, long-term nature of revegetation as well as short-term problem resolution (Moore et al., 1977); that revegetation technology must be integrated with that for all other aspects of ecosystem recovery (Brisbin, 1982); and that revegetation technology must be soundly based upon and directed toward functional ecological relationships (Sindelar and Murdock, 1985).

Considerable early work was conducted in the 1960's on revegetation of roadsides in the West (e.g., Cook et al., 1970; Hodder, 1970). Under regulatory stimulus, revegetation technology expanded rapidly in the early 1970's based upon mined land research conducted throughout the West (Wali, 1975; Vories, 1976; Wright, 1978). Much of this research has continued to the present, and has emphasized revegetation/reclamation in the great plains (Munshower et al. 1982; Munshower and Fisher, 1984), Rocky Mountain (Sims, 1977; Redente et al., 1985), intermountain (Van Epps and McKell, 1980) and southwestern (Thames, 1977; Aldon and Oaks, 1982) regions of the U.S., and western Canada (Thirgood and Ziemkiewicz, 1978). High altitude revegetation also became an important concern in the 1970's (Brown et al., 1978), as evidenced by the first High Altitude Revegetation Workshop in 1974 (Berg et al., 1974) and subsequent biennial workshops thereafter.

Current understanding of and technology for revegetation of drastically disturbed lands in the West are thus products of roughly twenty years of intensive, specific evolution, preceded by over fifty years of related development on non-drastically disturbed lands. The following section will generally summarize our current theoretical and technological knowledge.

THE PRESENT STATUS OF WESTERN REVEGETATION

Theoretical

Soil stabilization was early recognized as a mandate for revegetation of drastically disturbed lands in the West. Hodder (1975), for example, noted soil stability and erosion control to be essential precursors to success in all other aspects of revegetation and overall reclamation. Once achieved, soil stabilization allows the concurrent processes of plant succession and soil genesis, however induced, to proceed. Proper consideration of geomorphological principles during site preparation is necessary to make ultimate stabilization possible (Toy, 1984; Stiller et al., 1980). Much progress has been made in the application of such principles on western disturbed lands, in conjunction with other approaches to temporary stabilization(Verma and Thames, 1978). However, ultimate stabilization also depends upon successful, permanent revegetation.

The importance of basing revegetation technology on the ecological principles of plant community succession was discussed earlier in this paper. Our understanding of patterns, processes and causal factors of succession on western drastically disturbed lands has improved considerably during the past decade. Longer-term successional relationships have been inferred from a number of static studies on disturbed sites of varying ages or conditions (e.g., Sindelar, 1985; Wagner et al., 1978; Mackey and DePuit, 1985), while other research has described shorter-term succession by studying vegetation dynamics on individual sites over time (e.g., Redente et al., 1984; DePuit et al., 1978). Results of these and other studies have elucidated relationships important to the design and application of technology. For example, the influence of site conditions (topography and soils) and initial revegetation practices on succession is becoming better understood (e.g., Wollenhaupt, 1982; Redente et al., 1982, 1984; Stark and Redente, 1985; Doerr et al., 1983; DePuit et al., 1980; DePuit and Coenenberg, 1979), with implications for site preparation and revegetation methods. The nature and influence of competition among pioneer and later developing plant species has become more clear (e.g., Allen and Knight, 1984; Iverson and Wali, 1982a; Schuman et al., 1982; DePuit et al., 1978), with ramifications for plant materials selection and post-establishemnt management.

Research has also improved understanding of the interrelationships between plant succession, microbiological activity and soil genesis on disturbed lands (e.g., Schafer, 1984; Schafer and Nielsen, 1978; Cundell, 1977; Tate and Klein, 1985; Biondini et al., 1985), with implications for nearly every aspect of revegetation technology. For example, the importance of mycorrhizal fungi to disturbed land revegetation has become increasingly apparent (Williams and Allen, 1984; Call and McKell, 1982); certain studies (e.g. Allen and Allen, 1984) have suggested mycorrhizae to be major regulators of the rate and nature of succession. Accordingly, technology is now being developed to properly manipulate these (and other) microorganisms during revegetation (Lindemann et al., 1984; and others).

Our theoretical knowledge of western revegetation has greatly increased not only at the ecosystem and plant community level, but at the plant species level as well. As summarized during a recent symposium (Carlson and McArthur, 1985), major advances have been made in the development and understanding of improved plant materials for western revegetation. This progress has resulted from efforts in both selection and evaluation of existing plant materials (MacLauchlan, 1975), and breeding/genetic improvement of new plant materials (Asay, 1979). We consequently now have a wider array of plant species, ecotypes, released cultivars and hybrids to draw upon than ever before.

Technological

Progress in our theoretical understanding of western revegetation has allowed technology to develop rapidly. The current status of this technology will now be briefly reviewed with respect to site preparation, plant materials, plant introduction and establishment, and management.

Site Preparation. Revegetation programs must begin with practices that provide topographic and edaphic conditions conducive to both site stabilization and the type of revegetation ultimately desired.

To the extent possible, macrotopography should usually be constructed with slopes as gentle and short as possible to retard erosion and runoff (Verma and Thames, 1978), although in some arid situations increased runoff from properly designed slopes may be concentrated on flatter areas through water harvesting or spreading to enhance revegetation (Verma and Thames, 1976). Microtopographic surface manipulations have proved effective for both erosion control and water conservation on disturbed lands in the West, including various types of pitting, microimprinting, contour furrowing and trenching, terracing and primary tillage practices (Verma and Thames, 1978; Dollhopf et al., 1985; Dixon, 1980; Scholl and Pase, 1984; and others). In general, the necessity, beneficiality and required severity of microtopographic manipulation increase with aridity and slope of disturbed lands. Site stabilization and water conservation may also be enhanced by various mulching and chemical soil stabilization methods, as reviewed by Kay (1978). Organic mulches such as hay, straw and wood residues have been used most commonly on western disturbed lands, although pioneer crops used either as stubble (Schuman et al., 1980) or soil-incorporated mulches (Day et al., 1980) are sometimes effective alternatives.

Various types of amendments are often necessary to improve soil physiochemical characteristics for plant growth and soil development. Amendments such as gypsum and calcium chloride, organic materials and supplemental water for leaching may be applied to treat salt-affected soils (Sandoval and Gould, 1978), while various types of lime amendments (Mays and Bengtson, 1978) are possible to treat acidic soils. However, research has sometimes indicated such amendments to provide only partial or temporary alleviation of salt and acid soil problems (e.g., Dollhopf et al., 1985; Doll et al., 1984; Farmer et al., 1976). The best approach - if feasible - may be to isolate problem material beneath a sufficiently thick layer of non-inhibitory soil or subsoil.

Plant growth, microbiological activity and soil development have sometimes been stimulated by various types of organic soil amendments, such as hay/straw mulch, wood residues and sewage sludge (e.g., Fresquez and Lindemann, 1983; Smith et al., 1985; Farmer et al., 1974), although in other cases no benefits of organic amendments have been apparent (e.g., Gould et al., 1982). Reasons for these conflicting results probably relate to variations in site conditions; available research suggests that benefits of organic amendments may be most expressed when water availability and/or aggregate soil quality are lowest.

The salvage and application of topsoil is one of the most important facets of site preparation for revegetation. Proper topsoiling nearly always provides a superior growth medium for plants, as well as serving other important functions such as isolation of problem material, introduction of plant and microorganism propagules, and acceleration of soil development. Specific information on topsoiling methods and management on western disturbed lands has been compiled in several excellent, recent reviews (Hargis and Redente, 1984; Schuman and Power, 1981; McGinnies, 1980), and will not be reiterated here. As discussed by DePuit (1984), the specific nature of topsoiling can have a major influence on the nature and rate of revegetation. Studies in Colorado, for example, have noted varied responses among plant species to differences in topsoil thickness (Redente et al., 1982), and inverted responses of vegetation productivity and diversity (positive and negative, respectively) to increasing topsoil thickness (Stark and Redente, 1985). The latter authors suggested that increasing heterogeneity of topsoil reapplication and management may allow diversity to be increased without sacrificing area-wide productivity. Other authors have propounded separate salvage and reapplication of different types of topsoil as a means of promoting development of different plant communities over revegetated areas (e.g. Schafer, 1982).

Plant Materials. Revegetation success is strongly dependent upon proper selection of plant materials for introduction to disturbed sites. Selection of plants must consider ecological factors, the type of land uses ultimately desired, and any pertinent regulatory requirements. DePuit (1982) felt that proper selection of plant materials should be based upon an integrated consideration of several factors. First, autecological characteristics must be considered, since they influence such attributes as adaptation, nature of initial establishment and growth. Second, synecological relationships among plant species (partially a function of autecological characteristics) must be evaluated during selection, since such relationships will affect overall plant community establishment, function, composition and dynamics over time. Third, the utility of plant species must be considered, in terms of both suitability for desired land uses and ecological role in succession. Fourth, the availability and cost of obtaining propagules of plant species must be ascertained. DePuit (1982) concluded that any species, ecotype or cultivar selected for revegetation must be acceptable in terms of each of these criteria.

Several comprehensive reviews of plant materials for western revegetation are available (Thornburg, 1982; Wasser, 1982; Brown and Wiesner, 1984; Carlson and McArthur, 1985), as well as reviews of plant materials for specific geographical areas, environments and types of disturbance too numerous to list here. Plant materials for high altitude revegetation, for example, have been reviewed by several authors (Berg, 1974; Eamon, 1974; Plummer, 1976; Behan, 1983; and others). Recent publications have also summarized information on establishment and culture (Young et al., 1978; Eddleman, 1980; Vories, 1982; Fulbright et al., 1982; Redente et al., 1982; Wasser, 1982) and commercial availability (Brown et al., 1980; Everett, 1981) of plant materials for western revegetation. In short, a considerable volume of information currently exists on availability, autecological/ adaptational, establishment and utilitarian characteristics of plant species, ecotypes and cultivars for western revegetation. Unfortunately, knowledge of synecological relationships among species is not nearly as abundant.

Several authors have noted benefits, both ecologic and utilitarian, from use of properly designed mixtures of plant species on disturbed lands (e.g., Monsen, 1975; DePuit et al., 1980). Synecological relationships among species are of critical importance to proper mixture design. For example, inclusion of rapidly establishing pioneer species in mixtures has often been advocated to accelerate site stabilization, vegetational site modification and, hence, successional development (Moore et al., 1977). However, competitive relationships must also be considered in the composition and proportion of species in mixtures. Instances of competitive exclusion of less vigorous by more vigorous species in improperly designed mixtures are common on western disturbed lands (e.g., Schuman et al., 1982; DePuit et al., 1978). DePuit (1982) suggested a number of ways to improve competitive compatibility among species in mixtures, such as providing phenological and morphological variety among species, varying seeding rates and dates among species based upon competitive relationships, and excluding overly competitive species from mixtures when vegetation diversity is a goal. It must be recognized, however, that some change in vegetation composition over time will always occur as succession progresses, despite the degree of initial synecological compatibility achieved.

Current revegetation regulations strongly emphasize the use of native over introduced plant species for disturbed land revegetation in the West. Native species have in fact proved superior to introduced species in certain situations, such as on alpine disturbances (Brown et al., 1976). However, native species may not always prove readily establishable or adapted under the radically altered conditions of drastic disturbances (Moore et al., 1977; Brown et al., 1978), nor best suited for maximization of certain post-mining land uses (Laycock, 1980; Currie, 1981). Consequently, many now feel there to be a role for both native and introduced species in western revegetation, if selected and used properly (Monsen, 1975; Brown et al., 1978). The origin of a species was felt by DePuit (1982) to be irrelevant if it met all important ecological and utilitarian criteria for selection.

Plant Introduction and Establishment. The third technological mandate for successful revegetation, following site preparation and plant materials selection, involves proper methods for introduction and establishment of plants on disturbed sites. Several general reviews of such methods for western disturbed lands are available (e.g., Cook et al., 1974; Packer and Aldon, 1978; USDA Forest Service, 1979; Long et al., 1984); Brown and Johnston (1979) summarized methods for high altitude disturbances. Basically, propriety must be achieved both in techniques for plant introduction and cultural practices to enhance initial plant establishment.

Plant introduction to disturbed lands may be accomplished by either or both of two broad approaches: seed introduction and transplantation of live plants or plant parts (other than seeds). Seeds may be introduced in a number of ways during revegetation programs. Topsoiling represents one means of introducing seeds (and other plant propagules) to disturbed lands (e.g., Iverson and Wali, 1982b; Beauchamp et al., 1975), particularly if topsoil is reapplied before extended storage. The desirability of volunteer growth will depend upon species composition of the topsoil seed reservoir. Although diversity and other vegetation attributes are sometimes enhanced by such seed introduction, volunteer growth from seeds in topsoil is usually not adequate for rapid, complete site recolonization (Howard and Samuel, 1979). Consequently, other means of seed introduction are usually necessary.

The use of native hay as a seed source, as well as for mulching benefits, was developed during the drought years of the 1930's (Wenger, 1941), and has been recently reinvestigated as a means of introducing indigenous species on drastically disturbed lands in the West (Ries et al., 1980; Darling and Young, 1984; Friedlander and Van Ryn, 1985). Native hay mulch has been effective in introducing desirable, often commercially unavailable indigenous species, but also carries the risk of introducing unwanted species as well. The nature of plant establishment from mulch may be controlled by selection of mulch harvest sites with desired species composition, and proper seasonal timing of harvest based upon the phenology of species desired.

The most common means of seed introduction on western disturbed lands involve various types of direct seeding. Success with direct seeding requires proper selection of seeding methods, seedbed preparation for the method selected, seeding rates and scheduling of the seeding operation.

Selection of seeding methods must be based upon an integrated consideration of site conditions and characteristics of plant species to be seeded. Seeding methods may be broadly classified as either broadcast or mechanical; DePuit (1982) reviewed general advantages, disadvantages and seedbed requirements for each class of seeding. Although historically viewed as inferior to mechanical seeding (Cook et al., 1974), properly conducted broadcast seeding may have great utility in certain situations (DePuit et al., 1980). For example, broadcasting is the only practical approach on sites too steep or rough for mechanical seeding, and is especially well suited to sowing of diverse mixtures of species with widely varying seed characteristics and seeding depth requirements. Conversely, mechanical seeding may be more advantageous in situations where equipment operation is possible, where monocultures or mixtures of species with similar seed characteristics and requirements are to be sown, and/or when minimum-tillage interseeding is to be accomplished. Many advances have been made in design and variety of mechanical seeding equipment in recent years (e.g., Long et al., 1984; Larsen, 1980), the review of which is beyond the scope of this paper. DePuit (1982) suggested that in some cases joint use of both mechanical and broadcast seeding methods may be profitable. Preliminary results of industry research in Wyoming, for example, indicate excellent establishment of both small-seeded shrubs and large-seeded grasses from concurrent broadcasting of the former and drilling of the latter species.

Proper seeding rates are also necessary for success in direct seeding. Seeding rates should be derived through a combined consideration of site conditions, plant species characteristics, desired vegetation density and composition, and the type of seeding method to be employed (DePuit, 1982). Seeding rates for drastically disturbed sites must usually be higher than those for normal range or cropland seeding (Packer and Aldon, 1978). However, overly high seeding rates should be avoided for reasons both economic and ecologic. Excessive seeding rates may result in overly dense establishment of low-vigor seedlings, or may contribute to reduced vegetation diversity (DePuit et al., 1980). It may not always be advantageous to sow all species in a mixture at equal rates. For example, species desired for initial dominance should often be seeded at higher rates. Conversely, if maximum initial evenness of establishment among species in a mixture is desired, DePuit (1982) suggested that slower establishing, less vigorous species should be sown at higher rates than their more vigorous counterparts. However, recent field application of this approach in Colorado (Doerr et al., 1983) yielded only partial success.

Scheduling of direct seeding should be based upon seasonal weather patterns in conjunction with germination and growth characteristics of species to be seeded. Cook et al. (1974) noted that seeding should be accomplished immediately before or during seasons offering optimum climatic conditions for plant establishment and growth. Problems are frequently encountered when plant species are to be seeded whose seasonal germination or growth requirements do not match ambient weather patterns. The difficulties in warm-season grass establishment under the dry-summer environment of the Northern Great Plains exemplify this problem, and may sometimes necessitate additional cultural practices, such as temporary irrigation, for adequate establishment of such species (Ries, 1982).

Multiple seeding dates represent an aspect of direct seeding scheduling that has gained increasing attention in recent years. The previously discussed practice of stubble mulching in effect is a multiple seeding date approach, whereby a temporary crop of pioneer vegetation is established initially with minimum tillage interseeding of perennial species accomplished later. Manure cropping is a variant of stubble mulching under which pioneer vegetation is tilled into the soil while either green (DePuit et al., 1978) or cured (Day et al., 1980), and may have value where soil organic matter enrichment prior to permanent reseeding is desired.

A third multiple seeding date approach (sometimes termed multiple-phase seeding) involves sowing different perennial plant species within a given mixture at different times instead of sowing all species at a single date. Under this approach, differences in seeding date or sequence among species should be based upon interspecific differences in seasonal climatic requirements for establishment and growth, and/or differences in rapidity of establishment and competitive vigor. A number of multiple seeding date strategies are possible based upon such factors. For example, species within a mixture exhibiting different seasonal germination or growth patterns may be seeded separately at their respective optimum times. Another strategy involves sowing slower-establishing, less vigorous species in a mixture first, allowing at least one season for adequate establishment, and later interseeding more rapidly establishing, vigorous species. This approach has been noted to increase equity of initial establishment among species in mixtures (Coenenberg, 1982).

Transplantation of live plants or plant parts comprises a means of plant introduction alternative to or conjunctive with seeding. Although more expensive, transplantation is usually a more reliable approach to plant introduction than seeding. Consequently, transplantation is usually employed as a primary method of plant introduction on sites sufficiently harsh to reduce seeding success, or for plant species that are difficult to establish from seed. Considerable progress has been made in transplantation technology for western disturbed lands (e.g., Packer and Aldon, 1978; McKell et al., 1979; USDA Forest Service, 1979). Methods can be segregated into one of three broad classes: transplantation of individual plants, groups of plants and parts of plants (other than seeds).

Transplantation of individual plants is most applicable to woody species, although it has occasionally been used for herbaceous species as well. Individual plants are commonly transplanted as seedlings, either collected in the field as wildings for immediate transplanting or cultured in nurseries for later field introduction. Success with seedling transplantation depends upon methods to improve initial survival under field conditions, such as proper hardening before planting, planting during periods of dormancy or reduced climatic stress, initial irrigation and/or planting into specially prepared microsites. Protection of transplants from herbivory may often be necessary through fencing, application of chemical herbivore repellents or construction of micro-exclosures. Mechanical or chemical reduction of competition may also enhance transplant survival. While considerable debate has occurred over the relative merits of bare-root vs. containerized seedling transplantation methods, both approaches have worked if properly applied (USDA Forest Service, 1979).

Field excavation and transplantation of mature plants is another method of individual plant transplantation, and is usually accomplished with equipment such as tree spades and modified front-end loaders (Larsen, 1980; Jensen and Hoddder, 1979). Although costly, this approach assures ecotypic adaptation and allows rapid establishment of larger plants better able to cope with competition and herbivory.

Several methods have been developed for transplantation of groups of plants on disturbed lands. These include sodding (McGinnies and Wilson, 1982; Sindelar, 1973), shrub/tree pad transplantation (Carlson et al., 1982) and plug transplantation (USDA Forest Service, 1979). Such methods are costly. Consequently, they have been applied most commonly on sites where rapid erosion control is a major problem, or on scattered, localized sites where transplanted islands of plants will increase immediate diversity and serve as epicenters for future spread of plants and microorganisms.

Transplantation of plant parts is a possible approach for species capable of vegetative establishment through suckering, layering or sprouting. Various methods have been developed, such as culture and planting of stem or root cuttings, and field collection of sprigs, roots or rhizomes for planting (e.g., McKell et al., 1979; USDA Forest Service, 1979; Jensen and Hodder, 1979).

Plant establishment may either depend upon or be strongly influenced by cultural practices applied during and after plant introduction. Low fertility status (Bauer et al., 1978) and limited water availability (May, 1975) are often constraints to revegetation of disturbed lands in the West. Therefore, fertilization and/or irrigation are sometimes important cultural practices.

Although site preparation practices such as topsoiling may increase fertility to a point, "new" soils on disturbed lands may still be deficient in plant nutrients--particularly the macronutrients nitrogen (N) and phosphorus (P). The efficacy and required manner of fertilization in remedying this situation depend upon numerous factors, as reviewed by Bauer et al. (1978). Many have questioned the value of fertilization in promoting initial revegetation under extremely arid conditions without supplemental irrigation (e.g., Aldon, 1977; Gould et al., 1975), although longer-term benefits may ultimately be expressed (Righetti, 1982). Conversely, fertilization has often proven beneficial (although not always essential) to overall revegetation of nutrient-deficient disturbed lands in semiarid to humid portions of the West (e.g., Bauer et al., 1978; Brown and Johnston, 1979; Farmer et al., 1976). Such initial benefits have been noted to both persist (e.g., DePuit and Coenenberg, 1979) and decline over time (e.g. Doerr and Redente, 1983) under different environmental conditions.

Individual plant species within mixtures have frequently been noted to vary in response to types and rates of fertilization (Doerr et al., 1983; DePuit and Coenenberg, 1979), raising the possibility of manipulating vegetation composition with judicious variations in fertilization. Fertilization rates or durations that produce maximum vegetation productivity, for example, may not always be desirable due to concomitant negative effects on species composition (e.g., over-stimulation of weeds) and diversity, and in some cases may produce a plant community that cannot be sustained without refertilization.

The basic functions of fertilization on most disturbed lands in the West should be to promote soil development and to temporarily enhance revegetation until such soil development yields carbon and nutrient cycling adequate for "self-sustenance" of plant-soil systems. Fertilization programs therefore must be based upon soil developmental relationships as well as plant responses. For example, higher N fertilization rates are sometimes necessary on mulched sites both to accelerate mulch decomposition by microbes and to compensate plants for the pre-emptive use of N by microbes during decomposition (Berg, 1980). However, risks of over-fertilization always exist. Visser (1985) noted that decompositional processes may not be stimulated by fertilization to the same degree as plant productivity, causing eventual accumulation of a nutrient sink in undecomposed plant litter that may reduce subsequent plant growth--a relationship under excessive fertilization reported by other researchers as well (e.g., Schafer and Nielsen, 1978). Further, some researchers have noted reductions in certain components of the microbial community on disturbed lands, such as mycorrhizal fungi, coincident with high levels of fertilization (e.g., Klein et al., 1984).

While water conservation practices applied during site preparation may partially alleviate water deficiency, supplemental irrigation may sometimes be an important cultural practice on semiarid to arid disturbed lands in the West. Irrigation technology was reviewed by Ries and Day (1978), who distinguished between sustained irrigation and temporary irrigation for initial plant establishment. Sustained irrigation is usually recommended only if necessary for soil modification (e.g., salt leaching). Negative effects of over-long or heavy water application on vegetation are possible, such as artificially high plant densities, overly shallow root distribution or reduced diversity (DePuit et al., 1982).

Supplemental irrigation may not always be feasible, and even if feasible will always be an expensive cultural practice. Consequently, its use should be contemplated only if anticipated benefits are sufficient to justify costs. Both sprinkler and drip irrigation methods have been described and used on western disturbed lands (Ries and Day, 1978). Water harvesting or spreading comprise alternative means of irrigation that may be feasible in situations where water availability for conventional irrigation is low (Aldon and Springfield, 1977; Ferraiuolo and Bokich, 1982). Although poor quality (e.g., salty) water may sometimes have value for irrigation (Weiler, 1982, and others), such water carries the risks of soil deterioration and direct retardation of revegetation if improperly applied (e.g., Ferraiuolo and Bokich, 1982).

Temporary (one to two growing seasons) irrigation is often essential for adequate initial plant establishment in especially arid portions of the West (Aldon, 1978). Although usually not mandatory in semiarid areas, irrigation nonetheless may be beneficial to revegetation through increased reliability of plant establishment, enhanced growth, improved fertilizer use efficiency and extension of seeding season.

Studies in semiarid North Dakota (Ries et al., 1978) and Montana (DePuit et al., 1982; Young and Rennick, 1982) demonstrated varied initial responses to irrigation among species seeded, suggesting that irrigation may be applied to manipulate species composition and to enhance otherwise difficult to establish species. However, initial effects of irrigation may not always persist (e.g., Doerr and Redente, 1983), suggesting the major benefit of this cultural practice to be an acceleration rather than a permanent modification of revegetation.

Management. Proper longer-term management following site preparation, plant introduction and establishment is essential for revegetation success (Packer and Aldon, 1978); without it, benefits of even the best-applied initial technology may be lost. Broad goals of management are to further accelerate and direct ecosystem and vegetation development. Viewed in this context, management practices may be necessary to protect (usually temporarily) sites from deleterious outside influences, to correct any shortcomings of initial revegetation methods, and/or to manipulate initially revegetated sites toward desired ultimate conditions over time (DePuit, 1982).

Use of sites after initial revegetation should be minimized for a sufficient period of time to allow development of plants and soils capable of withstanding the impacts of use. Protection from excessive herbivory and trampling effects of livestock has commonly been recommended during early years of revegetation (Packer and Aldon, 1978; Cook et al., 1974), and human impacts also must be controlled in certain situations (Brown and Johnston, 1979). Livestock use may usually be controlled by proper fencing and grazing management. Control of small and large wild herbivores is usually more difficult, and may require unusual management practices--such as application of chemical herbivore repellants, specialized fencing or exclosure techniques, off-site habitat improvements to relieve on-site herbivory, or introduction of carnivores to control herbivores.

Various management practices are possible to correct persistent revegetation problems or manipulate vegetation (and ecosystem) development (Kleinman, 1983). For example, persistent weed infestations may be treated by practices such as use of selective herbicides, prescribed burning or mowing prior to seed set (Coenenburg, 1982). Partial failures of initial revegetation, including poor establishment of certain desired species, may be rectified by interseeding or interplanting techniques (Brock, 1982). Reduction of excessive soil organic matter accumulation, when such is a problem, may be accomplished by haying or burning, while mowing may accelerate soil organic matter accumulation if such is desired. These and other management practices, if properly applied, may not only correct problems but also may direct revegetation through effects on species composition and soils.

Although initial protection from grazing often is necessary, longer-term deferal may actually have negative effects on vegetation and soils. Properly controlled grazing has been initiated on revegetated disturbed lands in a number of cases in the West not only to demonstrate the capability of vegetation to withstand and support livestock, but also to evaluate the role of grazing management in ecosystem recovery (e.g., Jasmer et al., 1982; Hofmann et al., 1981; DePuit and Coenenburg, 1978; Laycock and McGinnies, 1985; Schuman et al., 1984). As reviewed by DePuit (1982), results of certain of these studies indicate that varied and proper grazing programs may be used as management "tools" to induce species compositional changes and influence diversity, to improve vegetation vigor and productivity, and to accelerate soil development by increasing litter incorporation, retarding excessive litter accumulation and breaking up soil crusts.

THE FUTURE: REMAINING NEEDS IN WESTERN REVEGETATION

As indicated by the above review, great progress has been made in our theoretical understanding of western revegetation and the technological application of such understanding. However, many shortcomings still exist. Will Rogers once said that solutions have an exasperating tendency to become new problems, a remark certainly relevant to the current status of western revegetation. A recent workshop on western reclamation research needs (Evans, 1982) well illustrated the breadth and magnitude of remaining problems, and the need for maintained theoretical and technological evolution. The following paragraphs provide some personal perceptions of current needs and future directions.

Our theoretical knowledge of western revegetation is still limited by incomplete understanding of functional relationships during ecosystem recovery, and how such relationships influence changes in reconstructed ecosystems as they evolve over longer-periods of time. Related to this, our understanding of the interactions among factors and processes influencing ecosystem reconstruction is far from adequate. Consequently, most current revegetation technology is still primarily based upon research describing cause-effect relationships emperically, over the short-term and in a non-holistic manner. In short, while our knowledge of what happens during ecosystem reconstruction is improving, we usually have limited understanding of why or how phenomena occur, or how long phenomena will be expressed. These shortcomings can be resolved through long-term, ecosystem-level research on western disturbed lands that emphasizes function (e.g., Redente et al., 1985), and by conducting shorter-term, limited-scope research in a manner that at least partially improves understanding of the functional interrelationships involved in ecosystem reconstruction.

Many specific technological problems remain in western revegetation, including a number related to the edaphic and physiographic facets of site preparation (e.g., Munshower, 1982; Williams et al., 1983). For example, improved methods are still needed for stabilization of exceptionally erodable sites (steep slopes, drainages, etc.), as are approaches for increasing topographic diversity on disturbed lands in a hydrologically acceptable manner. Soil chemistry questions are still manifold, such as proper evaluation of soil problems (e.g., acidity, salts, trace elements) and development of mitigative measures that are feasible and permanent; many of the soil improvement practices currently available are often impractical or temporary in effectiveness. Despite the amount of past research, certain aspects of topsoiling require further research, including thickness requirements for specific vegetational conditions, appropriateness of multiple-lift procedures, and feasibility of methods to promote edaphic diversity. Microbiological relationships in revegetation and applied methods for their manipulation are still very imperfectly understood.

Far more research is certainly warranted on a number of specific aspects of plant materials and plant introduction/establishment technology. Acquisition, evaluation and improvement of plant materials for specific situations and purposes on western disturbed lands remain important research areas. Further research on establishment requirements of "problem" species and applied methods to meet such requirements is strongly needed. A critical remaining problem in revegetation involves the proper design of species mixtures based upon synecological factors (Power, 1978). Related to these concerns, more research is necessary on the nature, value and feasibility of vegetation diversity on disturbed lands, and on methods to foster such diversity (Laycock, 1980; DePuit, 1984).

It is essential that future research addresses the nature and persistence of effects of initial revegetation practices over the long term (Power, 1978; Munshower, 1982). Drawing conclusions on effectiveness of varied site preparation, plant materials, plant introduction methods and cultural practices from only short-term data is risky, to say the least. Long-term research should include, if possible, concurrent evaluation of management practices for revegetated lands. Despite its recognized importance, management remains the least researched and, consequently, least understood aspect of western revegetation technology. Kleinman (1983) described management scenarios and a variety of management techniques developed elsewhere which potentially could be employed to good effect on disturbed lands. It is important that such techniques be implemented, evaluated and, if necessary, modified for use on disturbed lands.

A final problem area relates to perceptions and regulatory evaluation of revegetation "success", as evidenced by a plethora of controversy in recent years (Redente et al., 1983; Sindelar and Murdock, 1985; Munshower and Fisher, 1984; Laycock, 1980; and others). The difficulties in achieving many current regulatory goals under the ecological, temporal and technological constraints inherent to western ecosystem reconstruction were discussed earlier in this paper. Hopefully, perceptions, criteria and standards for determining revegetation success will evolve concurrent with future advances in revegetation theory and technology.

CONCLUSIONS

Revegetation is a critically important part of the complex process of ecosystem reconstruction on disturbed lands in the West. The theoretical and technological evolution of western revegetation has developed exponentially over the past 50 years, roughly paralleling society's concern over its impacts on the environment. Revegetation of disturbed lands is now perceived as a major environmental responsibility, and considerable knowledge of the processes of revegetation and their technological enhancement has accumulated.

Revegetation is presently recognized as a dynamic process directly or indirectly interrelated to all other aspects of ecosystem reconstruction. Revegetation technology basically strives to accelerate and direct this process, and must be soundly based upon theoretical understanding of ecological principles. The success of technology depends upon propriety in site preparation, plant materials selection, plant introduction and establishment practices, and subsequent longer-term management. As reviewed, technology in most of these areas has improved greatly in the West--particularly over the past 20 years.

Despite current progress, numerous general and specific problems remain which must be addressed by properly directed research. Western revegetation is still a relatively young field of basic and applied science; further maturation can be expected only with continued emphasis and support by the scientific and lay sectors of society. A recent and unfortunate result of past progress, however, has been reduced emphasis on further refinements of revegetation science. Unless reversed, this trend will have major ramifications on resolution of remaining problems.

LITERATURE CITED

Aldon, E.F. 1978. Reclamation of coal-mined land in the Southwest. J. Soil and Water Conserv. 33:75-78.

Aldon, E.F. and W.R. Oaks (ed.). 1982. Reclamation of Mined Lands in the Southwest: A Symposium. NM Chapter, Soil Conserv. Soc. Amer., Albuquerque, NM.

Aldon, E.F. and H.W. Springfield. 1977. Reclaiming coal mine spoils in the four corners. pp. 229-237 in Reclamation and Use of Disturbed Land in the Southwest. (ed. J.L. Thames), Univ. Ariz. Press, Tucson, AZ.

Allen, E.B. and M.F. Allen. 1984. Competition between plants of different successional stages: mycorrhizae as regulators. Can. J. Bot. 62:2625-2629.

Allen, E.B. and D.H. Knight. 1984. The effects of introduced annuals on secondary succession in sagebrush-grassland, Wyoming. Southwest. Naturalist. 29:407-422.

Allen, S.W. and G.W. Sharpe. 1960. American Forestry (3rd Edition). McGraw-Hill, NY. 466 p.

Asay, K.H. 1979. Grasses for revegetation of surface mining areas in the Western U.S. pp. 155-159 in Proceedings: Surface Coal Mining and Reclamation Symposium V, McGraw-Hill, NY.

Bauer, A., W.A. Berg and W.L. Gould. 1978. Correction of nutrient deficiencies and toxicities in strip-mined lands in semiarid and arid regions. pp. 451-466 in Reclamation of drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI.

Beauchamp, H., R. Lang and M. May. 1975. Topsoil as a seed source for reseeding strip-mine spoils. Wyo. Agric. Exp. Sta. Res. J. 90, Laramie, WY.

Behan, M.J. 1983. The suitability of commerically available grass species for revegetation of Montana ski slopes. J. Range Manage. 36:565-567.

Berg, W.A. 1980. Nitrogen and phosphorus fertilization of mined lands. pp. 20(1)-20-(8) in Proceedings: Symposium on Adequate Reclamation of Mined Lands, Soil Conserv. Soc. Amer. and WRCC-21, Billings, MT.

Berg, W.A. 1974. Grasses and legumes for revegetation of disturbed subalpine areas. pp. 31-35 in Proceedings: Workshop on Revegetation on High Attitude Disturbed Lands (ed. W.A. Berg, J.A. Brown and R.L. Cuany), Col. Water Resources Res. Inst. Inf. Series No. 10, Fort Collins, CO.

Berg, W.A., J.A. Brown and R.L. Cuany (ed.). 1974. Proceedings: Workshop on Revegetation of High-Altitude Lands. Col. Water Resources Res. Inst., Inf. Series No. 10, Colorado State Univ., Fort Collins, CO.

Billings, W.D. 1978. Aspects of the ecology of alpine and subalpine plants. pp. 1-15 in Proceedings: High Altitude Revegetation Workshop No. 3 (ed. S.T. Kenny), Water Resources Res. Inst. Inf. Series No. 28, Colorado State Univ., Fort Collins, CO.

Biondini, M.E., C.D. Bonham and E.F. Redente. 1985. Secondary successional patterns in a sagebrush community as they relate to soil disturbance and soil biological activity. Vegetatio. 60:25-36.

Bowling, K.C. 1978. History of legislation for different states. pp. 95-116 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI. 742 p.

Box, T.W. 1978. The significance and responsibility rehabilitating drastically disturbed lands. pp. 1-10 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASSA/CSSA/SSSA, Madison, WI. 742 p.

Brisbin, I.L. 1982. The principles of ecology as a framework for a total ecosystem approach to high altitude revegetation research. pp. 1-11 in Proceedings: High Altitude Revegetation Workshop No. 5 (ed. R.L. Cuany and J. Etra), Water Resources Res. Inst. Inf. Series No. 48, Colorado State Univ., Fort Collins, CO.

Brock, J.H. 1982. Interseeding and interplanting techniques for southwestern reclamation. pp. 192-195 in Proceedings: Symposium on Reclamation of Mined Lands in the Southwest (ed. E.F. Aldon and W.R. Oaks), Soil Conserv. Soc. Amer., Albuquerque, NM.

Brown, G.A., G.P. Weber and L.E. Wiesner. 1980. Revegetation of disturbed lands: guide to seed suppliers. Mt. Agr. Exp. Sta. Capsule Inf. Series No. 20, Bozeman, MT.

Brown, G.A. and L.E. Wiesner. 1984. Selecting species for revegetation: a guide for disturbed lands in the western coal region. Mt. Agric. Exp. Sta. Special Rep. No. 3, Bozeman, MT.

Brown, R.W. and R.S. Johnston. 1979. Revegetation of disturbed alpine rangelands. pp. 76-94 in Special Management Needs of Alpine Ecosystems (ed. D.A. Johnson), Soc. Range Manage., Denver, CO.

Brown, R.W., R.S. Johnston and D.A. Johnson. 1978. Rehabilitation of alpine tundra disturbances. J. Soil and Water Conserv. 33:154-160.

Brown, R.W., R.S. Johnston, B.Z. Richardson and E.E. Farmer. 1976. Rehabilitation of alpine disturbances: Beartooth Plateau, Montana. pp. 58-73 in Proceedings: Workshop on Revegetation of High Altitude Disturbed Lands (ed. R.H. Zuck and L.F. Brown), Col. Water Resources Res. Inst. Inf. Series No. 21, Fort Collins, CO.

Budy, J.D. and J.A. Young. 1979. Historical use of Nevada's pinyon-juniper woodlands. J. Forest Hist. 23:112-121.

Call, C.A. and C.M. McKell. 1982. Vesicular-arbuscular mycorrhizae-a natural revegetation strategy for disposed processed oil shale. Reclam. Reveg. Res. 1:337-348.

Carlson, J.R. and E.D. McArthur (ed.). 1985. Symposium: Range plant improvement. pp. 107-220 in Proceedings: Selected Papers Presented at the 38th Annual Meeting of the Society for Range Management, Salt Lake City, Utah. Soc. Range Manage., Denver, CO.

Carlson, K.E., J.L. Smith and C.R. Parkin. 1982. Shrub and tree establishment on strip-mined lands by mature transplanting. Abstract, 35th Ann. Meeting, Soc. Range Manage., Calgary, Alberta.

Chapline, W.R. 1978. Early beginnings. pp. 1-4 in 32nd Ann. Rep., Veg. Rehab. and Equipment Workshop, U.S. Dept. Agric-For. Serv., Washington, D.C.

Coenenberg, J.G. 1982. Methods for establishment of diverse native plant communities at the Rosebud Mine. pp. B6(1)-B6(20) in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains. Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

Cook, C.W., R.M. Hyde and P.L. Sims. 1974. Revegetation guidelines for surface mined areas. Range Sci. Dept., Sci. Ser. No. 16, Col. State Univ., Fort Collins, CO.

Cook, C.W., I.B. Jensen, G.B. Colthorp and E.M. Larson. 1970. Seeding methods for Utah roadsides. Ut. Agric. Exp. Sta., Ut. Resources Series 52, Logan, UT.

Cundell, A.M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30:299-305.

Currie, P.O. 1981. Revegetating mined land for grazing. J. Soil and Water Conserv. 36:213-215.

Darling, A.P. and S.A. Young. 1984. The effects of native hay mulch on soil stabilization and introduction of native species on strip-mined lands in southeastern Montana. pp. 296-306 in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Great Plains, Mt. State Univ., Bozeman, MT.

Day, A.D., T.C. Tucker, and J.L. Thames. 1980. Wheat establishment for mulch on coal mine soil in a semiarid environment. Desert Plants 2:123-126.

Dixon, R.M. 1980. Conservation tillage for mined land revegetation in southwestern United States. pp. 9(1)-9(16) in Proceedings: Workshop on Vegetative Reclamation of Mine Wastes and Tailings in the Southwest, Univ. Arizona, Tucson, AZ.

Denslow, J.S. 1985. Disturbance-mediated coexistence of species. pp. 307-323 in The Ecology of Natural Disturbance and Patch Dynamics (ed. S.T.A. Pickett and P.S. White), Academic Press, Orlando, FL. 472 p.

DePuit, E.J. 1985. An ecologist's perspectives on reclamation success. Invited Paper at Second Annual Meeting, Amer. Soc. Surface Mining and Reclamation, Denver, CO.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals and the Environ. 6:115-120.

DePuit, E.J. 1982. Cool-season perennial grass establishment on Northern Great Plains mined lands: status of current technology. pp. B1(1)-B1(24) in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

DePuit, E.J. and J.G. Coenenberg. 1979. Responses of revegetated coal strip mine spoils to variable fertilization rates, longevity of fertilization program and season of seeding. Mt. Agric. Exp. Sta. Res. Rep. 150, Bozeman, MT.

DePuit, E.J. and J.G. Coenenberg. 1978. Plant response and forage quality for livestock grazing on coal mine spoils in Montana. pp. 892-898 in Ecology and Coal Resource Development (ed. M.K. Wali), Pergamon Press, NY.

DePuit, E.J., J.G. Coenenberg and C.L. Skilbred. 1980. Establishment of diverse native plant communities on coal surface mined lands in Montana as influenced by seeding method, mixture and rate. Mt. Agric. Exp. Sta. Res. Rep. 163, Bozeman, MT.

DePuit, E.J., J.G. Coenenberg and W.H. Willmuth. 1978. Research on revegetation of surface mined lands at Colstrip, Montana: progress report 1975-1977. Mt. Agric. Exp. Sta. Res. Rep. 127, Bozeman, MT.

DePuit, E.J., C.L. Skilbred and J.G. Coenenberg. 1982. Effects of two years of irrigation on revegetation of coal surface-mined land in southeastern Montana. J. Range Manage. 35:67-74.

Doerr, T.B., E.F. Redente and T.E. Sievers. 1983. Effect of cultural practices on seeded plant communities on intensively disturbed soils. J. Range Manage. 36:423-428.

Doll, E.C., S.D. Merrill and G.A. Halvorson. 1984. Soil replacement for reclamation of stripmined lands in North Dakota. N. Dakota Agric. Exp. Sta. Bull. 514, Fargo, ND.

Dollhopf, D.J., D.W. Hedberg, S.A. Young, J.D. Goering, W.M. Schafer and C.J. Levine. 1985. Effects of surface manipulation on mined land reclamation. Mt. Agric. Exp. Sta. Special Rep. 18, Bozeman, MT.

Dollhopf, D.J., R.C. Postle, R.B. Rennick and S.A. Young. 1985. Chemical amendment and irrigation effects on sodium migration and vegetation characteristics in 7-year old sodic minesoils. Mt. Agric. Exp. Sta. Special Rep. 17, Bozeman, MT.

Eamon, T.K. 1974. Plant species potentials for high altitude revegetation. pp. 39-43 in Proceedings: Workshop on Revegetation of High Altitude Disturbed Lands (ed. W.A. Berg, J.A. Brown and R.L. Cuany), Col. Water Resources Res. Inst. Inf. Series No. 10, Fort Collins, CO.

Eddleman, L.E. 1980. Survey of viability of indigenous grasses, forbs and shrubs: techniques for initial acquisition and treatment for propagation in preparation for future land rehabilitation. Univ. Mt. Progress Rep. RLO-2232-T2-11 to U.S. Dept. Energy, Washington, D.C.

Evans, K.E. (Tech. Coord.) 1982. Proceedings: Western Mined Land Rehabilitation Research Workshop. June, 1982, Fort Collins, CO. U.S.D.A. For. Serv., Intermountain Forest and Range Exp. Sta., Ogden, UT.

Everett, W. 1981. Sources of seed and planting stock. U.S.D.A., For. Serv., Missoula Equip. Devel. Center, Missoula, MT.

Farmer, E.E., B.Z. Richardson and R.W. Brown. 1976. Revegetation of acid mining wastes in central Idaho. U.S.D.A. For. Service Res. Paper INT-178, Ogden, UT.

Farmer, E.E., R.W. Brown, B.Z. Richardson and P.E. Packer. 1974. Revegetation research at the Decker coal mine in southeastern Montana. U.S.D.A. For. Serv. Res. Paper INT-162, Ogden, UT.

Ferraiuolo, J.A. and J.C. Bokich. 1982. Irrigation, when is it necessary? pp. 170-173 in Proceedings: Symposium on Reclamation of Mined Lands in the Southwest (ed. E.F. Aldon and W.R. Oaks), Soil Conserv. Soc. Amer., Albuquerque, NM.

Fresquez, P.R. and W.C. Lindemann. 1982. Soil and rhizosphere microorganisms in amended coal mine spoils. Soil Sci. Soc. Amer. J. 46:751-755.

Friedlander, J.D. and F.R. Van Ryn. 1985. The effect of native hay mulch on reclaimed prairie in the Northern Great Plains. Paper Presented at 2nd Ann. Meeting, Amer. Soc. Surface Mining and Reclam., Denver, CO.

Fulbright, T.E., E.F. Redente and N.E. Hargis. 1982. Growing Colorado plants from seed, a state of the art. Volume II: Grasses and grasslike plants. U.S.D.I. Fish and Wildlife Serv. FWS/OBS-82/29, Fort Collins, CO.

Gould, W.L., J. Ferraiuolo, D. Leman and R. Gabehart. 1982. Use of grass-hay or straw mulch for revegetation of minesoils under irrigated conditions. N. Mex. Agric. Exp. Sta. Res. Rep. 484, Las Cruces, NM.

Gould, W.L., D. Rai and P.J. Wierenga. 1975. Problems in reclamation of coal mine spoils in New Mexico. pp. 107-121 in Practices and Problems of Land Reclamation in Western North America. (ed. M.K. Wali), Univ. N. Dak. Press, Grand Forks, ND.

Grandt, A.F. 1978. Industry's viewpoint of legislation affecting surface-mined lands. pp. 117-128 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI. 742 p.

Hargis, N.E. and E.F. Redente. 1984. Soil handling for surface mine reclamation. J. Soil and Water Conserv. 39:300-305.

Harthill, M. and C.M. McKell. 1978. Ecological stability - is this a realistic goal for arid land rehabilitation? pp. 557-567 in Ecology and Coal Resource Development (ed. M.K. Wali), Pergamon Press, NY.

Hodder, R.L. 1975. Montana reclamation problems and remedial techniques. pp. 90-106 in Practices and Problems of Land Reclamation in Western North America (ed. M.K. Wali), Univ. N. Dak. Press, Grand Forks, ND.

Hodder, R.L. 1970. Revegetation methods following highway construction. Mt. Agric. Exp. Sta. Rep. to Mt. State Highway Commission, Bozeman, MT.

Hofmann, L., R.E. Ries and R.J. Lorenz. 1981. Livestock and vegetative performance on reclaimed and non-mined rangeland in North Dakota. J. Soil and Water Conserv. 36:41-44.

Howard, G.S. and M.J. Samuel. 1979. The value of fresh stripped topsoil as a seed source of useful plants for surface mine revegetation. J. Range Manage. 32:76-77.

Imes, A.C. and M.K. Wali. 1978. Governmental regulation of reclamation in the Western United States: an ecological perspective. Reclam. Rev. 1:75-88.

Iverson, L.R. and M.K. Wali. 1982a. Reclamation of coal mined lands: the role of Kochia scoparia and other pioneers in early succession. Reclam. Reveg. Res. 1:123-160.

Iverson, L.R. and M.K. Wali. 1982b. Buried viable seeds and their relation to revegetation after surface mining. J. Range Manage. 35:648-652.

Jasmer, G.E., G.B. Donart and E.F. Aldon. 1982. Responses of re-established vegetation to simulated grazing. pp. 188-191 in Proceedings: Symposium on Reclamation of Mined Lands in the Southwest (ed. E.F. Aldon and W.R. Oaks), Soil Conserv. Soc. Amer., Albuquerque, NM.

Jensen, I.B. and R.L. Hodder. 1979. Tubelings, condensation traps, mature tree transplanting and root sprigging techniques for tree and shrub establishment in semiarid areas. Mt. Agric. Exp. Sta. Res. Rep. 141 (Vol. 2), Bozeman, MT.

Kay, B.L. 1978. Mulch and chemical stabilizers for land reclamation in dry regions. pp. 467-484 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI.

Klein, D.A., W. Metzger and B. Crews. 1984. Soil microorganisms and plant community development in disturbed ecosystems. pp. 37-50 in Ecological Studies of Natural and Established Ecosystems on Energy-Related Disturbance in Colorado, DOE/EV/04018-7, Fort Collins, CO.

Kleinman, L.H. 1983. Levels of management for reclaimed lands. pp. 105-107 in Proceedings: Symposium on Western Coal Mining Regulatory Issues-Land Use, Revegetation and Management, Sci. Ser. No. 35, Range Sci. Dept., Col. State Univ., Fort Collins, CO.

Larsen, J.E. 1980. Revegetation equipment catalog. U.S.D.A. For. Serv., Missoula Equip Devel. Center, Missoula, MT.

Cook, C.W., R.M. Hyde and P.L. Sims. 1974. Revegetation guidelines for surface mined areas. Range Sci. Dept., Sci. Ser. No. 16, Col. State Univ., Fort Collins, CO.

Cook, C.W., I.B. Jensen, G.B. Colthorp and E.M. Larson. 1970. Seeding methods for Utah roadsides. Ut. Agric. Exp. Sta., Ut. Resources Series 52, Logan, UT.

Cundell, A.M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30:299-305.

Currie, P.O. 1981. Revegetating mined land for grazing. J. Soil and Water Conserv. 36:213-215.

Darling, A.P. and S.A. Young. 1984. The effects of native hay mulch on soil stabilization and introduction of native species on strip-mined lands in southeastern Montana. pp. 296-306 in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Great Plains, Mt. State Univ., Bozeman, MT.

Day, A.D., T.C. Tucker, and J.L. Thames. 1980. Wheat establishment for mulch on coal mine soil in a semiarid environment. Desert Plants 2:123-126.

Dixon, R.M. 1980. Conservation tillage for mined land revegetation in southwestern United States. pp. 9(1)-9(16) in Proceedings: Workshop on Vegetative Reclamation of Mine Wastes and Tailings in the Southwest, Univ. Arizona, Tucson, AZ.

Denslow, J.S. 1985. Disturbance-mediated coexistence of species. pp. 307-323 in The Ecology of Natural Disturbance and Patch Dynamics (ed. S.T.A. Pickett and P.S. White), Academic Press, Orlando, FL. 472 p.

DePuit, E.J. 1985. An ecologist's perspectives on reclamation success. Invited Paper at Second Annual Meeting, Amer. Soc. Surface Mining and Reclamation, Denver, CO.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals and the Environ. 6:115-120.

DePuit, E.J. 1982. Cool-season perennial grass establishment on Northern Great Plains mined lands: status of current technology. pp. B1(1)-B1(24) in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

DePuit, E.J. and J.G. Coenenberg. 1979. Responses of revegetated coal strip mine spoils to variable fertilization rates, longevity of fertilization program and season of seeding. Mt. Agric. Exp. Sta. Res. Rep. 150, Bozeman, MT.

Munshower, F.F. 1982. Problems in reclamation planning and design. pp. C7(1)-C7(17) in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

Munshower, F.F. and S.E. Fisher (ed.). 1984. Proceedings: Symposium on Surface Coal Mining and Reclamation in the Great Plains. Mt.State Univ., Bozeman, MT.

Munshower, F.F., S.E. Fisher, and F. Sandoval (ed.). 1982. Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains. Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

Packer, P.E. and E.F. Aldon. 1978. Revegetation techniques for dry regions. pp. 425-450 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI.

Pickett, S.T.A. and P.S. White. 1985. Patch dynamics: a synthesis. pp. 371-384 in The Ecology of Natural Disturbance and Patch Dynamics (ed. S.T.A. Pickett and P.S. White), Academic Press, Orlando, FL.

Plummer, A.P. 1976. Shrubs for the subalpine zone of the Wasatch plateau. pp. 33-40 in Proceedings: High Altitude Revegetation Workshop No. 2, (ed. R.H. Zuck and L.F. Brown), Col. Water Resources Res. Inst. Inf. Series No. 21, Fort Collins, CO.

Power, J.F. 1978. Reclamation research on strip-mined lands in dry regions. pp. 521-535 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI.

Redente, E.F., C.W. Cook, J.M. Stark and C.L. Simmons (ed.). 1985. Semiarid ecosystem development as a function of resource processing and allocation. DOE/EV/04018-8, Range Sci. Dept., Colorado State Univ., Fort Collins, CO.

Redente, E.F., T.B. Doerr, C.E. Grygiel and M.E. Biondini. 1984. Vegetation establishment and succession on disturbed soils in northwest Colorado. Reclam. Reveg. Res. 3:153-166.

Redente, E.F., C.B. Mount and W.J. Ruzzo. 1982. Vegetation composition and production as affected by soil thickness over retorted oil shale. Reclam. Reveg. Res. 1:109-122.

Redente, E.F., P.R. Ogle and N.E. Hargis. 1982. Growing Colorado plants from seed, a state of the art. Volume III: Forbs. U.S.D.I. Fish and Wildlife Serv., FWS/OBS-82/30, Fort Collins, CO.

Redente, E.F., W.E. Sowards, D.G. Steward and T.L. Ruiter (ed.). 1983. Proceedings, Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation and Management. Sci. Ser. No. 35, Range Sci. Dept., Colo. State Univ., Fort Collins, CO.

Farmer, E.E., B.Z. Richardson and R.W. Brown. 1976. Revegetation of acid mining wastes in central Idaho. U.S.D.A. For. Service Res. Paper INT-178, Ogden, UT.

Farmer, E.E., R.W. Brown, B.Z. Richardson and P.E. Packer. 1974. Revegetation research at the Decker coal mine in southeastern Montana. U.S.D.A. For. Serv. Res. Paper INT-162, Ogden, UT.

Ferraiuolo, J.A. and J.C. Bokich. 1982. Irrigation, when is it necessary? pp. 170-173 in Proceedings: Symposium on Reclamation of Mined Lands in the Southwest (ed. E.F. Aldon and W.R. Oaks), Soil Conserv. Soc. Amer., Albuquerque, NM.

Fresquez, P.R. and W.C. Lindemann. 1982. Soil and rhizosphere microorganisms in amended coal mine spoils. Soil Sci. Soc. Amer. J. 46:751-755.

Friedlander, J.D. and F.R. Van Ryn. 1985. The effect of native hay mulch on reclaimed prairie in the Northern Great Plains. Paper Presented at 2nd Ann. Meeting, Amer. Soc. Surface Mining and Reclam., Denver, CO.

Fulbright, T.E., E.F. Redente and N.E. Hargis. 1982. Growing Colorado plants from seed, a state of the art. Volume II: Grasses and grasslike plants. U.S.D.I. Fish and Wildlife Serv. FWS/OBS-82/29, Fort Collins, CO.

Gould, W.L., J. Ferraiuolo, D. Leman and R. Gabehart. 1982. Use of grass-hay or straw mulch for revegetation of minesoils under irrigated conditions. N. Mex. Agric. Exp. Sta. Res. Rep. 484, Las Cruces, NM.

Gould, W.L., D. Rai and P.J. Wierenga. 1975. Problems in reclamation of coal mine spoils in New Mexico. pp. 107-121 in Practices and Problems of Land Reclamation in Western North America. (ed. M.K. Wali), Univ. N. Dak. Press, Grand Forks, ND.

Grandt, A.F. 1978. Industry's viewpoint of legislation affecting surface-mined lands. pp. 117-128 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI. 742 p.

Hargis, N.E. and E.F. Redente. 1984. Soil handling for surface mine reclamation. J. Soil and Water Conserv. 39:300-305.

Harthill, M. and C.M. McKell. 1978. Ecological stability - is this a realistic goal for arid land rehabilitation? pp. 557-567 in Ecology and Coal Resource Development (ed. M.K. Wali), Pergamon Press, NY.

Hodder, R.L. 1975. Montana reclamation problems and remedial techniques. pp. 90-106 in Practices and Problems of Land Reclamation in Western North America (ed. M.K. Wali), Univ. N. Dak. Press, Grand Forks, ND.

Schuman, G.E., F. Rauzi and D.T. Booth. 1982. Production and competition of crested wheatgrass-native grass mixtures. Agron. J. 74:23-26.

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

Sims, P.L. 1977. Rehabilitation potential and practiaces of Colorado oil shale lands. Progress Rep. COO-4018-1 to U.S. E.R.D.A., Col. State Univ., Fort Collins, CO.

Sindelar, B.W. 1985. Vegetation development on surface mined lands in eastern Montana. pp. 6/1-30 in Ecological Studies of Disturbed Landscapes, U.S. Dept. Energy, Washington, D.C.

Sindelar, B.W. 1978. Successful reclamation - how long? Rangeman's J. 5:123-124.

Sindelar, B.W. 1973. Dryland sodding for erosion control. Mt. Agric. Exp. Sta. Res. Rep. 43, Bozeman, MT.

Sindelar, B.W. and S. Murdock. 1985. The utilitarian concept for determining mined land reclamation success. pp. 84-86 in Proceedings: Second Annual Meeting, Amer. Soc. Surface Mining and Reclamation, Denver, CO.

Smith, J.A., G.E. Schuman, E.J. DePuit and T.A. Sedbrook. 1985. Wood residue and fertilizer amendment of bentonite mine spoils: spoil and general vegetation responses. J. Environ. Qual. 14:575-580.

Stark, J.M. and E.F. Redente. 1985. Soil-plant diversity relationships on a disturbed site in northwestern Colorado. Soil Sci. Soc. Amer. J. 49:1028-1033.

Stiller, D.M., G.L. Zimpfer and M. Bishop. 1980. Application of geomorphic principles to surface mined land reclamation in the semiarid West. J. Soil and Water Conserv. 35:274-277.

Stoddart, L.A., A.D. Smith and T.W. Box. 1975. Range Mangement. (3rd Edition), McGraw-Hill, NY. 532 p.

Tate, R.L. and D.A. Klein (ed.). 1985. Soil Reclamation Processes: Microbiological Analyses and Applications, Marcel Dekker, Inc., NY. 349 p.

Tausch, R.J., N.E. West and A.A. Nabi. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. J. Range Manage. 34:259-264.

Thames, J.L. (ed.). 1977. Reclamation and Use of Disturbed Land in the Southwest. Univ. Arizona Press, Tucson, AZ. 362 p.

Laycock, W.A. 1980. What is successful reclamation--a look at the concepts of adaptability, productivity, cover and diversity of seeded species. pp. 1-17 in Proceedings: Northwest Colorado Land Reclamation Seminar II, Steamboat Springs, CO.

Laycock, W.A. and W.J. McGinnies. 1985. Reclamation and grazing management on a surface coal mine in northwestern Colorado. pp. 73-76 in Proceedings, Second Annual Meeting, Amer. Soc. Surface Mining and Reclamation, Denver, CO.

Lindemann, W.C., D.L. Lindsey and P.R. Fresquez. 1984. Amendment of mine spoil to increase the number and activity of microorganisms. Soil Sci. Soc. Amer. J. 48:574-578.

Long, S.G., J.K. Burrell, N.M. Laurenson and J.M. Nyenhuis. 1984. Manual of revegetation techniques. U.S.D.A. For. Serv., Missoula Equip. Devel. Center 8471-2601, Missoula, MT.

Mackey, C.V. and E.J. DePuit. 1985. Natural revegeation of surface-deposited spent oil shale in Colorado. Reclam. Reveg. Res. 4:1-16.

MacLauchlan, R.S. 1975. The role of the Soil Conservation Service's Plant Materials Centers in reclaiming surface mined lands. pp. 131-139 in Proceedings: Third Symposium on Surface Mining and Reclamation, Nat. Coal Assoc., Louisville, KY.

May, M. 1975. Moisture relationships and treatments in revegetating strip mines in the arid West. J. Range Manage. 28:334-335.

Mays, D.A. and G.W. Bengtson. 1978. Lime and fertilizer use in land reclamation. pp. 307-328 in Reclamation of Drastically Disturbed Lands (ed. F.W. Schaller and P. Sutton), ASA/CSSA/SSSA, Madison, WI.

McGinnies, W.J. 1980. Topsoil management. pp. 235-242 in Proceedings: Northwest Colorado Land Reclamation Seminar II, Steamboat Springs, CO.

McGinnies, W.J. and A.M. Wilson. 1982. Using blue grama sod for rangeland revegetation. J. Range Manage. 35:259-261.

McKell, C.M., and others. 1979. Selection, propagation and field establishment of native plant species on disturbed arid lands. Ut. Agric. Exp. Sta. Bull. 500, Logan, UT.

Monsen, S.B. 1975. Selecting plants to rehabilitate disturbed areas. pp. 76-90 in Improved Range Plants (ed. R.S. Campbell and C.H. Herbal), Range Symp. Ser. 1, Soc. Range Manage., Denver, CO.

Moore, R.T., S.L. Ellis and D.R. Duba. 1977. Advantages of natural successional processes on western relcaimed lands. pp. 274-282 in Proceedings: Fifth Symposium on Surface Mining and Reclamation, Nat. Coal Assoc., Louisville, KY.

Wali, M.K. (ed.). 1975. Practices and Problems of Land Reclamation in Western North America. Univ. North Dakota Press, Grand Forks, ND. 196 p.

Wali, M.K. 1975. The problem of land reclamation viewed in a systems context. pp. 1-17 in Practices and Problems of Land Reclamation in Western North America (ed. M.K. Wali), Univ. North Dakota Press, Grand Forks, ND. 196 p.

Wallace, A., E.M. Romney and R.B. Hunter. 1980. The challenge of the desert: revegetation of disturbed desert lands. pp. 216-225 in Soil-Plant-Animal Relationships Bearing on Revegetation and Land Reclamation in Nevada Deserts, Great Basin Naturalist Memoirs No. 4, Brigham Young Univ., Provo, UT.

Wasser, C.H. 1982. Ecology and culture of selected species useful in revegetating disturbed lands in the West. U.S.D.I. Fish and Wildlife Service, FWS/OBS-82/56, Fort Collins, CO.

Weiler, G.J. 1982. The use of saline water to establish native species on topsoiled mine spoil. pp. 174 - 177 in Proceedings: Symposium on Reclamation of Mined Lands in the Southwest (ed. E.F. Aldon and W.R. Oaks), Soil Conserv. Soc. Amer., Albuquerque, NM.

Wenger, L.E. 1941. Establishing native grasses by the hay method. Kansas Agr. Exp. Sta., Fort Hays Circ. 208, Manhattan, KS.

Williams, R.D., W.J. Ruzzo and J.P. Reganold. 1983. Soil and overburden research needs. pp. 165-178 in Proceedings: Conference on Soil and Overburden Requirements for Successful Revegetation (ed. M.G. Berg), U.S. Office Surface Mining, Denver, CO.

Williams, S.B. and M.F. Allen (ed.) 1984. VA mycorrhizae and reclamation of arid and semiarid lands. Wyo. Agric. Exp. Sta. Sci. Rep. No. SA 1261, Laramie, WY.

Wollenhaupt, N.C. 1982. The role of topography in revegetation of disturbed lands. pp. C2(1)-C2(11) in Proceedings: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Mt. Agric. Exp. Sta. Res. Rep. 194, Bozeman, MT.

Wright, R.A. (ed.). 1978. The Reclamation of Disturbed Arid Lands. Univ. New Mexico Press, Albuquerque, NM. 196 p.

Young, J.A., R.A. Evans, B.L. Kay, R.E. Owen and F.L. Jurak. 1978. Collecting, processing and germinating seeds of western wildland plants. U.S.D.A.-Sci. and Educ. Admin., ARM-W-3, Berkeley, CA.

Young, S.A. and R.B. Rennick. 1982. Establishment of seeded species on coal minesoils following temporary irrigation. Mt. Agric. Exp. Sta. Res. Rep. 200, Bozeman, MT.

MITIGATING THE VISUAL IMPACT OF MAJOR CONSTRUCTION PROJECTS THROUGH COMPUTER SIMULATION

Kurt Culbertson
Design Workshop, Inc.
Aspen, Colorado

INTRODUCTION

For the last fourteen years, the "hows" of High Altitude Revegetation has been discussed with an emphasis on technical issues such as drainage, water quality, plant selection and soil productivity. It is probably worth a few moments, however, to examine some of the very reasons for the conference itself, to ask the question - why revegetate? A stated objective of the conference is to "promote the understanding of rehabilitation procedures and materials, and natural resource values and potentials when fragile high-elevation ecosystems are to be modified by human activities."

More specifically, the issue of revegetation may be important not only because of a technical need to stabilize a ski slope or roadway embankment, but because a revegetation plan or program is mandated by some public approval process. A successful revegetation program may be an important factor in maintaining a favorable business climate and in winning public support for a proposal.

VISUAL IMPACTS

A major element in the public's interest in revegetation is a major concern for visual quality. This is particularly true in high altitude mountainous environments which are extremely scenic, and when disturbed are difficult to revegetate due to steep slopes, poor soils, and arid climates.

Minimizing the negative impacts and maximizing the potential of landscape modification can be dealt with in two ways. At a minimum, revegetation efforts focus upon recreating, to the greatest extent possible, the pre-existing conditions. The primary emphasis here is upon the establishment of indigenous plant material; simply making the site green again. At its best, revegetation experts utilize the condition of landscape modification to actually enhance the project by creating wildlife and fish habitat, or perhaps even art.

In the ideal situation, the revegetation expert would work closely with the facilities operators and planners to insure that proper conditions for plant growth are provided, topsoil is stripped and stockpiled, maintainable slopes provided and drainage adequately addressed. As importantly, attention can be given to create an aesthetically appealing scene by shaping landforms, enhancing and preserving views, and strategically placing plant material.

TRADITIONAL ILLUSTRATION TECHNIQUES

Critical to addressing this issue is the ability to predict the final form of landscape modifications. In order to do this, a means must be found to accurately illustrate the proposed change or development. One technique traditionally used is the model. The three-dimensional quality of models is extremely useful in providing a sense of the scale of a facilities operation, contours can be easily illustrated, and elements of the plan such as trucks and plant material can be constructed in miniature. Models, however, have limitations. For example, unless you are extremely small, it is virtually impossible to view the scene as if you were actually in the space. Model scopes, periscope-like devices which allow the viewer to see into a scene at proportional eye level, are of value but are only of limited success. In addition, because large facilities can at times be seen from great distances, the ability to model the entire affected area can be cost prohibitive.

In analyzing the impact of a proposed development, it is usually necessary to view the development from certain key points, such as frequently traveled highways or major public facilities. To accomplish this objective, it is critical to know the viewers position in relationship to the object such as a ski slope, mine or utility corridor. Because a model usually provides an aerial view, the exact location of the viewer in space is unknown. Another visualization technique is therefore necessary to address the problem.

Anyone who has tried their hand at drafting has probably gone through the exercise of constructing a perspective. By following a set of mathematical procedures, a view can be created of an object from a predetermined position and angle. In order to view the object from a different position, one simply has to repeat the process with a new set of variables. For objects or scenes with discrete limits, such as a building sited on a city block, this technique is very useful.

Once the site expands to one of hundreds or thousands of acres, has an irregular boundary, or contains a great of deal of topography, the creation of each view becomes enormously time consuming if not practically impossible. Furthermore, the placement of a structure or a cut and fill slope within the perspective becomes extremely difficult to illustrate with any degree of accuracy. The "artist interpretation" and, in turn, the principal of artist license becomes a factor.

Another technique, the photomontage, suffers from similar accuracy problems. The degree of accuracy inherent in the technique usually does not meet the needs of the task. A public that finds that the finished product does not resemble the artist rendering quickly learns to mistrust such illustration techniques. A landscape designer utilizing such techniques may find that the finished project only remotely resembles the original design. It is because of this very problem that landscape architects began to search for a better way to visualize proposed development.

INTRODUCTION OF COMPUTER ILLUSTRATIONS

Concerned with the visual impact of major developments such as ski areas, utility installations and mines on public lands, the United States Forest Service in the early 1970's developed a computer program called perspective plot. The program harnessed the computing power of the machine to quickly perform the mathematical exercises once performed in the draftsman's head. Complicated perspective views could thus be created with much greater speed. Furthermore, by connecting the dots with a wire frame, some sense of the shape of the land can be depicted.

By previewing the proposed trail development, designers could then make adjustments to their plans to enhance the visual quality of the project. Tree lines could be feathered, islands left in trails, or landforms modified to create a more natural effect.

Perspective plot was clearly an important step in providing accurate representations of major land form modifications. Despite all its advantages, perspective plot has several significant shortcomings. The first is speed. In a world where time is money, a system which requires several hours to generate an image is very cumbersome. Secondly, perspective plot is not interactive. One cannot effectively "preview" an image before it is plotted and in turn, once a perspective is generated, one must recycle through the process if the image is not the one you are after. Thirdly, these systems use a series of stills to depict motion, thus reducing the ability to analyze a project from the user's viewpoint. In the case of a ski hill, this would be the skiers perspective.

Advancements in recent years offer important solutions to these problems. With the introduction of the 32 bit computer, real time graphics became a reality. Real time provides a continuous flow of visual information, and in turn, speed. The computer allows a user to quickly move from one viewing position to the next, while at the same time following his movement on the screen.

New computers also provide another advancement. By removing hidden lines and the modeling of solid forms, a more true to life picture can be created.

NEW COMPUTER TECHNOLOGY

Movie goers in recent years have been dazzled by the special effects created by directors such as George Lucas and Steven Spielberg in movies such as Star Wars, Raiders of the Lost Ark and Tron. These are films that stir the imagination and take us places we have never been before. These films utilize the ultimate in special effects are to create imaginary landscapes. Many of these special effects are achieved through the use of computer graphics to mathematically construct images that are too complex and expensive to model through conventional techniques, or to create environments in locations too difficult to reach or expensive to populate with a film crew (such as outer space).

These advancements have solved may of the shortcomings found in perspective plots. This new technology is often seen in traditional CADD systems to model major urban developments and individual structures. Different views can be chosen and simulated more rapidly and various alternatives can be examined.

The computers also solve the accuracy problem inherent in artist sketches. Objects can be placed in space with an accuracy of two decimal places. Thus, one can predict the outcome of landform modification with a high degree of accuracy.

The simulation of roadways, such as Vail Pass and Glenwood Canyon, or utility corridors can also be accomplished. As an example, a new interstate highway interchange can be constructed with the computer to analyze the impact of future plant schemes, grading and retaining schemes, and then can be viewed from the driver's level.

These advancements also solve an additional problem. Unlike the world depicted in our models and sketches, the world we live in is not static. While some objects, such as mountains, stand still, others, such as trucks, or more importantly people, move. If the view of a proposed mining operation, ski area or utility corridor from a highway is extremely important to the local citizenry, it seems desirable to illustrate that view as the driver of an automobile might see it in motion. By developing a series of sketches equal distances apart along a given path, and then viewing these sketches at a given time interval, the illustrator can create the sensation of motion. This system works simply because distance divided by time equals velocity or speed.

The introduction of time into a simulation might also be used in another way. Lets assume for a moment that the viewer stands still but the mine moves. Of course the position of the mine horizontally does not change, but what does change, however, is the configuration of the operation. In the case of a mine, the alignment of conveyors and the position of crushing or loadout equipment could change. Models and sketches paint the view of a facility as static. The fact is that the visual impact of a development changes over time. A mining project will have one impact as a small initial area is excavated, another as the limits of the full excavation are reached, still another as plant material is installed and begins to mature.

In an attempt to address the long term implications of mining operations or ski areas, sketches of the various phases of the development are often included as part of the visual analysis found in government approval applications. Sketches showing the possible state of the project in five year intervals are included. Such illustrations are useful but still fall short of providing a sense of the dynamic quality of the mining operation. Furthermore, because the generation of multiple images can be time consuming and costly, these series of sketches are often generated assuming that the viewer occupies a static position. As illustrated by the previous example of the view from the road, this is clearly not the case.

CONCLUSION

The importance of predicting the extent and form of landscape modification with an accurate illustration is clear. Communicating a proposal to the public and/or political entity requires the use of an illustration to show intent. It is the accuracy of these illustrations that builds a sense of trust and in turn, a greater chance to achieve a consensus among individuals.

With the use of a computer, the accuracy in predicting visual alterations of a site are without question. The computer allows a user to plot changes or objects to a degree of accuracy of two decimal places. Hence, the computer-generated sketch is perceived as more accurate than the illustrator constructed perspective.

In addition, new technology allows the accuracy of the computer to be enhanced by the elements of time and motion. This combination provides a powerful tool to illustrate the future and create new importance for high altitude revegetation.

PASSIVE MINE DRAINAGE TREATMENT USING ARTIFICIAL AND NATURAL WETLANDS

J. David Holm
Colorado Mined Land Reclamation Division
and
Thomas Elmore
Northwest Council of Governments

Introduction

Passive Mine Drainage Treatments (PMDT) Systems are designed to remove metals from mine water and to neutralize mineral acidity using low cost materials and construction techniques which do not require continual electrical or chemical inputs or frequent maintenance operations. Such systems have been developed in order to overcome the inherent difficulties in addressing acid mine drainage problems. Most acid mine drainage sources are in relatively remote areas with poor accessibility, lack of electrical power and extreme winter weather conditions. PMDT Systems must be designed on a site by site basis to compensate for problems related to access, elevation, surface hydrology, concentrations of specific pollutants and legal restrictions such as water rights, land use restrictions, and property ownership considerations.[1]

The goal of PMDT systems is to focus "bio-geochemical" water treatment mechanisms at or near the source of mine drainage, in order to accelerate the pollution removal that would otherwise occur naturally, but over a much longer reach of the receiving stream. PMDT systems provide at-source treatment for leachates from mine waste and mine drainage. Bio-geochemical treatment mechanisms include: bacterial oxidation and reduction of metal cations and anions; metal removal through adsorption or cation exchange using peat and other wetland substrates; plant uptake of pollutants; oxidation through aeration and precipitation; neutralization with alkalinity and precipitation; settling and filtration. These mechanisms can be established in many ways depending on the amenities and constraints of a particular site.

Applicability of PMDT Systems

PMDT Systems were devised to address situations where there is no clear cut responsibility for the water pollution from inactive and abandoned mines. Historically, it has been difficult to assign responsibility to surface owners because of the high cost of water quality restoration work and the small resultant land improvement benefits. Also, the ownership of surface and mineral rights are often held by different parties in the mining districts of the state. In many cases the water rights to a mine discharge have been severed from the mineral and surface estates. As a result clean up work for many mine drainage pollution problems has been left to local, state and federal agencies when funds have been available. Since public funds for environmental clean up operations are always limited, there is a need for low cost and low maintenance treatment systems, which improve water quality without necessarily providing complete pollution removal. PMDT Systems may also be appropriate when legally and financially responsible parties can be identified, and when beneficial uses can be restored to water resources using this approach in concert with others, to achieve applicable effluent and water quality standards.

Existing PMDT Systems in Colorado

The inspiration for developing PMDT Systems in Colorado was based on observations of several natural mine drainage treatment systems. The Shuster (Juniper) Mine near Oak Creek, Colorado, drains into a natural bog and beaver pond system. This acidic mine drainage contains large concentrations of iron and manganese along with significant concentrations cadmium, lead and zinc. However, these elevated levels of metals are not observed in Oak Creek which is the receiving stream. Mine water is cascaded down the face of the exposed sandstone outcrop below the mine adit which causes rapid oxygenation of the mine water. Beavers in the area have constructed several ponds in an elaborate system of canals and diversions below the mine adit. The net result is that the heavily oxidized mine drainage filters through the bog-like beaver dams and the effluent is gradually blended with stream water until it finally joins the mainstem of Oak Creek. The impact of the mine water on Oak Creek is insignificant.[2]

A second natural treatment system was observed below the Delaware Mine, near Keystone above Dillon Reservoir. The drainage from the Delaware Mine contains very high concentrations of copper, lead, zinc, iron, manganese and cadmium. The effluent from the Delaware Mine is routed into a small heavily sodded pond that was built long ago. The water which seeps out of the pond impoundment contains lowered concentrations of heavy metal pollutants. The pond and bog are responsible for settling out and filtering the suspended solid metal fractions and much of the dissolved metal appears to be absorbed onto the bog soil and organic materials in the pond embankment.[3]

The first actual PMDT System was installed in July of 1984, at the Marshall No. 5 Coal Mine, near Boulder, Colorado. This was the prototype system designed to test the concept of PMDT at a favorable site (elevation 5500 ft) with low flows (6-12 gpm) of only moderate mine drainage pollution. Three basic treatment facilities were incorporated in the system: An artificial peat bog; a limestone filled drainage channel; and several waterfalls. The artificial peat bog serves as an organic ion exchange and filter medium for removal of heavy metals from the mine drainage. The second stage of the treatment is a limestone filled channel approximately 300 feet long. The limestone provides for the neutralization of mineral acidity. The third component of the system is a series of three small drop structures placed in the limestone channel to provide aeration and carbon dioxide exsolution to drive the neutralization reaction.[4]

The second PMDT System designed and constructed in Colorado was at the Thompson No. 2 Coal Mine located near Carbondale, Colorado. The Thompson No. 2 PMDT System was constructed in early 1985. This system incorporates the same basic components as the Marshall No. 5 PMDT System. This system was designed to test the PMDT approach for low flows (10-15 gpm) at a higher elevation (7300 ft) and for severe mine drainage pollution.[5]

The third PMDT System designed and constructed in Colorado was at the Pennsylvania Mine. This mine is at an elevation of 11,000 ft, located nearly adjacent to the Delaware Mine, described earlier. The Pennsylvania Mine causes serious water quality degradation in Peru Creek, which is a tributary feeding Dillon Reservoir (Denver's water supply).[6]

The system constructed at the Pennsylvania Mine is very different than the the Marshall No. 5 and Thompson No. 2 PMDT systems. During the initial site investigations, a 13 acre natural wetland was discovered approximately 600 feet below the Pennsylvania Mine adit. This situation presented a new possibility for treating mine drainage. In other areas, natural wetlands perform mine drainage treatment functions with little apparent adverse affect on the biological integrity of the wetland. The near ideal location of the wetland and the opportunity to observe the performance of a natural wetland for mine drainage treatment, favored this approach at this site.[7] In addition, the large area of the wetland offered the possibility of treating a much larger flow of mine drainage than had been possible using the artificial peat bogs constructed for the earlier PMDT Systems. The discharge from the mine ranges from 30 to 100 gallons per minute containing very high concentrations of heavy metals and acidity.

The system design involved a collection system, a conveyance pipe and a leachfield system. The collection system intercepts the mine water discharging from the Pennsylvania Mine adit. The conveyance system is a buried 4" PVC pipe which delivers the mine water to the wetlands. A leachfield system was designed to allow exfiltration of mine water from a perforated 4" PVC pipe into the wetland at a minimal rate of flow per unit area.[8]

General Design and Construction Considerations

The process of designing a passive treatment system is dictated by both chemical and physical constraints. Understanding the chemical processes involved in PMDT is vital to the design process. These chemical processes determine the type and quantities of materials (peat, biomass, limestone, aeration devices, etc..) necessary to achieve desirable treatment goals. Once the necessary chemical processes are known, they must be adapted to the physical and the engineering constraints of the site. The treatment system must be integrated in its location well enough to function for long periods of time through extremes in weather, flow and variations in water quality. The design process requires:

- site evaluation;
- detailed hydrologic investigations;
- selection of treatment materials and system components;
- appropriate siting of treatment structures;
- development of construction specifications and reclamation plans;
- a system evaluation and monitoring plan.

Artificial bogs and wetlands are the cornerstone of PMDT. The sizing requirements for bogs and artificial wetlands are based on laboratory and field observations for cation change capacities and transmissivity characteristics of peat and wetlands environments. Cation exchange capacities for peat range from 100-400 meq/100 grams of peat (dry weight).[9] Rates of inflow must be held to less than 1 gallon per minute per 100-200 square foot of wetland area.[10,11] Generally it is desirable to place the ion exchange medium (i.e.. peat or wetlands) upstream of a neutralization medium such as limestone. Removal of heavy metals greatly reduces armoring of the limestone surfaces by metal oxides.

The plant species which are dominant in natural wetlands are often adapted to the acid conditions and elevated heavy metal and salt concentrations which are associated with acid mine drainage. Wetland plant species and the organic peat substrate in bog areas remove metals from acid water by adsorption or cation exchange, and filtration. The wetlands also remove metals by plant uptake. Some wetland species are able to concentrate high levels of metals above ambient conditions. In addition, iron and manganese oxidizing bacteria are important in removing metals from mine drainage. Iron and sulfur reducing bacteria may also be involved.[12]

Construction of wetlands requires careful attention to geomorphic considerations, vegetation requirements and hydrologic factors. The size and shape of the artificial wetlands must accommodate the annual flow regime of the mine drainage and yet be able to fit into the bottom land area available. Bogs and wetlands must be located in flat locations. It is desirable for the excavation to have an irregularly shaped shoreline with variable depth. This configuration provides multiple vegetative niches as well as a tortuous flow path for increasing residence time and discharge control. The excavation should provide habitat for submergent hydrophytes, floating hydrophytes, emergent rooted hydrophytes, and mosses and shrubs.[13] Some provision for draining the wetland is desirable.

Since the water level is the major factor influencing the development of a wetland it is beneficial to install water handling devices which can aid in the control of inflow and outflow from the bog system. A by-pass system to route water around the wetlands is also desirable.

Specific PMDT Design and Construction Considerations

The Marshall #5 PMDT system was constructed on a gently sloping surface. The slope was reduced to approximately 20:1 h:v in order to reduce the tendency for the mine water to channelize through the bog. A loose rock dam was built to retain the peat in the artificial bog and to provide for drainage. Mirafi Filter fabric was placed between the peat and the loose rock to prevent clogging of the rock drain. Water handling devices were designed to provide uniform inflow to the bog and the capability of bypassing water around the system. Eventually, these devices were disguised and buried in order to reduce tampering by vandals. The flow bypass system was needed to prevent excess inflow to the bog. Flows greater than 12 gpm simply washed across the bog surface with little or no contact with the peat. Consequently, the limestone in the trench below the bog became coated and was rendered useless on several occasions. A "passive valve" was developed to bypass flows in excess of 12 gpm.

The Thompson #2 PMDT system was partially constructed on fill material. A bentonite liner was placed below the peat in the bog area. This bog is wider than the Marshall bog. An infiltration system consisting of buried perforated PVC pipe was designed to insure uniform inflow of mine water to the bog. This system is subject to very harsh winter operating conditions. A number of wetlands species were introduced to the bog to test their adaptability to the conditions in the PMDT system.

The Pennsylvania Mine PMDT is located in an extreme environment. The entire system was placed underground to avoid freezing problems. The conveyance system was buried beneath an avalanche chute in order to drop the mine drainage 80' from the adit to the wetlands. Thrust blocks were provided at each bend to minimize hydraulic ram effects on the pipeline. A subsurface energy dissipator tank receives water from the conveyance pipeline and delivers the drainage to the leachfield. The buried exfiltration (mine water leachfield) system was insulated with outdoor polystyrene to prevent freezing and ice damming. The mine water is split into 5 sections, each 100' in length, to achieve a uniform wetting front of 500' into the wet meadow.

Effectiveness of PMDT

The early results of the operation of the existing PMDT Systems have been very encouraging. The Marshall No. 5 system efficiently removes iron and neutralizes mineral acidity. Total iron concentrations are reduced by 99% through the system and consistent increases in pH from 5.1 (influent to 7.4 effluent" have been observed.

It appears that the initial problems related to flow balancing which beset the Thompson No. 2 PMDT System have now been overcome and the system is removing metals and acidity from the drainage. Current water quality results are encouraging.

The natural wetlands treatment system at the Pennsylvania Mine will not be operational until this coming spring. The system was constructed in late fall, 1985, but the onset of winter prevented completion of a series of ground water monitoring wells, which will be installed and sampled prior to discharging the mine water into the wetlands. This will permit any changes in the wetlands to be related to water quality. Also, the plants in the wetlands will be monitored and evaluated closely before and after mine water is introduced. Given the large area of wetlands and the small discharge of mine water (approximately 1 gallon per minute for 5,600 ft^2 of wetlands) it is likely that high metal removal efficiencies will be observed at this site.

PMDT Design and Construction Costs

Mine drainage treatment system costs are associated with design, construction and operational expenses. Conventional treatment system construction costs for a plant sized to treat flows in the range of the existing PMDT systems were estimated at $150-200,000.00. Annual maintenance costs of $18,000.00 were anticipated. Design work was figured at 10% of construction costs.[14]

Design of the Marshall No. 5 PMDT System was accomplished for $14,120.00. Construction costs at Marshall No. 5 PMDT were $17,535.00. Higher than anticipated costs were incurred during construction of this system because it was a "first attempt" and numerous field revisions of the plans were needed. Annualized maintenance costs of $2,300.00 are expected.

The Thompson No. 2 PMDT System was designed at a cost of $7,790.00 and constructed at a cost of $17,170.00. Ongoing maintenance costs of $3,900.00 per year are expected. Costs for building this system were increased because construction took place in extremely cold winter weather. Unprecedented high flows from the mine adit resulted in excess inflow to the system and subsequent coating of the limestone in the channel below the bog. A long delay for achieving treatment effects was related to problems balancing flows through the system.[15]

The design cost for the Pennsylvania Mine Wetlands Treatment System amounted to $10,500.00. Construction costs were $24,400.00. This system, like the Marshall #5 PMDT was a prototype. Construction was hampered by heavy snowfalls. Costs were increased because of the need to accelerate construction to complete the project before the onset of winter.

Every PMDT system will require maintenance work at some interval. The frequency and intensity of required maintenance depends on the specific constraints of a site which influence the design capabilities for each system. Some provision for financing long term maintenance costs should be included for each PMDT application.

Regulatory Considerations

Construction of PMDT Systems requires careful consideration of applicable permit requirements. In the eastern coal regions, regulatory agencies often require that chemical treatment be available if needed to supplement wetland treatment since this approach is considered experimental. N.P.D.E.S. discharge permits are routinely required for systems constructed at active coal mines in the East. In Colorado, N.P.D.E.S. discharge permits have not been required for the existing treatment systems. These systems were allowed to be constructed by the State, at inactive mines, in order to evaluate the feasibility of the PMDT approach.

Section 404 (PL 92-500) dredge and fill permits may also be required for construction work in bottom lands in order to enhance or develop wetlands for mine drainage treatment. A 404 permit was not required for the particular work done at the Pennsylvania Mine. An effort is currently underway through the Northwest Council of Governments, to propose an appropriate and comprehensive regulatory framework for future PMDT applications.

Conclusion

Treatment of acid mine drainage using artificial and natural wetlands appears to be a promising new approach to a longstanding and serious environmental problem. The early results from the three existing systems in Colorado indicate that this approach is effective and inexpensive reletive to conventional mine drainage treatment system design, construction and operation. Many wetlands type systems have been installed in the last year and a half in the states of Pennsylvania, Ohio, West Virginia, and Alabama. Most of these systems are removing iron very effectively. Manganese removal has been accomplished with somewhat mixed success.[16] Many other metals are being handled by artificial bogs and wetlands, as well.

There is no long term monitoring data yet available for the PMDT approach but the amount of performance data is increasing rapidly with each passing year. Further research is needed on: microbial mechanisms for metal remaval; development of wetlands plant materials specifically adapted to acid mine drainage conditions; plant uptake of heavy metals; financing mechanisms for long term maintenance costs; and, flexible regulatory approaches to allow further PMDT development work to proceed.

References

1. Holm, J. D., dF. Guertin. Theoretical Assessment and Design Considerations for Passive Mine Drainage Treatment Systems, Proceeding National Symposium on Reclamation of Abandoned Mined Lands, Bismarck, North Dakota, June, 1984.

2. Holm, J. D., M. B. Bishop, "Passive Mine Drainage Treatment: Selected Case Studies", Medine, A., Anderson, M., (editors). Proceedings of the American Society of Civil Engineers Specialty Conference, 1983. National Conference on Environmental Engineering, Boulder, Colorado.

3. Ibid.

4. Holm, J. D., dF. Guertin, op. cit.

5. Holm, J.D., S. Jones, "Passive Mine Drainage Treatment: An Effective Low Cost Aletenative", Proceedings of the National Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, Lexington, Kentucky 1985.

6. Holm, J. D., T. Sullivan, B. K. Stenulson, "The Restoration of Peru Creek", Colorado Department of Health, Water Quality Control Division, October, 1979.

7. Elmore, T. K. "The Pennsylvania Mine Passive Mine Drainage Treatment System", Final report to the Colorado Department of Natural Resources, Mined Land Reclamation Division, Contract number C188072. February, 1986.

8. Ibid.

9. Fuchsman, C. H. Peat, Industrial Chemistry and Technology. New York: Academis Press, 1980.

10. Holm, J. D., Jones, S., op. cit.

11. Kleinmann, R. L. Treatment of Acid Mine Waste by Wetlands. Proceedings of Technology Transfer Seminar, Bureau of Mines Information Circular, September 27, 1985, Control of Acid Mine Drainage.

12. Kleinmann, R. L. et. al. "Constructing Wetlands for the Treatment of Mine Water", course notes, workshop at the National Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, Lexington, Kentucky 1985.

13. Brooks, R. " Ecological Aspects of Wetlands", course notes, workshop at the National Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, Lexington, Kentucky 1985.

14. Holm, J.D., Jones, S. op cit.

15. Ibid.

16. Emerick, J.C., Guertin, dF., Margulies, T. " An Inventory of Peat, Vegetation, and Limestone for Use in Low Maintenance Treatment Systems for Acid Mine Drainage in Colorado", Final report to the Colorado Department of Natural Resources, Mined Land Reclamation Division, Contract number 202-357, September, 1985.

IDENTIFICATION AND HANDLING OF[1] ACID MATERIALS

David Y. Boon[2]

INTRODUCTION

Acid producing materials have been identified with active and abandoned coal, uranium, bentonite and various sulfide ore mines throughout the western United States. Extensive research has shown that acid production results from the oxidation of chalcophilic minerals such as pyrite, marcasite, galena, sphalerite, arsenopyrite and chalcopyrite.

Regardless of whether acid production occurs with coal, uranium, bentonite, or various sulfide ore deposits proper site characterization is critical for identifying acid zones. If adequate site characterization is disregarded or conducted sporadically the results are often costly reclamation failures. Proper site characterization is essential if reclamation is to be a long term success.

The most commonly used methods for mitigating acid spoils involves liming to neutralize the acidity or selective placement. Numerous methods are frequently used to measure the lime requirement of acid mine spoils. Lime requirements based on many of these methods are subject to error and often result in reclamation failures. The most common method of selective placement involves burial of acid materials above the post-reclamation water table and below the surface four feet.

IDENTIFYING ACID MATERIALS

Most, if not all, State and Federal regulations concerned with surface mining require the identification and handling or proper treatment of acid materials. Regardless of the regulation, the objectives are to identify toxic

---

1 Paper presented at the Seventh High Altitude Revegetation Workshop; Fort Collins, Colorado; March 6-7, 1986.

2 Soil Scientist; Wyoming Department of Environmental Quality - Land Quality Division, 122 West 25th Street, Cheyenne, Wyoming 82002

and/or acid forming materials so mineral extraction can occur without damage to the surface root zone, groundwater, or surface water.

Occurrences

Acid producing materials have been identified with coal, uranium, bentonite, and various sulfide ore mines throughout the United States. Many of these sites involve minor areas of disturbance (less than 5 acres) while others may cover extensive areas (greater than 1000 acres) and contain acid spoils and mine tailings.

Coal

Highly carbonaceous materials (rider coal, partings, roof and floor shales) have been attributed with producing acidity upon oxidation. Carbonaceous materials often contain greater concentrations of pyrite than associated coal and non-carbonaceous shales (Hinkley et al., 1978; Miller et al., 1976). Sulfide minerals occur in significantly higher concentrations in the finer grained sedimentary rocks associated with coals such as roof shales, partings, and floor shales (Arora et al., 1980; Valkovic, 1983; Boon and Smith, 1985).

The simultaneous oxidation of pyritic iron and sulfur can be summarized as:

$$4FeS_2 + 15O_2 + 14H_2O \rightleftharpoons 8SO_4^{2-} + 16H^+ + 4Fe(OH)_3 \quad (1)$$

If the pH of the system drops below 4.0 and the microbial population of Thiobacillus ferroxidans is active then an accelerated rate of oxidation can occur by the following reaction:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightleftharpoons 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (2)$$

Although pyrite is the dominant sulfide mineral in coal and carbonaceous materials other chalcophilic minerals have been identified including: marcasite, sphalerite, galena, chalcopyrite and arsenopyrite (Finkelman, 1981; Valkovic, 1983; Dreher et al., 1985). It should be mentioned that a wide variety of textural materials other than carbonaceous shales are capable of producing acidity in the western United States (Fisher and Munshower, 1984). Table 1 demonstrates acid production from both pyritic sandstones (A) and carbonaceous shales (B).

Table 1

Acid Coal Mine Spoils
Powder River Basin and
Hanna Basin, Wyoming

Site	A	B
pH	2.8	3.8
ABP	-0.3	-21.3
%OC	3.9	12.2
SO_4-S mg/l	3024	2600

ABP = acid base potential in tons of calcium carbonate/1000 tons of material.
%OC = percent organic carbon.

Uranium

The distribution of pyrite, marcasite, and arsenopyrite in various uranium roll-front deposits throughout the western United States and Canada has been extensively described (Goldhaber and Reynolds, 1979; Reynolds and Goldhaber, 1983). Pyrite concentrations greater than 20% (200,000 ppm) have been reported for the Gas Hills uranium district of Wyoming along with arsenic concentrations exceeding 10,000 ppm (Harshman, 1974). A large portion of the pyrite in the deposits is associated with arsenic as arsenopyrite. The large concentration of reactive sulfides has resulted in extreme surface acidification (Table 2).

Bentonite

Approximately 75 million years ago the Black Hills region of Wyoming was covered by a shallow sea. Volcanic eruptions to the west deposited vast quantities of siliceous ash into the sea. The volcanic ash settled to the sea floor where it was chemically altered into bentonite (Davis, 1965). Since bentonite deposits are of marine environments of high S content they can contain appreciably more pyrite than freshwater deposits (Berner, 1984).

Table 2

Reclaimed Uranium Spoils
Gas Hills, Wyoming

Sample depth (ft)		pH	ABP
CW	0-1	2.0	-69.3
	1-2	NA	NA
	2-3	6.1	-38.1
	3+	7.2	-67.8
CB	0-1	2.2	-16.5
	1-2	NA	NA
	2-3	7.3	-150.7

NA = not analyzed

Abandoned bentonite spoils in Wyoming can contain pH values ranging from above 9 to values below 4.0 (Smith, 1984). Acidification resulting in pH values less than 4.0 are not common in bentonite spoils due to the large absorption capacity of the clay materials. Lower pH values could occur in sandstone materials associated with some bentonite deposits (Newcastle sandstone). Table 3 demonstrates the tremendous chemical variability of bentonite spoils. Bentonite spoils offer unique reclamation challenges since they may be generic, acidic, saline-sodic, or acid-saline-sodic.

<u>Sulfide ore deposits</u>

Acid production from sulfide ore deposits has occurred throughout the western United States. In Wyoming, a large portion of the sulfide ores are associated with copper-iron-zinc mineralization. During 1899-1908, Wyoming was among the leading copper producers in the United States. One of the major sulfide minerals occurring in Wyoming copper deposits is chalcopyrite. The oxidation reaction of chalcopyrite is given by the following equation:

$$4CuFeS_2 + 17O_2 + 10H_2O \rightleftharpoons 8SO_4^{2-} + 4Cu^{2+} + 8H^+ + 4Fe(OH)_3 \qquad (3)$$

Chalcopyrite oxidation has contributed to acid production at several abandoned mine land sites in Wyoming. The results of chalcopyrite oxidation are typified by low pH and high concentrations of water soluble copper and sulfate-sulfur as demonstrated by Table 4.

Table 3

Range of Chemical Properties
Abandoned Bentonite Spoils
AML Project 11-2
Crook County, Wyoming

Site ID	pH	ABP	SAR	ESP
65A SP3	3.7-5.2	-10 to -1	10.4-22.1	6.84-12.7
65B SP2	3.9-6.7	-10 to +9	10.9-23.9	7.98-18.4
66A SP1	6.3-7.8	-17 to -3	16.1-24.3	13.5-24.1
61E SP1	5.7-8.3	-3 to +3	22.3-28.9	20.7-47.2

Table 4

Laboratory Analysis of Spoil Material
AML Site 4-2

Sample ID	pH	Al*	Cu*	SO_4*
1 @ surface	3.6	840	6330	18,300
1 @ 12"	3.7	4.6	86.0	430
1 @ 24"	4.3	0.2	17.2	76
2 @ 12"	4.1	0.4	17.1	263
2 @ 24"	3.6	6.0	25.1	714

* mg/l in saturation extract

Site Characterization

Proper site characterization is essential regardless of whether acid production occurs with coal, uranium, bentonite, or various sulfide ore deposits. If adequate site characterization is disregarded or conducted sporadically the results are often costly reclamation failures. Proper site characterization is essential if reclamation is to be a long term success.

Pre-mining

Overburden characterization prior to mining is best accomplished through a two phase drilling program (Dollhopf et al., 1981; WDEQ, 1984). The initial sampling program (Phase I) should include a drill hole intensity of 4-8 holes per 640 acres. The exact intensity will depend on the variability of the overburden material. Holes should be relatively evenly spaced with at least two holes cored. Each lithologic unit should be analyzed with composite sampling of the same lithology not to exceed 10 feet with cores or 5 foot interval with chip samples. Phase II sampling is a progressive sampling scheme and consists of utilizing developmental and exploratory drilling to further delineate unsuitable zones discovered during Phase I.

The ability to characterize unsuitable overburden with drill holes 600 to 1500 meters apart has an accuracy of only 45-60% (Dollhopf et al., 1981). The low probability of accurately identifying all unsuitable material based on a drill hole intensity of 4 holes per section may result in toxic and/or acid materials being unknowingly placed either in future groundwater zones or within the surface four feet (root zone). To obtain an accuracy of approximately 90% would require a drilling intensity of approximately 100-200 foot centers. Sampling the overburden in a two phase program provides a compromise between accuracy and increased cost.

Once acid or potentially acidic zones have been identified and mapped, they can be handled or treated to prevent surface acidification and groundwater degradation.

Abandoned Mine Lands

Site characterization of abandoned mine lands differs significantly from a pre-mining program. Abandoned mine land sites can be extremely heterogeneous making adequate characterization a difficult task. Reclamation efforts which include massive grading as the first project task should be avoided or delayed until a thorough classification of spoil type can be obtained. Massive regrading may expose material with more potential acidity than the surface weathered mantle.

The first step in conducting a pre-reclamation site characterization should always include a determination of the intended post-reclamation land use. The second step involves identifying the existing vegetation and correlating the vegetation with the spoil chemical properties. The third step involves a detailed spoil sampling program which adequately characterizes both the physical and chemical properties of the exposed spoil and topsoil if present. The physical analysis should at least include a particle size analysis. The chemical properties warrant a detailed investigation including: a measure of all forms of acidity (solution, exchangeable, and potential), electrical conductivity, trace metals (Fe, Al, Mn, Cu, etc.), macro and micro nutrients, SAR-ESP relationships and any other analyses required on a site specific basis (As, Mo, and Se for uranium). From the information obtained in the first three steps a spoil chemical map can be constructed for the site. This will allow for specific regrading patterns to salvage available topsoil, avoid existing vegetation, preserve weathered non-acid spoil, and reduce the chances of exposing large quantities of potentially acidic material. By capitalizing on existing vegetation and previously weathered spoil materials, preservation and enhancement rather than grading and covering can be the basis for cost-effective reclamation of problem spoils.

Once regrading has been completed all regraded areas should be sampled through a regrading spoil sampling program. This sampling should be on 100-200 foot centers to a depth of 4 feet with samples taken from 0-12", 12-24", and 24-48". The samples should be analyzed for those parameters shown to be unsuitable during the initial spoil characterization program. The final steps involve amendments or burial of extremely acid materials.

Measuring Acidity

Three approaches are frequently used in measuring the acidity for determining lime requirements of acid mine spoils: 1) measurement of the spoil pH in a saturated paste or salt solution; 2) measurement of the pH of a buffer-spoil system; and 3) determination of the total potential acidity.

Thomas (1967) noted that three pH ranges are informative: a pH less than 4 indicates the presence of free acids generally from oxidation of sulfides; a pH of less than 5.5 suggests the likely occurrence of exchangeable aluminum; and a pH from 7.8 to 8.2 indicates the presence of calcium carbonate. Lime requirements based on pH values will result in reclamation failures if the spoil material contains unreacted sulfides.

Lime requirements based on buffer methods have been extensively reviewed (McLean, 1982; Adams, 1984). These methods are better for estimating current liming requirements since a buffer method measures both solution and exchangeable acidity (Barnhisel et al., 1982). However, lime requirements based on buffer methods are also subject to error and reclamation failures may result if unreactive sulfides are present.

An excellent assessment of the methodologies for iron sulfide determinations in coal mine spoils has been published (Dacey and Colbourn, 1979). A number of problems exist if lime requirements are based on pyrite determinations utilizing a nitric acid digestion procedure (Boon and Smith, 1985). First, the hydrochloric acid predigestion step can remove iron sulfates which hydrolyze water and produce additional acidity (Caruccio et al., 1981). In addition, hydrochloric acid removes acid volatile sulfides. Finally, pyritic sulfur determinations based on nitric digests will underestimate the total potential acidity of spoil material if other chalcophilic minerals are present.

The traditional method utilized for predicting the maximum acid potential in geological materials is defined as acid-base accounting (Smith et al., 1974). Two alternative procedures are outlined for determining the acid potential: a wet chemistry method (peroxide oxidation) and a high temperature induction furnace method. A recent modification of the peroxide oxidation procedure has resulted in increased reproducibility (O'Shay, 1982). However, problems associated with the peroxide method has resulted in the recommendation of the furnace procedure (WDEQ, 1984). The acid potential determined from the furnace method is balanced against any neutralization potential and the result is expressed in tons of calcium carbonate per thousand tons of material. This value is commonly called the acid-base potential (ABP). Although this method measures the maximum potential acidity it neglects to include acidity from solution and exchangeable sources. All forms of acidity (solution, exchangeable and potential) must be accurately measured and summed for predicting the total lime requirement of acid mine spoils.

HANDLING ACID MATERIALS

The most commonly utilized methods for mitigating acid materials include neutralization reactions (liming) and selective placement to eliminate surface acidification and groundwater contamination.

Liming

The purpose of liming is to raise the pH to an acceptable level. Field liming reaction rates vary with pH, lime particle size, and solubility of the liming agent. As mentioned earlier, if lime requirements are based on pH measurements or buffer systems the total lime requirement will be underestimated if unreactive sulfides are present. To maintain adequate pH values over an extended time period Akin (1966) and Ebelhar (1977) recommend that the lime requirement based on buffer solutions or potential acidity be doubled. Sorenson et al. (1980) recommended that the total lime requirement consists of the summation from all forms of acidity (solution, exchangeable, and potential).

Lime requirements are difficult to make for spoils that contain carbonates. The problem is due to the uncertainty of the particle size distribution of the natural carbonates. Native carbonates usually occur as large particles which are inefficient in neutralizing acidity generated by the oxidation of sulfides (Barnhisel, et al., 1982). Large lime particles can become coated with iron oxides during the neutralization reaction. Carbonates coated with iron oxides will be effectively eliminated from neutralizing any acid which is produced in the replaced spoil (Caruccio and Geidel, 1981). Carbonates are often occluded within a shell of geothite in the oxidized zone in lignite overburden from Texas (Dixon et al., 1982). Carbonates coated with iron oxides have been reported for sandstone spoils in Kentucky (Barnhisel et al., 1982) and Wyoming coal and uranium overburden and spoils (Boon and Smith, 1985).

The adequate mixing of lime is a serious limitation in reclaiming acid mine spoils. Under the most optimum conditions depths of only 15 to 20 cm may be obtained (Barnhisel et al., 1982). Mitigation of acid spoils with lime may only be a temporary solution since most plants require rooting depths of more than 15 to 20 cm and upward acidification may occur. Two alternative solutions for liming acid spoils when cover material is not available include liming the acid materials in lifts or application of high liming rates into cable trenches for the establishment of trees.

The Montana Abandoned Mine Land program has recently utilized a layering or sandwich approach to liming acid materials when insufficient cover material is available (Hagener, 1985). A layer of approximately 1 foot of acid material is overlaid by an adequate amount of lime to neutralize the underlying material. The lime is then incorporated into the acid material. Additional layers of acid material and lime are added with subsequent mixing until an adequate root zone is established.

The adequate liming of extremely acid material can be very difficult if not impossible to achieve. One approach to deep (>25") lime amendment utilizes a tractor-drawn cable trencher to prepare a 3-5" wide furrow without major disturbance of spoil profile. Lime is directly applied into the criss-cross cable trench pattern. This technique can provide deep rooting sites which support tree seedling survival at an 80% level compared to an adjacent untrenched site which suffered over 70% mortality (Nawrot and Yaich, 1984).

In areas of high precipitation, the applied lime may be leached from the surface horizon. Geidel (1979) has shown that infiltrating soil water quickly becomes saturated with respect to lime whereas the soil water system is continually undersaturated with respect to sulfides. In a replaced spoil situation it is quite possible to effectively leach all the lime from the surface materials and leave behind significant amounts of sulfides in an oxidizing environment. In the long term, this process could produce significant pH drops in the surface materials and create an unsuitable reclaimed surface. This process would be significantly reduced in the arid west but may be a major factor in higher precipitation areas common to many of the high altitude situations.

Selective Placement

The most common method of selective placement involves burial of acid materials above the post-reclamation water table and below the surface four feet. Four feet of non-acid spoil is recommended over acidic or potentially acidic spoil due to the upward movement of acid from the spoil. Barth and Martin (1984) demonstrated that acidification of topsoil placed over acid mine spoils can occur in arid portions of the western United States. Five years after plot construction acidification extended a maximum of 10 cm into the overlying soil and pH values had decreased up to 1.8 units. A soil depth of approximately 100 cm was necessary over acid spoils to achieve a grass production comparable to undisturbed rangelands.

If four feet of cover material is not available a combination of liming and cover can be utilized to produce an adequate root zone. When soil covering is necessary in combination with liming it is imperative that adequate neutralization of subsurface spoil is achieved to prevent upward acidification into the cover material.

A second alternative to selective placement may involve pneumatic transport of acid mine waste within dry abandoned underground mine workings. This technique has been utilized for disposal of large quantities of acid materials when no other alternatives were available (Hagener, 1985).

The burial of acid producing materials within a saturated zone should theoretically produce a pH of 6-8 for the saturated material (Ponnamperuma, 1972). Perhaps the best example of reclamation of acid mine spoils by saturation involves the Mandy Mine tailings (Hamilton and Fraser, 1978). Thirty two years after burial under a shallow lake the highly pyritic tailings (15.4%) remained unoxidized and the outlet water pH was 7.7. The ore material consisted of 20% copper as chalcopyrite. The outlet water contained only 0.02 mg/l copper and 21.7 mg/l sulfate demonstrating no acidification. Another example involves the burial of acid uranium mill tailings in the Elliot Lake District of Ontario (Cherry et al., 1980). The upper unsaturated zone was extremely acidic (pH 1-3) while the saturated zone exhibited pH values above 6. Nawrot and Yaich (1982) found that saturated acid coal mine slurry material in southern Illinois prevented pyrite oxidation.

The burial of acid materials within a saturated zone is a risky undertaking if a detailed hydrogeological understanding of the site is not known. If oxygen contacts the submerged material either through decreased water levels or air being purged through unsaturated spoil pore spaces, acid mine drainage or acid seeps may result.

Pyrites have been tested for several agricultural purposes in the past, mainly as an acidifier to improve soil structure of sodic soils (Smith, 1930; McGeorge and

Breazeale, 1955; Vlek and Lindsay, 1978). In addition, pyrite mine tailings have been used as a source of iron in calcareous, iron-deficient soils (Banath, 1969; Fuller and Lanspa, 1975; Banath and Holland, 1976; Barrau and Berg, 1977; Vlek and Lindsay, 1977). These are very site specific methods and require the close proximity of acid mine tailings and sodic or iron deficient soils.

SUMMARY

Acid material and potentially acidic materials have been identified with most segments of the mining industry. These segments include coal, bentonite, uranium, and various sulfide ore mines. Although acid production is most commonly associated with pyrite, a variety of other chalcophilic minerals (galena, sphalerite, arsenopyrite, and chalcopyrite) can produce acidity upon oxidation.

Adequate site characterization is essential if reclamation is to be a long term success. Overburden characterization prior to mining is best accomplished through a two phase drilling program. The initial sampling program (Phase I) should include a drill hole intensity of 4-8 holes per 640 acres. Phase II sampling is a progressive sampling scheme and consists of utilizing developmental and exploratory drilling to further delineate unsuitable zones discovered during Phase I. Once acid or potentially acidic zones have been identified and mapped, they can be handled or treated to prevent surface acidification and groundwater degradation.

Abandoned mine land sites can be extremely heterogeneous making adequate characterization a difficult task. Reclamation efforts which include massive regrading as the first project task should be avoided or delayed until a thorough classification of spoil type can be obtained. Massive regrading may expose material with more potential acidity than the surface weathered mantle. Proper site characterization of abandoned mine lands involves development of vegetation, topsoil and spoil chemical maps of the site. This will allow for specific regrading patterns to salvage available topsoil, avoid existing vegetation, preserve weathered non-acid spoil, and reduce the chances of exposing large quantities of potentially acidic materials. By capitalizing on existing vegetation and previously weathered spoil materials preservation and enhancement rather than grading and covering can be the basis for cost-effective reclamation of problem spoils.

Three approaches are used for determining the lime requirement of acid mine spoil. These include measuring the spoil pH, measuring the pH of a buffer-spoil system, and measuring the total potential acidity. All forms of acidity (solution, exchangeable, and potential) must be accurately measured and summed for predicting the total lime requirement of acid mine spoils.

The most commonly utilized methods for mitigating acid materials include liming and selective placement. Neutralizing acidity through liming may only be a temporary solution due to difficulties of adequate incorporation, coating of carbonates with iron oxides, leaching of carbonates from the surface horizon or inadequate predictions of the lime requirement. The preferable method for selective placement involves burial of acid materials above the post-reclamation water table and below the surface four feet. However, acid materials have been adequately reclaimed by flooding in a number of wetland areas. The burial of acid materials within a saturated zone is a risky undertaking and requires detailed hydrogeological understanding of the site.

With proper pre-reclamation planning and adequate site characterization even the most acidic of sites can be reclaimed and returned to a productive land use.

REFERENCES

Adams, F. (ed). 1984. Soil acidity and liming. ASA Monograph No. 12., Madison, WI.

Akin, G. W. 1966. Evaluation of chemical changes and forage responses as a result of lime and phosphorus treatments on orphan surface-mined coal spoils. Unpublished M.S. Thesis, Univ. of Kentucky, Lexington. 177 pp.

Arora, H. S., C. E. Pugh, L. R. Hossner, and J. B. Dixon. 1980. Forms of sulfur in east Texas lignite coal. J. Environ. Qual. 9:383-386.

Banath, C. L. 1979. Iron pyrite as a sulfur fertilizer. Aust. J. Agric. Res. 20(4):697-708.

Banath, C. L., and J. F. Holland. 1976. Iron pyrites as a sulphur fertilizer in an alkaline soil. Aust. J. Exp. Agric. Amin. Husb. 16:376-381.

Barnhisel, R. I., J. L. Powell, G. W. Akin, and M. W. Ebelhar. 1982. Characteristics and reclamation of "acid sulfate" mine spoils. pp.225-234. In Acid Sulfate Weathering. SSSA Special Publication NO. 10. Madison, WI.

Barrau, E. M., and W. A. Berg. 1977. Pyrite and mill tailings as a source of iron in a calcareous Fe-deficient soil. Soil Sci. Soc. Am. J. 41:385-388.

Barth, R. C. and B. K. Martin. 1984. Soil depth requirements for revegetation of surface-mined areas in Wyoming, Montana, and North Dakota. J. Environ. Qual. 13:399-404.

Berner, R. A. 1984. Sedimentary pyrite formation: An update. Geochemica et Cosmochimica Acta 48:605-615.

Boon, D. Y. and P. J. Smith. 1985. Carbonaceous materials: Problems associated with reclamation. pp 248-256. Proceedings of the second annual meetings of the American Society for Mining and Reclamation. Denver, CO.

Caruccio, F. T., G. Geidel, and M. Pelletier. 1981. Occurrence and prediction of acid drainages. Proceedings of the American Society of Civil Engineers, 107:167-178.

Caruccio, F. T., and G. Geidel. 1981. Estimating the minimum acid load that can be expected from a coal strip mine. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. Lexington, KY. pp. 117-122.

Cherry, J. A., R. J. Blackport, N. Dubrovsky, R. W. Gillham, T. P. Lim, D. Murray, E. J. Reardon, and D. J. A. Smith. 1980. Subsurface hydrology and geochemical evolution of inactive pyritic tailings in the Elliot Lake Uranium District, Canada. Symp. on Uranium Mill Tailings Management. Fort Collins, CO. 11:353-385.

Dacey, P. W. and P. Colbourn. 1979. An assessment of methods for the determination of iron pyrites in coal mine spoils. Reclamation Review 2:113-121.

Davis, J. C. 1965. Bentonite deposits of the Clay Spur district, Crook and Weston Counties, Wyoming. Geological Survey of Wyo. Prelim. Rep. 4. Laramie, WY.

Dixon, J. B., L. R. Hassner, A. L. Senyaki, and K. Egashira. 1982. Mineralogical properties of lignite overburden as they relate to mine spoil reclamation. pp. 160-191. In: Acid Sulfate Weathering, SSSA Publ. No. 10. Madison, WI.

Dollhopf, D. J., J. D. Goering, C. J. Levine, B. J. Bauman, D. W. Hedberg, and R. L. Hodder. 1981. Selective placement of strip mine overburden in Montana. V summary report. Reclamation Research Unit. Montana Agricultural Experiment Station. Bozeman, Montana. 195 pp.

Dreher, G. B., R. B. Finkelman and E. I. Sandvik. 1985. Factors affecting groundwater quality in the Caballo mine backfill: Status report. Exxon Production and Research Company, Houston, TX. 66 pp.

Ebelhar, M. W. 1977. The response of common bermudagrass to nitrogen, lime, potassium and phosphorus treatments and their effects on the chemistry of acid surface-mined coal spoils in western Kentucky. Unpublished M.S. thesis, Univ. of Kentucky, Lexington. 178 pp.

Finkelman, R. B. 1981. Mode of occurrence of trace elements in coal. U.S. Geological Survey. Open-file report. 81-99.

Fisher, S. E. and F. F. Munshower. 1984. Extremely acid soils, overburden and minerals in the Great Plains. pp.186-200. Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains. Billings, MT. March, 1984.

Fuller, W. H., and K. Lanspa. 1975. Uptake of iron and copper by sorghum from mine tailings. J. Environ. Qual. 4:417-422.

Geidel, G. 1979. Alkaline and acid production potentials of overburden material: The rate of release. Reclamation Review 2:101-107.

Goldhaber, M. B. and R. L. Reynolds. 1979. Origin of marcasite and its implications regarding the genesis of roll-front uranium deposits. U.S. Geol. Survey Open-File Report. 79-1696, 38 pp.

Hagener, J. 1985. Utilization of mine dump materials. Presented at the Abandoned Mine Land Technology and Design Reclamation Workshop, Casper, Wyoming, May 8-10, 1985.

Harshman, E. N. 1974. Distribution of elements in some roll-type uranium deposits. IAEA Proceedings. IAEA - SM - 183/4, Vienna, Austria.

Hamilton, R. and W. W. Fraser. 1978. A case history of natural underwater revegetation: Mandy mine high sulfide tailings. Reclamation Review 1861-65.

Hinkley, T. K., R. J. Ebans, and J. G. Boerngen. 1978. Overburden chemistry and mineralogy at Hanging Woman Creek, Big Horn County, Montana, and recommendations for sampling at similar sites. U.S. Geological Survey. Open-file report 78-11-5, pp. 150-168.

McGeorge, W. T., and E. L. Breazeale. 1955. The value of pyrite and pyrhotite as soil conditioner. Rep. 124, Agric. Exp. Stn., College of Agric., Univ. of Arizona, Tucson.

McLean, E. O. 1982. Soil pH and lime requirement. pp 199-223. In: A. L. Page (ed) Methods of Soil Analysis, Part 2., ASA Monograph No. 9, Madison, WI.

Nawrot, J. R. and S. C. Yaich. 1982. Wetland development potential of coal mine tailings basins. Third annual meetings of the Society of Wetland Scientists. Wetlands 2:179-190.

Nawrot, J. R. and S. C. Yaich. 1984. The role of weathering and aging in acid spoils reclamation. Proceedings of the Conference on Reclamation of Abandoned Acid Spoils. Osage Beach, MO.

O'Shay, T. A. 1982. The determination of potential acidity in overburden sediments. M.S. Thesis, Texas A & M, College Station, Texas. 111 p.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Reynolds, R. L. and M. B. Goldhaber. 1982. Iron disulfide minerals and the genesis of roll-type uranium deposits. Economic Geology 78:105-120.

Smith, H. V. 1930. The effect on plant growth of treating soils with copper-bearing pyrite. Agron. J. 22:903-915.

Smith, J. A. 1984. Wood residue and fertilizer amendments for reclamation of orphan bentonite mine spoils. M.S. Thesis, University of Wyoming, Laramie, WY.

Smith, R. M., W. E. Grube, T. Arkle, and A. Sobek. 1974. Mine spoil potentials for soil and water quality. Env. Prot. Agency-670/2-74-070. Cincinnati, OH.

Sorenson, D. L., W. A. Kneib, D. B. Porcella, and B. Z. Richardson. 1980. Determining the lime requirement for the Blackbird Mine spoil. J. Environ. Qual. 9:162-166.

Thomas, G. W. 1967. Problems encountered in soil testing methods. pp. 37-54. In: Soil Testing and Plant Analysis, Part 1, Soil Sci. Soc. Am. Spec. Pub. No. 2, Madison, WI.

Valkovic, F. 1983. Trace elements in coal. CRC Press Inc., Boca Raton, Florida. p. 210.

Vlek, P. L. G. and W. L. Lindsay. 1978. Potential use of finely disintegrated iron pyrite in sodic and iron-deficient soils. J. Environ. Qual. 7:111-114.

Wyoming Department of Environmental Quality - Land Quality Division. 1984. Guideline No. 1 - Topsoil and Overburden. Cheyenne, WY.

REVEGETATION SUCCESS AT EXXON'S COLONY SHALE OIL PROJECT

Warren R. Keammerer
Stoecker-Keammerer & Associates
Boulder, Colorado

D. Michael Barker
Exxon Company, USA
Grand Junction, Colorado

Ben Northcutt
Mountain West Environments, Inc.
Steamboat Springs, Colorado

INTRODUCTION

The Colony Shale Oil Project site is located in the Piceance Basin in northwestern Colorado. It is approximately 45 miles northeast of Grand Junction and approximately 12 miles north of the town of Parachute. The Colony site varies in elevation from approximately 5800 to 8400 feet. Mean annual precipitation is 12-14 inches, which occurs mostly in the form of snowfall.

Since 1981, Exxon has been engaged in reclamation and stabilization of approximatley 1100 acres of disturbed land at the Colony site. This work is being conducted in accordance with the terms of Colony's permit with the Colorado Mined Land Reclamation Division (MLRD). The permit requires reclamation of areas in which construction and mining activities are complete, in order to return these lands to their approved post-mining use. In other disturbed areas which remain active, the permit requires stabilization by various means to protect the environment while the mining or development activity is in progress. The reclamation and stabilization program makes extensive use of revegetation to satisfy the requirements of the MLRD permit.

Most of the disturbed areas were seeded in the Fall of 1982 and Spring of 1983. In July 1983, the High Altitude Summer Tour visited the Colony site. At that time, most of the reclaimed and stabilized areas were in their first growing season. The purpose of this paper is to present the results of revegetation evaluation studies that have been conducted on the site during the 1984 and 1985 growing seasons.

RECLAMATION TECHNIQUES

The reclamation designs for the disturbed areas on the Colony Site consist of several different programs: 1) establishment of grasses and forbs, 2) establishment of shrubs and 3) establishment of rare plant species.

Establishment of Grasses and Forbs. Most of the disturbed areas have been reclaimed using relatively standard techniques. Drill seeding was used on all areas where the topography was not too severe. Steep slopes were hydroseeded or broadcast seeded by hand or using a helicopter. When possible, areas were seeded in the Fall, but Spring seedings have also been used when it was not possible to complete the work in the Fall. All areas were fertilized at the time of seeding with 400 lbs/acre of 18-46-0 fertilizer. The areas were fertilized at the beginning of the first and second growing seasons using 300 lbs/acre of 34-0-0 fertilizer. These applications were broadcast using either a tractor or a helicopter. After seeding, most reclaimed areas were mulched with a hay mulch at a rate of 4000 lbs/acre. On areas seeded in 1985, hay from certified seed fields was used in an attempt to reduce establishment of undesirable grasses or weeds which may be present in the mulch. Many steep slopes were hydromulched with 2000 lbs/acre of wood fiber mulch. Most areas have been seeded with a seed mix consisting of native and introduced grasses. The primary mix consists of streambank wheatgrass, western wheatgrass, mountain brome, pubescent wheatgrass, green needlegrass, Great Basin wildrye, cicer milkvetch, tufted hairgrass, and big bluegrass. On some areas Indian ricegrass has been included. The mix also includes winterfat, however, direct seeding of shrubs has not been successful on the reclaimed sites. Seeding rates have been between 15 and 20 pounds of pure live seed per acre. Hyroseeding and broadcasting rates have been 2-3 times greater than the drill seeding rates.

Shrub Establishment. Re-establishment of shrubs on reclaimed areas has been approached in four ways: 1) inclusion of seed with grass seed mix, 2) broadcast seeding along with forb seeds prior to seeding grasses, 3) seeding in small cleared gardens, and 4) planting tubeling stock derived from seed collected on site.

Inclusion with Grass Seed Mix. With this approach shrub seeds are planted at the same time as the grass seed. Winterfat, big sagebrush, and antelope bitterbrush have been seeded in this manner.

Broadcast Seeding Prior to Seeding Grasses. This approach was tried at the beginning of the 1985 growing season in attempt to give the shrubs a head start for establishment prior to seeding the perennial grasses. The shrubs were broadcast seeded in the Spring; the grasses were hand broadcast seeded in the Fall.

Seeding in Cleared Gardens. This approach has been used on approximately 60 acres of reclaimed areas. With this approach, small areas (4 feet by 4 feet) are cleared using a combination of herbicide (Round-up) and physical tilling with a hoedad. Once the area has been cleared and tilled, small amounts of shrub seed are spread on the surface and then covered with soil. Each "garden" is planted with only one species. Seven species have been planted in this manner: antelope bitterbrush, mountain mahogany, Gambel's oak, mountain snowberry, serviceberry, wood's rose, and rubber rabbitbrush. Approximately 8000-10,000 gardens were planted in this manner in the Fall of 1984. The planting was done by Mountain West

Environments, Inc. of Steamboat Springs.

Planting Tubeling Stock. This approach has been used on approximately 60 acres of reclaimed areas. Seeds of shrub species were collected from the Colony site by NPI, Inc. in the late Summer and Fall of 1984, and were taken to Salt Lake City where they were planted, innoculated with vescicular-arbuscular mycorrhizae and allowed to develop. These tubelings were then planted on site in October, 1985. No evaluations of these plantings have been conducted yet, however, the success of this approach will be evaluated over the next several growing seasons.

Planting Rare Species. Two rare plant species occur on the Colony Project site : sedge fescue (*Festuca dasyclada*) and Barneby columbine (*Aquilegia barnebyi*). Populations of these species were disturbed as part of the construction activities at Colony. In order to mitigate these losses, these rare species have been planted in suitable habitats on reclaimed sites. The materials for use in this planting program were propagated by the Environmental Plant Center in Meeker from seeds collected from various places in the Piceance Basin including the Colony Site. In 1985, 600 plants of Barneby columbine were planted around seeps and waterfalls, and 1500 individuals of sedge fescue were planted on rocky slopes and other exposed reclaimed sites. The success of this planting program will be evaluated during the 1986 growing season.

EVALUATION PROGRAM

Beginning in 1984 a revegetation evaluation program was initiated on the Colony site. The program consisted of obtaining cover and production data from selected reclaimed areas as well as obtaining comparable data from the native vegetation types that characterize the site. In all, 18 reclaimed areas or combinations of areas and 4 native vegetation types were sampled in 1984 and 1985. Cover data were collected using a quadrat method in which cover was visually estimated. Production data were collected using a harvest method. All grasses, forbs, and low-growing shrubs were clipped. Larger shrubs and trees were not clipped.

RESULTS AND DISCUSSION

Establishment of Grasses and Forbs. After three growing seasons, all of the reclaimed areas that were drill seeded or hydroseeded have equalled or exceeded production of native vegetation types (Table 1). It should be emphasized that the production values for the mixed mountain shrublands and aspen woodlands do not include values for trees or large shrubs. If these values were available, the biomass production in the mixed mountain shrublands would be greater than the values for the big sagebrush shrublands, and the aspen woodlands would have the highest production values of all types. Production in native vegetation types ranged from 64-208 grams per square meter in 1984 and from 82-209 grams per square meter in 1985. Production in reclaimed areas ranged from 110-360 grams per square meter in 1984 and from 138-407 grams per square meter in 1985.

Table 1. Mean total vegetation cover, mean total production, mean number of species per square meter and total number of species observed for native vegetation types and reclaimed areas on the Colony Project site. 1984 and 1985 data.

Areas	Total Vegetation Cover (%)		Total Production (g/sq. m)		Mean No. Of Species/sq. m		Total Number of Observed Species
	1984	1985	1984	1985	1984	1985	
Native Vegetation Types							
Big Sagebrush Shrublands	40	33	208	176	10.8	12.0	94
Mixed Mountain Shrublands	52	42	183	209	14.6	12.0	83
Indian Ricegrass Communities	14	10	80	82	8.6	9.4	55
Aspen Woodlands	21	28	64	87	12.2	14.0	59
Reclaimed Roadsides							
Area 3	26	18	175	238	8.2	6.6	61
Area 19A	23	23	110	163	6.8	5.3	45
Area 11	24	25	124	270	8.5	8.0	44
Area 13	34	17	227	138	8.1	7.4	37
Area 19D	25	29	144	140	8.7	7.0	40
Areas 11, 13, 19D Combined	28	24	167	181	8.4	7.6	64
Area 8	-	8	-	-	-	5.8	41
Reclaimed Roads							
Area 8A	35	24	278	184	9.9	9.4	50
Conveyor and Pipeline Routes							
Area 16B	34	23	208	140	8.8	9.1	66
Area 17B	48	22	234	233	11.7	9.8	54
Area 17C	40	24	335	150	13.0	10.1	58
Area 18B	45	38	360	407	10.3	8.0	44
Area 17B, 17C, 18D Combined	44	27	312	252	11.8	9.4	84
Topsoil Stockpiles							
Area 12	34	26	219	291	7.9	9.6	60
Area 14	40	31	226	223	10.8	8.8	55
Other Areas							
Area 5	31	15	300	193	8.3	6.6	59
Helicopter Seeded Slope	8	-	31	-	5.8	-	34
Base of Davis Gulch Falls	13	14	-	-	7.6	8.1	61

The high production values in the reclaimed areas may well be related to the amounts of fertilizer that have been applied. Current plans call for no more fertilizer to be applied to the reclaimed areas. With no additional fertilizer, it is likely that total production will stabilize at a lower level.

The results from the cover studies (Table 1) parallel those obtained with the production studies. Cover values for the native vegetation types tend to be somewhat higher than the cover values for reclaimed areas. Total vegetation cover in native areas ranged from 14-52 percent in 1984 and from 10-42 percent in 1985. On reclaimed areas, cover values ranged from 23-48 percent in 1984 and from 15-38 percent in 1985. The higher values in the native vegetation types relate to the more complex structure associated with these communities. The reclaimed areas tend to have only a single stratum of plants (herb layer). The native shrublands on the other hand have several strata within each type. In addition to the herb layer, the shrublands have a low shrub layer as well as a tall shrub layer. This greater complexity of vegetation structure increases the amount of overlap of plants and also increases the total amount of coverage by plants.

Species diversity on the reclaimed areas tends to be somewhat less than that for the native vegetation types (Table 1). For the native vegetation types the total number of observed species ranged from 55-94 species. For reclaimed areas the number of observed species ranged from 37-84 species. For native types the mean number of species per square meter ranged from 8.6-14.6 in 1984 and from 9.4-14.0 in 1985. On reclaimed areas these values ranged from 6.8-13.0 in 1984 and from 5.3-10.1 in 1985. In general, the reclaimed areas have fewer total species and fewer species per square meter than the native area do. The species composition is also different. Native vegetation types tend to have a greater number of native perennial forbs than the reclaimed areas. Conversely, the reclaimed areas tend to have more annual forb and introduced perennial forbs than the native areas. Also, because of the nature of the seed mixes and mulches, the reclaimed areas tend to have more introduced grass species than the native vegetation types.

The major differences between the native vegetation types and the reclaimed areas occur in the way in which cover and production are distributed among the various life form groups. In the native vegetation types, introduced perennial grasses account for only a small percentage of the total cover (Table 2). On reclaimed areas, introduced perennial grasses account for more than 70 percent of the total cover. Also the cover attributable to all grasses is much higher on the reclaimed areas. It is interesting to note that on 63 percent of the reclaimed areas the leading dominant species came from seed present in the mulch rather than from the seed mix. The most successful of the mulch species was timothy which occurred as the dominant on eight of the reclaimed areas. Other successful mulch species included orchard grass and smooth brome.

In the native big sagebrush and mixed mountain shrublands, most

Table 2. Percent of total cover attributable to cool season native perennial grasses and introduced perennial grasses in native vegetation types and reclaimed areas on the Colony Project site. 1984 and 1985 data.

	Percent of Total Cover Attributable to Native Perennial Grasses		Percent of Total Cover Attributable to Introduced Perennial Grasses	
	1984	1985	1984	1985
<u>Native Vegetation Types</u>				
Big Sagebrush Shrublands	9.6	14.8	5.3	5.5
Mixed Mountain Shrublands	12.7	16.4	2.3	3.7
Indian Ricegrass Communities	43.2	37.5	0.0	0.9
Aspen Woodlands	39.1	29.0	0.8	0.3
<u>Reclaimed Roadsides</u>				
Area 3	28.0	13.5	56.0	78.7
Area 19A	15.9	3.9	73.3	90.9
Area 11	18.5	6.0	69.1	72.3
Area 13	27.1	12.3	67.5	77.7
Area 19D	27.6	14.0	49.8	76.2
Areas 11, 13, 19D Combined	25.0	11.3	62.3	75.0
Area 8	-	44.6	-	45.2
<u>Reclaimed Roads</u>				
Area 8A	28.7	18.9	66.2	66.7
<u>Conveyor and Pipeline Routes</u>				
Area 16B	19.1	11.7	71.7	75.8
Area 17B	12.2	16.4	17.0	75.8
Area 17C	20.4	9.5	62.3	79.0
Area 18B	32.4	12.1	63.6	74.9
Areas 17B, 17C, 18B Combined	21.3	12.3	48.4	67.3
<u>Topsoil Stockpiles</u>				
Area 12	14.0	20.4	33.1	69.6
Area 14	7.9	8.1	69.7	76.4
<u>Other Areas</u>				
Area 5	39.6	16.1	56.7	79.4
Helicopter Seeded Slope	58.4	-	35.2	-
Base of Davis Gulch Falls	56.6	34.5	18.6	55.2

of the total production is attributable to shrub species (Table 3). Grasses account for 20-35 percent of the total production. In the Indian ricegrass communtities and the understory of aspen woodlands grasses are more abundant and account for 45-70 percent of the total production. On reclaimed areas, introduced perennial grasses account for approximately 80 percent of the total production. Most of the remaining production is attributable to native perennial grasses.

These results are consistent with what would be expected in early stage of secondary succession in shrubland vegetation types. It will take a number of years before shrubs become well enough established to assume the dominant roles that they currently play in the native shrubland types. In the interim, the perennial grasses provide adequate cover to protect the soils from eroding and also provide herbaceous biomass for grazing species.

Shrub Establishment. The purpose of the shrub establishment program is to enhance the process of secondary succession and shorten the time required for shrubs to attain dominance on the reclaimed areas. Most of the disturbance that has occurred on the Colony site has been in the big sagebrush shrubland and mixed mountain shrubland vegetation types. To date, the vegetation on the reclaimed areas has reached a stage in which grasses occur as dominants. By planting shrubs in these areas, the length of time required to develop shrublands on these sites will be decreased.

The success of the shrub garden seeding program was evaluated after one growing season. Of the species that were seeded, the best results were obtained with antelope bitterbrush, mountain snowberry, and Gambel's oak. Seedlings of these species were found in approximately 50 percent of the plots in which they were planted. Mean seedling density for these species was 4.3, 6.1 and 1.4 seedlings per plot, respectively. Intermediate success was obtained with woods rose and serviceberry which occurred in approximately 30 percent of the plots in which they were planted. Mountain mahogany occurred in about 20 percent of the plots in which it was planted. The only species that was not observed in any of the planted plots was rubber rabbitbrush. It is possible that the seeds that were planted were no longer viable. Overall, seedlings were observed in approximately 36 percent of the plots that were evaluated, and the mean number of seedlings per plot was 2.3. Based on the number of plots per acre, the mean seedling density translates to approximately 400 shrub seedlings per acre which is within the desired range of density for the reclaimed areas.

One of the problems with the shrub seedling establishment during 1985 was that the reclaimed areas were grazed by cattle. When the plots were planted in the Fall of 1984, approximately 10 percent of the plots were marked with metal stakes. During the 1985 growing season, the cattle used these stakes as rubbing posts and consequently many of the seedlings were trampled.

Seedling establishment was least successful on steep south-facing slopes. Apparently these slopes were too dry and hot

Table 3. Percent of total biomass contributed by cool seasaon perennial grasses (CSPG), introduced perennial grasses (INPG), and shrubs in native vegetation types and on reclaimed areas on the Colony Project site. 1984 and 1985 data.

	Percent of Total Biomass 1984			Percent of Total Biomass 1985		
	CSPG	INPG	Shrubs	CSPG	INPG	Shrubs
Native Vegetation Types						
Big Sagebrush Shrublands	13.6	5.9	68.0	24.5	7.9	55.2
Mixed Mountain Shrublands	20.5	4.7	50.6	24.9	4.6	55.2
Indian Ricegrass Communities	52.9	0.0	1.6	44.8	0.7	9.2
Aspen Woodlands	66.1	0.2	15.7	44.4	0.1	22.7
Reclaimed Roadsides						
Area 3	25.4	67.9	-	7.9	83.8	-
Area 19A	27.3	65.5	-	3.8	91.3	-
Area 11	18.5	75.8	-	6.9	85.9	-
Area 13	28.8	68.4	-	14.8	83.9	-
Area 19D	28.4	59.9	-	23.3	76.7	-
Areas 11, 13, 19D Combined	26.4	67.5	-	13.2	83.1	-
Reclaimed Roads						
Area 8A	31.2	67.5	-	21.5	73.4	-
Conveyor and Pipeline Routes						
Area 16B	15.6	78.7	-	13.4	83.5	-
Area 17B	17.6	37.0	-	21.0	55.7	-
Area 17C	17.6	73.5	-	11.7	84.0	-
Area 18B	20.0	78.2	-	19.0	76.3	-
Areas 17B, 17C, 18D Combined	19.0	66.3	-	17.9	72.8	-
Topsoil Stockpiles						
Area 12	17.4	41.5	-	20.4	77.1	-
Area 14	11.9	80.1	-	11.1	79.8	-
Other Areas						
Area 5	26.2	73.4	-	12.7	85.7	-
Helicopter Seeded Slope	54.6	43.2	-	-	-	-

for the seedlings to survive. Seedling survival was also low on areas with dark, fine textured soils that occurred in full sun. While these soils apparently had excellent nutrient characteristics, the dark color may have caused the temperature to exceed the range of tolerance for the seedlings.

Some of the reclaimed areas show a considerable amount of native shrub invasion. This is especially true on long narrow parcels of reclaimed lands. Numerous big sagebrush seedlings have become established in some of the reclaimed pipeline routes. Gambel's oak and mountain snowberry have also spread into the reclaimed areas, however these appear to have become established as root sprouts rather than as seedlings.

Rare Plant Species. Preliminary results suggest that the planting program for the rare plant species was initially successful. Some of the Barneby's columbine plants were eaten by grazers; possibly insects or small rodents. The sedge fescue transplants, were apparently doing well at least up until the time of snowfall. The success of this program will be evaluated more fully during the 1986 growing season.

SUMMARY

In general, the overall revegetation programs at the Colony Project site have been successful. Almost all of the reclaimed areas have cover and production values that are comparable to the native vegetation types that occur on the site. Species diversity on the reclaimed areas is not as great as in the native areas, and the species composition is somewhat different. The major differences between the reclaimed areas and the native vegetation is that the reclaimed areas have greater percentages of perennial grasses, while the native areas tend to have more shrubs and forbs. The combination of the shrub planting program and native invasion by shrubs will tend to make the reclaimed areas more similar to the native vegetation types as time progresses.

ACKNOWLEDGMENTS

The results presented in this paper represent the work of many individuals. D. Michael Barker has had the responsibility of implementing the reclamation plan for the Colony Site and also coordinating all the reclamation contractors that have worked on the Colony Site. Warren Keammerer has had the responsibility of conducting evaluation studies on the reclaimed areas, and Ben Northcutt has been responsible for much of the revegetation and shrub seeding at the Colony site. In addition to these three people, many others have assisted in planting, mulching, fertilizing and collecting field data over the past four years.

RECONSTRUCTION OF A POND, SPRING AND CREEK SYSTEM FOR FISH AND WILDLIFE ENHANCEMENT

Dale E. Miller
INTER-FLUVE, Inc.
408 N. Bozeman
Bozeman, Montana 59715

ABSTRACT

A large-scale fish and wildlife habitat enhancement program in southwestern Montana was designed and implemented to improve the recreational potential of a riparian environment. The paper addresses the factors involved in the evaluation, design and reconstruction of a complex pond and spring creek system. In particular, the constraints of an existing irrigation system required special considerations in both design and construction. Enhancement involved deepening several ponds, constructing spawning streams to connect these ponds and the complete reconstruction of over 1200 meters of stream channel. The problems encountered, and their eventual solutions, are discussed. The principal goals were to create ideal habitat for rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*), and to improve waterfowl habitat.

INTRODUCTION

Reconstruction of fish and wildlife habitat has long been undertaken by state and federal agencies in an attempt to improve these resources on public lands (U.S.D.C. Bureau of Fisheries, 1935; U.S.D.A. Forest Service, 1936, 1952). Depending on the method of application and the complexity of the system, early results were mixed between success and failure (for example, Hunter, et.al., 1940; Ehlers, 1956). In the past, enhancement methods were derived primarily from a biological perspective, with very little attention given to the physical processes at work within streams. More recently, land managers have worked with teams of specialists who combine their understanding of the many variables affecting the creation and utilization of fish habitat in river systems (Keller, 1976; Tourbier and Westmacott, 1981; Milhous, 1982). With these advances, reclamation has been utilized successfully in mitigation for a variety of developments (for a review, see Wydoski and Duff, 1982). Furthermore, recognition of the economic benefits of enhancement (i.e., improved recreational and aesthetic values) has led to the implementation of certain private-sector developments focused around enhancement (O'Brien, 1985).

In this respect, the Big Spring Creek Project is a private-sector undertaking focused on the recreational benefits of habitat improvement. The enhancement techniques utilized in this case do not rely on placement of discrete habitat improvement structures, but rather, on the application of physical principles to create and maintain fluvial features (c.f. Koonce and Urbani, 1983).

PROJECT SITE

The Big Spring Creek system arises within the 100-year floodplain of a major river in southwestern Montana.* The site is 1.5 kilometers in length. The aquatic system can be divided into three different reaches, which include: 1) a series of small springs that combine to form an inlet stream; 2) a group of four shallow and interconnected ponds; and 3) Big Spring Creek, which flows out of the lowermost pond and eventually discharges into the river. Two irrigation diversions are associated with the Big Spring Creek system. The first, located near the upper end of the Inlet Stream, brings water from another stream to irrigate land north of the project site. Unused water is diverted back into the spring creek system. The second diversion is parallel to Big Spring Creek; water is diverted from the lowermost pond to irrigate land to the south. Refer to Figure 1 for the relative location of these features.

BACKGROUND

The principal goal in reconstructing the Big Spring Creek system was to enhance the fish and wildlife resources, thereby improving the recreational potential of the property. Prior to reconstruction, the system supported limited wildlife populations. Wild geese and other birds utilized the open water during the winter. Moose used the upper portion of the system as winter range, where thick willows undamaged by cattle offered food and cover. The ponds were of limited depth and offered little fish habitat.

Many years of poor grazing practices (i.e., cattle allowed unlimited access throughout the system) had left the stream channel with degraded banks, extreme sedimentation and a lack of fish habitat. In many locations, the stream consisted of shallow, multiple channels. Compounding matters, the springs were used as a source for irrigation water during late May, all of June, July and August, thereby reducing flows during the warm summer months.

One goal for the reconstruction of the pond and spring creek system was to enhance the fishery resource. Another goal for the reconstructed system was to provide a diversity of challenging angling water. The landowners requested that, at a minimum, the enhanced stream be on the order of 8 meters in width to offer sufficient surface area for fly casting. Instream habitat was to be created to facilitate the establishment of a naturally sustaining resident trout population. The ponds were to be reconstructed to provide fish habitat as well as waterfowl habitat. Finally, additional species of vegetation (native to the region) were to be introduced to increase the diversity of riparian habiat.

---

* The landowners have graciously allowed us to use the following information, with the request that the specific location of the project not be identified in order to preserve their privacy -- and the quality of the resource.

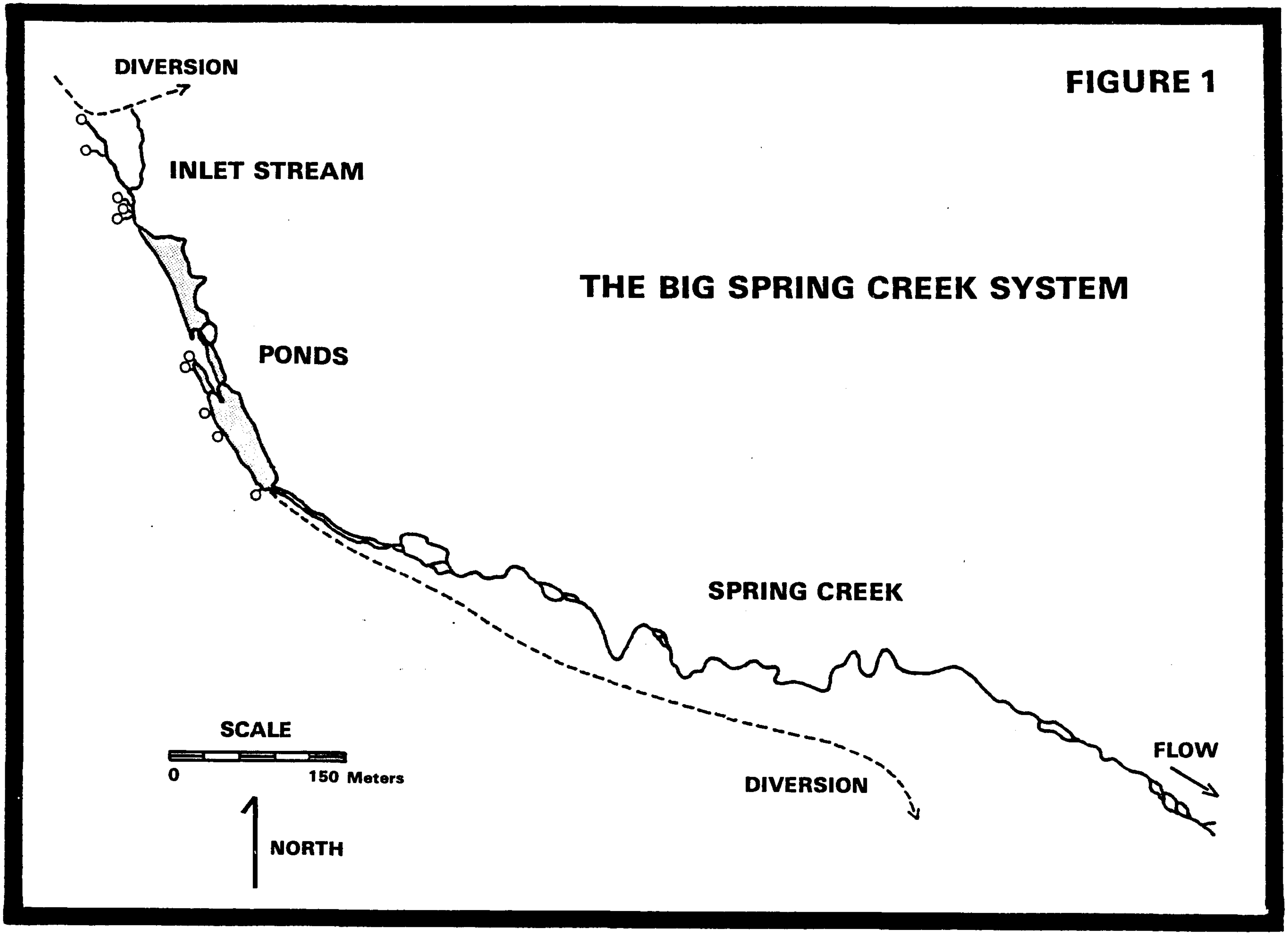


FIGURE 1
THE BIG SPRING CREEK SYSTEM
DIVERSION
INLET STREAM
PONDS
SPRING CREEK
DIVERSION
FLOW
SCALE
0
150 Meters
NORTH

ENHANCEMENT PROGRAM

FEASIBILITY STUDY

A feasibility study was conducted in March of 1985 to evaluate the potentials for enhancement. Water rights, water quality, fish population dynamics, aquatic invertebrate community diversity, hydrology, surface topography and present and future land use were investigated.

Following discussions with the landowner, it was decided that land use would be adjusted; cattle would be grazed on only certain portions of the property and hay production would be reduced somewhat. Therefore, only a limited amount of water would be withdrawn from the spring creek system for irrigation. Sufficient water rights for the property existed so that additional water could be diverted into the system between April 1 and October 1. This additional water was instrumental in the creation of a wider, more fishable stream.

Water quality data indicated no factors which might potentially limit trout production, other than water temperatures slightly colder than ideal for maximum growth rates.

Electrofishing sampling results showed a sizable population of brook trout (*Salvelinus frontinalis*) [1520 per kilometer] and a smaller population of brown (*Salmo trutta*) [432 per kilometer] and rainbow trout (*Salmo gairdneri*) [392 per kilometer]. Few large fish were sampled, whereas numerous fish in the under-15 centimeter size classes were observed. This population structure was reflective of the existing channel conditions, i.e., low to moderate slope; extensive deposits of fine-grained sediment; poor pool development; and a large quantity of instream organic debris. The presence of brown trout (a desirable species for sport fishing) was considered very favorable, since sections of the adjacent river supported very few browns. Enhancement would focus, in part, on providing optimal brown trout habitat.

Evaluation of the macroinvertebrate community indicated a moderately stressed environment, a result of extensive silt deposition in the stream. For example, two midge species and a filter-feeding caddisfly accounted for 51% of the fauna; furthermore, true flies (Dipterans) and caddisflies (Trichoptera) accounted for 84% of the number of bugs and 83% of the total biomass.

Discharge measurements of the spring creek showed low flow during March to be about 0.12 cubic meters per second (4 cubic feet per second). High flow during the summer months, due to aquifer recharge through irrigation return, amounted to about 0.5 cubic meters per second (18 cubic feet per second).

Topographic surveys, in addition to the above information, indicated the feasibility of creating a Stilling Basin at the head of the system, from which a single stream would flow into the uppermost pond. This Stilling Basin would prevent sediment from entering the system proper. The two larger ponds could be deepened, and a spawning stream created between these ponds by filling the two smaller ponds. Finally, it was determined that the total reconstruction of the spring creek system was feasible, despite a number of logistical problems. The major obstacle for construction was the soft, wet ground which prevented heavy equipment access along the entire length of the system. In order to excavate the ponds and stream channel, as well as place gravels and cobbles in the stream, temporary haul roads would need to be constructed. One idea was to use material excavated from the ponds to create access roads, thereby minimizing the amount of fill required.

DESIGN PROCESS

Reconstruction measures were applied to the three distinct reaches of the Big Spring Creek system. To review, these reaches include: 1) the springs and Inlet Stream; 2) the group of four interconnected ponds; and, 3) Big Spring Creek proper. Two diversions are associated with the Big Spring Creek system. The first diversion, located near the uppermost spring of the Inlet Stream, is considered part of the first reach. The second diversion, parallel to Big Spring Creek proper, is considered part of the third reach. Table 1 summarizes the pre-enhancement conditions and post-construction goals for each of these reaches.

Springs and Inlet Stream

Determination of the Stilling Basin location was based on the orientation of the diversion and shape of adjacent topography. A kidney shape was utilized to create a circular flow pattern in the pond, which would encourage sediment deposition. Consequently, specific locations for the Diversion Inlet, the headgates for the Diversion Outlet, and the Inlet Stream were chosen in order to further reduce rates of sediment transport. It was also hoped that excavation of a basin might stimulate spring flow activity, and thereby, increase available flow.

The rough plan of the Inlet Stream was meandered between the Stilling Basin and the existing inlet to the upper pond to simulate natural conditions. A longitudinal profile of the ground surface in the proposed location of the Inlet Stream provided both an indication of the available slope and the difference in elevation between the channel bed and the ground surface. Combined with knowledge of the range in flows expected to be supplimented through irrigation water (up to 2.5 cubic meters per second, or10 cubic feet per second), proper channel morphology could be determined. Elements in the design of the Inlet Stream included: 1) channel elevation; 2) channel length; 3) cross-sectional areas at different discharges; 4) channel stability; and, 5) creation of the proper flow conditions for spawning. Existing vegetation was also incorporated into the design to provide habitat and bank stability.

The Pond System

The two larger ponds offered the most potential for enhancement due to their size and shoreline morphology. Original water levels would be preserved to protect riparian vegetation. Excavation depths would vary between 4 and 6 meters to provide a substantial increase in usable area. Submerged trout habitat would be created with large trees and logs, anchored to boulders with steel cable, and then placed in the pond bottoms as excavation proceeded.

The two smaller ponds would be filled, and a spawning and rearing stream constructed in their place. This stream would follow an old pond margin to utilize exisitng vegetation. The difference in water surface elevation between the two ponds dictated the average grade of the channel. Actual pool and riffle locations were dependent on channel meanders and adjacent topography.

Big Spring Creek

A preliminary longitudinal profile of the stream bed and the corresponding stream bank gave an indication of the existing bed slope and the potential for raising water to an optimal level

TABLE I. Beginning at the upstream end of the project and proceeding downstream, the following is a simplified description of the existing conditions before enhancement and the desired conditions after construction.

Before Conditions	After Conditions
The Inlet Stream	
Partially functional diversion and headgate providing irrigation water to north property and overflow to the Big Spring Creek system.	Improved diversion leads into a 12 meter diameter Stilling Basin (average 2.7 meters in depth). Two adjustable headgates allow separate or simultaneous diversion of water toward the north property or the Inlet Stream.
A series of springs, with a large percentage of water as subsurface flow through peat bog. The final portion consists of a defined stream, though lacking in habitat.	A single channel (from Stilling Basin to upper existing pond, 100 meters in length) providing both increased conveyance of water (for periods of water suppliment) and spawning habitat.
Ponds	
Group of four interconnected ponds--2 larger ponds (0.3 hectares each) and 2 smaller ponds (0.05 hectares each). All shallow (0.5 meter in depth), with water maintained at relatively constant levels by well established beaver dams.	The two larger ponds deepened to 4 meters, the original shorelines and water surface elevations maintianed. The 2 smaller ponds filled and landscaped similar to immediately adjacent landforms. A stream (100 meters in length) connecting the large upper and lower ponds; pools and riffles incorporated to provide spawning habitat for pond-dwelling trout.
Big Spring Creek Proper	
Naturally meandering channel, 1200 meters in length, bordered by willows. Numerous locations where braiding and multiple channels separate flow. Average width, 5 meters. Little variation in water depth, average 0.3 meter with no areas deeper than 0.6 meter. No distinct pool-riffle formations. Almost the entire length of channel covered with fine silt and sand to a depth of as much as 0.5 meter.	Single meandering channel, partially lined by willows. Average width, 9 meters. Pronounced pool-riffle sequences with water depth varying 0.2 to 2.5 meters. Submerged logs and rocks incorporated into the channel provide instream cover. Gravels in riffles and runs provide spawning habitat.

relative to the stream bank. Major breaks in slope were identified so that changes might be made during rough excavation. In order to provide diversity, the average channel grades (which varied from one end of the system to the other) were maintained. The existing spring creek channel was used as a basis for the new, enlarged channel. Where possible, meander patterns were preserved given the slight changes in angle required of a wider channel.

Following initial excavation of the channel, a second profile was surveyed. Flow characteristics for various channel sections, such as width, depth and velocity, were estimated through a series of hydraulic programs. The first program, based on the Manning roughness coefficient, discharge and cross-sectional coordinates, computes water surface elevation, cross-sectional area, wetted perimeter and average flow velocity. Selected sections were then checked with another program that computes critical values of various hydraulic parameters. Once typical cross-sections were delineated, the stability of these sections was checked by using a well-known tractive force procedure (Lane, 1955). The results were used to determine the morphology and elevation of riffle and run features relative to adjusted conditions. Standardized profile and cross-section maps were constructed to be used as guidelines during the next construction phase.

In order to replicate natural conditions, the bed morphology was manipulated to create rhythmic pool-riffle sequences. Natural streams create and maintain pools and riffles in accordance with the amount of water and sediment supplied to them. They do not rely on the existence of artificial structures to create these features. Instead, natural streams tend to create shear zones, within which energy is expended over a relatively discrete area. The result is a self-maintaining, stable and aesthetically pleasing stream. Thus, in order to create the best possible habitat, shear zones were created through excavation and fill. Figure 2 is a schematic representation of the morphometric components of a shear zone.

Although the dominant species in the system was brook trout, it was decided to develop habitat more suited to rainbow and brown trout. Where feasible, channel morphology was designed to provide the range of depths and velocities preferred by these fish (Bovee, 1978). In addition, spawning gravels screened for placement were slightly larger (2 to 3.8 centimeters on the intermediate axis) and more suited to rainbow and brown rather than brook trout.

CONSTRUCTION SEQUENCE

Construction commenced in May, 1985 and continued into 1986; certain work has yet to be completed at the time this paper was written. All construction was supervised and coordinated by personnel from INTER-FLUVE, Inc. The activities in the construction phase are outlined in Table 2. Refer to Figure 3 for an illustration of the temporary access road locations relative to the Stilling Basin, Inlet Stream and ponds.

A rather complicated construction sequence was needed to build 1.5 kilometers of access road from material excavated from the bottom of two ponds located midway in the system. Thus, partial excavation of the ponds began first, with the construction of roads occurring at the same time. Because the road was actually within the ponds, the upper pond excavation could not occur until the Inlet Stream was entirely completed. Similarly, the lower pond could not be excavated until the connecting stream was completed. Once the access road was completed, work on Big Spring Creek could occur concurrently with pond excavation.

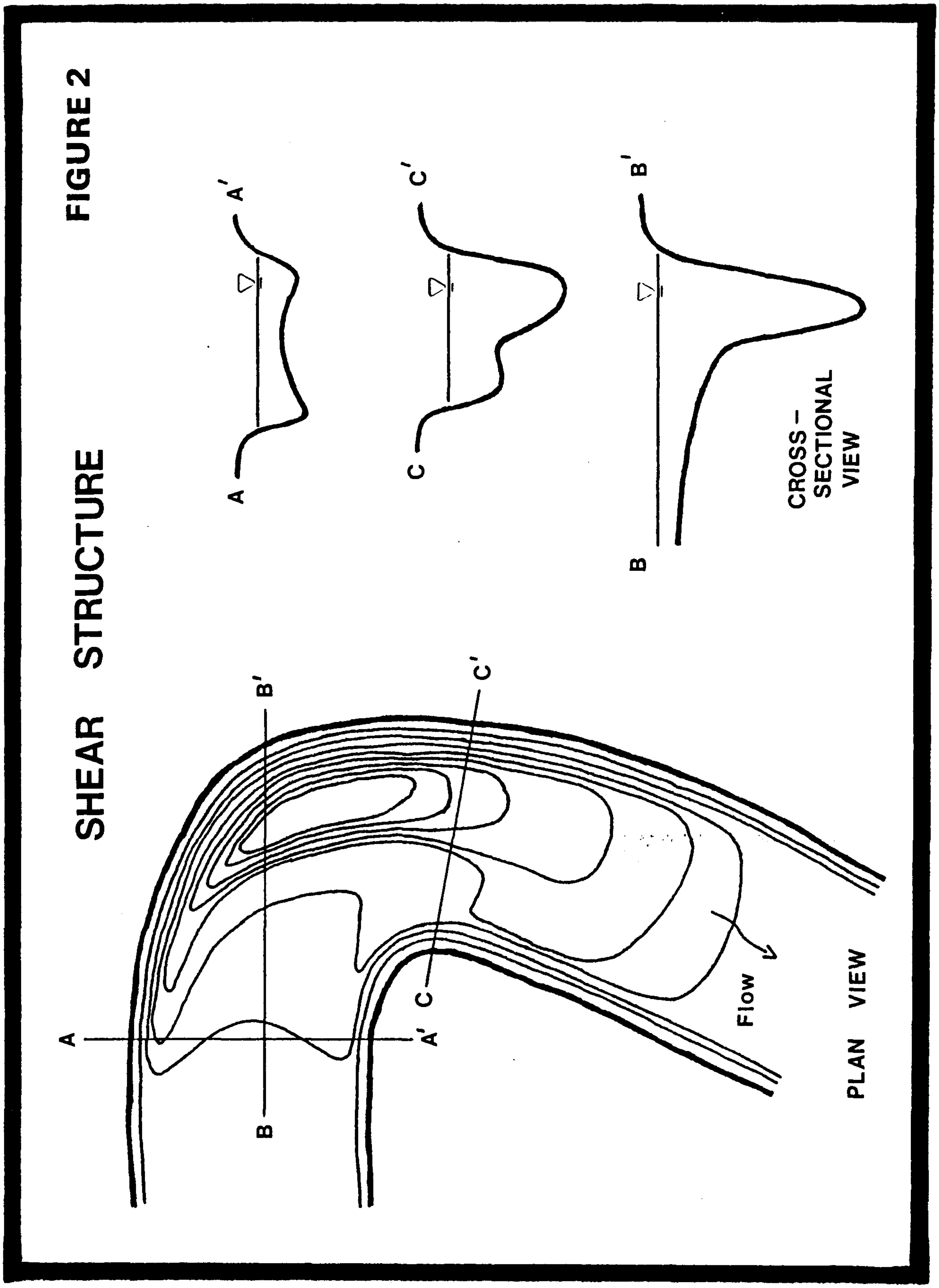

SHEAR STRUCTURE
FIGURE 2
A
A'
B
B'
C
C'
Flow
PLAN VIEW
CROSS - SECTIONAL VIEW

TABLE 2. Generalized events in construction phase. Although not always indicated, some activities occurred simultaneously and others sequentially.

Pre-Excavation

- Install filter screen and fabric assembly at confluence of spring creek and river; maintain as necessary.

Access Road Construction

- Fill portion of lower diversion to create access road to lowermost pond.
- Place culvert at outflow of pond; continue with access road.
- Excavate pond material: unsuitable road material transported and stockpiled for later use as topsoil, suitable road material used to construct road within north edge of lower pond.
- Concurrently, excavate and construct road along southern edge of lower pond in similar manner; place culvert midway to accommodate springflow.
- Continue road construction through 2 smaller ponds.
- Continue construction of 1 road through middle of upper pond; place culvert midway to accommodate springflow.
- Terminate southern road at junction with upper pond; allow water to flow parallel to southern edge of this road.
- Excavate southern road within lower pond as final excavation of this portion of the pond; transport road material to along the spring creek and grade as access road.
- Construct access road along north edge of proposed Inlet Stream; utilize geotextile fabric and dry fill from off-site.

Inlet Stream and Stilling Basin Construction

- Excavate Stilling Basin; transport and stockpile material for later use as topsoil.
- Excavate rough channel between Basin and upper pond with elevations below design grade.
- Line channel with geotextile fabric; place sub-base of cobble.
- Install headgates in Basin, leading to Inlet Stream and upper diversion.
- Raise channel to grade with gravel and cobbles; introduce water and adjust riffle elevations.
- Situate cobbles and boulders to provide habitat and direct flow.
- Remove access road adjacent to Inlet Stream; transport material for use as road along spring creek.
- Grade and landscape area adjacent to Stilling Basin and Inlet Stream, completing all construction in this area.

Upper Pond Excavation

- Excavate road within middle of upper pond and all area within pond margins as final excavation of this pond; transport material as fill between upper and lower ponds.
- As excavation proceeds, submerge trees and log masses anchored to large boulders as fish habitat.
- Raise elevation of upper pond outlet with cobbles to create desired pond water surface elevation, completing all construction in this area.

TABLE 2 (Continued) Generalized events in construction phase.

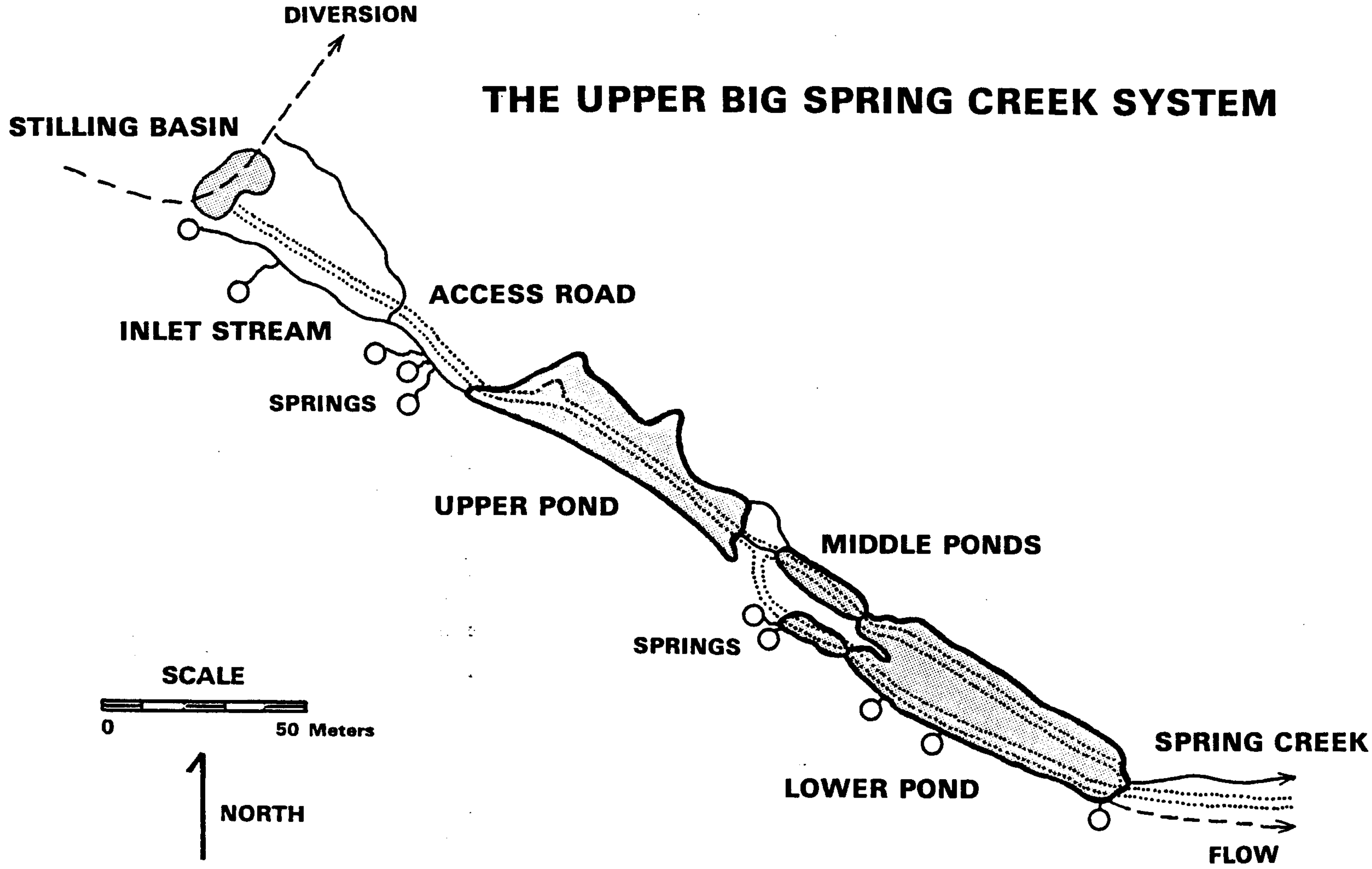
Connecting Stream Construction
- -Form rough connecting channel between upper and lower ponds.
- -Raise channel to rough grade with fill.
- -Adjust final grade with gravel and cobbles; introduce water and adjust riffle elevations.
- -Situate logs, cobbles and boulders to provide habitat and direct flow.
- -Grade filled area between ponds; transport and grade topsoil, completing construction in this area.

Lower Pond Excavation
- -Excavate road along northern edge of upper pond and all remaining area within pond margins as final excavation of this pond; transport material for use as road along spring creek.
- -As excavation proceeds, submerge trees and log masses anchored to large boulders as fish habitat.
- -Raise elevation of lower pond outlet with cobbles to create desired pond water surface elevation, completing all construction in this area.

Spring Creek Construction
- -Excavate rough channel (equipment within channel) to design width and to depth of old river cobble; place material on access road for later removal.
- -Push any material remaining in channel into piles for removal (equipment within channel); excavate (equipment on road) and transport to disposal site.
- -Progressing downstream, dig pools and construct riffles with excavated material (equipment within channel) according to meander pattern.
- -Place logs and boulders at select locations in channel (from road) to create habitat.
- -Place cobbles and gravels at riffles in channel (using crane/hopper/ conveyor system from road) to create spawning habitat.
- -Introduce water and adjust riffle elevations, adjust bar dimensions, and complete fine-tuning of habitat.

Miscellaneous
- -Place culvert in upper section of diversion off lower pond; construct headgates; fill and landscape.
- -Grade all remaining access roads; transport topsoil and landscape.
- -Construct wooden bridge across Big Spring Creek.
- -Plant area with native trees, shrubs and grasses.

FIGURE 3


THE UPPER BIG SPRING CREEK SYSTEM
DIVERSION
STILLING BASIN
ACCESS ROAD
INLET STREAM
SPRINGS
UPPER POND
MIDDLE PONDS
SPRINGS
SCALE
0
50 Meters
NORTH
LOWER POND
SPRING CREEK
FLOW

CONSTRUCTION FIGURES AND COSTS

Although much of the project occurred simultaneously, records dept for each piece of heavy equipment allowed a quantitative evaluation of separate portions of the work. At various times, different heavy equipment used on the project included: 4 tracked excavators, 5 dozers, 5 front-end loaders, 6 tandem-wheeled dumptrucks, a road grader, a gas-powered screening plant, a track-mounted crane and a custom-built hopper/conveyor system for placing gravels and cobbles in the stream. A careful record-keeping system accounted for all equipment time expended and quantity of work accomplished. This system was particularly useful for reviewing the rate of work for dumptrucks (loads of material per hour) and backhoes (distance per hour).

Material removed from the upper and lower ponds totalled 5200 and 6500 cubic meters in volume, respectively. Heavy equipment costs (exclusive of design and construction supervision fees) totalled $5.35 and $6.09 per cubic meter removed for the upper and lower ponds, respectively.

Construction of a connecting spawning stream in the former location of the two smaller ponds required extensive road building, filling and finish work. Heavy equipment costs for this work amounted to roughly $100 per meter of stream. However, due to the associated work involved, a cost-per-length reference does not necessarily yield a valid comparative figure. Equipment costs associated with construction of the Stilling Basin, the Inlet Stream and the upper portion of the access road could not be delineated separately.

Reconstruction of Big Spring Creek proper involved extensive excavation and subsequent placement of gravel, cobble, boulders and logs. Extensive landscaping and revegetative plantings were also required. Since some work remains to be completed at the time this paper was written, exact costs are not available. However, based on approximately 1200 meters of spring creek channel, total heavy equipment costs are expected to reach $75 per meter. This figure does not reflect the cost for gravel and cobble, nor does it reflect the cost of road building, as this was included under material disposal costs for pond excavation.

Additional project costs included screening of 1200 cubic meters of gravel and cobble at a total cost of about $20 per cubic meter and placement of 120 meters of irrigation ditch culvert at $100 per meter. Again, the aforementioned figures are limited to material and heavy equipment fees; they do not include costs associated with the feasibility study, the design process and construction supervision.

UNANTICIPATED PROBLEMS AND THEIR SOLUTIONS

MATERIAL EXCAVATED FROM PONDS

Haul road construction within the ponds and their subsequent excavation proceeded much slower than estimated due to the discovery of a substrate composition different than expected. During the design process, hand probes provided an estimate of the silt depth in the ponds. However, since heavy equipment could not be brought in to test the character of the underlying rock layer, factors such as particle size and compaction could not be estimated. Regardless, costs would have been prohibitive to import fill to construct 1500 meters of access road and haul it out once again (in addition to pond excavation). Therefore, the rock layer of the pond had to be utilized regardless of what was found.

A tracked backhoe constructed an access road within the pond systems from material it excavated out of the ponds from one side of the road. The silt and sand layer was excavated and trucked to disposal sites. Rock material was then excavated and placed in front of the backhoe to construct a road. This process continued until over 500 meters of road were built within the ponds. Problems arose when the tracked backhoes attempted to dig into the rock layer, both during road construction and later during final excavation of the ponds. Rocks and boulders were severely compacted, and some were as wide as 2.3 meters on the primary axis. The backhoes had difficulty breaking into the rock material, and at times had problems picking up the rocks themselves. Three moderate-sized tracked excavators were initially used, at different times, with limited success. These machines, and their capacities, are listed below.

Poclain 115	bucket, 1.15 cubic meters
Bucyrus-Eire	bucket, 1.15 cubic meters
Koehring 466	bucket, 0.75 cubic meters; boom extension, 8.3 meters

Two larger tracked excavators were required for final pond excavation, as the above equipment simply did not have the necessary weight or power. These larger machines, listed below, had almost double the weight and capacity of the smaller excavators.

Hein-Warner C-28	weight, 45 metric tons; bucket, 2 cubic meters; boom extension, 12.2 meters
P & H 2500	weight, 57 metric tons; bucket, 2.3 cubic meters; boom extension, 12.2 meters

The larger equipment performed well, yet all their power was needed to accomplish the work. As an indication of the energy expended by these excavators, their hardened-steel bucket teeth were replaced over a dozen times as they were worn to smooth stubs.

HEAVY EQUIPMENT ACCESS ROADS

As previously stated, the initial evaluation of the pond substrate indicated that excavated material would be suitable for construction of heavy equipment access roads. Design plans called for access roads to be 5 meters wide and 0.7 meters deep. However, since many of the boulders were quite large, the roads needed to be deeper in order to "bury" these bigger rocks. Therefore, in many areas the roads ultimately exceeded 1.2 meters in depth. Such larger dimensions required almost twice as much fill material per meter of road as originally estimated. To reduce costs, designs were subsequently altered; roads would be landscaped when no longer needed rather than removed and hauled off-site as originally planned.

HIGH FLOW PERIOD

In late May, approximately two weeks after the beginning of irrigation season in the valley, flow from numerous springs began to increase dramatically. The 0.6 meter diameter culvert placed at the outflow of the lower pond (beneath the access road) was of insufficient capacity to carry the increased flow. A second culvert, 1 meter in diameter, was placed parallel to the smaller pipe. Even with this additional culvert, the water level in the lower pond continued to rise above the access road. Consequently, an open channel was made in the road to relieve pressure and prevent road failure, thereby preventing access above the lower pond.

Concurrently, numerous springs appeared at the base of the terrace along the access road. In a few days, additional springs appeared in the haul road itself, despite the fact that the road was 1.5 meters higher than the immediately adjacent stream. In time, the road was unable to support loaded tandem-wheeled trucks, as the rising water created quick-like conditions. As a result, the project was temporarily shut down due to high water--in what turned out to be one of the driest summers in Montana history.

CURRENT LAND USE AND IRRIGATION REQUIREMENTS

Throughout the construction phase of the project, the property continued to be leased as a hay and cattle operation. Although the spring creek system was to be given first priority in land use, the owners had not yet reached an agreement with the ranch lessee. In other words, construction work proceeded with cattle having open range within the project site. Their presence created some problems, mostly centered on potential destruction of finished work. Damage was reduced by erecting temporary fences and by working with the lessee to rotate herds out of more sensitive areas.

Another conflict ocurred regarding irrigation of land adjacent to the project. As much as 0.3 cubic meters per second (10 cubic feet per second) of flow was historically diverted from Big Spring Creek to irrigate property to the south. When the irrigation season commenced in late May, 500 meters of the lower diversion ditch had been filled to serve as an access road. By agreement, irrigation water had to be made available to the lessee.

Initially, a large capacity diesel-powered pump was placed midway in the spring creek to pump water to the ditch (over a distance and head of 30 and 3 meters, respectively). The pump was a 15.2 centimeter (6 inch) Cornell, Model 6Y-2, driven by a D-880 Cat engine. The capacity of this arrangement proved insufficient; a second pump to be operated simultaneously was installed soon thereafter. The second outfit consisted of a 15.2 centimeter (6 inch) electric Crisafulli driven by a diesel generator. After operating for a period of one month, mechanical problems developed with the pumps and another method of supplying water was needed.

Eventually, it was decided to re-excavate the lower irrigation ditch. Unfortunately, space was limited in the upper 150 meters along the stream. Therefore, excavated material cast to one side in some cases completely buried willows bordering the stream channel. In other places, the ditch was so close to the base of the adjacent terrace that unstable conditions caused minor slope failure. However, these difficulties proved short-term, as re-opening the diversion offered beneficial options when construction commenced in the fall.

After the spring flow declined and work began again in September, castings from the ditch were graded to re-create an access road, with additional material supplemented where necessary. With flows reduced and the ditch open, water could be diverted from the Lower Pond into either the creek or the ditch. It was decided to install a headgate at the Lower Pond, 120 meters of culvert (1.22 meter diameter) along the initial course of the diversion, and to keep the remaining ditchline open. The ability to divert water from the creek provided the following benefits:

1) excavation of the stream could proceed under minimal flow conditions;
2) sedimentation and turbidity contributed to the main river could be minimized;
3) habitat construction and fine-tuning of the channel could be observed under a variety of flows, allowing adjustment as necessary; and,
4) potentially available irrigation water opened options for land use of the property to the south.

Additionally, piping this section of the ditch facilitated landscaping the narrow 150 meter-long strip between the terrace and the stream, thereby providing a remedy to unsightly slope failures.

REGULATORY PERMITS

A number of local, state and federal permits were required for work within the Big Spring Creek system. These included:

1) An electrofishing permit through the Montana Department of Fish, Wildlife and Parks (DFW&P);
2) a property easement from a group of adjacent landowners;
3) the Montana Natural Streambed and Land Preservation Act permit (310) through the DFW&P and the County Conservation District;
4) a Water Right Change of Appropriation through the Montana Department of Natural Resources and Conservation (DNRC);
5) a Short-Term Exemption from Surface Water Quality Turbidity Standards through the Water Quality Bureau of the Montana Department of Health and Environmental Standards; and,
6) the Federal 404 (Clean Water Act) permit through the U.S. Army Corps of Engineers.

Permits were approved for the initial work. The major concern of regulatory agency personnel was preventing sedimentation and turbidity from reaching the main river. Therefore, a series of filter screens were installed in the spring creek just above the confluence with the river. A metal screen attached to a hardwood frame was erected to catch organic debris. The screen (4.3 meters long, 1 meter wide, with a 1 centimeter diameter mesh) was inclined at a 45 degree angle to provide maximum surface area. A geotextile fabric barrier (Supac®, 5NP) was placed downstream, similarly mounted on a hardwood frame and at an angle. This frame was 7.5 meters long, 1.2 meters wide; the fabric had a pore size of 40, EOS, U.S. Standard Sieve (for further specifications, see Phillips Petroleum Company, 1985).

During Pond excavation, this system worked relatively well since the Ponds themselves acted as settling basins. The metal screen also tended to impound water for 40 meters upstream, creating a small settling basin 1000 meters downstream of the Ponds. However, the filter fabric clogged easily, and was not used on a continual basis. Initial problems arose when final excavation of a portion of the Lower Pond reached below a depth of 4 meters. At this level, a clay lens was encountered, and excavation resulted in a significant quantity of colloidal suspension. No means of filtering could prevent passage of these clays into the river, with the possible exception of a settling basin as large as the entire project itself.

Additional permit difficulties arose prior to recommencement of construction following irrigation season. Agency personnel were reluctant to extend the permits which allowed exceedence of turbidity standards, especially since a summer-long drought had severely reduced river levels. Furthermore, it was felt that turbidity could not be effectively reduced by the present screening system, given the amount of sediment disturbed by construction within the creek itself. This entire issue was eventually resolved with the diversion of spring creek water into the irrigation ditch during construction which eliminated sediment input into the river.

UNSTABLE GROUND CONDITIONS ADJACENT TO INLET STREAM

A road was needed in order to provide heavy equipment access to the Inlet Stream area. Designs called for excavation of 800 cubic meters of material to construct the Stilling Basin, as well as excavation and subsequent gravel placement in 100 meters of Inlet Stream. Unfortunately, the ground in this area consisted of peat to a depth of 3 meters with water flowing through subsurface channels. In addition, large willow clumps covered much of the ground and a stable road base was nonexistent.

The following technique was used to construct this portion of the access road. A tracked excavator and a dozer worked alternately as dumptrucks brought in dry fill material (excavated from a source on the terrace). First, working from the end of the road, the excavator would reach as far as possible and crush any willows in the road path until they were relatively level. The same geotextile fabric used in the filter screen described above (Supac®, 5NP) was then rolled out directly over the bushes and ground. The fabric was 4.5 meters wide in rolls almost 100 meters long. The dozer would then push fill out onto the fabric, creating a road about 0.7 meters deep, until standing willows prevented further progress. The excavator would again return to level bushes as far as its reach extended, and the sequence would begin again. A culvert (46 centimeters in diameter, 6 meters in length) was placed midway to allow free passage of water.

Obviously, alternating equipment to build the narrow road reduced efficiency and speed, but in the end proved effective. Dry fill material was used so that it would set up too rapidly. The road remained very stable, and was finally removed after completion of the Inlet Stream. However, it is interesting to note the surrounding ground was so unstable that, as trucks drove along the road, the adjacent willows would shake as if in a strong wind.

Similar problems with peat were confronted when the primary Inlet channel was excavated. Cobbles for the stream channel would literally disappear into the peat. Furthermore, the fine organic particles of the peat would certainly clog spawning gravels, rendering them unuseable by fish. To solve this difficulty, the same filter fabric was laid in the roughly excavated channel. A layer of cobbles (minimum of 0.5 meter depth) was then placed in this blanket and compacted to establish a firm sub-base. Excess fabric was trimmed from the stream margins. Smaller gravels and rocks were then placed at final design grade, and with the introduction of flow, adjusted to create habitat. Since the fabric allows free passage of water while preventing migration of soil particles, the channel should remain both clean and stable over time.

WEATHER

During a few evenings in early October and again in mid-November, temperatures dropped to 23 degrees below zero Centigrade (10 degrees below zero Fahrenheit). Aside from the usual problems in starting desiel equipment in these temperatures, another difficulty was encountered. During the night, the tracks on the large excavator working in the stream would freeze solid. Despite the power of hydraulics, propane fires were needed to melt and loosen the tracks.

CONCLUSION

Fish and wildlife enhancement offers an opportunity to improve recreational potentials within riparian areas. In this case, a series of 4 ponds were rehabilitated and over 1200 meters of spring creek were reconstructed to increase fishing and hunting opportunities. Complete reconstruction of the spring creek was based on natural fluvial features rather than traditional habitat improvement structures. Unfavorable ground conditions required the construction of over 1500 meters of temporary access roads along the length of the system; other difficulties required modification of design schemes as the project progressed. However, the difficulties, delays and distractions encountered were more than overshadowed by the realization that the work benefited not only the sportsman, but more importantly, fish and wildlife resources.

REFERENCES CITED

Bovee, K.D., 1978. Probability-of-use criteria for the Family Salmonidae, Instream Flow Information Paper No. 4, Cooperative Instream Flow Service Group, Ft. Collins, CO, 81 pp.

Ehlers, R., 1956. An evaluation of stream improvement devices constructed 18 years ago, California Fish and Game 42(3): 203-217.

Hunter, G.W., L.M. Thorpe, and D.E. Grosvenor, 1940. An attempt to evaluate the effect of sttream improvements in Connecticut, Transactions 5th North American Wildlife Conference, 276-291.

Keller, E.A., 1976. Channelization: environmental, geomorphic and engineering aspects, In Geomorphology and Engineering, D.R. Coates, editor, Proceedings of the 7th Annual Binghampton Symposia Series, Dowden, Hutchinson & Ross, 115-140.

Koonce, G.P., and J. Urbani, 1983. Channel bedform manipulation: an alternative to traditional structure oriented stream enhancement methods, Proceedings of the Colorado-Wyoming Meeting of the American Fisheries Society, 9pp.

Lane, E.W., 1955. Design of stable channels, Transactions of the American Geophysical Union 28: 443-444.

Milhous, R.T., 1982. Effect of sediment transport and flow regulation on the ecology of gravel-bed rivers, In Gravel-Bed Rivers-Fluvial Processes, Engineering and Management, R.D. Hey, J.C. Bathurst and C.R. Thorne, editors, John Wiley & Sons, 819-842.

O'Brien, R.J., 1985. Construction of aquatic amenities within planned developments: a method to enhance aesthetics and fish habitat, 2nd Biennial Throne Ecological Institute Symposium, 36 pp.

Phillips Petroleum Company, 1985. Supac®, Phillips Fibers egineered geotextiles, 12 pp.

Seber, G.A.F., and E.D. LeCren, 1967. Estimating population parameters from catches large relative to the population, Journal of Animal Ecology 36(3): 631-643.

Tourbier, J.T., and R. Westmacott, 1981. A Handbook of Measures to Protect Water Resources in Land Development, Water Resources Protection Technology, The Urban Land Institute, Washington, D.C., 178 pp.

U.S. Department of Agriculture, Forest Service, 1936. Fish Stream Improvement Handbook, 39 pp.

U.S. Department of Agriculture, Forest Service, 1952. Fish Stream Improvement Handbook, 21 pp.

U.S. Department of Commerce, Bureau of Fisheries, 1935. Methods for the improvement of streams, Memorandum I-133, 27 pp.

Wydoski, R.S., and D.A. Duff, 1982. Indexed bibliography on stream habitat improvement (revised), U.S.D.A. Forest Service, Intermountain Experiment Station, 143 pp.

Water Quality Improvement and Erosion Control at Heavenly Valley Ski Area, Lake Tahoe Basin

JULIE ETRA, Botanist, WILLIAM N. JOHNSON, Watershed Staff Officer
USDA Forest Service, Lake Tahoe Basin Management Unit, CA

INTRODUCTION

Heavenly Valley is a heavily used ski area located in the Lake Tahoe Basin. Twenty square miles of skiable terrain include acreage in both Nevada and California. Heavenly Valley overlooks Lake Tahoe, one of the largest alpine lakes in the world. Lake Tahoe's uniqueness, however, is not in its size, but in its remarkable color, clarity, and the purity of its waters. The factors of altitude, geology, climate, topography, and hydrology all determine the unique Tahoe environment, an environment in which the integrity of the land directly determines the quality of the water. The exceptional clarity and purity of Lake Tahoe's water are extremely sensitive to sediments and nutrients carried into the lake by runoff. The soils are of low fertility and exhibit a high erosion rate when disturbed. This, coupled with the short, dry growing season and high elevation creates a unique restoration and erosion control challenge.

The development of Heavenly Valley Ski Area took place in the early fifties, during a time when bulldozing with heavy equipment was a common method of run construction. The loss of soil created by these techniques has resulted in a site condition in which it is impossible to suppoort vegetation without major mitigating efforts to control erosion. Revegetation of disturbed areas is a complex and difficult problem at Heavenly Valley. Heavenly Valley Creek is a major recipient of sediments derived from erosion on the mountain. This creek is a tributary of Trout Creek which eventually drains into Lake Tahoe. A circular problem exists as slopes must be stabilized long enough to allow establishment of vegetation.

Native vegetation is typical of Sierra flora of this region. Dominant conifers include Jefferey pine (Pinus jeffreyi), Western white pine (P. monticola), white and red firs (Abies concolor, A. magnifica) and lodgepole pine (Pinus contorta ssp. murrayana). Species of shrubs are numerous and include bitterbrush (Purshia tridentata), whitethorn (Ceanothus cordulatus), squaw carpet (C. prostratus), pinemat and greenleaf manzanita (Arctostaphylos nevadensis, A. patula), huckleberry oak (Quercus vaccinifolia) and chinquapin (Castenopsis sempervirens). Important sub-shrubs include mountain pride Penstemon newberryi) and buckwheat flower (Eriogonum spp.).

Grasses do not form a major part of the landscape except in drainages where species of native bluegrass (Poa nevadensis, for example), sedges (Carex spp.) and rushes (Juncus spp.) occur with introduced pasture grasses. Exceptions exist, however, and robust stands of squirreltail (Sitanion hystrix) and needlegrass (Stipa occidentalis), both native bunchgrasses, occur on moderate to steep, sunny slopes with poor to fair soils. Vegetative cover is not continuous and large patches of unvegetated soil commonly occur between low-growing stands of shrubs.

In summary before revegetation could begin the following problems had to be addressed:

1. Drainages ranging from intermittent to perennial had been drastically disturbed
2. Topsoil and vegatation had been removed from large areas.
3. Drainage patterns had been changed.
4. Water had been diverted from one drainage to another.
5. Land stability problems.
6. Burning of stumps.
7. Debris in stream channels.
8. Increased runoff due to vegetative removal and impervious surfaces.
9. Major unstable cuts from ski runs, road, and lift construction.
10. Lack of summer precipitation.
11. Short growing season.
12. Highly erodable and infertile soils.

Disturbances to the integrity of natural drainages posed the most serious problem to be addressed. Early efforts at revegetation failed in may cases because uncontained runoff washed away seed and mulch. This prompted a drainage and runoff study to identify major problem areas. This effort took place during the spring runoff and during high intensity thunder showers, when drainage patterns were quite evident. It was discovered that rilling of the highly erodable decomposed granitic soils occurred in a shorter distance than previous studies indicated.

DRAINAGE CONSIDERATIONS

Several considerations must be taken into account in the design of drainage facilities for ski areas. They include:

1. Exposure
2. Effects of snowpacking by grooming equipment
3. Dense snow created by snowmaking
4. Increased runoff from vegetative removal and snowmaking
5. Bulking factors from debris and increased erosion
6. Freezing problems

Cross Drains

The installation and maintenance of cross drains on ski trails is essential to the control of runoff from ski slopes. Their primary function is to slow the velocity of water, discharge it onto undisturbed areas and to avoid large concentrations of runoff on bare soil. There are several techniques for their construction. One method is by use of a small dozer; another technique involves hand labor, which is particularly effective for their construction on steeper slopes.

The following guidelines should be followed when laying out and constructing cross drains:

1. The overall grade should not exceed ten percent. It is sometimes effective to start the grade at four percent and increase it to ten percent, which helps the drainage be self-cleaning.

2. Cross drains should discharge into undisturbed areas, preferably rocky ground or areas well protected with slash or vegetative cover.

3. They should be located so they promptly intercept runoff that may result in water concentrations. Terrain feature should be considered when locating cross drains.

4. Cross drains should be constructed separately and not allowed to discharge into other water bars.

5. Where possible, cross drains should discharge water alternately to either side of the trail to avoid excessive concentration of water in one area.

6. All cross drains should be flagged or staked using as a minimum a hand level.

Once the cross drains have been constructed, all vehicular traffic on the ski run should be prohibited.

Drop Inlet Systems

A sophisticated system of drop inlets was designed to collect runoff in areas where the integrity of natural drainages had been destroyed and surface runoff increases were severe due to removal of vegetation and topsoil (Figure 1). The inlet systems when properly installed proved to be an effective way to control surface runoff and allow for vegetative establishment. The following considerations were taken into account in the design and placement of facilities:

1. Drop inlets should have adequate capacity for sediment storage.

2. Drop inlets should be located in an exposed area where they are not subject to icing or freezing conditions.

3. Proper design of inlets to eliminate skier hazard and blockage by debris.

4. Easy method of clean out.

5. Easy to locate.

6. Minimum diameter of 12 inch CMP connecting drop inlets.

Drop inlet systems should only be used as a last resort. They are expensive and have a high susceptibility to failure if not adequately installed and maintained.

Rock Lined Ditches

In some locations drop inlets are combined with rock lined ditches to convey runoff in areas which once carried intermittent drainages. Rock lined ditches will not work in areas that are expected to carry a high sediment load. The size of rock used is dependent upon soil type, and velocity of flows expected. The steeper areas may require a lining with filter cloth, to prevent undercutting of the rock. Rock is an excellent mulch. Ditches should be seeded prior to laying down rock when not using filter cloth. The vegetation will reduce the visual impact and further stabilize the channel. When properly installed they will not create a snow retention problem or hazard to skiers and grooming equipment.

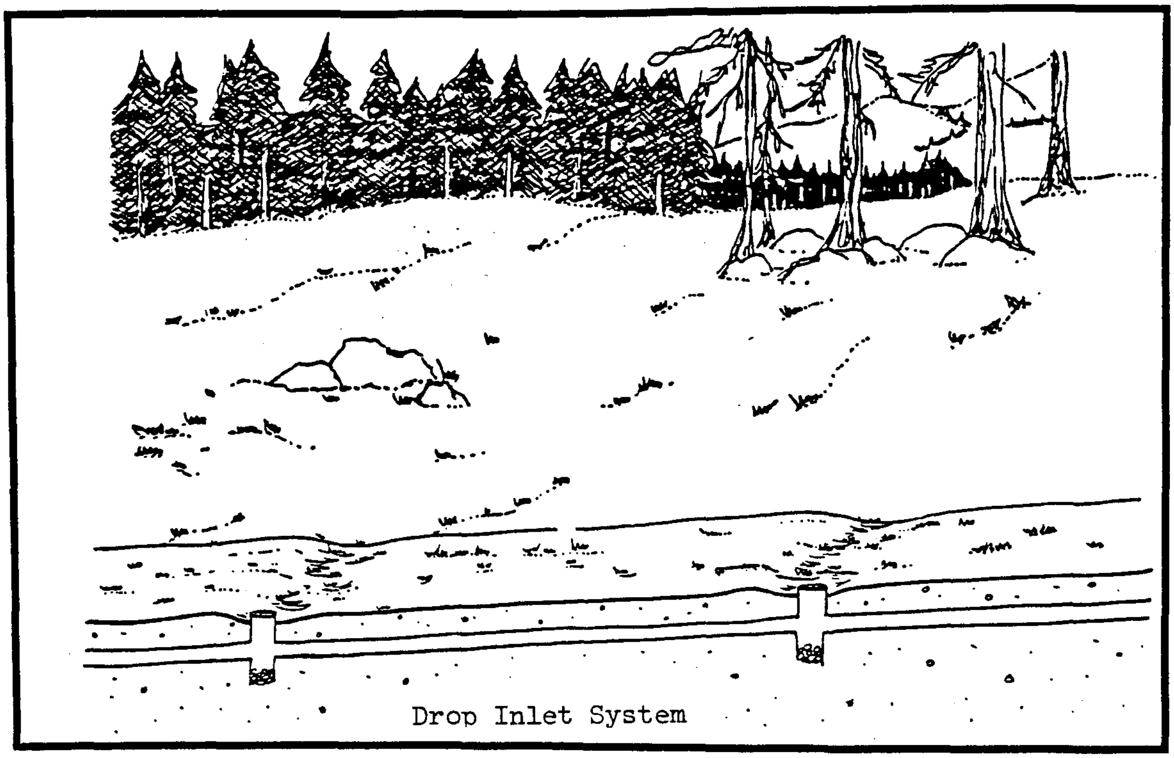
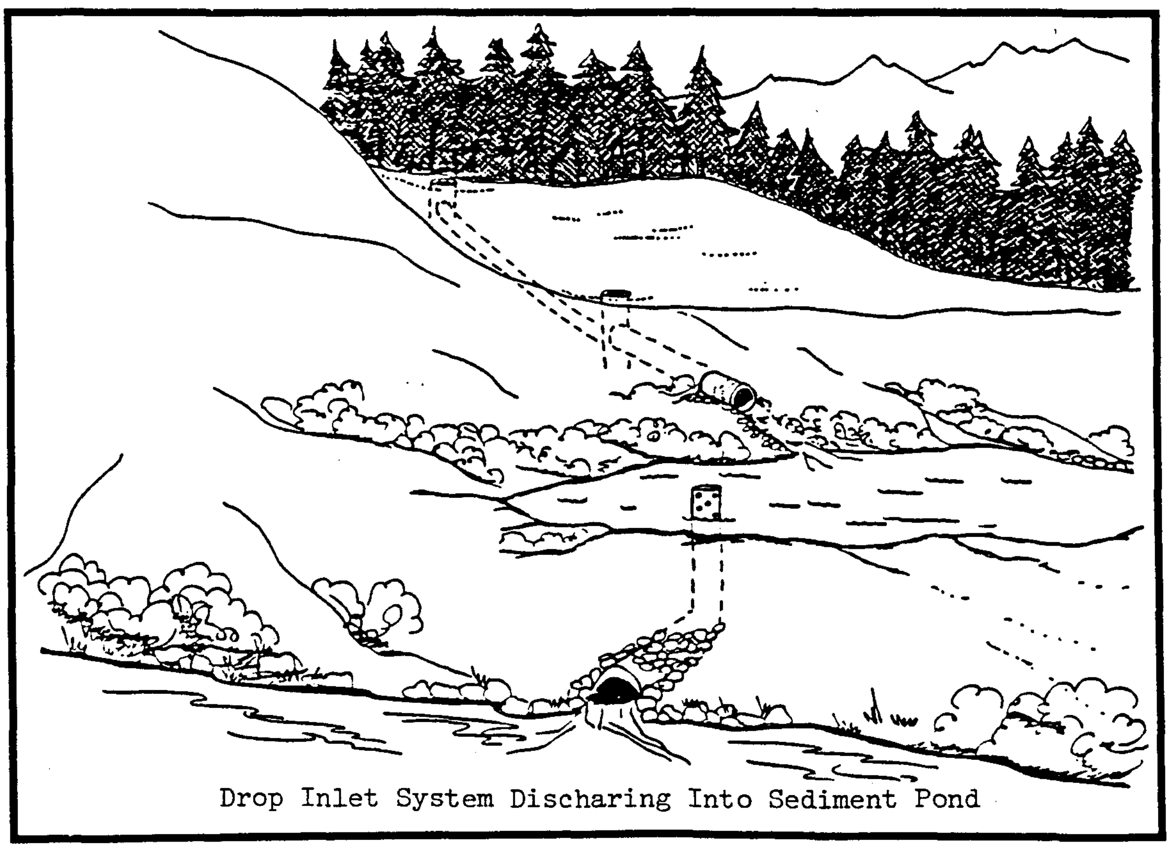

Drop Inlet System

Figure 1.


Drop Inlet System Discharing Into Sediment Pond

Irrigation and Snowmaking Systems

In order to establish a quick stand of vegetation under the harsh conditions found at Heavenly Valley it was necessary to provide an artificial supply of nutrients and moisture. Snowmaking systems were designed to provide both irrigation and snowmaking capabilities with a minimum of maintenance and operating time. A small earthen dam was utilized to provide water for the system. The existing system provided snowmaking and irrigation to approximately 150 acres. This system coupled with the controlled surface runoff helps improve the chances for successful revegetation.

REVEGETATION

Revegetation has improved over the years as the ecology of the area has become better understood and as techniques have been modified. Grasses, the primary plant material used, have established on some areas on the California side of the mountain. Since grasses do not comprise a major part of the native plant community they would not be expected to easily re-establish, especially in the absence of topsoil. This is indeed the case and successful revegetation has occurred only with intensive efforts to improve soil fertility and the moisture regime. These efforts include applying heavy rates of seed and fertilizer, mulching, crimping, tacking, and irrigating if possible. Maintenance applications of fertilizer are necessary to enhance and maintain growth. These are expensive operations that do not necessarily guarantee the establishment of stable, vegetatiave cover. In addition, grasses often fail to control surface runoff that results from spring melt off, probably the greatest contribution to erosion problems and sediment load in drainages. Shrubs would better control these flows and would require little maintenance over an extended period of time.

1984 Plantings

In 1984, the Forest Service began a careful review of past revegetation efforts and assessed performance of previously used species. Smooth brome (Bromus inermis), timothy (Phleum pratense), white dutch clover (Trifolium repens), yellow sweet clover (Melilotus officinalis), and intermediate wheatgrass (Agropyron intermedium) were recommended to be removed from use because of their poor success and new species were considered.

In order to improve the quality and lower the costs of revegetation, development of a stable, persistent plant community is essential. A return to native species would greatly reduce or even eliminate the need for maintenence fertilization, supplementary watering, etc. Since we were unable to acquire certain desirable species, growth form became an important selection criteria. For example, bunchgrasses, rather than sodformers, predominate the mixes. It was felt that these grasses are both morphologically and physiologically better adapted to the xeric and nutrient-poor conditions of the site. Bunchgrasses are also less likely to physically inhibit the invasion of native shrubs species that form more advanced seral stages. Other criteria used in species selection included availabilty, cost, drought tolerance, phenology, seedling vigor, natural occurence, rate of growth, diversity, past perfomance in test plantings and aesthetics (Appendix Table 1).

Bromus marginatus (mountain brome) and Agropyron trachycaulum (slender wheatgrass) are rapidly establishing but short-lived native species that were expected to provide rapid cover but yield to successional species while Poa canbyi (Canby bluegrass) is found at high elevations in the Great Basin and is one of the first grasses to appear in the spring. Sitanion hystrix (squirreltail), which occurs throughout the Lake Tahoe Basin, was used sparingly because of its expense although successful establishment, would justify greater use in the future. Two varieties of Dactylis glomerata (orchardgrass) were tested for perfomance under identical growing conditions. Lupinus grayi (Gray's lupine) was selected for its ability to control erosion via its matt-like growth form and for its ability to add nitrogen to the soil through fixation. It is very common in the Basin and is an alternative to pasture legumes, which have met with little success in past erosion control plantings on harsh sites in Tahoe. Linum lewisii (Lewis flax) is a beautiful and hardy wildflower added for aesthetic reasons. A total of eight mixes were developed to test species and variety performance on 5 1/2 acres of unvegetated disturbed land (Appendix Table 2).

Site Selection and Description

Sites were selected at several locations to test species performance over a variety of conditions (Appendices B & C). Variables included slope, aspect, elevation and soil. Soils were similar and consisted primarily of decomposed granite, although some areas had more organic matter. Waterfall was the only site that had access to irrigation water and all other sites depended on natural precipitation for plant growth. Total area seeded at each site was usually a function of access, which was limited on steep ski runs.

Techniques

Standard procedures for revegetation were modified according to study design and as site conditions dictated. Basic steps followed at all sites were as follows: rip, seed, fertilize, harrow, mulch and hydromulch. Revegetation efforts began on September 25 and were completed by October 10. Fall seedings are in many cases more successful than spring seedings in the Basin, especially where irrigation is unavailable. Seeds lie dormant during the winter and emerging seedlings make efficient use of the limited moisture from spring snow melt.

Most sites tested two seed mixes. These were planted side by side, usually dividing the ski run longitudinally in half. Besides type of seed, we also tested application rates of seed, mulch, and hydromulch. Fertilizer rates did not vary (250 lbs./A). Seed and fertilizer (16-20-0 + sulfur) were applied with hand-held cyclone seeders.

Straw mulch was applied with a straw blower, usually at 2 tons/acre. This rate varied slightly as wind often carried ejected straw. A D-3 catepiller was modified with a ball and penal hitch that enabled attachment of the straw blower and crimper for use on steep slopes. The cat was also used on these slopes to distribute bales of straw. Crimping all but gently sloping sites was abandoned after Dipper since it did more harm than good. When crimping perpendicular on the contour of the slope the cat tended to slide over the straw, making turning difficult and greatly disturbing the freshly seeded area. Crimping parallel to the slope creates runoff problems as water flows down the furrows.

Conwed 2000, a hydromulch that includes a tackifier, was applied at rates of 500-800 lbs of mulch/acre over the straw. Again, wind had a tendency to carry the material. A 3800 gallon capacity water truck provided an immediate source of water for the 1300 gallon capacity hydromulcher. Dissolution rates were between 3 and 5:1 water (gallons) to hydromulch. Although 3:1 ratios are usually recommended, we were especialy concerned about clogging the equipment as the water truck supplied the only readily available water source.

A description of procedures followed at each site is included in the following section. Plot plans are included in Appendix C.

Test Plots

Nevada Flats

This small site was divided into 2 plots, the "native" plot (Flats #1) covering approximately 1/20 acre and Flats #2 covering 1/10 acre. The native seed mix was hand collected from local sources. Needlegrass was collected at Heavenly in late July. Although approximately 2.5 lbs. of plant material were collected, a PLS of only .44% resulted (germ = 60, purity = .73). To insure a seeding rate of 25 lbs./acre we would have needed to seed the test plot with 280 lbs. of this material. Our rate was slightly more than 1/5 lb./acre. Approximately 3.5 lbs. of uncleaned squirreltail plant material (PLS = 24%) was seeded at a rate of about 17 lbs./acre. About 3000 seeds of Gray's lupine were also planted, half of which were pre-treated with a boiling water bath. One hundred to 120 lbs. of topsoil, removed from around plants that provided the seed, were mixed into existing soil before planting. We hoped that the soil included some species-specific bacteria that will infect young seedlings and hasten growth.

Nevada Flats #2 was seeded at about 100 lbs./acre (standard rate is 40-50 lbs./acre). Straw was applied at about 2.5 tons/acre and crimped in. Hydromulch was applied at about 700-800 lbs. mulch/acre.

Olympic Run

Olympic run is an extremely harsh site. Several attempts by Heavenly personnel to establish grasses had failed and the "soil" was extremely compacted. Some natural invasion by conifers and mountain pride seedlings (*Penstemon newberryi*) had occurred. A new water bar was cut, extending from the access road. After ripping, seed was applied at abut 100 lbs./acre. Due to distribution problems arising from hand application and windy conditions, it was felt that this was better than standard rates. In addition, 1/4-1/2 oz. of mountain pride seeds were planted on the upper part of the run. This site was crimped, which was expected to result in poor stand establishment in areas where the cat slipped. These disturbed areas were re-fertilized and mulched. Six-hundred lbs. of hydromulch were applied which required using three 50' lengths of fire hose to reach the upper sections of the slope.

Perimeter

Soils on Perimeter run were perhaps the best for all areas planted as they appeared to have the most organic matter. The slope was gentle and this long strip probably provided the best site for plant growth. Here we tested seed mixes and types and rates of mulch application. One-half acre (in two 1/4 acre plots with mixes 5 and 6) was straw mulched at 4 tons/acre, twice the normal rate. This was done in two applicaitions, crimping at each conclusion. The other 1/2 acre (including mixes 5 and 6) was only hydromulched, at 600 lbs./acre.

Dipper (Orion's Run)

Procedures followed at Dipper were similar to those for other sites. Ripping began on October 4 and there was already some snow cover. Only the bottom half of the run was crimped, providing a good test of its effectiveness. Hydromulch was applied at about 5-600 lbs./acre. One hundred feet of fire hose was needed to reach the lower slope.

Canyon

This site is on the California side of the mountain. A total of 2 acres were seeded, in 1 acre plots separated by a strip of vegetation. A road bisects both plots (Figure 5). The area was not crimped but was hydromulched at 500-600 lbs. mulch/acre over the straw.

Waterfall

Also on the California side of Heavenly, two small areas totalling slightly less than 1/2 acre near the charilift were revegetated. A vegetated area separating the plots was left undisturbed. About 1 1/2 tons of straw was crimped and then hydromulched.

Cost Estimates

Cost estimates are included in Appendix Table 3 and 4. Cost of seed is higher than usual due to the inclusion of several expensive species (particularly squirreltail) and high seeding rates. Vehicles were supplied by the Forest Service fleet and costs were calculated on a monthly use and maintenance basis.

Preliminary Results 1984 Plantings

The 1985 growing season was very stressful as the Basin experienced a drought. There was no measurable precipitation in either May or August while June and July averaged 52% of normal (.51"). September was wetter than normal, with .47".

No cover studies were conducted on 1984 test plots during the 1985 field season as many seedlings were immature and some species were difficult to identify. Although sites will be discussed individually, general trends will be addressed here.

Mulches and Tackifiers

Maximum application of straw should be between 2.5-3 tons/acre, depending on the exposure and wind patterns for a given site. Although moisture retention was good where mulches were especially thick, straw prevented the soil from warming, and low soil temperatures may have been the primary inhibitor of plant growth. Seedling emergence was also probably physically inhibited. Application of hydromulch without straw was also unsuccessful. A concrete-like surface formed on Perimeter Run and the hydromulch did little to retain soil moisture. It also did not penetrate into the straw and frequently formed a crust or separate layer that was easily eroded or carried away by wind.

Species

Seedling composition varied from site to site but only the following species set seed: slender wheatgrass, mountain brome, pubescent wheatgrass, needlegrass and squirreltail. Slender wheatgrass and mountain brome appeared to be the most vigorous grasses and they produced the most above-ground growth. No seedlings of Lewis flax were found. Birdsfoot trefoil produced many seedlings on the two sites tested but growth was poor. The commercial source of sqirreltail yielded few plants while local sources were highly productive. Native seed, however, was not planted in a mix and the commercial seed may have suffered from competition from other species.

Test Plots

Nevada Flats

NATIVE PLOT (#1)-Spring and mid-summer growth for squirreltail and needlegrass was slow but by the end of September both species had set seed and many plants had achieved over a foot of growth. Lupine plants began to emerge at the end of July and one excavated plant with a 1/2" diameter had a 6 1/2" nodulated rootlet. A fall count found 16 lupines in the treated and 13 plants in the untreated plot. Birdsfoot trefoil seedlings were many but small.

NON-NATIVE PLOT (#2)- Growth was good for all establishing grasses and mtn. brome and slender wheatgrass had set seed by the end of September.

Olympic Run

Seedling density was high which was expected since the seeding rate was 100 lbs. This may have led to seedling competition for moisture and subsequent drought stress. Mix #4 did not establish as well as #5 probably because of wind erosion and loss of mulch and/or seed. Areas disturbed by crimping had fewer seedlings. By early August the effects of the drought were apparant, especially on the upper end of the run, and many seedlings were brown. Few seedlings of squirreltail (commercial source) were found. Snow depth was less here than on other runs sampled (by taking snow cores), and patches of straw were evident in early February. Both 'Paiute' and 'Potomac' orchardgrasses showed vigorous growth at this site. No seedlings of mtn. pride were discovered.

Perimeter

This plot is very shaded and seedling growth was slow until late summer when soil temperatures finally began to rise. Results were mixed. Pubescent wheatgrass was the only species identified in the area recieving the 'hydromulch-only' treatment. Many of these plants produced seed and were as high as two feet. In contrast, by far the dominant species in the 'straw mulch only' plot was mtn. brome, which also went to seed in late September. Effects of wind erosion were obvious and areas lacking mulch had fewer seedlings. Seedling density was lower where straw applications were exceptionally heavy.

Dipper

This highly exposed site which was also at the highest elevation tested produced much better cover than expected. However, mix #2 was very windblown and no seedlings of either 'Paiute' orchardgrass or squirreltail were found. The fescues and bluegrasses dominated the mix and had achieved as much as 3" of top growth by September. Mix #3 appeared to be more vigorous although site conditions (less wind and therefore less loss of moisture retaining mulches) rather than species composition may have been responsible.

Canyon

Growth was exceptionally slow on Canyon. A NNW exposure and high elevation (9600') contributed to the late warming of soils, which were still cool in late August. No species were particularly outstanding but mix #7 appeared to produce more cover than #6. This could be attributed to the uneveness of the terrain on that run which created pockets for water accumulation and provided protection from dessicating forces.

Waterfall

Periodic irrigation from rainbirds began in mid-July. No records of rates of application were kept. The mix was not dominated by a particular species but 'Paiute' orchardgrass, mtn. brome and slender wheatgrass showed excellent growth. Irrigation undoubtedly alleviated droughty conditions and seedlings remained green throughout the growing season. Over fifty seedlings of birdsfoot trefoil were counted in mid-July but numbers decreased by late August.

1985 Plantings and Preliminary Results

Plantings

Legume and shrub plantings on Olymic Run began in late May when snow had melted enough to allow access. Soil moisture was good and patches of snow were still evident.

Approximately 350 plugs of Gray's lupine were interplanted with emerging grasses. These plugs, grown by the Nevada Division of Forestry from Sierra germplasm in super cells, had been successfully innoculated by lupine rhizobia strain 'H' (donated by the Nitragin Co., Milwaukee, Wisconsin). A small test plot of 100 plants in 2' spacing (Appendix C) was established to test the effectiveness of a starch polymer (trade name Aqualox) which was expected to reduce moisture stress, and hence mortality, in the root zone. The remaining 250 plants were randomly planted between the upper two water bars. A small amount of topsoil, collected from near seed source plants, and about 1/4 tsp. of aqualox (except non-treated plants in the test plot), were added to each planting hole. Plants were lightly watered in and mulched with straw.

Mountain pride and pinemat manzanita were selected for on-site shrub transplants. Mtn. pride is a beautiul low-growing sub-shrub that naturally invades unstable, gravelly slopes. It is easy to handle and has successfully established in many Basin test plantings. Pinemat manzanita is a prostrate shrub that literally forms extensive and dense green mats. It is often found on dry, rocky slopes. Although it is an excellent soil stabilizer, it is difficult to propagate and is slow-growing. Both species occur adjacent to the ski run.

A total of 18 mtn. pride and 38 pinemat manzanita plants, or parts thereof, were carefully removed from adjoining slopes and randomly transplanted to the slope between the lower two water bars. Plants were hand watered and mulched with straw. Osmocote (18-6-12), a slow release fertilizer, was applied several weeks later. Pinemat manzanita was difficult to transplant as separate plats were difficult to distinguish and woody roots bore few fibrous rootlets.

Preliminary Results

Lupine transplants initially appeared very successful. By early August, many plants had more than quadrupled in size and six plants flowered. However, by September numbers were greatly reduced. Extensive grazing by small mammals was a major cause of mortality but other factors, such as drought, may have contributed. Results from the test plot were inconclusive and there were too few replications to allow for valid statistical analysis. Ten and twelve plants in were counted in the treated and untreated plots, respectively. No count was conducted for the remaining 250 plants.

Preliminary results for the shrub plantings were mixed. Mtn. pride survived the transplanting better than the pinemat manzanita. By early August six penstemon plants had flowered. By September, 72% remained. In contrast, only 23% of the manzanita plants survived. Both lupine and shrub plantings will be re-evaluated in the summer of 1986.

Conclusions and Recommendations

Species recommendations were not made after only one season of growth. In the Lake Tahoe Basin grasses may require several years to emerge. However, slender wheatgrass and mtn. brome generally showed excellent vigor and rapid establishment. Locally collected germplasm of squirreltail and needlegrass established very well but may be impractical on a large scale. Unless small mammal grazing is controlled, lupine transplantings may also be uneconomical. Direct seeding of lupine is less labor-intensive but more data is needed before conclusions can be reached. Initial survival of on-site mtn. pride transplants was very high and this may be a viable alternative or addition to other revegetation techniques. Greenleaf manzanita may be more successful from transplanted container-grown stock since root systems would be intact when transplanted. We concluded that as long as straw was tacked, crimping was either ineffective or detrimental. As an alternative to applying hydromulch (with fiber) we suggest spraying a tackifier directly over the straw. It effectively penetrates and holds the fibers together.

Future Research and Erosion Control Objectives

Cover studies will be conducted on all plots during 1986 according to the Daubenmire method (Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northw. Sci. 33:43-64). Rectangular quadrats measuring 20 cm X 50 cm will be placed one meter apart on alternative sides of a randomly located 15 m transect yielding a total of 30 sample quadrats. Two transects will be located on each seed mix for each site. Percent survival will be determined for transplanted lupines and shrubs.

Due to these and other tests, the Forest Service is encouraging the increased use of shrub and sub-shrubs for erosion control. Promising species are listed in Appendix Table 1 although *Eriogonum marifolium*, *Chrysothamnus viscidiflorus*, several species of manzanita (*Arctostaphylos* spp.) and buckthorn (*Ceanothus* spp.) are also being considered. Additional plantings will take place at Heavenly in the spring and fall of 1986. Two sites have been selected, with and without water (Patsy's and the top of Dipper, respectively). Selected species are being grown from Sierra germplasm. Availabilty will determine plot design but species will be distributed randomly. The largest individuals will be planted at the top of the slope for most effective erosion control. Forest Service personnel will train two Heavenly Valley employees in proper planting and revegetation techniques. The ski area will ultimately assume full responsibility for implementing Forest Service recommendations.

We are also in the process of revising our erosion control specifications for the ski area. The most severely disturbed slopes posing the greatest threat to water quality will be revegetated first. We maintain the flexibilty to change prescriptions as species availabilty and techniques change.

APPENDIX A

Tables

Table 1.
Selected Species

1984 PLANTING

Agropyron trachycaulum
slender wheatgrass
Agropyron tricophorum
'Luna' pubescent wheatgrass
Bromus marginatus
'Bromar' mountain brome
Dactylis glomerata
'Potomac' and 'Paiute' orchardgrass
Festuca ovina
sheep fescue
Festuca ovina ssp. duriuscula
'Durar' hard fescue
Linum lewisii
Lewis flax
Lotus corniculatus
birdsfoot trefoil
Lupinus grayi
Gray's lupine
Poa ampla
'Sherman' big bluegrass
Poa canbyi
'Canbar' Canby bluegrass
Sitanion hystrix
squirreltail
Stipa occidentalis
needlegrass

1985 PLANTING

Arctostaphylos nevadensis
pinemat manzanita
Lupinus grayi
Gray's lupine
Penstemon newberryi
mountain pride

RECOMMENDED SPECIES FOR 1986 PLANTING

Chrysothamnus nauseosus
rabbitbrush
Eriogonum umbellatum
sulphur flower
Lupinus grayi
Gray's lupine
Penstemon newberryi
mountain pride

Table 2.
Seed Mixes, Sites, and Rates

Mix #	Species	Sites Planted/# of Acres	lbs/Mix	Percent of Mix	Seeding Rate: lbs/acre
1	*Sitanion hystrix* squirreltail	Nevada flats 1/20	3.5		1/5
	Stipa occidentalis needlegrass		2.5		
	Lupinus grayi lupine		approx. 3000 seeds		
	Lotus corniculatus birdsfoot trefoil		1/2		
2	*Sitanion hystrix* squirreltail	Dipper 1/2	15	10	100
	Festuca ovina ssp. *duriuscula* 'Durar' hard fescue		9	18	
	Festuca ovina sheep fescue		8	20	
	Poa ampla 'Sherman' big bluegrass		6	19	
	Poa canbyi 'Canbar' canby blugrass		4	13	
	Dactylis glomerata 'Paiute' orchardgrass		8	20	
	Linum lewisii Lewis Flax		1/2		
3	'Durar' hard fescue	Dipper 1/2	8	21	100
	sheep fescue		5	16	
	'Sherman' big bluegrass		5	20	
	'Canbar' Canby bluegrass		3	13	
	'Potomac' orchardgrass		7	20	
	Agropyron trachycaulum slender wheatgrass		22	10	
	Linum lewisii Lewis Flax		1/2		

Table 2. (con't.)

Mix #	Species	Sites Planted/# of Acres	lbs/Mix	Percent of Mix	Seeding Rate: lbs/acre
4	squirreltail	Olympic Run	15	16	100
	'Durar' hard fescue	1/2	6	18	
	sheep fescue		4	15	
	'Sherman' big bluegrass		3	14	
	'Canbar' Canby bluegrass		3	15	
	'Paiute' orchardgrass		4	14	
	Agropyron tricophorum		15	8	
	'Luna' pubescent wheatgrass				
	Linum lewisii		1/2		
	Lewis Flax				
5	'Durar' hard fescue	Olympic Run	8	21	100
	sheep fescue	1/2	5	16	
	'Sherman' big bluegrass	Perimeter	5	20	50
	'Canbar' Canby bluegrass	1/2	3	13	
	'Potomac' orchardgrass		7	20	
	'Luna' pubescent wheatgrass		22	10	
	Linum lewisii		1/2		
	Lewis Flax				
6	'Durar' hard fescue	Perimeter	5	20	50
	sheep fescue	1/2	2	10	
	'Sherman' big bluegrass	Nevada Flats 2[1]	2	13	50
	'Canbar' Canby bluegrass	1/10	2	13	
	'Paiute' orchardgrass	Canyon	3	14	50
	slender wheatgrass	1	13	15	
	Bromus marginatus	Waterfall[2]	23	15	50
	'Bromar' mountain brome	1/2			
	Linum lewisii		1/2		
	Lewis Flax				
7	'Durar' hard fescue	Canyon	6	20	50
	sheep fescue	1	5	20	
	'Sherman' big bluegrass		3	15	
	'Canbar' Canby bluegrass		2	11	
	'Potomac' orchardgrass		4	15	
	'Luna' pubescent wheatgrass		7	4	
	slender wheatgrass		15	7	
	'Bromar' mountain brome		8	8	
	Linum lewisii		1/2		
	Lewis Flax				

[1] 1/4 lb. of birdsfoot trefoil was added to the mix for this site.
[2] 2 lbs. of birdsfoot trefoil were added to the mix.

Table 3.
Cost Estimates of Supplies

Supply	Unit	Price/Unit [1]	Cost Per Acre	Total
Hydromulch (conwed 2000)	60 lb bales	$ 20.00	160.00	890.00
Fertilizer (16-20-0 + sulphur)	lb	$ .15	36.00	200.00
Mulch (straw)	75 lb bales ($70.00/ton)	$ 2.50	135.00	740.00
Seed	lb	$ 3.00	145.00	800.00
Vehicle [2]	1-2 wk. rental	$145.00 (average)	190.00	1030.00
Equipment Rental (water truck)	hr. rental	$ 45.00	400.00	2230.00
Totals			1070.00	5900.00

[1] includes delivery costs
[2] six pack
lowboy
dump truck
cat
1 four wheel drive PU
1 two wheel drive PU
stakeside truck

Table 4.
Cost estimates of labor

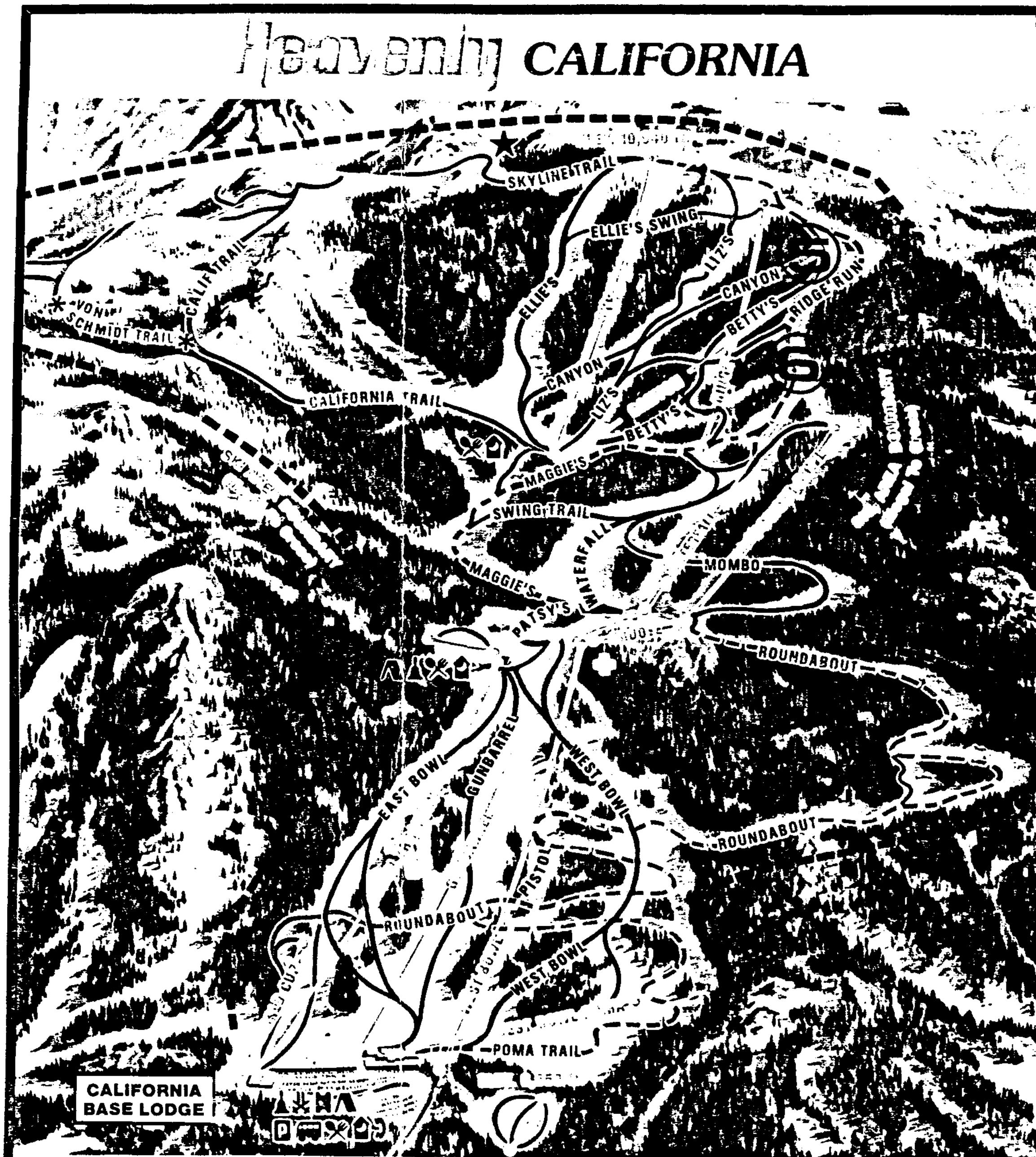
Type of Labor	Person hours Per Acre	Cost Per Acre [1]	Total
Ripping	2	20	110.00
Seeding amd Fertilizing	5	50	275.00
Harrowing (by catepiller)	1	10	55.00
Mulching	20	200	1100.00
Crimping	1	10	55.00
Hydromulching	20	200	1100.00
Miscellaneous	60	600	3300.00
equipment maintenance			
travel			
materials delivery			
rock removal			
other			
Totals	90/acre	1090	6000.00

[1] based on an average labor cost of $10.00/hr.

APPENDIX B

Location of Test Plots

#1 Nevada Flats	#3 Perimeter
#2 Olympic	#4 Dipper



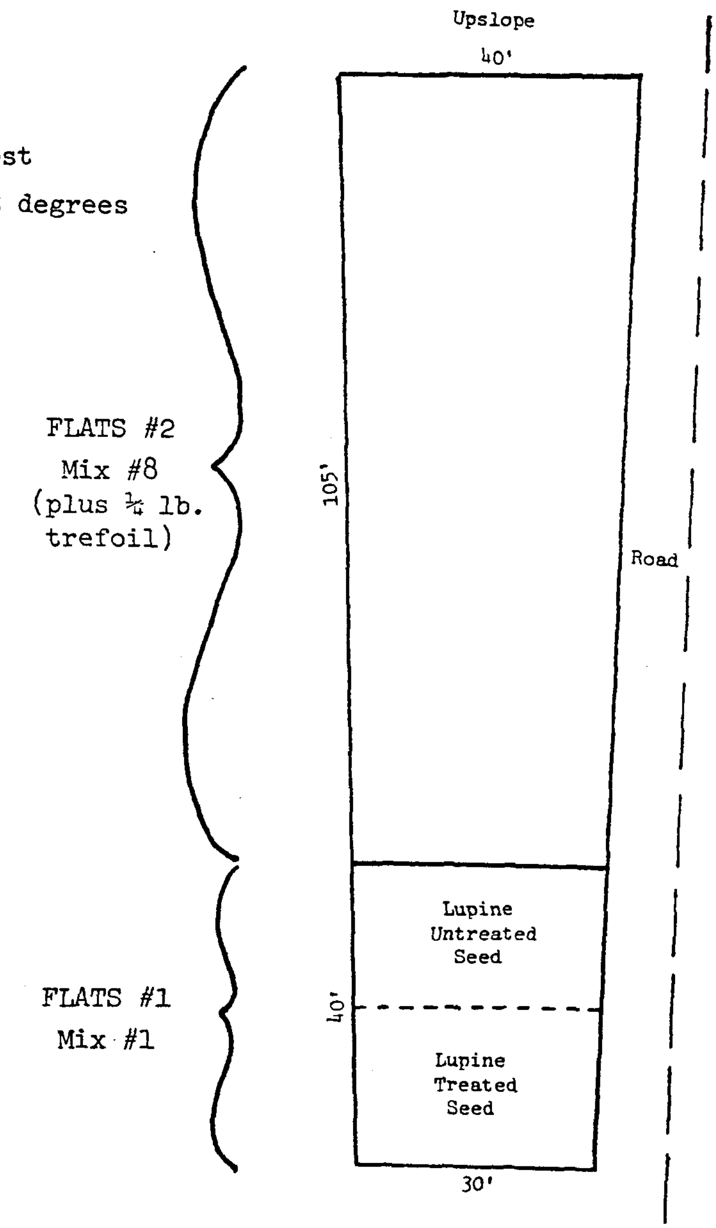
#5 Canyon #6 Waterfall

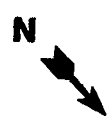
APPENDIX C

Plot Designs

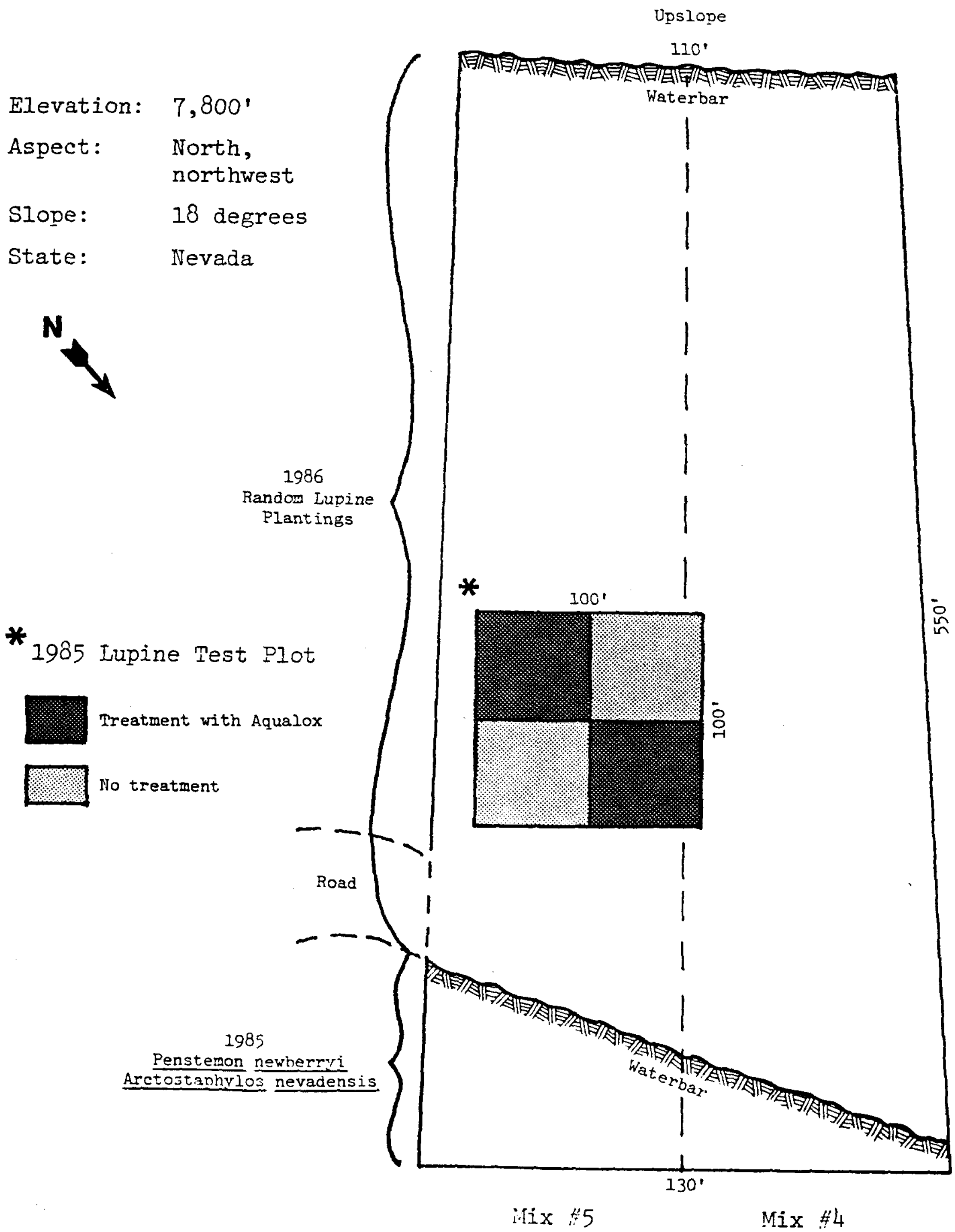
Plot Design 1. Nevada Flats

Elevation: 8,000'
Aspect: Northwest
Slope: Flat, 3 degrees
State: Nevada





Plot Design 2. Olympic



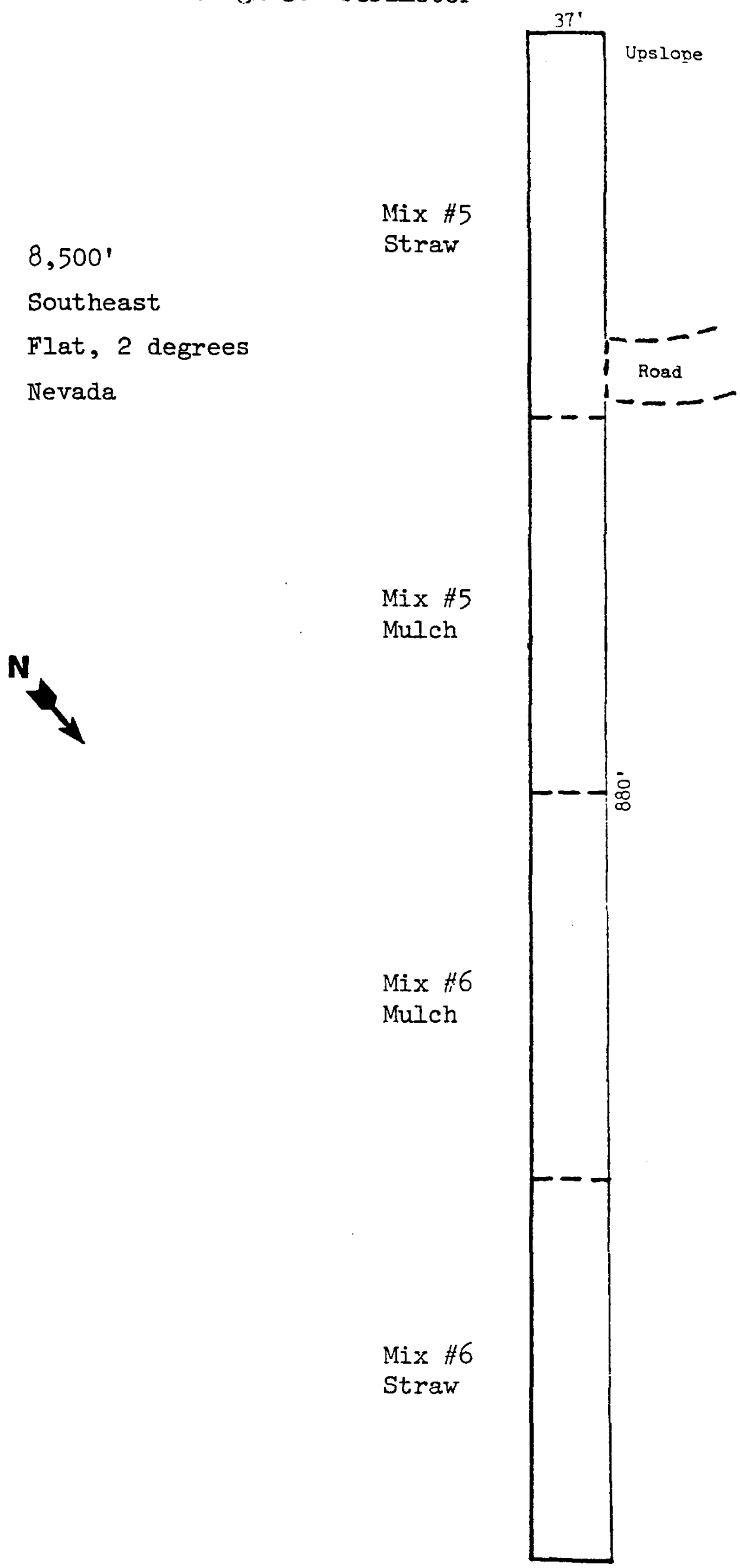
Plot Design 3. Perimeter

Elevation: 8,500'

Aspect: Southeast

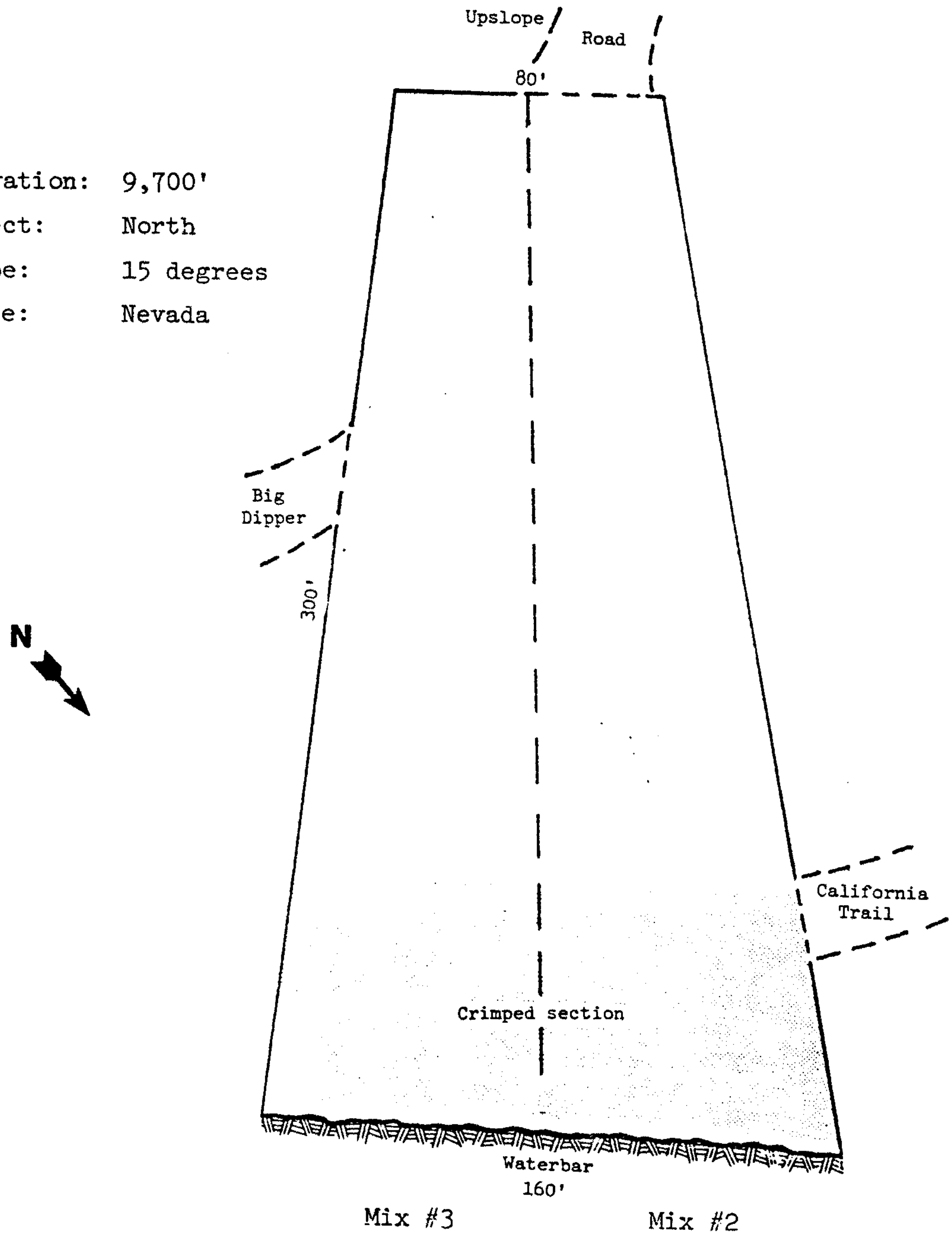
Slope: Flat, 2 degrees

State: Nevada

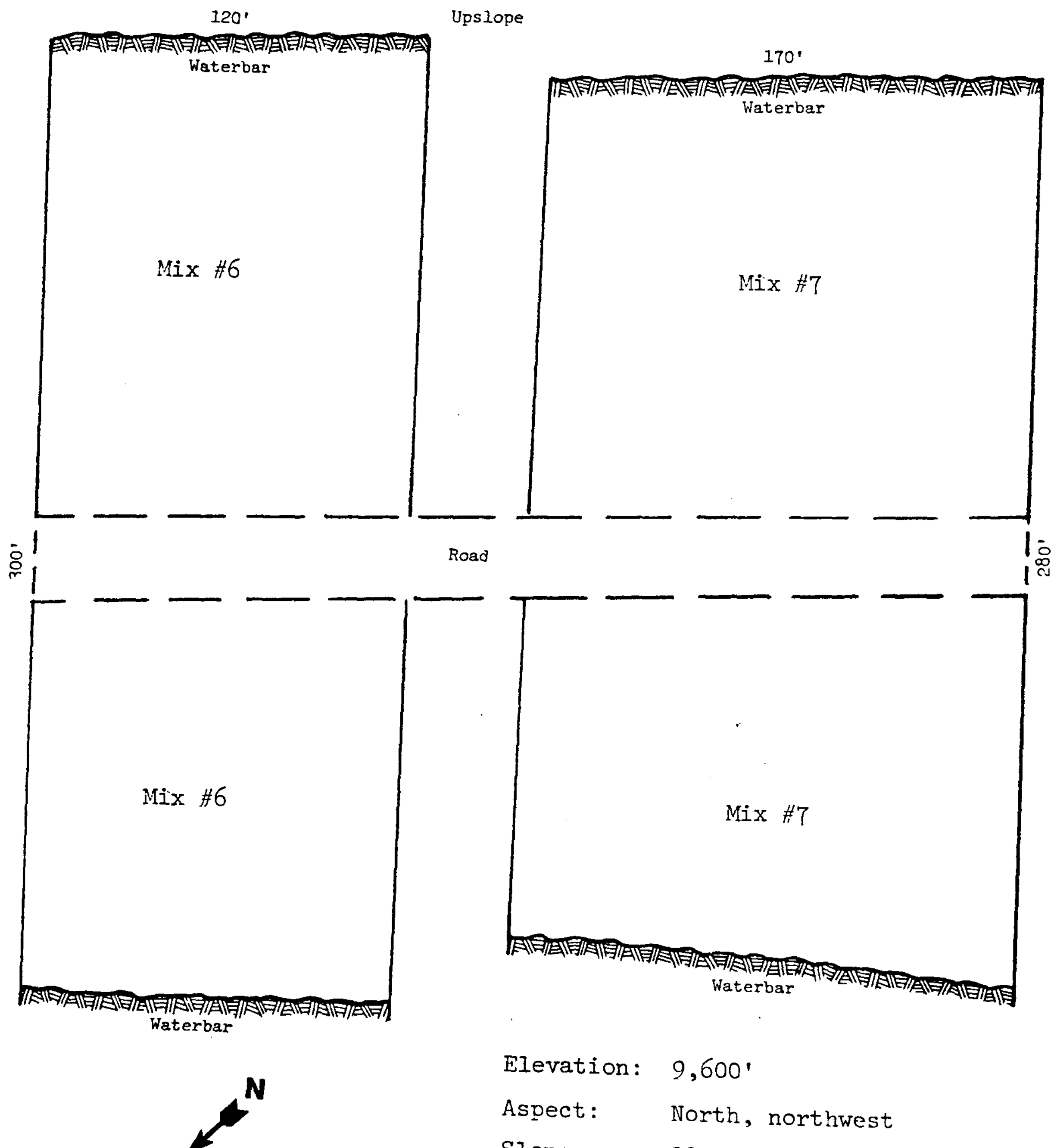


Plot Design 4. Dipper (Orions)

Elevation: 9,700'
Aspect: North
Slope: 15 degrees
State: Nevada



Plot Design 5. Canyon



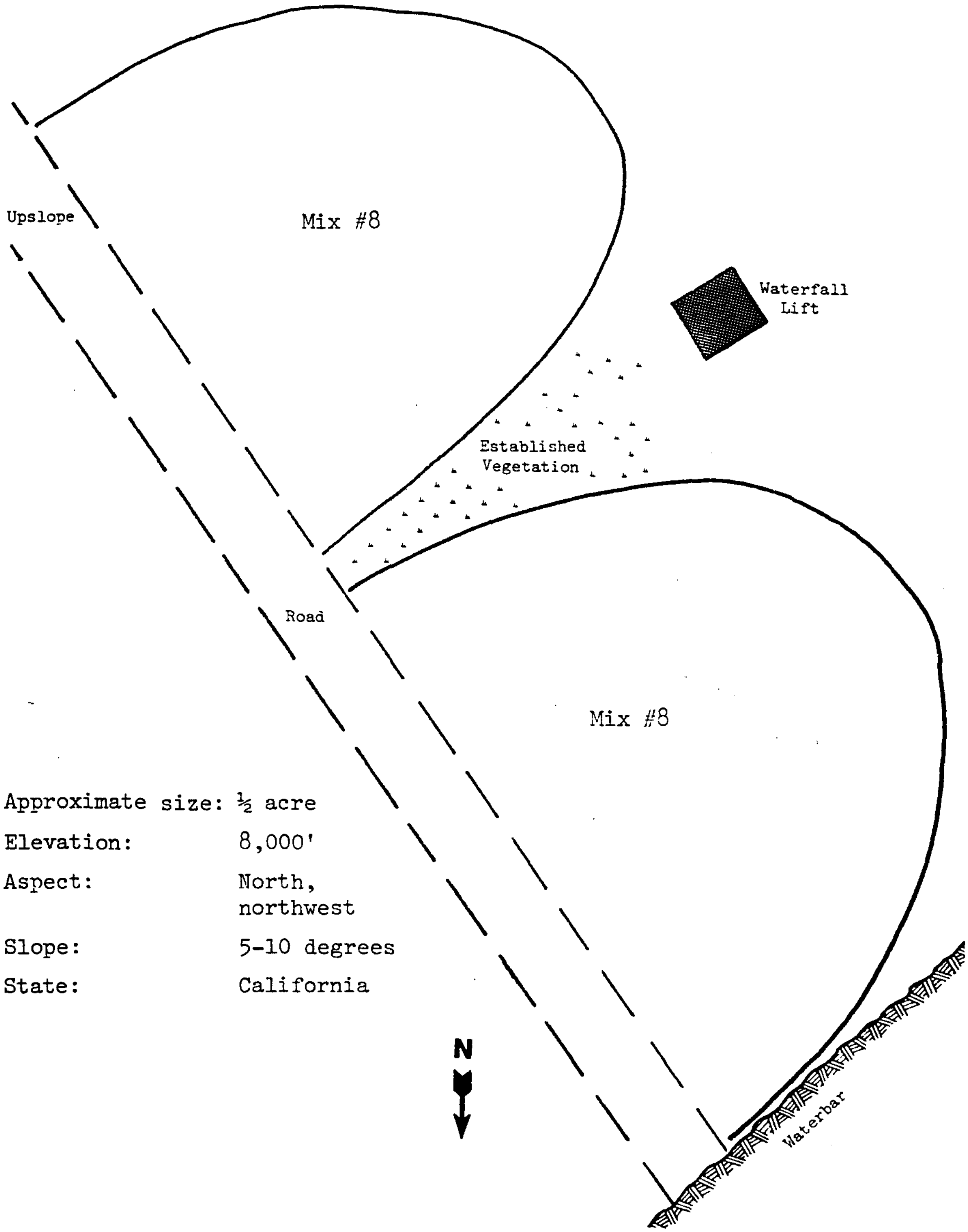
Elevation: 9,600'

Aspect: North, northwest

Slope: 20 degrees

State: California

Plot Design 6. Waterfall



Approximate size: ½ acre

Elevation: 8,000'

Aspect: North, northwest

Slope: 5-10 degrees

State: California

THE EROSION CONTROL AND REVEGETATION MAT...PRODUCT & APPLICATION

James S. Martin
Mirafi, Inc.,

The erosion control and revegetation mat (ECRM) is a new concept in erosion control products and technology that offers a cost effective alternative to riprap and paved linings. ECRM can be generically described as a flexible three dimensional web of bonded synthetic monofilaments which provides ground armor to resist erosion while allowing natural vegetation to establish. Erosion control and revegetation mats have been developed especially for use in areas where simple mulching techniques do not work because of severe erosive forces, i.e., steep slopes, ditches, and banks. The area to revegetate is simply seeded, fertilized, and covered by the mat.

Erosion control and revegetation mats perform three basic functions: temporary erosion control, mulching, and permanent erosion control. The mat serves the temporary erosion control function by providing adequate ground cover to shield the soil surface from the impact of rainfall and the erosive force of overland flow. In addition, the mat conforms closely to the ground surface to retain soil and seed in place.

Mulching is generally required to establish new vegetation on freshly graded soil surfaces. Erosion control and revegetation mats provide this vital function by retaining the moisture and heat necessary to promote seed germination. In addition, the mats retain sediment from runoff. This sediment provides a medium for root growth. Most importantly, the mat provides adequate porosity for uninhibited stem growth and maturation through the mat.

Once vegetation is established, the erosion control and revegetation mat provides a permanent erosion control function as it becomes imbeded in the new stem and root system. The mat reinforces and anchors the vegetation in place as a cohesive unit, protecting against scouring of the ground around the root system and subsequent washout of the vegetation.

ECRM can be used in a variety of applications where revegetation is desired but overland flow or minor wave action causes erosion that prohibits the establishment of vegetation. The major end use categories for ECRM are as follows:

- in ditches for roadway and parking lot runoff
- In storm and irrigation channels
- at outlets for pipes and culverts
- on banks of ponds and lakes
- on slopes of roadway berms, bridge abutments and building sites

The following is a case history that illustrates the performance and benefits of erosion control and revegetation mats over conventional erosion control alternatives.

CASE HISTORY: Erosion protection of natural stream channels at the Castle Pines Golf Course, Castle Pines, Colorado.

The development of the Castle Pines residential area and golf course, a 4,000 acre project located south of Denver provided engineers and architects with formidable erosion control challenges. In particular, the stablization of the major stream channels within the golf course required careful design in order to meet the erosion protection and aesthetic requirements of the Castle Pines development.

Within the stream channels at Castle Pines concrete and rip-rap drop structures were constructed to help minimize the erosive effect of the change in elevation of the stream as it flows through the golf course. One of the major prerequisites established by the golf course architects was that the slopes of the stream banks where the drop structures were located be protected from erosion up to the one hundred year flood level and also be aesthetically pleasing. The natural stream flowed through a very attractive steep pine forest terrain. It was important, therefore, that a material be chosen that was visually attractive and able to prevent erosion from occurring from the stream bank's fifty year flood depth to its one hundred year flood depth. Rip-rap was rejected because it did not meet the aesthetics requirement. The material chosen to meet this criteria was Miramat Erosion Control and Revegetation Mat. Miramat was chosen because it would allow for revegetation of the native grasses along the stream banks yet provide stablization of the banks during extreme water flows.

The Miramat installation and seeding operations began in the early Fall of 1985. In Eastern Colorado the early fall planning season is ideal for seed germination and root development prior to winter dormancy. During the winter the Miramat provided added protection by protecting the seed against rainfall and storm water runoff. In the Spring of 1986 the grasses will begin their optimum growth and the channel will be completely vegetated and ready for the high water flows associated with the Spring season.

Miramat is ideal for high altitude installations because of the way it conforms to the contours of the terrain while promoting rapid growth of mountain grasses through the mat. In addition, Miramat does not degrade as a result of climatic change, but rather provides a permanent root reinforcement of the grass system. This benefit helps protect the roots against high velocity storm water flows over the life of the erosion control project.

NEW DEVELOPMENTS IN PLANT MATERIALS FOR HIGH ELEVATIONS

Jack R. Carlson
USDA-Soil Conservation Service
West National Technical Center

Revegetation of high elevation disturbed sites is primarily accomplished using introduced pasture grasses and legumes, or turf species. These species are readily available on the commercial market and relatively low priced. Species include tall fescue *(Festuca arundinacea)*, smooth brome *(Bromus inermis)*, meadow foxtail *(Alopecurus pratensis)*, perennial ryegrass *(Lolium perenne)*, timothy *(Phleum pratense)*, orchardgrass *(Dactylis glomerata)*, intermediate wheatgrass *(Thinopyrum intermedium)*, hard fescue *(Festuca longifolia)*, creeping red fescue *(Festuca rubra)*, and Kentucky bluegrass *(Poa pratensis)*. Most cultivars of this introduced group were developed for lower elevations and most have been available for several years. New varieties have been either imports from Canada or Europe, or have been the result of private breeding efforts to improve forage production or turf quality. Very little work has been done to develop cultivars of introduced species specifically for high-elevation revegetation in the western United States. Emphasis in the past has been to evaluate existing cultivars on these sites. Since many have performed well, they are used extensively. Several papers at previous High-Altitude Revegetation conferences (Berg 1974, Townsend 1974, Eamon 1974, Cuany 1974, Plummer 1976, Kenny and Cuany 1978, and Hassell 1980) have reported experience with introduced species as well as identified high potential native species and efforts to improve them.

Development of new plant materials for high-elevation sites has focused on the collection, evaluation, selection, and increase of native germplasm. During the seventies, projects were initiated by the Soil Conservation Service (SCS), U.S. Forest Service (USFS), Colorado State University (CSU), and others, which have resulted in the release of new cultivars. Emphasis has been placed on native species that are prevalent in the upper forest to alpine zones.

In general, native species are more tolerant of low fertility, soil acidity, short growing seasons, and other site factors characteristic of high elevations. The introduced species listed above require considerably more nutrients to maintain adequate stands. They "evolved" under a high nutrient environment. Also as a result of their domestication, introduced species have better seedling vigor and produce vigorous growth, at least in the first few years. Where managed correctly with adequate fertilizer, stands can be maintained on high-elevation sites as one would manage a pasture or turf. Where low maintenance is desired, however, cultivars selected under tougher environments should be used instead. Some turf varieties are suited to harsh conditions, such as certain cultivars of creeping red, hard, or sheep *(F. ovina)* fescue. However, native species contain a vast source of germplasm to develop for this use.

High-elevation erosion control seed mixtures usually are designed to include 3-4 components:

Component	Type
1	Rapidly developing, usually short-lived grass with strong fibrous root system; gives way to longer-lived components.
2	One or more persistent perennial grasses, each with special tolerances that complement each other.
3	One or more forbs, preferably including at least one legume to provide nitrogen; forbs also may be useful for initial cover.
4	One or more shrubs; usually an option, but sometimes a requirement when other component species may be lacking; shrubs usually use moisture deeper in the soil profile.

In the past decade superior accessions have been selected from evaluations of several of the important high-elevation plant species. Some have been released for commercial production. In the near future, revegetation specialists will have several new native cultivars to recommend for each of the components above. This paper summarizes these new developments.

GRASSES FOR RAPID INITIAL COVER

Many introduced species, particularly perennial ryegrass, smooth brome, and tall fescue, have excellent seedling vigor and provide rapid cover. They also are very competitive and often must be specified at lower seeding rates to permit slower developing species to establish. There are some native alternatives that are increasingly being used.

Mountain Brome (*Bromus carinatus*). Mountain brome has been seeded sporadically since the forties for rapid cover on mountain sites. 'Bromar' a selection from western Montana, was released in 1946 for grass-legume cover in rotation with grain crops in eastern Washington. It also has performed well in erosion control seedings in forest habitats, and recent testing on high-elevation sites in the Rocky Mountains show this cultivar provides adequate cover. However, the Meeker (Colo.) Environmental Plant Center (EPC) selected five new strains of mountain brome in 1984 with superior characteristics to 'Bromar' and are increasing seed for further field testing. 'Bromar' will continue to be recommended until a new cultivar is released, probably in the early nineties.

Slender wheatgrass (*Elymus trachycaulus*). 'San Luis' was released in 1984 by the Meeker EPC based on its performance at high elevations. Original seed was collected from Rio Grande County, Colorado at 7,500 feet (2,280 m) elevation. This cultivar establishes well and persists at high altitudes compared to other varieties. Except for 'San Luis', available seed usually is grown and harvested in the northern plains states and Canada.

Slender wheatgrass encompasses a highly variable species complex. Barkworth and Dewey (1985) includes bearded wheatgrass (*Elymus trachycaulus* subsp. *subsecundus*) in this complex. In addition, there is subsp. *latiglume* and *trachycaulus*. 'San Luis' belongs to the latter. As with all *Elymus*, slender wheatgrass contains the S genome from bluebunch wheatgrass (*Pseudoroegneria spicata*) and H genome from *Critesion*, formerly *Hordeum* (Dewey 1984). These SH grasses tend to have excellent seedling vigor and are relatively short-lived, characteristics contributed by *Critesion*. Other native SH grasses adapted to high elevations include blue wildrye (*E. glaucus*), squirreltail (*E. elymoides*), thickspike wheatgrass (*E. lanceolatus*), and Scribner wheatgrass (*E. scribneri*). Of this group, only thickspike wheatgrass, which is rhizomatous, has improved varieties. However, both 'Critana', from north central Montana, and 'Sodar', from eastern Oregon, originate from collections at low elevations and are marginally adapted to subalpine sites and higher.

All of these SH species have been evaluated, at least to a limited degree. Most work currently is centered on squirreltail and blue wildrye. However, the SH species have not been systematically examined as a whole for high elevation sites. Scribner wheatgrass warrants an intensive evaluation because of its adaptation to extreme altitudes. The thickspike wheatgrass complex also needs to be reevaluated in light of the newly discovered biological relationships.

GRASSES FOR LONG-TERM COVER

Smooth brome, tall fescue, red fescue, hard fescue, and intermediate wheatgrass are introduced grasses that have persisted well with proper management on high elevation sites. The fine leaf fescues, such as red and hard fescue, are well suited because they are relatively tolerant of harsh sites, are low-growing, attractive, and often form tight stands. In a sense they have native counterparts in Thurber fescue (*Festuca thurberi*), sheep fescue (*F. ovina*), Idaho fescue (*F. idahoensis*), and Arizona fescue (*F. arizonica*). These and other native species have potential for long-term cover.

Fine-Leaf Fescues. The native fine-leafed fescues are commercially available only in limited quantities. However, selection and breeding efforts have produced four cultivars that are adapted to mountain sites.

'Redondo' Arizona fescue was selected and released in the mid-seventies for revegetation of sites where this species occurs naturally. It originates from the mountains in north central New Mexico. It was selected for overall vigor and improved seed production. Currently, between 2,500 and 7,500 pounds of seed are used annually, but this demand has been judged by revegetation specialists to be less than the projected need for this grass. It should be specified in more seeding mixes.

'Covar' sheep fescue actually is an introduction from the mountains of central Turkey, selected from PI109497 and released by the Pullman (Wash.) Plant Materials Center (PMC) in 1977. However, it is the same species, very similar to native sheep fescue, and has performed very well on a variety of sites in the western United States. 'Covar' persists on droughty soils at lower elevations especially where Idaho fescue and western fescue (*F. occidentalis*) are native. In the Siskiyou Mountains in southwestern Oregon, following the burning of chaparral vegetation, it has excluded the reinvasion of *Ceanothus* and *Arctostaphylos* as well as introduced annual *Bromus* and *Festuca*. 'Covar' also has performed well at higher elevations, where higher elevation strains of Idaho fescue and sheep fescue grow naturally. Although like other fine-leaf fescues in establishing slowly, 'Covar' forms a competitive, low-growing, blue-green cover with a wider amplitude of site adaptation. After a slow start, it is starting to establish its reputation on the commercial market.

Two new varieties of Idaho fescue, 'Joseph' and 'Nezpurs', recently have been released with improved seed production potential. Both cultivars are synthetic varieties developed by the University of Idaho (Ensign 1984) to overcome the low seed production characteristic of this species. Seed is just beginning to appear in the retail seed trade. Idaho fescue grows from sagebrush plant communities to subalpine sites in the northern intermountain area of the western United States. At high elevations, it grades ecologically into sheep and Thurber fescues and to the south into Arizona fescue. 'Joseph' and 'Nezpurs' are adapted to the more mesic parts of the range of Idaho fescue.

Thurber fescue is an important high-altitude fine leaf fescue. However, efforts to domesticate it at the Meeker EPC have been frustrating. Direct seedings on conventional seedbeds have been difficult to establish and, therefore, no appreciable seed production has been achieved.

In 1983, the Bridger (Montana) PMC initiated work with rough fescue (*F. scabrella*) evaluating 40 accessions collected in western Montana in a uniform garden nursery at Missoula. The Corvallis (Oregon) PMC has evaluated 60 accessions of western fescue (*F. occidentalis*) identifying one accession with superior attributes to 'Covar' sheep fescue. The 60 accessions originate from native stands in the Siskiyou Mountains of southern Oregon and northern California. A systematic evaluation of native fine-leaf fescue germplasm, involving *ovina*, *idahoensis*, *arizonica*, *occidentalis*, *thurberi*, *viridula*, *scabrella*, and *californica*, would be useful in helping to select strains for high altitudes.

<u>Tufted hairgrass (*Deschampsia cespitosa*)</u>. This widely adapted species found on moist subalpine to alpine ridges and slopes in the mountains of the western United States should be a standard in high altitude seed mixtures in the near future. Research by Ray Brown with the U.S. Forest Service (USFS) (see Chambers et al. 1984) has culminated in the selection and initial seed increase of superior accessions at the Meeker EPC. Selections originate from populations in the North Park and Peru Creek areas of Colorado, and from the Wallowa Mountains in northeastern Oregon. These strains show best overall performance on several high altitude sites in the Rocky Mountains. Studies at the Corvallis Plant Materials Center (PMC) show this species to be a prolific seed producer in the Willamette Valley.

Beardless wildrye *(Leymus triticoides)*. This native grass is closely related to basin wildrye *(L. cinereus)*, which usually is associated with sagebrush *(Artemisia)* plant communities, occupying bottomland, often somewhat saline, sites. Certain beardless wildrye strains are much more salt tolerant. 'Shoshone' was released by the Bridger (Montana) PMC in 1980 after it performed well on saline seeps with salinities as high as 20 mmhos/cm.

According to Dewey (1984), beardless wildrye, a member of the Triticeae tribe, contains a J and N genome, the J is contributed by *Thinopyrum* (intermediate wheatgrass is a J species) and N is contributed by *Psathrostachys* (Russian wildrye is a N species). Other JN grasses include basin wildrye, giant wildrye *(L. racemosus)*, American dunegrass *(L. mollis)*, Altai wildrye *(L. angustus)*, and beach wildrye *(L. arenarius)*. With this generic evidence of adaptation to saline and sandy environments, it is not surprising to find native strains of beardless wildrye on hard rock mine tailings at high altitudes in the Rocky Mountains. A collection from Cripple Creek, Colorado, has shown exceptional rhizome development at the Meeker EPC. 'Volga' giant wildrye (a JN species) has performed well at the Silverton mine tailings in Colorado. Beardless wildrye represents a native alternative.

Needlegrasses. Although the taxonomic picture of the genus *Stipa* is somewhat unclear, there are four species found at high elevations in the western United States. Letterman *(S. lettermanii)* and pine *(S. pinetorum)* needlegrasses both have a base chromosome number n=16 (Johnson 1972). Columbia *(S. nelsonii*, formerly *columbiana)* and western *(S. occidentalis)* needlegrasses have a base number n=18. This suggests that there are two germplasm pools to evaluate for high-altitude revegetation. There is some evidence of natural hybrids between *nelsonii* and *occidentalis* (Johnson 1972). The geographic ranges of *pinetorum* and *lettermanii* overlap, suggesting in the abscence of crossing data, a common origin and subsequent divergence to different habitats and reproductive isolation.

Very little selection or evaluation of these species has been completed. However, the Meeker EPC has selected three accessions of *nelsonii* and is increasing seed for further trials. There is a need to collect more germplasm of all four species for evaluation. A major obstacle to domestication is low seed production. Nevertheless, the first commercial release may be ready within five years. Future selection and breeding must take into account the biological relationships among the species.

Other grasses. The Meeker EPC is evaluating several collections of alpine timothy *(Phleum alpinum)*, but preliminary results show this species relatively difficult to handle agronomically, with low seed production a major limitation. Little or no selection work is being conducted with alpine bluegrass *(Poa alpina)*, trisetum *(Trisetum spicatum)*, or sedges *(Carex* spp.). 'Reubens' Canada bluegrass *(Poa canadensis)*, although not native to high elevation sites, has performed well with its low-growing, sod-forming habit.

FORBS

Past revegetation efforts at high elevations have included several introduced forb species such as sweetclover (*Melilotus* spp.), alfalfa (*Medicago sativa*), clover (*Trifolium* spp.), trefoil (*Lotus* spp.), and cicer milkvetch (*Astragalus cicer*). 'Monarch' cicer milkvetch, developed by C. E. Townsend at CSU, has greatly improved seedling vigor and has performed very well in high elevation revegetation projects. Evaluations are underway for some of the native forbs.

Sweetvetch (*Hedysarum boreale*). In the past several years, numerous accessions of Utah sweetvetch (var. *utahensis*) have been evaluated by R. L. Cuany at Corvallis State University, M. L. Rumbaugh (Agricultural Research Service (ARS), Logan, Utah), the Meeker EPC, and the USFS Shrub Sciences Laboratory. Selections from a population on the Orem Bench in central Utah are being increased for further evaluation and possible release. This species is adapted to mountain sites at moderate elevations. Breeding efforts are attempting to improve establishment success. Germination and seedling development are characteristically slow.

Penstemons. 'Bandera' Rocky Mountain penstemon (*Penstemon strictus*) was released by the Los Lunas PMC in 1973 for revegetation in the southern Rocky Mountains. It has faired well on the commercial market, due in part to its ornamental value. It has proven a useful component of seed mixtures at elevations between 6,000 and 11,000 feet (1,830 and 3,355 m).

Although there are numerous penstemons that occur at high altitudes in the western United States, and some have been included in evaluation nurseries in the past decade, one species ready for immediate increase and use in revegetation projects is mountain pride penstemon (*P. newberryi*). This species occurs at moderate to high elevations in the Sierra Nevada Mountains. It forms a low-growing mat with attractive rose-red flowers. It has been extensively tested in the Lake Tahoe Basin (Edmunson 1976, Clary 1983) and shown to establish, persist, and provide good cover on harsh sites. Limited seed and plants are commercially available and an effort is needed to increase and release the Lake Tahoe strain to encourage wider use.

SHRUBS

In the past 15 years, numerous native shrub species have been evaluated in high elevation revegetation trials, resulting in new plant releases and increased use in revegetation projects.

Louisiana sage (*Artemisia ludoviciana*). 'Summit' Louisiana sage was released in 1985 by the Meeker EPC and USFS Shrub Sciences Laboratory based on its ability to stabilize disturbed sites at high elevations in the Rocky Mountains. This cultivar originates from a population at Georgetown Summit in southeastern Idaho. The species is highly variable and occurs on a variety of sites from low elevations over much of the western United States. 'Summit' is strongly rhizomatous and establishes quickly. It provides an environment that aids the establishment of grasses and plants of later successional stages. It is recommended for plantings on critical areas between 6,000 and 10,500 feet (1,800 and 3,500 m) elevation.

Bitterbrush *(Purshia tridentata)*. The first cultivar of this species, 'Lassen', was released in 1984 by the USFS, SCS, Utah Department of Wildlife Resources (DWR), and six other agencies. It originates from a large population along the eastern foothills of the Sierra Nevada Mountains near Susanville, California. 'Lassen' represents a tall upright ecotype, which has been used in range seedings and critical area plantings since the mid-fifties. It has established and provided good cover in the Lake Tahoe Basin between 6,000 and 8,000 feet (1,950-2,600 m) and other moderate to high elevation sites in the intermountain area. Seed and plants are available commercially.

Mountain Mohogany *(Cercocarpus montanus)*. 'Montane' mountain mohogany was released in 1978 by the Los Lunas (New Mexico) PMC, a selection from a native population in the Santa Fe Mountains near Coyote, New Mexico. It has proven well suited for revegetation of disturbed sites where the species occurs naturally, between 3,500 and 9,500 feet (1,130 and 3,050 m) elevation. Plants are available commercially.

Other Shrub Species. Several other shrub species are in final stages of testing and are nearing release, which are proving adapted to high altitudes. The 'Hobble Creek' strain of mountain big sagebrush *(Artemisia tridentata* subsp. *vaseyana)* selected by the USFS from a population in central Utah is planned for release in 1986. PI421013 sulfur buckwheat *(Eriogonom umbellatum)*, from the central Sierra Nevada Mountains, is being increased at the Lockeford (California) PMC and will be released soon.

The Meeker EPC and USFS Shrub Sciences Laboratory have selected several woody accessions for increase and further testing at high elevations, including the following:

Accession	Species	Origin
T21438	Saskatoon serviceberry *(Amelanchier alnifolia)*	Garfield Co, CO
T21471	Fringed sage *(Artemisia frigida)*	Rio Blanco Co, CO
T24047	Shrubby cinquefoil *(Potentilla fruticosa)*	Park Co, CO
T38528	Bitterbrush *(Purshia tridentata)*	Fountain Green, UT
T24417	Bitterbrush *(Purshia tridentata)*	Maybell, CO

Several shrubs have been evaluated by the Lockeford (Calif.) PMC at moderate to high elevations in the Sierra Nevada Mountains. The following accessions have performed the best and warrant further testing for possible release:

Accession	Species	Origin
T6504	Greenleaf manzanita *(Arctostaphylos patula)*	Tahoe Basin, NV
PL238-71	Squaw carpet *(Ceanothus prostratus)*	Tahoe Basin, NV
PL139-72	Whitethorn *(Ceanothus cordulatus)*	Tahoe Basin, NV
PL140-72	Snowbrush *(Ceanothus velutinus)*	Tahoe Basin, NV

SUMMARY

Considerable plant selection and development is underway by SCS, USFS, ARS, CSU, and others to support revegetation efforts at high elevations in the western United States. This work is concentrating primarily on native species. The work will not be complete until the major species representing the primary and early seral stages of succession on disturbed sites are commercially produced in sufficient quantities to meet the demand for planting. Because the overall demand for seed for high elevations is limited compared to agricultural crops, cultivars should be developed that are adapted to all major mountain ranges in the western United States. Evaluations should be coordinated so that selected strains are tested over a wide area. For example, the Meeker EPC mountain brome selections should be evaluated in the Cascades, Sierra Nevadas, Arizona mountains, and throughout the Rocky Mountain system where the species occurs naturally.

LITERATURE CITED

1. Barkworth, M. E. and D. R. Dewey. 1985. Genomically based genera in the perennial triticeae of North America: identification and membership. Am. J. Bot. 72(5): 767-776.

2. Berg, W. A. 1974. Grasses and legumes for revegetation of disturbed subalpine areas. Proc. Workshop Reveg. of High-Altitude Disturbed Lands. CSU CWRRI Info. Series No. 10: 31-35.

3. Clary, R. F. 1983. Planting techniques and materials for revegetation of California roadsides. Research Report FHWA/USDA LPMC-2. CALTRANS, Sacramento, CA. 161 pp.

4. Cuany, R. L. 1974. Plant breeding and its role in supplying new plant materials. Proc. Workshop Reveg. of High-Altitude Disturbed Lands. CSU CWRRI Info. Series No. 10: 44-54.

5. Dewey, D. R. 1984. The genomic system of classification as a guide to intergeneric hybridization with the perennial Triticeae. From: Gene Manipulation in Plant Improvement, J. P. Gustafson (ed.) 16th Stadler Genetics Symposium. pp. 209-279.

6. Eamon, T. K. 1974. Plant species potentials for high-altitude revegetation. Proc. Workshop Reveg. of High-Altitude Disturbed Lands. CSU CWRRI Info. Series No. 10: 39-43.

7. Edmunson, G. C. 1976. Plant materials study, a search for drought-tolerant plant materials for erosion control, revegetation, and landscaping along California highways. Research Project USDA SCS LPMC-1. CALTRANS, Sacramento, CA. 276 pp.

8. Ensign, R. D., U. G. Hickey, and T. J. Bakken. 1984. Joseph and Nezpurs Idaho fescue: forage grasses for the Intermountain-Northwest. Ida. Agric. Exp. Sta. CIS No. 736.

9. Hassell, W. 1980. Latest advance in plant materials development at the Meeker Environmental Plant Center. Proc. High-Altitude Revegetation Workshop No. 4. CSU CWRRI Info. Series 42: 153-172.

10. Hassell, W., J. Carlson, and J. Doughty. 1983. Grasses for mountain sites. Proc. Symposium: Managing Intermountain Rangelands - Improvement of Range and Wildlife Habitats. USFS General Tech Report INT-157, pp. 95-101.

11. Johnson, B. L. 1972. Polypoidy as a factor in the evolution and distribution of grasses. In The Biology and Utilization of Grasses, U. B. Younger and C. M. McKell (eds). Academic Press, New York. pp. 19-35.

12. Kenny, S. T. and R. L. Cuany. 1978. Grass and legume improvement for high altitude regions. Proc. High-Altitude Revegetation Workshop No. 3. CSU CWRRI Info. Series No. 28: 84-100.

13. Plummer, A. P. 1976. Shrubs for the subalpine zone of the Wasatch Plateau. Proc. High Altitude Revegetation Workshop No. 2. CSU CWRRI Info. Series No. 21: 33-40.

14. Townsend, C. E. 1974. Legume selection and breeding research in Colorado. Proc. Workshop Reveg. of High-Altitude Disturbed Lands. CSU CWWRI Info. Series No. 10: 36-38.

PERFORMANCE OF NATIVE AND INTRODUCED SPECIES SEVEN YEARS AFTER SEEDING ON ALPINE DISTURBANCES

M. Guillaume, W. A. Berg and J. T. Herron

Addresses are Pinedale High School, Pinedale, WY 82941; USDA-ARS, 2000 18th Street, Woodward, OK 73801; Colorado Mined Land Reclamation Div., 1313 Sherman, Denver, CO 80203, respectively.

ABSTRACT

Limited information is available on species selection for revegetation in the Rocky Mountain alpine zone. In this study, seed was collected from 23 native species in the Colorado alpine zone and then seeded as monocultures into topsoil on an alpine site having continuous winter snow cover. Ten commercially available introduced species were also seeded. Most of the species established readily. Seven growing seasons after seeding, eight of 10 native graminoids produced vegetation ground cover of 20% or more, and 5 of 13 native forbs produced vegetation ground cover of 10% or more. Seed of 16 of the native species was combined into a mixture and seeded into subsoil and mine rock waste sites. After 7 growing seasons, four grasses, Deschampsia caespitosa, Phleum alpinum, Poa alpina and Trisetum spicatum were much more abundant than the other species planted in the native mixture. The frequency of forbs was extremely low on plots planted to the native mixture. Native forbs showing some promise for alpine seeding included Achillea millefolium, Antennaria rosea, Polygonum bistortoides, and Potentilla diversifolia. Of 10 introduced species in the study Poa pratensis, Festuca ovina, and F. rubra were the most persistent and vigorous.

INTRODUCTION

The superiority of native species over introduced species for revegetation of alpine disturbances has been documented by Brown and Johnson (1979). In the study reported here, our major objective was to evaluate an array of native and introduced species for seeding into alpine disturbances on sites that have winter snow cover. Monocultures of 23 native species seeded in topsoil and a mixture of 16 native species seeded in subsoil and mine rock waste were evaluated after 2 and 7 growing seasons. Ten introduced species seeded in monocultures and as a mixture were also evaluated.

STUDY AREAS

The study was carried out at the Climax Mine, Climax, Colorado on three different sites (Guillaume, 1984). The topsoil and subsoil sites are near the upper edge of a Deschampsia meadow on a west-facing 6% slope. These sites normally have continuous snow cover from November to May. The altitude is 3630 m (11,900 ft), about 130 m above treeline. The silty clay loam soil (Cryochrept) was about 1-m deep developed in red micaceous sandstone. These sites were prepared by removing 8 to 10 cm of sod from an area 40 x 90 m. An additional 15 cm of topsoil was then removed from three 9 x 90 m blocks to expose the subsoil site. The excavated topsoil was placed in two 6 x 90 m blocks to make the topsoil site. The topsoil contains 3.6% organic matter and an estimated 15% coarse fragments. The subsoil contains 1.3% organic matter and an estimated 20% coarse fragments. The coarse fragments are mostly less than 8 cm in diameter.

The 40 x 100 m rock waste site is located on a nearly level bench formed by bulldozer leveling of truck deposited open-pit mine waste. The site is bordered on the south and east by alpine fellfield that slopes steeply upward creating a site that has winter snow cover persisting later in the spring than on the disturbed soil sites. The altitude of the rock waste site is 3840 m (12,600 feet), about 330 m above treeline. The rock waste contains an estimated 75% coarse fragments ranging upward to 1 m diameter and the texture of the soil size material is sandy loam.

METHODS

Seed was collected from native stands around the Climax Mine and in Rocky Mountain National Park in the late summer and early fall of 1978. The species collected were selected on the basis of observations on pioneer species invading alpine disturbances (Guillaume, 1984) and abundance of seed. Hand collection of seed took about 60 man-days to collect 3.9 kg (8.6 lb) of pure live seed. The collection and seeding were on a tight schedule that did not allow time for germination tests prior to seeding in early October 1978. Germination and seeds/unit mass were determined subsequently and are reported elsewhere (Guillaume, 1984).

Individual species plots (Table 1) were seeded only on the topsoil site. Individual species plots are 0.45 x 6 m with the seed planted in 3 rows 15 cm apart. Each species is replicated 3 times. Fertilizers were spread and then raked into the soil, the area was then furrowed, seeded, and raked lightly. The species plots were split, half of each plot was fertilized with 18-46-0 at the rate of 336 kg/ha (300 lb/acre). The other half of each plot received sewage sludge at the rate of 22 Mg/ha (10 ton/acre). By 1985, no differences due to these fertility treatments on the topsoil were evident and all data were collected without regard to the fertility treatments. Straw mulch at the rate of 4.5 Mg/ha (2 ton/a) was applied and covered with plastic netting. The plots were seeded and mulched on October 14, 1978. Vegetation ground cover on the individual species plots was estimated in August 1980 in 10 randomly placed 40 cm square quadrats in each plot. In August 1985, vegetation ground cover was estimated by stretching a tape diagonally across each plot and determining the presence or absence of vegetation cover (living vegetation) under each of 100 inch marks. Frequency was estimated by determining species present within each of eighty 10 x 10 cm quadrats within each plot.

A seed mixture of 16 native species (Table 2) was made up for seeding on subsoil and rock waste plots. The mix was based on the amount of seed available rather than what a desirable mixture might include. This native mixture was seeded at the rate of 8.6 kg/ha (7.7 lb/a) pure live seed (pls). This is equivalent to 1350 pls/m^2 (125 pls/ft^2).

In the late summer of 1979, Ron Zuck used a small combine to harvest seed from the alpine meadow surrounding the topsoil and subsoil site. The seed was planted in the fall of 1979 into 3x9 m subsoil plots receiving 88 Mg sewage sludge/ha and mulched with excelsior. The seeding rate is unknown. There were three blocks in this study.

The seed mixture of introduced species was based on the mixture developed by the Climax Molybdenum Company for revegetation of disturbances in the upper subalpine lifezone. A seeding rate of 45 kg/ha (40 lb/a) was used on the plots. Similar rates are commonly used in subalpine seedings. The rate is equivalent to 5060 pls/m^2 (470 pls/ft^2).

This paper presents data on species frequency trends over time (5 years) as affected by site (subsoil or rock waste). Results from the mulch and fertility treatments are presented in Berg et al. (1986). Frequency of native species was determined on straw + plastic net and jute mulch treatments receiving 18-46-0 at 336 kg/ha (300 lb/a) or sewage sludge (dry) at 22 Mg/ha (10 ton/a) on subsoil or 66 Mg/ha on rock waste. Frequency of each species was determined in one hundred twenty 10x10 cm quadrats on each of these plots on the disturbed soil site for a total of 1440 observations (120 quadrats x 4 treatments x 3 blocks). Eighty 20x20 cm quadrats were used on each plot on the rock waste for a total of 960 observations. Frequency of the introduced species in the subsoil was determined in one hundred twenty 10x10 cm quadrats in each plot mulched with straw + plastic net and fertilized with sewage sludge at 22 Mg/ha (360 observations). On the rock waste the frequency of the introduced species was determined in eighty 20x20 cm quadrats placed in each plot mulched with straw + plastic net and fertilized with sewage sludge at 66 Mg/ha (240 observations).

Vegetation cover was measured at 200 points on each 3x9 m plot planted to the seed mixtures by determining if living vegetation was present in a vertical projection downward from the 10 cm marks on four random placements of a 5 m tape stretched across each plot.

RESULTS AND DISCUSSION

Native Species Seeded as Monocultures in Topsoil

Establishment and persistence was good for most of the native species seeded in 1978 as monocultures in the topsoil. This is illustrated by the relatively high frequencies in 1980 and 1985 (Table 1). The seeding rates of Agropyron scribneri, Mertensia viridis, and Trifolium dasyphyllum were very low and do not allow a good comparison

Table 1. Seeding rate, calculated plant density, vegetation ground cover, and frequency of native species planted as monocultures in topsoil.

	Viable seed planted in 1978	Calculated plant density 1985	Vegetation Ground Cover			Frequency within 10x10 cm quadrats		
			1980	1985		1980	1985	
	--- number/m^2--		---- % ----			---- % ----		
Graminoids								
Agropyron latiglume	300	78	8	20	ns	66	54	ns
Agropyron scribneri	7	1	2	0		38	1	†
Carex atrata	1400	9	0	1		1	9	
Carex ebenea	2900	63	1	22	*	40	47	ns
Deschampsia caespitosa	4700	147	9	56	ns	81	77	ns
Festuca thurberi	2200	71	3	16	*	87	51	†
Phleum alpinum	2900	161	10	41	*	78	80	ns
Poa alpina	10600	281	17	59	*	83	94	ns
Poa glauca	1500	117	8	39	*	53	69	†
Trisetum spicatum	3000	253	11	28	ns	83	92	ns
Forbs								
Androsace septentrionalis	12500	4	7	1		79	4	†
Antennaria rosea	8300	143	8	28	*	57	76	†
Artemisia arctica	27500	53	4	12	ns	33	41	ns
Castilleja spp.	5700	1	0	1		1	1	
Geum rossi	1600	65	1	10	ns	40	48	ns
Hymenoxys grandiflora	2600	34	1	8		52	29	†
Mertensia viridis	70	4	<1	1		8	4	
Oxyria digyna	1500	67	10	9	ns	63	49	ns
Polemonium viscosum	800	37	1	4		39	31	ns
Polygonum bistortoides	unknown	62	3	11	*	23	46	†
Potentilla diversifolia	6900	127	6	44	*	63	72	ns
Rumex spp.	1900	31	2	7		52	27	†
Trifolium dasyphyllum	70	2	0	0		2	2	

†frequency is significantly different (P<0.05) between years by Chi-square test; when frequency<10% for both values Chi-square not calculated.
*Ground cover is significantly different (P=<0.05) between years by F test; when ground cover <10% for both years F not calculated.

of these species with the remainder of the species which were seeded at moderate to high rates (Table 1). The frequencies of Agropyron scribneri and Androsace septentrionalis showed a dramatic decrease from 1980 to 1985 and the frequencies of Festuca thurberi, Hymenoxys grandiflora, and Rumex spp. decreased significantly (Table 1). Significant increases in frequency are shown for Poa glauca, Antennaria rosea, and Polygonum bistortoides.

Calculation of plant density per m^2 from the frequency data (Grieg-Smith, 1964) shows that 8 of 10 graminoids had a density of 60 plants/m^2 (5 plants/ft^2) or greater in 1985. Five of 13 forb species had densities of 60 plants/m^2 or greater (Table 1).

Vegetation ground cover in 1980, two growing seasons after seeding, was 17% or less for all species (Table 1). By 1985, ground cover had increased substantially for most of the graminoids (Table 1). Three of the forbs, Antennaria rosea, Polygonum bistortoides, and Potentilla diversifolia, had significant increases in ground cover from 1980 to 1985.

Native Species Seeded as a Mixture in Subsoil or Rock Waste

In plots planted to the mixture of 16 native species, the frequencies of four grasses were much greater than the frequencies of the other species (Table 2). Among these four grasses, Deschampsia caespitosa did not have a change in frequency from 1980 to 1985, Phleum alpinum and Poa alpina increased in frequency, and Trisetum spicatum increased in frequency on the subsoil. We believe that the increases in frequency are probably a reflection of both: 1) an inability to identify very small seedlings in 1980, and 2) an increase in number of plants due to natural seeding. In 1985 numerous small grass seedlings were present in these plots.

Eight species not intentionally seeded, but present by invasion or inadvertently included in the seeds collected, were found on the plots (Table 2). Of these species, only Poa reflexa on the rock waste was present in significant amounts.

Within the plots seeded to the native mixture, the frequency of forbs was extremely low in relation to the frequency of the graminoids (Table 2). Some of the forbs performed relatively well in monocultures on the topsoil (Table 1) but apparently could not compete with graminoids when seeded in the mixture on subsoil or rock waste. Among the forbs seeded in the mixture, individual Potentilla diversifolia plants had outstanding vigor. In nearby upper subalpine trials P. diversifolia was rated good in vigor and persistence (Hassell, 1980).

The native mixture seeding rate of 1350 pls/m^2 (125 pls/ft^2) resulted in vegetation ground cover by 1985 of 65 and 76% on the subsoil when used with fertility treatments of 44 and 88 Mg/ha sewage sludge, respectively (Berg et al., 1986). Thus, with adequate fertility, site preparation, and mulching, this seeding rate appears adequate. However, time is required for vegetation ground cover to develop, these same high fertility plots had ground cover of only 8% in 1980, two years after seeding.

Table 2. Native species frequency in 1980 and 1985 on subsoil and rock waste sites seeded to a mixture of native species in 1978.

	Viable Seed Planted in 1978	Frequency			
		Subsoil 10x10 cm quadrats		Rock Waste 20x20 cm quadrats	
		1980	1985	1980	1985
	number/m²	%			
Graminoids					
Agropyron latiglume	10	2	3	4	<1
Carex spp.	100	3	2	2	8
Deschampsia caespitosa	280	15	15 ns	23	23 ns
Festuca thurberi	60	<1	<1	0	4
Phleum alpinum	180	9	16 †	16	32 †
Poa alpina	240	16	33 †	20	53 †
Poa glauca	0	0	<1	0	6
Poa reflexa	0	0	1	0	38 †
Trisetum spicatum	120	13	21 †	20	22 ns
Forbs					
Achillea lanulosa	0	0	<1	0	0
Androsace septentrionalis	8	1	<1	0	0
Artemisia arctica	30	1	<1	0	<1
Castilleja spp.	110	0	<1	0	<1
Geum rossi	12	0	<1	<1	0
Hymenoxys grandiflora	6	0	0	0	0
Lepidium spp.	0	<1	<1	<1	0
Oxyria digyna	0	<1	<1	0	<1
Polemonium viscosum	30	<1	<1	2	2
Polygonum bistortoides	0	<1	<1	1	<1
Potentilla diversifolia	110	<1	1	<1	1
Rumex spp.	50	3	1	1	<1
Taraxicum spp.	0	0	<1	0	0
Trifolium dasyphyllum	0	0	<1	0	0

†frequency is sign. different (P<0.05) between years within a site by Chi-square test; when frequency <10% for both years Chi-square was not calculated.

Seed harvested with a combine in September 1979 from the surrounding alpine meadow and seeded in 1979 into the subsoil resulted in frequencies of greater than 10% for each of 8 species by 1985 (Table 3). Four of these species, Deschampsia caespitosa, Phleum alpinum, Poa alpina, and Trisetum spicatum also performed well in the 1978 plantings of hand-harvested native seed mixtures (Table 2). Other species from the combine seed harvest with a frequency of greater than 10% were Agropyron latiglume, Carex spp., Poa glauca, and Achillea millefolium.

The performance of Achillea millefolium is of particular interest. This forb was not seeded in other alpine plots, however, it was seeded on rock waste in the upper subalpine zone (Guillaume, 1984) where its frequency was high in 1985 (W. A. Berg, unpublished data).

Thus, the planting of the native seed mixture harvested with a combine resulted in a considerably greater number of species contributing to the bulk of the revegetation population (Table 3) than did the seed mixture made up of hand-collected natives (Table 2). The amount of vegetation ground cover (70%) in 1985 on the subsoil plots planted with the combine-harvested seed was not significantly different from the vegetation cover (76%) on plots planted to the hand-collected native seed mixture on plots treated with comparable sewage sludge rates (88 Mg/ha).

Table 3. Frequency of species in 1985 in subsoil site seeded in 1979 with seed combine harvested from adjacent native alpine meadow.

	Frequency within 10x10 cm quadrat
	%
Graminoids	
Agropyron latiglume	20
Carex spp.	17
Deschampsia caespitosa	27
Festuca spp.	1
Phleum alpinum	23
Poa alpina	26
Poa glauca	23
Poa reflexa	6
Trisetum spicatum	15
Forbs	
Achillea millefolium	13
Castilla spp.	<1
Epilobium angustifolium	<1
Geum rossi	<1
Lepidium spp.	<1
Polygonum bistortoides	1
Potentilla diversifolia	5
Rumex spp.	2

Overall, the grasses, Deschampsia caespitosa, Phleum alpinum, Poa alpina, and Trisetum spicatum performed well in these alpine seedings as they did in trials reported by Brown and Johnson (1979). Performance of the forbs in the grass-forb seed mixtures was disappointing with the exception of Achillea millefolium which was included in only one of the four alpine seedings reported here. Among the other forbs tested, Antennaria rosea, Polygonum bistortoides, and Potentilla diversifolia may hold some promise for seeding into alpine disturbances. The latter 3 species were found by Chambers et al. (1984) to be ranked high as colonizers on alpine disturbances in Montana.

Introduced Species Seeded as Monocultures in Topsoil

Nine of the 10 introduced species had high frequencies two-years after seeding in monocultures in topsoil (Table 4). Five years later the frequencies of Alopecurus arundinaceus, Festuca ovina, F. rubra, and Poa pratensis had not changed. Over the same 5 years the following species decreased in frequency; Agrostis alba, Bromus inermis, Dactylis glomerata, Phleum pratense, and Trifolium repens.

Table 4. Seeding rate, calculated plant density, vegetation ground cover, and frequency of introduced species planted as monocultures in topsoil.

	Viable seed planted in 1978	Calculated plant density 1985	Vegetation Ground Cover		Frequency within 10x10 cm quadrats	
			1980	1985	1980	1985
Grasses	----number/m^2----		----%----		-----%----	
Agrostis alba	17700	0	6	0	99	0 †
Alopecurus arundinaceus 'Garrison'	1630	190	8	34 *	88	85 ns
Bromus inermis 'Manchar'	360	16	4	0	80	15 †
Dactylis glomerata 'Potomac'	1200	31	5	11 ns	89	27 †
Festuca ovina 'Durar'	1490	204	16	37 ns	91	87 ns
Festuca rubra 'Pennlawn'	2140	212	17	48 *	91	88 ns
Phleum pratense 'Climax'	3620	87	17	15 ns	88	58 †
Poa pratensis 'Newport'	7100	139	6	28 *	91	75 ns
Legumes						
Astragalus cicer 'Lutana'	900	<1	0	0	4	<1
Trifolium repens	4420	0	6	0	73	0 †

† frequency is signifiantly different ($P<0.05$) between years by Chi-square test.
* ground cover is significantly different ($P<0.05$) between years by F test.

Two growing seasons after seeding in monocultures a maximum of 17% vegetation ground cover was present on plots of the introduced species (Table 4). After another 5 growing seasons vegetation ground cover had increased significantly on plots of Alopecurus arundinaceus, Festuca rubra and Poa pratensis (Table 4). The amount of ground cover produced by these species was comparable to that produced by the more vigorous of the native grasses (Table 1).

Introduced Species Seeded as a Mixture in Subsoil or Rock Waste

When the 10 introduced species were planted as a mixture, the frequency of the Festuca spp. and Poa pratensis increased over the period 1980 to 1985 (Table 5). Over this same period, the frequency of Phleum pratense remained the same, and the frequency of Alopecurus arundinaceus, Bromus inermis, Dactylis glomerata and Trifolium repens decreased. The only introduced species with good vigor in 1985 were the Festuca spp. and Poa pratensis. Observations, particularly on the rock waste site, were that Poa pratensis was spreading by rhizomes on the high fertility treatments. We were unable to differentiate between Festuca ovina and F. rubra growing in plots seeded to the mixture. All fescue had a bunch growth form with no evident tendency to spread by rhizomes. The performance of Alopecurus arundinaceus was not consistent among the studies - the frequency of this species remained the same in the monocultures on topsoil and decreased over the 1980 to 1985 period in the subsoil and rock waste plots seeded to the introduced mixture. In plots in the upper subalpine zone we have observed that A. arundinaceus grows well and spreads by rhizomes on moist fertile sites, but just survives on infertile drier sites (unpublished data).

Table 5. Introduced species frequency in 1980 and 1985 on subsoil and rock waste sites seeded to a mixture of the species in 1978.

Species	Viable seed planted in 1978	Frequency: Subsoil 10x10 cm quadrats		Frequency: Rock Waste 20x20 cm quadrats	
		1980	1985	1980	1985
	seeds/m^2	%		%	
Grasses					
Agrostis alba	1670	4	15 †	0	0
Alopecurus arundinaceus	410	21	6 †	15	5†
Bromus inermis	150	31	<1 †	8	9
Dactylis glomerata	200	24	7 †	23	7†
Festuca ovina + F. rubra	650	55	87 †	27	46†
Phleum pratense	540	18	22 ns	7	8
Poa pratensis	540	10	32 †	15	52†
Legumes					
Astragalus cicer	100	0	0	0	0
Trifolium repens	770	4	0	7	0

† Frequency is significantly different ($P<0.05$) between years within a site by Chi-square test; when frequency was <10% for both years Chi-square was not calculated.

Thus, among the introduced species Poa pratensis and the small fescues (F. ovina and F. rubra) were the outstanding species. Most of the larger introduced grasses established well but did not persist. A comparison of the amount of vegetation ground cover produced by mixtures of native or introduced species as affected by fertility treatments is in the second paper in this series (Berg et al. 1986).

CONCLUSION

A number of species, both native and introduced, can be initially established on alpine disturbances that have continuous winter snow cover. However, seven years after seeding into drastic disturbances (subsoil and rock waste), four native grasses and three introduced grasses dominated in plots seeded to mixtures of native or introduced species, respectively.

The dominant native grasses, Deschampsia caespitosa, Phleum alpinum, Poa alpina and Trisetum spicatum have also performed well in other alpine seedings (Brown and Jackson, 1979) and are common colonizers on alpine and upper subalpine disturbed sites having winter snow cover. Numerous grass seedlings were observed in 1985 in the subsoil and rock waste plots seeded to natives. Since the utility of these native grasses has been demonstrated, we suggest agencies or companies anticipating reseeding alpine disturbances having winter-long snow cover contract for seed of these species in advance of the need. The supply might be by commercial seed production techniques, or possibly, harvest of native stands by mechanical seed strippers (Dewald and Beisel, 1983). The species diversity in plots seeded with the combine-harvested natives adds interest to harvest of native stands.

Poa pratensis was the only introduced species in the study that reproduced readily on the subsoil and rock waste. This was by rhizomes. The small introduced fescues established readily and persisted over 7 years but did not produce heads or rhizomes. Screening among Poa pratensis and rhizomatous Festuca rubra selections may be of interest in future alpine revegetation research.

Users of information presented in this report are cautioned that the species information will apply only to alpine disturbances with winter snow cover.

ACKNOWLEDGEMENTS

We wish to acknowledge and say thank you for the extensive help received on this study. Ron Zuck and Mark Schuster helped in seed collection and were our liaison with the Climax Molybdenum Company in providing materials and labor to establish the plots. Robin Cuany aided in species selection and seed collection. Betty Willard made suggestions on species to collect. Laurel Pye, Tim Sullivan, and Ron Zuck helped on the 1985 vegetation analysis. The Climax Molybdenum Company provided the sites and financial support for on-site work. This study was initiated in 1978 while the authors were at Colorado State University, the overall support of the CSU Experiment Station is gratefully acknowledged. And finally, thank you to our present employers for allowing us the time in 1985 and 1986 to gather and present this information.

REFERENCES

Berg, W. A., M. Guiliaume and J. T. Herron. 1986. Effect of fertility treatments and mulches on alpine revegetation. (In this publication)

Brown, R. W. and R. S. Johnson. 1979. Revegetation of disturbed alpine rangelands. p. 76-94. In D. A. Johnson (ed), Special Management Needs of Alpine Ecosystems. Range Science Series 5, Soc. for Range Mgt., Denver.

Chambers, J. C., R. W. Brown and R. S. Johnson. 1984. Examination of plant successional stages in disturbed alpine ecosystems: a method of selecting revegetation species. p. 215-224 In T. A. Colbert and R. L. Cuany (eds) Proceedings: High Altitude Revegetation Workshop No. 6. Colorado Water Resources Res. Inst. Info. Series 53. Colorado State Univ., Fort Collins.

Dewald, C. L. and A. Beisel. 1983. The Woodward flail-vac seed stripper. Trans. ASAE 26:1027-1029.

Grieg-Smith, P. 1964. Quantitative Plant Ecology 2nd ed. Butterworths, Washington.

Guillaume, Michael. 1984. The effect of seed source, mulches, topsoil and fertility on alpine revegetation. MS thesis, Colorado State University, Fort Collins. 175 p.

Hassel, W. 1980. Latest advances in plant materials development at the Meeker Environmental Plant Center. p. 153-172. In C. L. Jackson and M. A. Schuster (eds.) Proceedings: High Altitude Workshop No. 4. Colorado Water Resources Res. Inst. Info. Series 42. Colorado State Univ., Fort Collins.

Effect of Fertility Treatments and Mulches on Revegetation of Alpine Disturbances

W. A. Berg, M. Guillaume and J. T. Herron

Addresses are USDA-ARS, 2000 18th Street, Woodward, OK 73801; Pinedale High School, Pinedale, WY 82941; Colorado Mined Land Reclamation Div., 1313 Sherman, Denver, CO 80203, respectively.

ABSTRACT

The effects of mulch and fertility treatments applied at or near the time of seeding were determined seven years after seeding disturbed alpine sites. The two sites were a silty clay loam subsoil 130 m above treeline, and mine rock waste 330 m above treeline. Both sites normally have snow cover from November into May. The seventh growing season after seeding, vegetation ground cover was 1.5 to 2.5 times greater on 44 to 88 Mg/ha (20 to 40 ton/acre) sewage sludge treatments than on treatments receiving 336 kg/ha 18-46-0, or 336 kg/ha 18-46-0 plus 112 kg N/ha. Low rate sewage sludge treatments (11 to 22 Mg/ha) produced vegetation ground cover similar to or slightly greater than that produced on the chemical fertilizer treatments. The frequency of native species was similar on low and high fertility treatments. The type of mulch (straw, jute, excelsior, woodchips) did not affect the amount of vegetation cover produced during the seventh growing season. A no-mulch treatment was also used on the rock waste since there was no erosion potential, here vegetation cover and species frequency were similar on the no-mulch treatment as compared to the straw mulch treatment.

INTRODUCTION

Disturbances by road and utility line construction, mineral development, and recreation activities are continuing in alpine ecosystems in the western United States. Appropriate plant species, fertility, and cultural methods are requisites to successful revegetation programs on drastic land disturbances in these severe environments. This paper reports on the longer term (7 years) effects of fertility treatments and mulches upon vegetation ground cover and frequency of native species seeded into two infertile alpine sites.

STUDY AREAS

The study was carried out at the AMAX Inc. Climax Mine, Climax, Colorado on two different sites (Guillaume, 1984). The subsoil site is near the upper edge of a _Deschampsia_ meadow on a west-facing, 6% slope. This site is usually snow covered from November into May. The altitude is 3630 m (11,900 ft), about 130 m above treeline. The silty clay loam soil (Cryochrept) was about 1-m deep developed in red micaceous sandstone. The site was prepared by removing 20 to 25 cm of sod and topsoil from three 9 x 90 m blocks to expose the subsoil. The subsoil contain an estimated 20% coarse fragments and tested low in NO_3-N, P and K (Table 1).

The 40 x 100 m rock waste site is located on a nearly level bench formed by bulldozer leveling of truck deposited open-pit mine waste. The site is bordered on the south and east by alpine fellfield that slopes steeply upward creating a site that has winter snow cover which persists later in the spring than on the subsoil site. The altitude of the rock waste site is 3840 m (12,600 feet) which is about 330 m above treeline. The rock waste contains about 75% coarse fragments ranging upward to 1 m diameter. The texture of the soil size material is sandy loam which tested low in organic matter and NO_3-N, but adequate in P and K (Table 1).

Table 1. Chemical characteristics of subsoil, rock waste, cover soil, and sewage sludge used in fertility and mulch studies.

Material	pH †	E.C.	Organic Matter	NO_3-N	P	K	Zn	Fe
		mmhos/cm	%	ppm				
Subsoil	5.0	0.1	1.3	1	11	35	1	83
Rock Waste	5.1	0.6	0.4	1	20	113	4	124
Cover Soil	6.3	0.6	4.7	5	6	73	69	170
Sewage sludge	6.7	11.0	13	62	142	825	204	145

† all analysis by CSU soil testing laboratory (Soltanpour and Workman, 1981), E. C. determined in saturated extract; P, K, Zn, Fe in NH_4HCO_3-DTPA extract.

METHODS

A seed mixture of 16 native species (Guillaume, 1984; Guillaume et al. 1986) was seeded on most of the plots. This mixture was based on the amount of hand-collected seed available rather than what a desirable mix might include. The native mix was seeded at the rate of 8.6 kg/ha (7.7 lb/a) pure live seed (pls). This is equivalent to 1350 pls/m^2 (125 pls/ft^2).

On some plots a seed mixture of introduced species was used (Guillaume et al. 1986). The species composition of this mixture was developed by the Climax Molybdenum Company for revegetation of disturbances in the upper subalpine zone. A seeding rate of 45 kg/ha (40 lb/a) was used, which is equivalent to 5060 pls/m^2 (470 pls/ft^2).

The fertility treatments applied to individual 3 x 9 m plots included chemical fertilizers and sewage sludge (Guillaume, 1984). Two rates of chemical fertilizer were used: 1) diammonium phosphate (18-46-0) applied at the rate of 336 kg/ha (300 lb/acre) prior to seeding in October 1978, 2) same as 1 above plus 112 kg N/ha (100 lb N/acre) as $NH_4 NO_3$ applied in June 1980. Sewage sludge rates ranged from 11 Mg/ha (5 ton/acre) to 88 Mg/ha (40 ton/acre). The sewage sludge was dry anaerobically digested primary sludge from the Denver Metro northside plant. The sludge contained 13% organic matter (Table 1) which is low for this type of sludge (personal communication B. R. Sabey). Woodchips at the rate of 44 Mg/ha were added to all sewage sludge treatments applied to the rock waste.

Mulch treatments applied to the subsoil site after seeding in October 1978 included: 1) 4.4 Mg/ha (2 ton/acre) wheat straw held in place wth plastic netting (Conwed), 2) jute, 3) excelsior erosion blanket, 4) 44 Mg/ha woodchips (softwood), 5) 4.4 Mg/ha wheat straw + plastic netting, net removed in 1979. Treatment 5 was applied to simulate a straw mulch held in place with a tackifier. Mulch treatments applied to the rock waste were the same as above except treatment 5 where no-mulch was applied. A treatment of 7.5 cm (3 in) of cover soil (Table 1) taken from a topsoil stockpile was also applied to the rock waste. On the cover soil treatment the three fertility treatments were: 1) none, 2) 336 kg/ha 18-46-0 applied in 1978, 3) same as 2 plus 112 kg N/ha applied in 1980. The cover soil plots were mulched with straw and plastic net.

The subsoil site was chiseled to a depth of 10 cm, and the rock waste site was ripped to a depth of 30 to 60 cm prior to applying treatments. Inorganic fertilizer or sewage sludge (plus woodchips on the rock waste) was broadcast on individual plots and worked into the soil material with rakes and picks. The seed mix was then broadcast by hand over the plot area and the surface raked lightly to cover the seed. The mulches were then applied and held in place with staples (subsoil) or rocks (rock waste). Three blocks (replications) were used for all fertility and mulch treatments on each site.

Vegetation ground cover was estimated on the subsoil site in August 1980 in 10 randomly placed 40 cm square quadrats in each plot. In August 1985, vegetation ground cover was estimated at 200 points on each 3 x 9 m plot by determining if living vegetation was present in a vertical projection downward from the 10 cm marks on four random placements of a 5-m tape stretched across each plot on the subsoil and rock waste sites. Species frequency was estimated by determining the species present within each of one hundred twenty 10 x 10 cm quadrats in August of 1980 and 1985. Frequency was estimated on the rock waste within each of eighty 20 x 20 cm quadrats/plot. The standing crop of native species was sampled by clipping plants in four 50 x 50 cm quadrats on each of 27 plots in August 1985. The quadrats were randomly placed and the plants were cut as close as possible to the ground with scissors.

RESULTS

Fertility Treatments

The second growing season (1980) after seeding, vegetation ground cover averaged only 5 to 8% on the subsoil site with no significant differences among fertility treatments (Guillaume 1984, Fig. 1). By the seventh growing season (1985) after seeding,

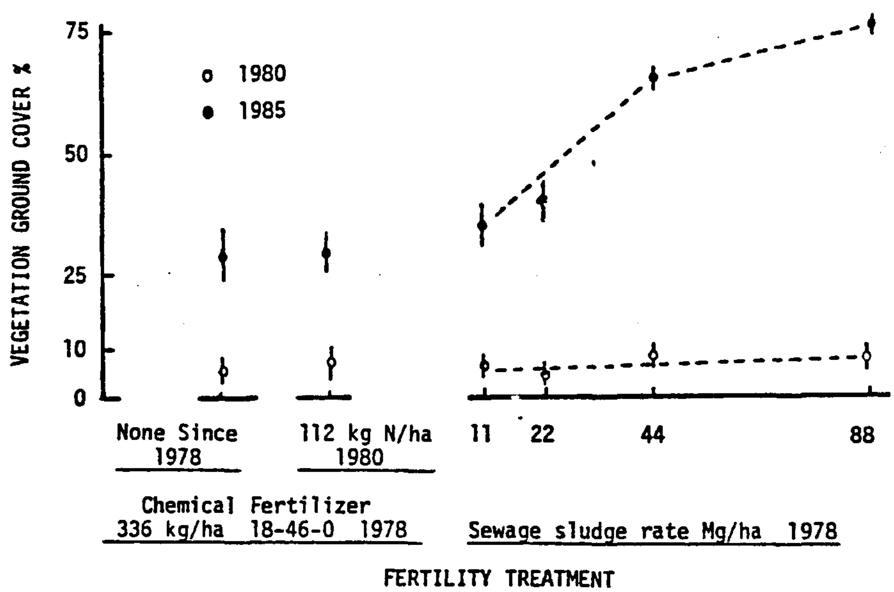


Figure 1. Vegetation ground cover in 1980 and 1985 by native species as affected by fertility treatments on subsoil seeded in 1978 and mulched with straw + net. Bars represent one standard error of the mean.

vegetation ground cover was 1.5 to 2.5 times greater on the high-rate sewage sludge treatments than on the chemical fertilizer treatments (Table 2, Fig. 1). Our 1985 observations were that the native grasses were larger, had more heads, and a darker green clover on the high-rate sewage sludge treatments than on the chemical fertilizer treatments. The darker green color indicates that the major benefit received from the high-rate sewage sludge is a greater supply of plant-available nitrogen. No consistent difference in vegetation cover was evident between the two chemical fertilizer treatments (Table 2). The lower rates of sewage sludge generally produced vegetation cover in amounts similar to or slightly greater than on the chemical fertilizer treatments (Table 2).

The fertility treatment x mulch interaction was not statistically significant ($P = 0.05$) on either site (Table 3). This indicates that the increases in vegetation cover produced in response to the fertility treatments were not affected by the type of mulch used.

Table 2. Effect of Fertility Treatments on Vegetation Cover on Subsoil or Rock Waste Sites

Site Mulch Species	Fertility Treatment						
	336 kg/ha 18-46-0 1978	336 kg/ha 18-46-0 1978 100 kg N/ha 1980	Sewage Sludge Mg/ha 1978 †				
			11	22	44	66	88
	%						
Subsoil							
Straw+net							
Native	28 c ‡	29 c	35 c	38 c	65 b	-	76 a
Introduced	22 e	26 de	30 d	37 c	45 b	-	53 a
All Mulches							
Native	25 c	32 b	-	44 a	-	-	-
Rock Waste							
Straw+net							
Native	17 c	21 bc	-	22 bc	31 ab	42 a	-
Introduced	-	-	-	21 a	31 a	19 a	-
All Mulches							
Native	18 b	19 b	-	-	-	33 a	-

† On rock waste all sewage sludge rates also received 44 Mg woodchips/ha
‡ Means within a row across the table followed by a common letter are not significantly (P=0.05) different. Do not use for comparison of means within a vertical column.
- Treatment not in study.

Table 3. Analysis of variance for fertility treatment and mulch effects on vegetation ground cover of native species in 1985 on subsoil and rock waste sites.

Source	Subsoil df	Subsoil Mean square	Rock Waste df	Rock Waste Mean square
Fertility Treatment	2	1332 **	2	951 **
Mulch	4	76 ns	4	87 ns
Fertility x mulch	8	33 ns	8	15 ns
Error	28	47	28	62

The treatments of 7.5 cm (3 in) of stockpiled topsoil applied over the rock waste in 1978 resulted in vegetation cover in 1985 of 15+2 (std error)%. With the topsoil treatment + 336 kg/ha of 18-46-0 applied in 1978 the vegetation cover in 1985 was 22+1%. With topsoil + 336 kg/ha of 18-46-0 in 1978 + 112 kg N/ha in 1980 the vegetation cover in 1985 was 26+4%. Thus, treatment of rock waste with approximately 1100 Mg/ha (500 ton/acre) of stockpiled soil appears to be little more effective than treatment with chemical fertilizers

(Table 2) in production of vegetation ground cover after 7 growing seasons. This result is surprising and may relate to the quality of the cover soil (Table 1) which probably had a high C/N ratio.

The frequency of the dominant native grasses two and seven years after seeding does not appear to be influenced by fertility treatment (Table 4). The relationship between herbage produced as affected by fertility or mulch treatments is also of interest. However, plot clipping would probably bias future observations in the study. As a compromise, a limited number of treatments were sampled (four 50 x 50 cm quadrats on each of 27 plots) for standing crop and the dry matter

Table 4. Effect of fertility treatments applied in 1978 on frequency of native species growing in 1980 and 1985 on subsoil or rock waste.

Site Species	Frequency †			
	1980		1985	
	336 kg/ha 18-46-0	High rate ‡ sewage sludge	336 kg/ha 18-46-0	High rate sewage sludge
SUBSOIL				
Deschamosia caespitosa	21	18	12	22
Phleum alpinum	15	15	20	30
Poa alpina	20	16	42	50
Trisetum spicatum	12	16	31	25
ROCK WASTE				
Deschamosia caespitosa	23	19	21	10
Phleum alpinum	13	20	28	31
Poa alpina	15	13	39	35
Poa reflexa	0	0	14	27
Trisetum spicatum	9	19	11	21

† Frequency on 10 x 10 cm quadrats subsoil, 20 x 20 cm quadrats rock waste.
‡ 88 Mg/ha on subsoil, 66 Mg/ha on rock waste.

yields plotted against vegetation ground cover determined over each plot (Fig. 2). The relationship shown below indicates that

$$\text{Dry Matter (kg/ha)} = -54 + 13 \times \text{vegetation cover (\%)}, \quad r^2 = 0.81$$

vegetation ground cover can be used to predict standing crop on these sites.

Mulches

Type of mulch applied on subsoil had no significant effect on amount of vegetation cover produced during the seventh growing season (Table 5). A no-mulch treatment was not attempted on the subsoil because of the high potential for erosion of the silty clay loam soil onto other treatments. Rill erosion was obvious in 1985 on subsoil plots mulched with woodchips. Erosion was not evident in other mulch treatments.

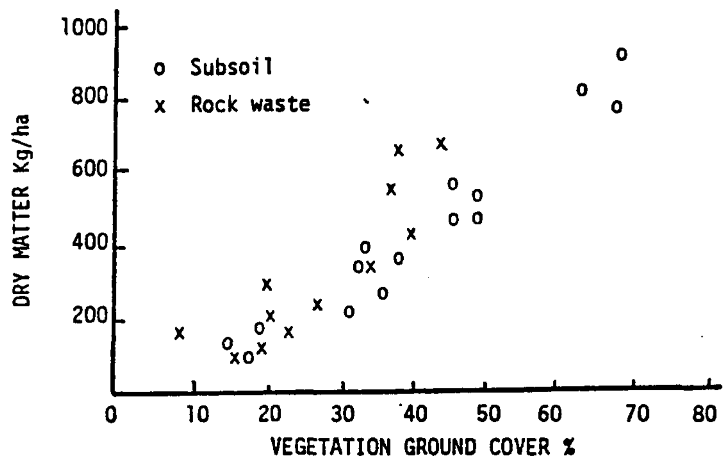


Figure 2. The relationship between dry matter production and vegetation ground cover by native species in early August 1985 on subsoil or rock waste plots receiving different fertility treatments.

Table 5. Vegetation cover of native species in 1985 on subsoil or rock waste as affected by mulches applied after seeding in 1978.

Mulch	Site	
	Subsoil †	Rock Waste ‡
	%	%
Straw + net	34 a §	23 ab
Jute	37 a	28 a
Excelsior	33 a	23 ab
Woodchips	31 a	25 ab
Straw - net (1979)	37 a	-
No mulch	-	19 b

†Mean of the two chemical fertilizer plus 22 Mg/ha sewage sludge fertility treatments.
‡Mean of the two chemical fertilizer plus 66 Mg/ha sewage sludge fertility treatments.
-Treatment not in study.
§Means within a site followed by a common letter are not significantly (P=0.05) different.

A no-mulch treatment was included on the rock waste since there was no erosion potential on this coarse material. Vegetation cover on the rock waste in August of the seventh growing season was similar among the mulches, and between all mulches and the no-mulch treatment except for the jute (Table 5).

The first growing season, more plants were found on plots mulched with excelsior than on plots mulched with other materials, but after two growing seasons this effect was not found (Guillaume, 1984). Two years after the mulch application, Guillaume (1984) noted little degradation of the jute, excelsior or woodchip mulches. Straw was more clumped under the net in 1980 and ground cover by straw was reduced from about 90% in 1978 to 75% in 1980.

Seven years after application most of the mulch materials had decomposed. No straw remained, but the plastic net used to hold down the straw was intact, although brittle. An estimated 10 to 20% of the jute remained as isolated strands, indicating variability in decomposition rates among strands. No excelsior remained except under rocks (20-30 cm diameter) placed to hold the mat down. The green plastic net on the excelsior had disintegrated to pieces no larger than 1 cm. A few woodchips were present, largely in clumps, and made up no more than 5% ground cover.

Four or five grass species dominated the vegetation on plots seeded to the mixture of native grasses and forbs (Guillaume et al. 1986). Frequencies of these grasses on the rock waste in either 1980 or 1985 appear to be similar on the straw mulch treatment and the no-mulch treatment (Table 6). Forb frequency was extremely low on all treatments.

Table 6. Effect of no mulch or straw mulch applied after seeding in 1978 on frequency of native species growing on rock waste in 1980 or 1985.

Species	1980		1985	
	No mulch	Straw + net	No mulch	Straw + net
	%			
Deschampsia caespitosa	23	21	18	22
Phleum alpinum	11	17	18	37
Poa alpina	17	14	51	49
Poa reflexa	0	0	29	18
Trisetum spicatum	12	10	16	20

DISCUSSION

The alpine sites revegetated in this study have continuous winter snow cover, usually from November into May, and thus are more amenable to revegetation than wind-swept sites. The information presented in this paper on species or on mulch and no-mulch treatments may have limited application to windswept alpine sites. The fertility information should be applicable to most infertile revegetation sites.

The high-rate sewage sludge treatments (44 to 88 Mg/ha) were the only fertility treatments used in this study which appear to offer the potential for a no or minimum maintenance approach to alpine revegetation on infertile soil materials. At these sewage sludge rates enough vegetation cover was produced to control erosion and ameliorate the visual effect of disturbance. However, even at the highest sewage sludge rate, dry matter production on the exposed subsoil in 1985 was estimated to be about half of that produced on the adjacent native Deschampsia meadow. The increase in vegetation cover of native species with increased rates of sewage sludge (Fig. 1, Table 2) indicates that fertility, probably plant-available nitrogen, is limiting plant growth. Higher rates of sewage sludge than used in this study in a one-time application may not be a solution to increasing plant production on these infertile materials. This is because salt in sludge applied at very high rates can have adverse effects on plant establishment and growth (Topper and Sabey, 1986; also see Sabey this publication).

Repeated chemical fertilizer additions over a number of years (Berg and Barrau, 1978) would probably increase plant growth on the low-rate sewage sludge and chemical fertilizer treatments. A minimum nitrogen capitol of 1000 kg N/ha to develop a self-sustaining nitrogen cycle was suggested by Marrs and Bradshaw (1982) for China clay waste. However, Brown et al. (1984) reported no differences in plant growth the fourth year between treatments receiving no fertilizer and those receiving fertilizer every year in an alpine seeding where all treatments received a total of 110 kg N/ha/yr in the four years before the N rate study was started.

Woodchips were added to all sewage sludge treatments on the rock waste. The purpose of the woodchips is to immobilize and thus conserve some of the nitrogen in the sludge applied to the coarse rock waste (Sabey et al., 1977, Jackson, 1982). The effectiveness of the woodchip treatment was not evaluated in this study. Such a study would be appropriate since hauling and spreading woodchips add greatly to revegetation expenses.

Dry matter production on subsoil comparable to that of the adjacent native Deschampsia meadow may be an unrealistic goal in view of the abundance of small stature grasses on the revegetated subsoil and the overall reduction in soil depth and organic matter caused by stripping off 20 to 25 cm of sod and topsoil. In the longer term (100-1000 years), nitrogen inputs from the atmosphere (Woodmansee et al. 1979) and plant succession may result in greater dry matter production on the disturbed sites.

Mulch is probably a necessity on many alpine revegetation sites because of the high erosion potential. Straw + net, Jute, or excelsior performed equally in this study when evaluated on the basis of vegetation cover of plants established after seven growing seasons. On the rock waste site, which was very coarse textured, the advantage of mulches in producing vegetation cover was not conclusively shown.

ACKNOWLEDGEMENTS

We wish to acknowledge and say thank you for the extensive help received on this study. Ron Zuck and Mark Schuster helped in seed collection and were our liaison with the Climax Molybdenum Company in providing materials and labor to establish the plots. Robin Cuany aided in species selection and seed collection. Betty Willard made suggestions on species to collect. Laurel Pye, Tim Sullivan, and Ron Zuck helped on the 1985 vegetation analysis. The Climax Molybdenum Company provided the sites and financial support for on-site work. This study was initiated in 1978 while the authors were at Colorado State University, the overall support of the CSU Experiment Station is gratefully acknowledged. And finally, thank you to our present employers for allowing us the time in 1985 and 1986 to gather and present this information.

REFERENCES

Berg, W. A. and E. M. Barrau. 1978. Management approaches to nitrogen deficiency in revegetation of subalpine disturbances. p. 174-181. In S. T. Kenny (ed) Proceedings: High altitude revegetation workshop No. 3. Colorado Water Resources Res. Inst. Info. Series No. 28. Colorado State Univ. Fort Collins.

Brown, R. W. and R. S. Johnson. 1979. Revegetation of disturbed alpine rangelands. p. 76-94. In D. A. Johnson (ed), Special Management Needs of Alpine Ecosystems. Range Sci. Series 5, Soc. for Range Mgt., Denver.

Brown, R. W., R. S. Johnson and J. C. Chambers. 1984. Responses of seeded native grasses to repeated fertilizer applications on acidic alpine mine spoils. p. 200-213. In T. A. Colbert and R. L. Cuany (eds), Proceedings: High altitude revegetation workshop No. 6. Colorado Water Resources Res. Inst. Info. Series No. 53. Colorado State Univ., Fort Collins.

Guillaume, Michael. 1984. The effect of seed source, mulches, topsoil and fertility on alpine revegetation. MS thesis, Colorado State Univ., Fort Collins. 175 p.

Guillaume, M., W. A. Berg, and J. T. Herron. 1986. Performance of native and introduced species seven years after seeding on alpine disturbances. (In this publication).

Jackson, C. L. 1982. An update of Urad mine reclamation. p. 79-105. In R. L. Cuany and J. Etra (eds), Proceedings: High altitude revegetation workshop No. 5. Colorado Water Resources Res. Inst. Info. series no 48. Colorado State Univ., Fort Collins.

Marrs, R. H. and A. D. Bradshaw. 1982. Nitrogen accumulation, cycling and the reclamation of china clay wastes. J. Environ. Manage. 15:139-157.

Sabey, B. R., N. N. Agbim, and D. C. Markstrom. 1977. Land application of sewage sludge: IV. Wheat growth, N content, N fertilizer value and N use efficiency as influenced by sewage sludge and wood waste mixtures. J. Environ. Quality 6:52-58.

Soltanpour, P. N. and S. M. Workman. 1984. Soil-testing methods used at Colorado State University soil testing laboratory. CSU Exp. Sta. Tech. Bull. 142.

Topper, K. F. and B. R. Sabey. 1986. Sewage sludge as a coal mine spoil amendment for revegetation in Colorado. J. Environ. Quality 15:44-49.

Woodmansee, R. G, J. D. Reeder, and W. A. Berg. 1979. Nitrogen in drastically disturbed lands. p. 376-392. In C. T. Youngberg (ed), Forest Soils and Land Use. Dept. of Forest and Wood Sciences, Colorado State Univ., Fort Collins.

MONITORING SCHEMES FOR EVALUATING RECLAMATION SUCCESS

Warren R. Keammerer

Stoecker-Keammerer & Associates
5858 Woodbourne Hollow Road
Boulder, Colorado 80301

INTRODUCTION

After a site has been mined and revegetation activities are complete, one of the questions that remains unanswered is whether the reclamation effort has been successful. Answers to this question can be obtained by carefully monitoring changes in vegetation structure and composition over time. There may be other important parameters which are important for monitoring and determining reclamation success such as characteristics of soil fertility and ground water, however this paper focuses on monitoring schemes for evaluating changes in plant communities on reclaimed surfaces.

Interest in monitoring and evaluating revegetation success has increased over the last few years primarily as a result of state and federal environmental legislation. One of the primary reasons for evaluating revegetation success is to demonstrate to state and federal regulatory agencies that revegetation efforts have been successful. Once it has been determined that the vegetation on a reclaimed site is acceptable, it is then possible for a mining company to have reclamation bonds released. Lengths of bonding periods are variable, but may be as long a 10 years for coal mined lands in the West. A second important reason for monitoring revegetation success, is that it anables reclamation specialists to evaluate different revegetation techniques. Through an iterative process of on site evaluations, it is possible to ultimately develop optimal revegetation programs for any particular site. In a more generic sense, vegetation monitoring may be used to evaluate impacts of land uses, changes in grazing patterns, and potential changes related to operation of industrial facilities.

MONITORING PARAMETERS

When monitoring vegetation, there are a variety of parameters that can be selected for keeping track of changes. The most commonly used parameters include cover, production, species diversity, and density. Density measurements are usually restricted to woody plants, however, it is possible, and in some case of great interest, to evaluate seedling densities during the first growing season. Counting seedlings of herbaceous species allows for a quick evaluation of germination success and can provide insight into reasons for subsequent success or failure of vegetation establishment on reclaimed areas. In addition to these commonly studied parameters, other parameters such as root biomass, plant height, leaf lengths and widths, and chemical characteristics of above ground biomass can also be monitored. The selection of monitoring parameters for any particular site will depend on the purposes for conducting the monitoring studies.

APPROACHES TO MONITORING

The actual methods used for obtaining monitoring data are not critical as long as they are accepted approaches for obtaining vegetation data, and they are used consistently. It does not matter whether quadrat methods or transect methods are used to to obtain cover data. It is important, however, to be consistent with these methods. Do not use quadrats one year and transects the next. Inherent errors associated with different sampling methods can make yearly evaluation of results difficult. The problems are compounded if the year-to-year sampling methods are changed. It is possible to change the sampling methods if currently used techniques are judged to be inadequate. If it is necessary to change methods, change the methods on new areas but keep using the same methods on areas that have been previously sampled. This approach will allow for flexibility in the choice of methods, but will also provide consistency for data collection on any particular area.

LEVELS OF DETAIL FOR MONITORING STUDIES

A comprehensive monitoring program for reclaimed areas can be flexible regarding the level of intensity for any given year of data collection. Four different levels of sampling detail could be implemented during any growing season. Each increasing level of study requires greater effort and provides increasing amounts of quantitative data.

Visual Observations. The simplest approach to monitoring is to walk through a reclaimed area, make observations on the current status of the vegetation, and write down notes regarding the success of the revegetation efforts. Photographs could be taken to provide a record of the appearance of the vegetation. The advantages of this approach are that data collection is rapid and it is possible to evaluate many areas in a short time. The primary disadvantage is that this approach is entirely qualitative. The evaluations are completely dependent on the perceptions of the person conducting the evaluations.

Prepare Species Lists. The second level of investigation includes the activities associated with the first level as well as the preparation of a list of species observed growing within the area being studied. The species list provides data on community composition, and repeated observations over time provide insight into changes in composition which may be related to invasion by native species. The data to be recorded include the species name and the year it was first observed. With a species list, it is also possible to compare the list of seeded species with the species actually observed. The advantage of this approach is that it provides actual data on species composition and total species diversity. The major disadvantage is that this approach provides no quantitative data on community structure.

Cover and Density Data. The third level of investigation includes all the activities associated with the first two levels and includes a sampling program designed to obtain cover and shrub density data. This approach provides quantitative data on community structure as well as composition. Also, it provides information on three of the most commonly used parameters for judging reclamation success: cover, shrub density and species diversity. The primary disadvantage of this approach is that it takes more time than the previous two levels of intensity which means that fewer areas can be evaluated using this approach.

Production Data. The fourth level of monitoring includes all the elements of the first three levels as well as collection of production data. This approach is the most comprehensive and is also the most time consuming. The major advantage of this approach is that it provides data on all the key monitoring parameters. Also, meaningful statistical evaluations can be conducted using the production data. The major disadvantage of this approach is the length of time necessary to obtain the data.

It is important to emphasize that the levels of intensity for monitoring any reclaimed area can change from year to year. During the first growing season, it may appropriate to simply prepare general comments and descriptions on the current status of the vegetation. More detailed investigations could be conducted in the second or third growing seasons. The levels of investigation can be implemented in whatever combination is deemed necessary.

SAMPLING INTERVALS

In a monitoring program designed to last for 10 years, it may be desirable to sample as many as four or five times. It is not necessary to sample every reclaimed area on a site every year, but it is important to conduct some sampling every year. On reclaimed coal lands, sampling in the ninth and tenth year is mandatory. Prudent operators will most likely want to sample reclaimed areas prior to year nine, since if remedial actions are necessary, the ten year bond period will start all over from the date of remedial action. The question arises regarding in which of the first eight years should sampling data be collected. The first growing season may not provide very much useful information on cover and production. Early successional stages on reclaimed areas tend to be dominated by weedy species. It may take two or three years for the perennial species to become well enough established to evaluate whether a successful stand of vegetation will become developed on a reclaimed site. If the sampling is conducted during the second growing season, subsequent sampling could be conducted in the fifth and seventh years. This would provide 5 years of data and would enable meaningful evaluation of any observed trends in community structure.

While it is important to develop a complete plan for monitoring a site, the actual sampling schedule should not be rigid. Areas which are marginally successful may need to be evaluated more frequently in order to determine if some sort of management is necessary. Other areas that are obviously successful by the second or third growing season may not need to be sampled until the ninth and tenth years.

SAMPLE ADEQUACY

Sampling intensity should be high enough to allow for meaningful evaluation of results, but does not need to be as high as agencies may require for baseline studies. For example, sampling at an intensity sufficient to detect a 15 percent difference with 85 percent confidence may be adequate for the purposes of evaluation of revegetation success during the first eight years of monitoring. During years nine and ten, when evaluations are required by agencies, sample adequacy requirements will need to be more stringent.

SAMPLING REFERENCE OR CONTROL AREAS

One of the important aspects of evaluation of revegetation success is comparison of reclaimed areas with native vegetation types. This may be accomplished by sampling remnants of the original vegetation on the site or by sampling established reference areas or control plots. It may not be necessary to sample every reference area each year, but rather a more appropriate approach would be to sample only the major native vegetation types. Actual sampling programs for the native vegetation types would be dependent on the goals of the evaluation program.

DATA ANALYSIS

Data from a revegetation monitoring program can be evaluated using a variety of techniques. Statistical approaches can be used to compare data from reclaimed areas to data from native vegetation types, to compare data from areas reclaimed using different techniques, and to evaluate year-to-year trends in levels of production. Trend analyses can provide powerful insight into vegetation development and can be used to provide a strong argument for successful revegetation. Trends in cover, production, species diversity, and shrub density are all important parameters to evaluate. More complex analyses, like ordination and other multivariate techniques may also be used to evaluate the relationships between reclaimed areas and native vegetation types.

CREATION AND MAINTENANCE OF DATA BASES

One of the key elements of being able to successfully evaluate revegetation success is maintaining complete and readily accessible data bases for historical information as well as for vegetation sampling data. If records on how an area has been reclaimed are not accurately kept, then evaluations regarding which revegetation techniques provide the best results are not possible. If careful records are kept, then it is possible to duplicate those approaches which provide the best results. Conversely, it reduces the chance for repeating techniques which produce undesirable results.

The vegetation sampling data need to be organized and accessible.

If the data are stored in file drawers or three-ring binders, they may be organized but they are not very accessible. The best way to accomplish both organization and accessibility is with a microcomputer. Software designed to handle both historical and vegetation data is currently available (Revegetation Information Monitoring and Analysis Program by Warren Keammerer). The amount of data that needs to be kept track of is staggering. If one assumes a 40 year mining project reclaiming 200 acres per year (5-10 parcels), it is likely that at any one time as many as 50 to 100 separate parcels of land will be in various stages of revegetation. With five years of sampling data for each of these parcels, it is easy to see the scope of the data management problem. If only person is responsible for handling the data, the problems of access and organization are not as severe as if several people are involved. If the primary person responsible for data management leaves the project, it would be very difficult for a new person to step in unless the data have been computerized. Also, once the data have been entered into a computer, the drudgery of data summarization is eliminated and emphasis can be placed on data analysis and interpretation.

If the data are well organized, it will be possible to prepare detailed, well documented requests for bond release and complete evaluations of revegetation techniques. When considering all the money and effort that go into reclamation, it becomes clear why monitoring the revegetation results becomes an important issue.

SUMMARY

When monitoring vegetation, the first step is to decide on the parameters to be evaluated. The most common monitoring parameters include cover, production, species diversity, and shrub density.

Methods of data collection should be consistent from year to year on each parcel of land being evaluated. Keeping the same methods will eliminate one of the sources of variability present in the data.

A schedule of monitoring frequency and intensity should be developed. The schedule should be flexible, yet complete enough to allow for yearly planning of monitoring efforts.

The vegetation data can be evaluated using a variety of analytical techniques, including statistical testing, trend analysis, and multivariate analyses.

Complete records should be kept regarding revegetation techniques and sampling data for each site for each year of sampling. The only realistic way to keep these records complete, organized and accessible is with a microcomputer.

USE OF SEWAGE SLUDGE FOR RECLAMATION OF COAL MINE SPOILS

Burns R. Sabey, Karl Topper, and Gerard Voos
Colorado State University
Disturbed Lands Laboratory
Fort Collins, CO 80523

INTRODUCTION

Recycling of human treated and untreated fecal wastes on the land is as old as the history of mankind on the earth and in some areas it has been a means of maintaining soil productivity for long periods of times. However it has only been in this century that we have become concerned about the environmental and economic impact of this practice. The concern has resulted from the excessive accumulation of sewage sludge due to the concentration of large human populations in confined areas (cities) and from an increased environmental conscience. Primary concerns are associated with pathogen buildup and spread, entrance of heavy metals in the food chain, salt accumulation in soil and ground water, nitrate leaching into the ground water, and other potentially toxic substance accumulation in the soil, plants and other components of the food chain.

Waste water treatment facilities have been developed to a high degree of technology which have helped to control disease spread in our waters and foods, yet treatment facilities do not render the product of the treatment (sewage sludge) aseptic. Thus the concern, whether warranted or unwarranted. Various disposal mechanisms of the sludge have been used including incineration, land filling, ocean dumping as well as recycling on the land. All of these methods of disposal have the potential for pollution of our environment. Land recycling, if well managed and controlled has potential for beneficial use, turning sewage sludge into a resource rather than a waste. Applying sewage sludge to crop land as a soil amendment has been shown to be beneficial in many instances and detrimental in other instances. It depended on the sludge, the soil properties, the crop grown, the climate, and the management practices. Some soils do not respond to fertilizer or any other soil amendment, because the physical, biological and chemical properties may already be near optimum. At other times this may not be the case and a response may be evident.

Drastically disturbing an area of land due to surface mining or other activity destroys the natural soil profile and removes the topsoil and vegetation (Box 1978). When the disturbing activity is completed the spoils are graded and are often left exposed to the atmosphere at the surface. These spoils are often (usually) low or devoid of organic matter, plant available nitrogen and phosphorus. Spoils often have a poor physical condition for plant growth, therefore without some amendments, promoting plant growth may be difficult if not impossible. Problems of low fertility status and poor physical properties of spoils can usually be improved by the addition of some municipal sewage sludges. This has been shown at many sites in the Midwest and Eastern U.S.A. (Sopper and Seaker, 1983). Few studies using sewage sludge on mine spoils have been performed in the Intermountain West. We know that the climate, soils, and plant species, along with other important factors affecting plant growth are very different in the western part than that of eastern U.S.A., but the extent of the benefit under western conditions, has not been fully investigated.

Western coal mining is expected to increase in the future from 320 million tons in 1985 to about 500 million tons by 1990 (Silverman, 1983). When the mining operation occurs near a sludge source so that transportation is not too costly, the use of municipal sewage sludge as a spoil amendement for enhancing revegetation should be considered.

LITERATURE REVIEW

Several investigators in the East have shown an increase in availability of nitrogen and phosphorus along with improved physical condition of the spoil, and a decrease in the acidity of acid forming coal mine spoils from sludge additions (Barnhisel et al., 1980; Briebal et al., 1979; Kerr and Sopper, 1982; Stucky and Bauer, 1979). In some cases productive lands have been developed from barren spoils previously unable to support vegetation growth (Kardos et al., 1979; Sopper and Kerr, 1982; Stucky and Bauer, 1979; Sutton and Vimmerstedt, 1973).

Sewage sludges contain 2 to 6% nitrogen (N) or more, the majority of which is in the organic form (Sommers et al., 1976). The rate of mineralization of this organic N to NH_4-N and the subsequent nitrification to NO_3-N is therefore important in determining safe and beneficial loading rates.

One of the major concerns and at the same time one of the greatest benefits of the application of digested sewage sludge to lands disturbed by surface mining and other pertubations is the release of inorganic N into the environment. Responsible for some of the cautious attitudes towards the use of sewage sludge as a soil amendment on disturbed lands is the potential leaching of NO_3-N into ground water and the surface runoff of inorganic P into lakes and streams possibly resulting in eutrophication. The levels of N needed if deficient to stimulate moderate increases in biotic productivity in lakes and streams are at least an order of magnitude lower than the levels thought to pose a risk to human health which has been set at 10 mg L^{-1} by the U.S. Public Health Service (Brezonik, 1978).

Until recently most laboratory incubation experiments used to estimate N mineralization in soils have utilized a procedure devised by Stanford and Smith (1972) in which columns of soil are leached with $CaCl_2$ and a N free nutrient solution. Using this method Stanford and Smith originated the concept of the N mineralization potential (No) of a soil. Recently the leaching process has been shown to underestimate the N mineralization potential of a soil by leaching out not only the inorganic N but also the water soluble organic compounds which may contain mineralizable N (Sommers et al., 1980; Smith et al., 1980; Parker and Sommers, 1983). A procedure used by Sommers et al. (1980) employed nondestructive subsampling to minimize underestimation of N mineralization potential of sewage sludge. The non-leaching procedure is also less tedious and time consuming than the leaching procedure of Stanford and Smith (Sommers et al., 1980).

The literature suggests that mineralization of the organic N contained in sewage sludge is a complex process that is dependent on several factors. Laboratory analyses indicate that the type of secondary treatment process, anaerobic or aerobic, has a significant effect on the mineralization rate. Factors having an influence on the chemical composition of the sewage sludge include the extent of industralization of the district producing the sewage and the seasonal variability of sewage entering the treatment facility (Sommers et al., 1976).

Terry et al. (1981) tested the effects of soil pH, moisture level, incubation temperature, and the addition of a nitrification inhibitor on nitrogen mineralization. Temperature was the only factor evaluated which significantly affected the mineralization of sludge organic N.

There is some disagreement among researchers concerning the effect of the rate of sewage sludge addition on the percentage of added organic N mineralized. Terry et al. (1981), using sewage sludge application rates of 11.2, 22.4, and 44.8 Mg ha^{-1} found that the percent of added organic N mineralized was significantly greater at the two higher rates than the lower rate of sludge addition. Epstein et al. (1978) and Magdoff and Chromec (1977) observed no rate effect on the percent of added organic N mineralized. Premi and Cornfield (1971) using sludge rates of 0.5%, 1.0%, and 2.0%, found 4.2% of the added organic N mineralized in the 0.5% treatment over a 6 week period. This decreased to 2.3% where the 2.0% sludge treatment was used. Following this trend Sabey et al. (1977) and Parker and Sommers (1983) observed that the percent of added organic N mineralized decreased as the amount of N added increased.

At low levels of sludge addition almost all of the inorganic N measured after the incubation period is in the form of NO_3-N while at high rates of sewage sludge addition there are considerable amounts of NH_4-N still left in the system (Premi and Cornfield, 1971; Ryan et al., 1973; Magdoff and Chromec, 1977; Epstein et al., 1978; Terry et al., 1981).

Mineralization of sewage sludge organic N has been shown to be a rapid process with the majority of mineralization occurring shortly after application for aerobically digested sludges and remaining constant from weeks 4-16. Anaerobically digested sewage sludges exhibited greatest mineralization between 4 to 8 weeks decreasing to a constant value after that (Parker and Sommers, 1983). Epstein et al. (1978) observed varying lengths of time for mineralization to stabilize with times of 5, 9, and 13 weeks for treatments of 454 kg N ha^{-1}, 907 kg N ha^{-1}, and 1814 kg N ha^{-1}, respectively.

Studies by Hinesley et al. (1982) using anaerobically digested sewage sludge at rates up to 896 Mg ha^{-1} from the Chicago Metropolitan Sanitary District on coal mine spoil showed that tall fescue, perennial ryegrass and western wheatgrass responded more to sludge application rate of 224 Mg ha^{-1} than other grasses used in the study. The greatest sludge application rates resulted in reduced yield, presumably due to excess salt accumulations. Based on this and other studies on the Fulton County coal mine spoils, a program of reclamation was developed by shipping sewage sludge from Chicago via the Illinois River to Fulton County and applying the sludge to the spoils as an amendment for promoting plant growth (Peterson et al., 1982).

Subsequently corn, wheat and soybeans have been grown successfully on the spoils. During a 5 year period, overall increases in yields were reported by Peterson et al. (1982) but the responses were variable among years, as would be expected (Pietz et al., 1982). Hinesley et al. (1982) noted improved physical conditions in proportion to sludge loading rates. Among these were increased water holding capacity and percent water stable aggregates. These results indicated that in semi-arid climates sewage sludge could be beneficial, yet little work has been done in this area.

Suhr (1982) indicated that revegetation benefits from sewage sludge in semi-arid climates were not well documented, but that a few studies have been performed. Aldon (1982) reported increased plant growth in a greenhouse study with increasing sludge addition. An increase in number and variety of fungi and actinomycetes were reported with sludge amended spoils.

Fresquez and Lindemann (1982) examined the soil and rhizosphere microorganisms in a greenhouse study wherein northwestern New Mexico mine spoils were treated with fertilizers, topsoil inoculation, and sewage sludge. The topsoil inoculant did not increase microbial parameters of the spoil but the sewage sludge added at 89.6 Mg ha^{-1} did. They stated that a source of available carbon is critical for development and growth of a varied soil miniflora. The carbon supplied in sludge appears to fulfill this requirement.

In a Wyoming greenhouse study Howard et al. (1977) reported that the addition of sewage sludge, manure and inorganic N and P increased growth of forage plants and range shrubs. Our field plot studies on topsoil over retorted Paraho oil shale also showed the benefit of sewage sludge to native plant species growth (Sabey et al., 1980).

A 1978 study on mine spoils at Climax by Guillaume and Berg included some sewage sludge treatments. Recent data indicated a greater beneficial effect of the sludge treated plots compared to other treatments (Berg, Personal communication).

Finally, a practical demonstration of the use of sewage sludge for revegation of molybdenum tailings and spoils was carried out by AMAX corporation (Brown and Jackson, 1984). Starting in 1974, 125 acres of rather infertile and unstable mine tailings were successfully revegetated and stabilized. This may have been the first actual mine reclamation project in the intermountain west using extensive quantities of sewage sludge as an amendment for unproductive plant growth media.

These studies have indicated beneficial effects of sludge addition to drastically disturbed lands but much more detailed data are needed to help guide our management practices leading to successful revegetation in the semi-arid West.

Two problems have plagued us and have prohibited the development of sound management of a sewage sludge recycling program on mine spoils. They are: 1) The lack of definitive data indicating the rate of mineralization of the organic N in the sludge. Until we know this information we cannot make a sound recommendation for the amount of sewage sludge needed to supply the plant N requirements and 2) The lack of data showing the N and P equivalent of various application rates of sewage sludge. Again, without this information we don't know how much sludge is required to meet plant needs without overapplication that could lead to potential pollution from NO_3 and other salts. Our attempt to resolve these two problems are outlined in the following brief discussions of two studies done on coal mine spoils in northwest Colorado.

LABORATORY MINERALIZATION STUDY

METHODS AND MATERIALS

The first study was a laboratory incubation experiment designed to determine the rate of mineralization of the sludge organic N to form NO_3 and NH_4 (the plant available forms of N) in 6 plant growth materials as follows: 1) Undisturbed topsoil, 2) Stockpiled topsoil, 3) Coal mine spoils, 4) 1:1 w/w mixture of coal mine spoil and undisturbed topsoil, 5) 1:1 w/w mixture of coal mine spoil and stockpiled topsoil, 6) pure quartz sand. The first five materials were taken from the Colorado Yampa coal mine near Oak Creek, Colorado. These materials were treated with the equivalent of 0, 40, 80, and 120 Mg ha^{-1} of sewage sludge and there were 5 replications. The analyses of the plant growth materials and the sewage sludge used in the study are found in Tables 1 and 2, respectively. One hundred gram samples of the above 6 materials were placed in plastic lined soil testing bags and treated with appropriate amounts of dried sewage sludge obtained from the Steamboat Springs treatment plant. Sufficient water was added to bring the materials to field capacity and the bags were closed. The bags were opened each week for aeration and were brought to field capacity if needed before reclosing. Subsamples of 5g

Table 1. Soil and mine spoil characteristics.

	Organic Matter†	Organic C‡	Inorganic N§§ NH_4	Inorganic N§§ NO_3	C/N	Organic N §	pH¶	SAR¶	Conductivity#	Field†† Capacity (θ_v)	Texture‡‡
	g kg^{-1}		mg kg^{-1}		wt wt^{-1}	g kg^{-1}			ds m^{-1}	$cm^3 cm^{-1}$	
Stockpiled Topsoil	30	17.4	3.3	10.1	9.3	1.86	6.35	0.3	0.53	13.15	loam
Undisturbed Topsoil	43	24.9	3.3	10.1	9.4	2.62	6.30	0.6	0.64	16.39	loam
Spoil	40	23.2	10.1	10.1	12.3	1.86	6.98	0.5	3.09	13.44	clay loam
Sand	--	--	3.3	3.3	--	0.09	5.99	0.8	0.42	8.19	sand

†Broadbent
‡Allison, 1954
§Bremner, 1965a
§§Bremner, 1965b
¶Sandoval and Power, 1978
#Bower and Wilcox, 1965
††Danielson, 1982
‡‡Day, 1965

Table 2. Characteristics of Steamboat Springs sewage sludge.

Analysis	Concentration mg kg^{-1}	Analysis	Concentration mg kg^{-1}	Analysis	Concentration mg kg^{-1}
Organic C ‡	360,000	Total Hg¶	4,700	Total Cd¶	6
Total N §	40,800	Total Na¶	1,800	Total Ti¶	92
NH_4^+-N§§	176.8	Total Fe¶	13,700	Total Cr¶	69
NO_3^--N§§	10.1	Total Al¶	18,100	Total Sr¶	181
Organic N	40,600	Total Zn¶	716	Total Ba¶	730
C/N	8.8	Total Mn¶	1,140	Total Pb¶	166
Total P¶	15,900	Total Cu¶	1,660	pH#	6.26 †
Total K¶	5,700	Total Ni¶	30	Conductivity,# dS·m^{-1}	2.19 †
Total Ca	17,100	Total Mo¶	16	SAR ††	3.19 †

† Units - not mg kg^{-1}
‡ Allison, 1965
§ Bremner, 1965a
§§ Bremner, 1965b
¶ HNO_3+$HClO_4$ digest, analyzed for metals using Jarrell-Ash Model 975 Plasma Atom Cmp
# Street, 1976
†† Sandoval and Power, 1978

were removed from each bag at 0, 1, 2, 4, 6, 8, and 16 weeks for determination of NO_3 and NH_4 using the micro-kjeldahl distillation procedure (Bremner, 1963b).

RESULTS AND DISCUSSION

Table 3 shows the data for each of the 6 plant growth materials, for each sludge treatment, and for each incubation time period. The total amount of inorganic N (NH_4-N + NO_3-N) that accumulated during the 16 week period increased significantly with increasing rates of sewage sludge in each of the materials tested. There were significant differences among the different materials in the amount of native organic N that was mineralized. Six hundred and thirty-six mg of N kg^{-1} of soil accumulated in the unamended undisturbed topsoil (UTS). This value and subsequent total inorganic N values were derived from adding the NH_4-N and NO_3-N values in Table 3. The stockpiled topsoil (STS) accumulated 392 mg N kg^{-1} of soil at the 0 Mg ha^{-1} treatment rate. This 38% difference between the two topsoils in the amount of inorganic-N that accumulated was most likely a result of the undisturbed topsoil having 43% more organic matter and consequently a greater pool of indigenous organic N, as well as favorable physical features such as structure and aeration. The spoil, STS + spoil, UTS + spoil, and sand materials accumulated 274, 319, 359, and 40 mg N kg^{-1} of soil, respectively at the 0 Mg ha^{-1} treatment rate. There were significant differences (P value < 0.001) in the amount of inorganic N accumulated in 16 weeks, in each material due to sludge treatment level tested. The undisturbed topsoil had accumulated the greatest amount of inorganic N after the 16 week period with 1023, 936, 731, and 636 mg N kg^{-1} soil at the 120, 80, 40, and 0 Mg ha^{-1} sludge treatments, respectively.

Although the spoil initially had greater amounts of organic N and inorganic N than the stockpiled topsoil, it accumulated much less net inorganic N at each sludge treatment level. This may have been due, as Clark (1977) suggested, to the organic N in the spoil being removed from the fast cycling portion of the system and accumulating as a very resistant humic fraction. N immobilization by the heterotrophic microorganisms or fixation of NH_4-N in the lattice structure in the clay portion of the spoil may also have occurred (Stevenson, 1962; Reeder et al., 1975).

The amount of NO_3-N accumulated during the 16 week incubation remained quite constant among different sludge treatments for the same soil material. Significant differences occurred between the sludge treatment level of

Table 3. Mean results for inorganic-N (NH_4-N + NO_3-N) measured for each sewage sludge treatment level at the seven sampling intervals.
* initial amounts of inorganic-N have been subtracted

Sludge Treatment	Week 1		Week 2		Week 4		Week 6		Week 8		Week 11		Week 15	
	NO_3	NH_4*	NO_3	NO_4*	NO_3	NH_4*	NO_3	NH_4*	NO_3	NH_4*	NO_3	NH_4*	NO_3	NH_4*
	mg Kg^{-1}													
STOCKPILED TOPSOIL														
Control	22	181	43	194	51	241	129	197	133	218	158	210	181	211
40 Mg ha^{-1}	12	277	55	336	62	355	141	363	142	375	178	394	209	405
80 Mg ha^{-1}	22	377	22	468	32	502	86	602	118	618	151	635	210	654
120 Mg ha^{-1}	12	404	35	522	12	574	70	710	70	731	107	767	194	754
UNDISTURBED TOPSOIL														
Control	40	196	102	206	152	265	256	238	280	276	314	250	346	290
40 Mg ha^{-1}	33	276	111	288	136	372	259	328	281	367	321	355	369	362
80 Mg ha^{-1}	19	358	94	377	123	459	291	429	308	494	353	502	432	504
120 Mg ha^{-1}	17	438	55	541	64	582	282	590	320	624	388	643	384	639
MINE SPOIL														
Control	1	26	1	59	1	128	15	231	13	256	30	239	43	231
40 Mg ha^{-1}	7	185	3	277	13	284	16	331	14	351	23	363	24	378
80 Mg ha^{-1}	4	217	2	301	4	301	4	440	0	459	1	469	1	504
120 Mg ha^{-1}	1	249	1	288	5	311	2	546	1	559	0	579	18	599
STOCKPILED TOPSOIL + MINE SPOIL														
Control	8	143	17	187	17	170	126	91	136	101	196	69	271	48
40 Mg ha^{-1}	9	217	14	271	18	272	114	284	103	306	157	302	227	60
80 Mg ha^{-1}	4	282	8	330	8	364	55	454	47	474	73	487	116	487
120 Mg ha^{-1}	4	322	12	373	8	426	13	654	18	644	31	651	39	645
UNDISTURBED TOPSOIL AND MINE SPOIL														
Control	16	146	51	181	65	204	246	72	239	88	300	37	331	28
40 Mg ha^{-1}	15	230	33	258	47	280	238	207	244	209	310	169	387	167
80 Mg ha^{-1}	16	305	28	346	35	375	253	280	266	312	359	276	388	247
120 Mg ha^{-1}	13	338	11	357	16	423	159	473	158	496	245	456	304	426
SAND														
Control	2	4	0	15	2	19	0	57	0	58	0	53	0	40
40 Mg ha^{-1}	6	138	3	161	1	140	0	146	0	144	1	136	0	110
80 Mg ha^{-1}	4	225	2	260	5	245	0	271	0	225	0	222	0	191
120 Mg ha^{-1}	11	320	5	345	4	301	0	336	5	315	2	274	0	273

the stockpiled topsoil + spoil mixture only. There were, however, significant differences at each sludge treatment level due to each soil material. This lack of sludge rate effect on the rate of nitrification followed what has been reported in the literature (Premi and Cornfield, 1971; Ryan et al., 1973; Magdoff and Chromec, 1977; Epstein et al., 1978; Terry et al., 1981) and may be due either to the high amounts of NH_4-N introduced with the sludge, which when transformed into NH_3 is toxic to the nitrifying organisms, or immobilization of inorganic N. The amount of NO_3-N that was produced in the spoil samples at all sludge treatment levels was considerably less than that produced in most of the other soil materials and essentially no NO_3-N was detected in any of the sand samples. The bacteria responsible for the oxidation of NH_4^+ to NO_2^- and NO_3^- only number in the thousands per gram of soil under optimum conditions and only in the hundreds per gram of soil in poor conditions (Mengel and Kirkby, 1979). Considering this, the population of nitrifying organisms in the sand and spoil materials may have been very low at the initiation of the experiment, since the sand was almost entirely inorganic quartz material with little moisture and nutrient holding capacity. The spoil material originated below the soil profile where aeration and moisture conditions were less than optimum for microbial growth. Other possible reasons for limited NO_3-N production are the presence of substances toxic to the nitrifying organisms in the sludge and/or soil materials, NH_4 fixation by spoil materials, and a high NH_4-N content in the initial soil-sludge mixture combined with high pH values. These may also explain the period in which the rate of net nitrification declined between the two and four week sampling periods (Premi and Cornfield, 1971; Reeder 1971; Hsieh et al., 1981).

The amount of NH_4-N that accumulated increased significantly as the rate of sewage sludge addition increased. In all of the soil materials except the undisturbed topsoil (UTS) plus spoil mixture the rate of ammonification had stabilized after 8 weeks with only slight increases or decreases during the remainder of the incubation period. The UTS + spoil samples at the 0, 40, and 80 Mg ha^{-1} sludge treatments exhibited a distinct decrease in the amount of NH_4-N at the same time the level of NO_3-N was increasing. This increase in NO_3-N was much greater than the decrease in the NH_4-N, indicating rapid nitrification of available NH_4-N at that particular time in the incubation period. The 0 Mg ha^{-1} sludge treatment samples for the STS + spoil combination also showed the same pattern. This may have been caused by the establishment of a sizable population of nitrifying organisms at the 4 week time period which would have greatly accelerated the nitrification process. The reason that this only occurred in the samples for these four sludge treatments is not known.

Sewage Sludge Organic Nitrogen

The quantities of inorganic N accumulated over 16 weeks at the sludge treatment levels of 40, 80, and 120 Mg ha^{-1} were statistically compared after subtracting the amount of N accumulated in the control treatments (0 Mg ha^{-1}). A significantly greater percent of the organic N added with the sewage sludge in each of the three higher treatment levels was mineralized in the stockpiled topsoil samples than in the other materials (Table 4). The treatments were tested for equality within blocks and two distinctive results were attained. When all blocks were compared simultaneously, shadowing any inter-block effects, all treatment levels were found to be different as to the amount of added organic N mineralized, with a level of significance of less than 0.003. When the blocks were analyzed separately, the treatments for the sand and spoil materials were not found to be significantly different, while the four other materials were found to be significantly different in the amount of added organic N mineralized at each treatment level.

As noted in Table 4 the amount of organic N that was mineralized in the 16 weeks ranged from about 10% on the sand to over 30% in the stockpiled topsoil. Other materials varied within these values.

In summary, the application of sewage sludge increased the amount of inorganic N that would be available for plant growth in coal mine spoil and topsoils. The use of sewage sludge did not increase the amount of NO_3-N in any of the materials and therefore nitrate leaching may not be a rate limiting factor for these topsoils and spoil.

Table 4. Effect of application rate of sewage sludge on net N mineralization rates in coal mine topsoils, spoil, a 1:1 mixture of each, and a silica quartz sand.

Sewage Sludge Treatment Levels	Total net N‡ mineralized in 16 weeks	N recovered as† NH_4-N in 16 weeks	NO_3-N ‡	Predicted net N¶ mineralized in 16 weeks (No)	Sludge organic# N mineralized in 16 weeks	Rate constant¶ (k)
	---------- $mg\ kg^{-1}$	----------	----------	----------	------% ------	$weeks^{-1}$
STOCKPILED TOPSOIL						
0 $Mg\ ha^{-1}$	392	211	181(46) ‡‡	356	---	0.595
40 $Mg\ ha^{-1}$	614	405	209(34)	549	31.3	0.573
80 $Mg\ ha^{-1}$	864	654	210(24)	779	33.7	0.451
120 $Mg\ ha^{-1}$	938	744	194(21)	858	26.5	0.457
UNDISTURBED TOPSOIL						
0 $Mg\ ha^{-1}$	636	290	346(54)	590	---	0.385
40 $Mg\ ha^{-1}$	730	362	368(51)	678	13.3	0.426
80 $Mg\ ha^{-1}$	935	504	431(46)	872	21.4	0.350
120 $Mg\ ha^{-1}$	1023	639	384(38)	991	18.7	0.401
MINE SPOIL						
0 $Mg\ ha^{-1}$	274	231	43(16)	270	---	1.944
40 $Mg\ ha^{-1}$	402	378	24(6)	371	17.9	0.626
80 $Mg\ ha^{-1}$	505	504	1(<1)	471	16.3	0.429
120 $Mg\ ha^{-1}$	617	599	18(3)	621	16.5	0.286
STOCKPILED TOPSOIL AND MINE SPOIL						
0 $Mg\ ha^{-1}$	319	48	271(85)	253	---	0.721
40 $Mg\ ha^{-1}$	487	260	227(47)	438	23.6	0.489
80 $Mg\ ha^{-1}$	603	487	116(19)	555	20.3	0.446
120 $Mg\ ha^{-1}$	684	644§	36(6)	678	17.5	0.419
UNDISTURBED TOPSOIL AND MINE SPOIL						
0 $Mg\ ha^{-1}$	359	28	331(92)	335	---	0.563
40 $Mg\ ha^{-1}$	554	167	387(70)	494	27.4	0.409
80 $Mg\ ha^{-1}$	635	247	388(61)	604	19.7	0.471
120 $Mg\ ha^{-1}$	730	426	304(42)	700	18.0	0.375
SAND						
0 $Mg\ ha^{-1}$	37	37	0	51	---	0.249
40 $Mg\ ha^{-1}$	110	110	0	--	10.2	††
80 $Mg\ ha^{-1}$	190	190	0	156	10.9	0.625
120 $Mg\ ha^{-1}$	272	272	0	--	11.4	††

† Mean results of 5 replications.
‡ Amount of N mineralized in control not subtracted from these values.
§ Initial amounts of NH_4^+-N and NO_3^--N in sewage sludge and soil subtracted from these values.
¶ No and K obtained from non-linear least squares regression equation: N_m = No[1 - exp (-kt)].
# [(N mineralized in treatment - N mineralized in Control)/Sludge organic N added] x 100
†† Data did not fit first-order equation.
‡‡ % N recovered as NO_3-N in 16 weeks.

FIELD STUDY

The next study was designed to evaluate the comparative influence of sewage sludge and inorganic N and P on revegetation of coal mine spoils.

METHODS AND MATERIALS

The test plots were established in the Fall of 1982 on coal mine spoils at the Colorado Yampa Coal Mine. The spoils were composed largely of sandstone and shale overburden and were originally graded in 1976 with a 8-15% slope facing a northwesterly direction. Treatments consisted of the following:

1. 0, 14, 28, 55, and 83 Mg ha^{-1} of dry sewage sludge
2. 0, 40, 80, 120, and 160 kg ha^{-1} of inorganic N fertilizer (each rate had 160 kg ha^{-1} of elemental P)
3. 0, 40, 80, 120, and 160 kg ha^{-1} of inorganic P fertilizer (each rate had 160 kg ha^{-1} of elemental N).

Each of the 15 treatments were replicated 5 times in a completely randomized block design. Calculated amounts of sludge, N, and P were hand spread on the plots after the plots were chisel plowed along and across the contour to a depth of about 25 cm. After treatment application, a single passage of the chisel plow partially incorporated the material into the spoil. The anerobically digested sewage sludge was obtained from the Steamboat Springs sewage treatment plant and contained 3.22% total N with 1500 ppm of NH_4^+-N and 43 ppm of NO_3^-N. Total P was 1.36% with 1,067 ppm of AB-DTPA extractable P (Soltanpour and Schwab, 1977). The grass seed mixture in Table 5 was broadcast on the plots at a bulk rate of 28.19 kg ha^{-1}.

Vegetation data were obtained during the first weeks in August of 1983 and 1984, a time when a majority of the grasses were recognizable by their inflorescence. Vegetation measurements consisted of percent canopy cover, above ground biomass, and total N and total P concentration of grass tissue. Soil samples collected at a depth of 8 cm during the month of August in 1983 were analyzed for organic C, electrical conductivity (EC<, pH in a saturated paste and saturation percentages. Spoil samples which were collected from the top 15 cm during the first week of June 1984, were

Table 5. Pasture grass mixture seeded during November, 1982.

Species	Bulk	PLS †	PLS ‡
	--- kg/ha ---		no/m^2
Slender wheatgrass (*Agropyron trachycaulum*)	5.12	3.69	78
Intermediate wheatgrass 'Amur' (*Agropyron intermedium*)	4.82	3.47	55
Pubescent wheatgrass 'Lunar' (*Agropyron trichophorum*)	4.68	3.88	64
Crested wheatgrass 'Nordan' (*Agropyron desertorum*)	3.89	3.25	119
Smooth brome (*Bromus inermis*)	4.69	3.88	88
Meadow brome (*Bromus erectus*)	2.69	1.98	20
Timothy 'Climax' (*Phleum pratense*)	1.52	1.40	369
Orchardgrass 'Potomic' (*Dactylis glomerata*)	1.49	1.14	103
TOTAL	28.90	22.69	788

† PLS = Pure Live Seed. Purity values were obtained from Merkel and Herbel (1973).
‡ Values for the no. seeds kg^{-1} were obtained from Heady (1975) for all species except *Agropyron trachycaulum* which was located in AOSA (1978).

analyzed using AB-DTPA extract (Soltanpour and Schwab, 1977).

RESULTS AND DISCUSSION

Figure 1 shows that in the first growing season invading annual forbs dominated all the plots. The plots with the sewage sludge additions had less than 5% seeded grasses making up the above ground biomass, whereas on the inorganic fertilizer plots (data not shown) the value was up to 10%. Weedy forb invasion during the first growing season is typical of revegetation efforts when fertilizer amendments are added to spoils in this region (Heikes, 1980).

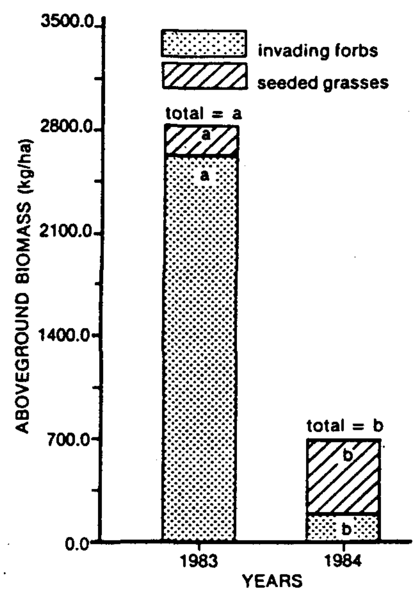


Fig. 1. Mean dry weight of aboveground biomass comparing consecutive years based on pooling data from the control and sludge amended plots. Means with different letters within life-forms are significantly different ($p = 0.01$).

Total production of vegetation in 1983 on the sewage sludge and N plots significantly increased compared to the control. A linear increase in total above ground biomass up to 4300 kg ha^{-1} occurred with increasing sludge addition. The N fertilizer additions resulted in a quadratic plant growth response, leveling off at 1800 kg ha^{-1} total production. There were no significant plant growth responses due to P additions.

Similar responses occurred with the canopy cover of total vegetation. The first level of sludge application increased total canopy cover from 5% for the control to about 18% which was significantly greater than any of the inorganic fertilizer treatments.

In the second growing season seeded grasses dominated the stand composition with sludge treated plots ranging from 61 to 94% whereas the invading annual forbs ranged from 5 to 39% (Table 6). Similar results occurred in the inorganic fertilizer plots. Invading grasses represented an insignificant life form component in any of the plots.

Figure 1 indicates a difference in above ground biomass between the first and second year. Total biomass was greater in 1983 than in 1984 but seeded grass biomass in 1984 was greater than in 1983. Again, the same trends occurred with canopy cover comparisons. A comparison of the total ground cover between 1983 and 1984, which included a litter component in 1984, revealed that there was no significant difference between years. This implies that cover for erosion control was maintained at approximately comparable level both years.

All treatments in 1984 increased seeded grass production in a quadratic manner when compared to the control. However with the exception of 83 mg ha^{-1} the sludge treated plots again produced significantly greater grass biomass than the inorganic N and P treated plots (Figure 2). There may be several reasons for this

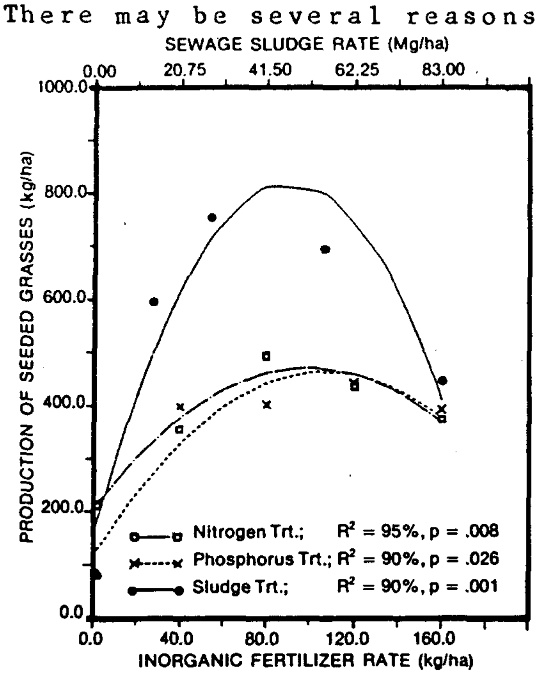


Fig. 2. Relationship between biomass of seeded grasses and spoil treatments, 1984. Regression lines and observed means are shown. Each N level has 160 kg ha^{-1} P and each P level has 160 kg ha^{-1} N.

Table 6. Relative life-form composition of sewage sludge amended coal mine spoil from 1983-1984.

Life Form	Level	Life form composition† 1983	1984
	Mg/ha	--------- %	-------
Seeded grasses	0	3.1	84.7
	14	3.3	94.0
	28	3.4	76.5
	55	4.3	66.7
	83	2.3	61.3
Invading Grasses	0	0	0.2
	14	T‡	1.2
	28	T	1.1
	55	0.2	0.1
	83	T	0.0
Invading annual forbs	0	96.9	15.1
	14	96.7	4.8
	28	96.6	22.5
	55	95.5	33.2
	83	97.6	38.7

† Aboveground biomass values were used to calculate life-form composition.

‡ Trace amount: less than 0.1% of composition.

greater response including: 1) improvement in physical properties, i.e., water supply to plants, improved soil structure and aeration, 2) continuous release of inorganic N and P over the growing season, 3) enhanced supply of micronutrients (though AB-DTPA analyses belie this) and 4) more ideal biological properties. Note that for the highest sludge rate a significant decrease in seeded grass production was observed compared to the other sludge treatment levels. Information in Table 6 may provide a possible explanation for this phenomenon. The seeded grasses reached a peak in 1984 of 94% of the life-form composition with 14 Mg ha^{-1} of sludge. The three higher sludge levels followed a decreasing trend of seeded grass composition with increasing sludge. Sludge applications > 14 Mg ha^{-1} may have provided surplus N which stimulated invading annual forbs more than the seeded grasses. This may have created greater competition to the grasses causing a decline in seeded grass growth.

Seeded grasses were chemically analyzed for total N and total P concentrations. Linear increases in N concentration with increasing levels of N fertilizer and sludge application were measured in 1984 (Fig. 3). The lowest sludge level (14 Mg ha^{-1}) was the only sludge rate which resulted in comparable N concentration in the seeded grass tissue to the N fertilizer treatments. All the

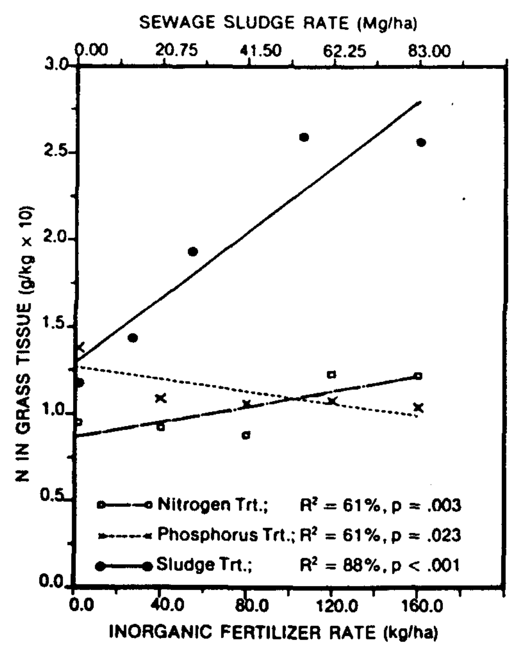


Fig. 3. Effect of spoil treatments on total N concentration of seeded grasses, 1984. Regression lines and observed means are shown. Each n level has 160 kg ha^{-1} P and each P level has 160 kg ha^{-1} N.

higher sludge rates resulted in greater N concentrations than the inorganic fertilizers. These trends also occurred for samples analyzed in 1983. These results were consistent with N availability calculations for sludge applications, showing that sludge rates > 14 Mg ha^{-1} had more N available than the highest N fertilizer treatment (160 kg ha^{-1}). Figure 3 indicates that increasing P levels produced a significant decline in total N concentration for 1984. The zero application level of P fertilizer is the only treatment which had a significantly higher N concentration than the other P treatments. The lower N concentration values associated with higher P applications appears to be due to a dilution effect caused by increased grass production.

A linear increase of total P concentration in the grass tissue with increasing sludge levels occurred in the second growing season (Fig. 4). This same trend was measured for samples analyzed in 1983. The concentrations of P in seeded grass tissue in 1983 and 1984 were significantly increased by inorganic P fertilizer additions, but a significant decline in P content occurred for the highest P fertilizer rate during the first year of growth. P availability calculations suggested that P values for the sludge applications would be similar to the inorganic P treatments. The lowest level of sludge, however, was the only comparable sludge rate to the inorganic P fertilizers.

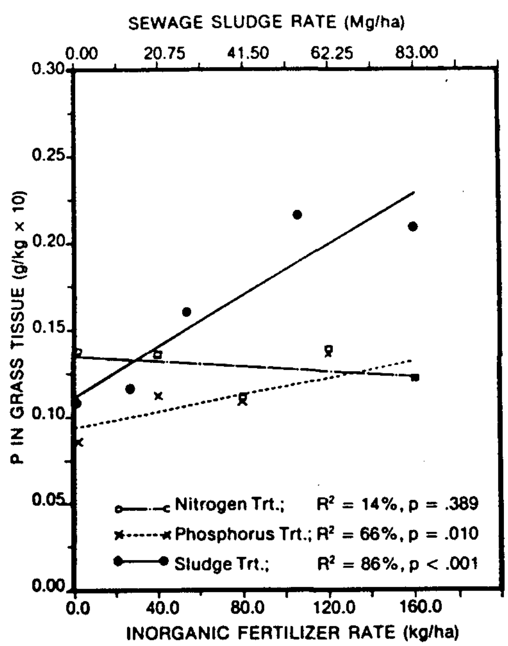


Fig. 4. Effect of spoil treatments on total P concentration of seeded grasses, 1984. Regression lines and observed means are shown. Each N level has 160 kg ha^{-1} P and each P level has 160 kg ha^{-1} N.

Based on the data presented it was not possible to determine a N and P equivalency of each sewage sludge rate since the responses were seldom similar. Apparently sewage sludge application rates lower than 14 Mg ha^{-1} should have been used to approach N and P equivalency.

AB-DTPA extractable NO_3 and P values for the untreated spoil indicated that they were the only elements that were present at levels limiting to dryland grasses. As sewage sludge was added, there were significant increases in extractable levels for all the elements tested except zinc. The accumulated levels, however, were not high enough to cause plant growth problems with the possible exception of the 83 Mg ha^{-1} rate. Table 7 shows the pH, EC, organic C and % water saturation changes with increases in sewage sludge. The pH decreased, the EC increased, the organic C increased and the percent water saturation increases with increasing sludge additions. The greatest potential problem to plant growth (of the 4 listed) may be the high salt content at 83 Mg ha^{-1}. With an EC of 5.48 ds m^{-1} some grasses might have been affected adversely and caused the decrease in grass production at that rate. Hinesley et al. (1982) noted similar increases in EC with increasing sludge addition but values comparable to ours were reached at much higher sludge additions.

CONCLUSIONS

Based on the data of the first two growing seasons, it is suggested that revegetation specialists consider the use of sewage sludge as a spoil amendment in environmental conditions similar to this study site if a sludge source is close and is deemed economical. These results indicated that sewage sludge levels applied at rates <83 Mg ha^{-1} may benefit seeded grass growth. The highest level of sewage sludge was detrimental to revegetation efforts when compared to the lower sludge rates. This may have been due to increases in soluble salt concentration and/or increase in invading annual forbs competition. Whether this was the controlling influence was not resolved. It was speculated that the invading annual forbs competition was one of the main factor causing the decline in seeded grass growth.

Since seeded grasses performed best at 14 Mg ha^{-1}, and this sludge rate was superior to inorganic fertilizer additions, it is tentatively concluded this was the most beneficial sewage sludge level. Sludge levels of 28 and 55 Mg ha^{-1} had superior seeded grass growth but a lower life-form dominance of seeded grasses when compared to the 14 Mg

Table 7. Effect of sludge additions on measured spoil parameters.

Measurement	Sludge application rate (Mg ha^{-1}) 0	14	28	55	83	F ratio
pH	7.10a	6.82b	6.56	6.32d	6.16d	110.6
EC(ds/m)	2.59a	3.16a	3.31ab	4.50bc	5.48c	37.7
Organic C (g kg^{-1})	56.8a	66.2ab	72.2bc	80.0c	93.8d	67.5
% saturation	27.88	27.30a	35.62ab	41.94b	43.16b	18.9

Means on the same line followed by the same letter do not differ significantly (LSD, $\alpha/2$ = .025
F ratio values are linearly significant at $p < 0.001$.

ha^{-1} sludge rate. The stimulation of invading annual forbs at the three highest sludge levels in 1984 was believed to be due to the capacity of the forbs to utilize the extra available N more efficiently. To accurately determine the most beneficial sludge rate at this study site, several more years of data collection must be evaluated.

ACKNOWLEDGEMENTS

We express appreciation to Getty Mining Company for permitting use of the plot on the Colorado Yampa Coal Mine and for assistance in the study.

LITERATURE CITED

Aldon, E. F. 1982. Use of organic amendements for biomass production on reclaimed strip mines in the southwest. Land reclamation and biomass production with municipal wastewater and sludge. pp. 317-320. W. E. Sopper, E. M. Seaker, and R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Allison, L. E. 1965. Organic carbon. p. 1367-1378. In C. A. Black (ed.) Methods of Soil Analysis. Am. Soc. of Agron., Madison, Wisc.

Association of Official Seed Analysts. 1978. Rules for testing seeds. J. Seed Tech. 3:1-126.

Barnhisel, R. I., M. D. Ellis, and T. A. Fauerbacher. 1980. Utilization of municipal sewage sludge as a spoil amendment in the reclamation of lands surface mined for coal. Symposium on surface mining hydrology, sedimentology, and reclamation. pp. 187-192, D. H. Graves, ed. Univ. of Kentucky. Publ. ed., R. W. BeVore.

Bower, C. A., and L. V. Wilcox. 1965. Soluble salt. p. 933-951. In C. A. Black (ed.), Methods of Soil Analysis. Am. Soc. of Agron., Madison, Wisc.

Box, Thadis W. 1978. The significance and responsibility of rehabilitating drastically disturbed land. p. 1-10. In Shaller, F. W. and Paul Sutton (eds.), Reclamation of drastically disturbed lands. Am. Soc. of Agron., Madison, Wisc.

Bremner, J. M. 1965a. Total nitrogen. p. 1149-1178. In C. A. Black (ed.), Methods of Soil Analylsis. Am. Soc. of Agron., Madison, Wisc.

Bremner, J. M. 1965b. Inorganic forms of nitrogen, p. 1179-1232. In C. A. Black (ed.), Methods of Soil Analysis. Am. Soc. of Agron., Madison, Wisc.

Brezonik, P. L. (Chr.). 1978. Panel on Nitrates. Nitrates: An environmental assessment. National Acad. of Sci., Washington, D.C.

Broadbent, F. E. 1965. Organic matter. p. 1397-1400. In C. A. Black (ed.). Methods of Soil Analysis. Am. Soc. of Agron., Madison, Wisc.

Brown, Larry T., and Charles L. Jackson. 1984. Reclamation of the URAD molybdenum mine. Minerals and the Environment, Vol. 6, #2, pp. 77-82.

Clark, F. W. 1977. Internal cycling of 15-Nitrogen in short grass prairie. Ecology 58:1322-1333.

Danielson, R. E. 1982. Soil physics laboratory manual. Dept. of Agron., Colorado State Univ., Ft. Collins, CO.

Day, P. R. 1965. Particle fractionation and particle size analysis. In C. A. Black (ed.), Methods of Soil Analysis. Amer. Soc. of Agron., Madison, Wisc.

Epstein, E., D. B. Keane, J. J. Meisinger, and J. O. Legg (1978) Mineralization of nitrogen from sewage sludge and sludge componet. J. Env. Qual. 7:217-221.

Fresquez, P. R., and W. C. Lindemann. 1982. Soil and rhizosphere microorganisms in amended coal mine spoils. Soil Sci. Soc. Am. J. 46:751-755.

Griebel, G. E., W. H. Armiger, J. F. Parr, D. W. Steck, and J. A. Adam. 1979. Use of composted sewage sludge in revegetation of surface-mined areas. Utilization of municipal sewage efflcuent and sludge on forest and disturbed lands. pp. 293-303. W.E. Sopper and S. N. Kerr, eds. The Pennsylvania State University Press, University Park and London.

Heikes, E. 1980. Weed control on disturbed lands. Northwest Colorado land reclamation seminar II proceedings. pp. 194-197. S. Haslem, ed. Routt County Extension Office, C.S.U.

Hinesley, T. D., K. E. Redborg, E. L. Ziegler, and I. H. Rose-Innes. 1982. Effects of chemical and physical changes in strip-mined spoil amended with sewage sludge on the uptake of metals by plants. Land reclamation and biomass production with municipal wastewater and sludge. pp. 339-352. W. E. Sopper, E. M. Seaker, and

R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Howard, G. S., G. E. Schuman, and F.Rauzi. 1977. Growth of selected plants on Wyoming surface-mined soils and flyash. J. Range Mgmt. 30:306-310.

Hsieh, Y. P., L. A. Douglas, and H. L. Motto. 1981. Modeling sewage sludge decomposition in soil: II. Nitrogen transformations. J. Environ. Qual. 10:59-64.

Kardos, L. T., W. E. Sopper, B. R. Edgerton, and L. E. DiLissio. 1979. Sewage effluent and liquid digested sludge as aids to revegetation of strip mine spoil and anthracite soil refuse banks. Utilization of municipal sewage effluent and sludge on forest and disturbed lands. pp. 315-331. W. E. Sopper and S. N. Kerr, eds. The Pennsylvania State University Press, University Park and London.

Kerr, S. N., and W. E. Sopper. 1982. One alternative to ocean disposal of sludge: recycling through land reclamation. Land reclamation and biomass production with municipal wastewater and sludge. pp. 105-117. W. E. Sopper, E. M. Seaker, and R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Magdoff, F. R., and F. W. Chromec. 1977. N mineralization from sewage sludge. J. Environ. Sci. Health A12 (4 and 5): 191-201.

Mengel, K., and E. A. Kirkby. 1979. Principles of plant nutrition. International Potash Institute. Bern, Switzerland. pp. 593.

Parker, C. F., and L. E. Sommers. 1983. Mineralization of nitrogen in sewage sludges. J. Environ. Qual. 12:150-156.

Peterson, J. R., C. Lue-Hing, J. Gschwind, R. I. Pietz, and D. R. Zenz. 1982. Metropolitan Chicago's Fulton County sludge utilization program. Land reclamation and biomass production with municipal wastewater and sludge. pp. 322-337. W. E. Sopper, E. M. Seaker, and R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Pietz, R. I., J. R. Peterson, T. D. Hinesly, E. L. Ziegler, K. E. Redborg, and C. Lue-Hing. 1982. Sewage sludge application to calcareous strip-mine spoil: I. Effect on corn yields and N, P, K, Ca, and Mg compositions. J. Environ. Qual. 11:685-689.

Premi, P. R., and A. H. Cornfield. 1971. Incubation study of nitrogen mineralization in soil treated with dried sewage sludge. Environ. Pollut. 2:1-5.

Reeder, J. D., and W. A. Berg. 1977. N mineralization and nitrification in cretaceous shales and coal mine spoils. Soil Sci. Soc. Am. J. 41:922-927.

Ryan, J. A., D. R. Keeney, and L. M. Welsh. 1973. Nitrogen transformations and availability of an anaerobically digested sewage sludge in soil. J. Environ. Qual. 6:488-492.

Sabey, B. R., N. N. Agbim, and D. C. Markstrom. 1977. Land application of sewage sludge: IV. Wheat growth, N content, N fertilizer value, and N use efficiency as influenced by sewage sludge and wood waste mixtures. J. Enviorn. Qual. 6:52-58.

Sabey, B. R., W. A. Berg, and M. K. Corwin. 1980. Long term fertility study on land drastically disturbed by oil shale development. In Cook, W. C. and E. F. Redente (eds.) Reclamation studies on oil shale lands in northwestern Colorado. Rept. to USDOE from Colorado State University, Range Science Dept., Ft. Collins, CO 80523.

Sandoval, F. M., and J. F. Power. 1978. Laboratory methods recommended for chemical analysis of mined-land spoils and overburden in western United States. U. S. Department of Agriculture, Agriculture Handbook No. 525. Washington, D.C. pp 31.

Silverman, A. J. 1983. Energy future of the United States: The contribution of the American west. Coal development: collected papers. pp. 3-37. O. Brooks, L. Branch, and C. Fischer, eds. Bureau of Land Mgmt.

Smith, J. L., R. R. Schnabel, B. L. McNeal, and G. S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potentials. Soil Sci. Soc. Am. J. 44:996-1000.

Soltanpour, P. N., and A. P. Schwab. 1977. A new soil test for simultaneous extraction of macro- and micronutrients in alkaline soils. Commun. Soil Sci. Plant Anal. 8(3):195-207.

Sommers, L. E., D. W. Nelson, C. Parker, and J. Graveel. 1980. Optimum utilization of sewage sludge on agricultural land. Annual Report from Purdue Agric. Exp. Sta. to Regional Project W-124.

Sommers, L. E., D. W. Nelson, and K. J. Yost. 1976. Variable nature of chemical composition of sewage sludges. J. Environ. Qual. 5:303-306.

Sopper, W. E., and S. N. Kerr. 1982. Mined land reclamation with municipal-sludge Pennsylvania's demonstration program. Land reclamation and biomass production with municipal wastewater and sludge. pp. 55-74. W. E. Sopper, E. M. Seaker, and R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Sopper, W. E., and E. M. Seaker. 1983. A guide for revegetation of mined land in eastern United States using municipal sludge. The Pennsylania State University Press, University Park and London.

Stanford, G., and S. J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stevenson, F. J. 1962. Chemical state of the nitrogen in soil. Geochemica et cosmochimica Acta. 26:797-809.

Street, J. J. 1976. Solubility and availability of cadmium in cadmium-sludge amended soil. Ph.D. Thesis, Dept. of Agronomy, Colorado State Univ., Ft. Collins, CO.

Stucky, D. J., and J. Bauer. 1979. Establishment, yield, ad ion accumulation of several forage species on sludge-treated spoils of the Palzo mine. Utilization of municipal effluent and sludge on forest and disturbed lands. pp. 379-387. W. E. Sopper and S. N. Kerr, eds. The Pennsylvania State University Press, University Park and London.

Suhr, L. G. 1982. Utilization of municipal wastewater and sludge for land reclamation and biomass production - An engineering assessment of its potential in the western United States. Land reclamation and biomass production with municipal wastewater and sludge. pp. 481-497. W. E. Sopper, E. M. Seaker, and R. K. Bastain, eds. The Pennsylvania State University Press, University Park and London.

Sutton, P., and J. P. Vimmerstedt. 1973. Treat stripmine spoils with sewage sludge. Ohio Report, Vol. 58, No. 6.

Terry, R. E., D. W. Nelson, and L. E. Sommers. 1981. Nitrogen transformation in sewage sludge - amended soils as affected by soil environmental factors. Soil Sci. Soc. Am. J. 45:506-513.

RECLAMATION ART

Paul Klite
1450 Logan St.
Denver, CO 80203

INTRODUCTION

This report demonstrates strategies of environmental art that are compatible with land reclamation practices. It will, hopefully, motivate you to confront the aesthetics of your earth repair projects.

Modern environmental art has its roots in the monumental outdoor constructions of the past. This relationship has been the subject of several excellent books and reviews (1-4). Prehistoric stone works, Indian burial mounds, amphitheaters, and elaborate terracings constructed centuries ago continue to inspire and fascinate us.

The reclamation and environmental laws of the '70s have provided an opportunity for sculptors, landscape architects, artists and designers to devise aesthetic solutions to a variety of "low profile" landscapes including mining waste, landfills and the like. These efforts are a vivid testimony to the power of human imagination.

ARTISTIC EXAMPLES

Robert Smithson pioneered the use of mine wastes as an art medium. Before his untimely death in 1972, Smithson completed earthworks in a quarry in Holland, a lake in Texas and the Great Salt Lake in Utah (Figure 1).

His ideas and writings have exerted great influence in the art world (5).

Robert Morris. In 1979, the King County Arts Commission, Seattle, WA, commissioned Morris to design and oversee construction of a 3.5 acre abandoned gravel pit into an earth sculpture. Morris's solution is a concave, curving, terraced amphitheater, revegetated in rye grass (Figures 2 & 3).

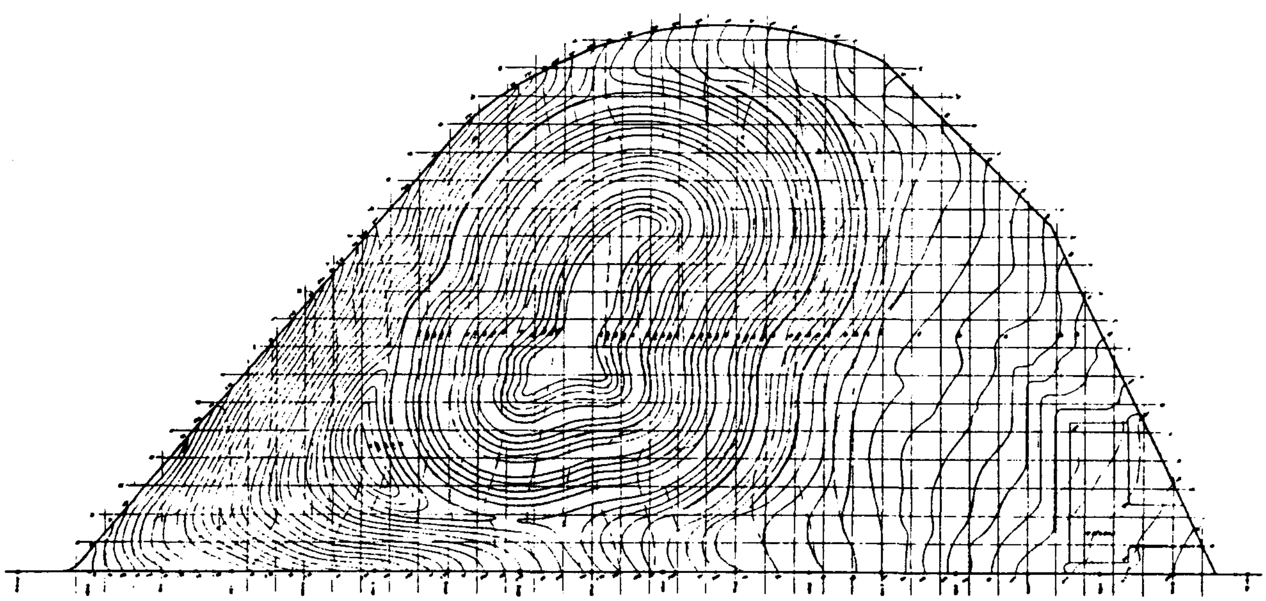
(1) Robert Smithson - "Spiral Jetty," 1970, Great Salt Lake, Utah, Length 1500', rock & earth, from Earthworks and Beyond.

The Morris earthwork was completed in 11 months at a cost of $184,000. Estimates for "standard" reclamation at the site ranged from $102,000 to $132,000. The project was funded by a cross section of interested parties (Table 1).

Table 1
Donors to the Seattle Project

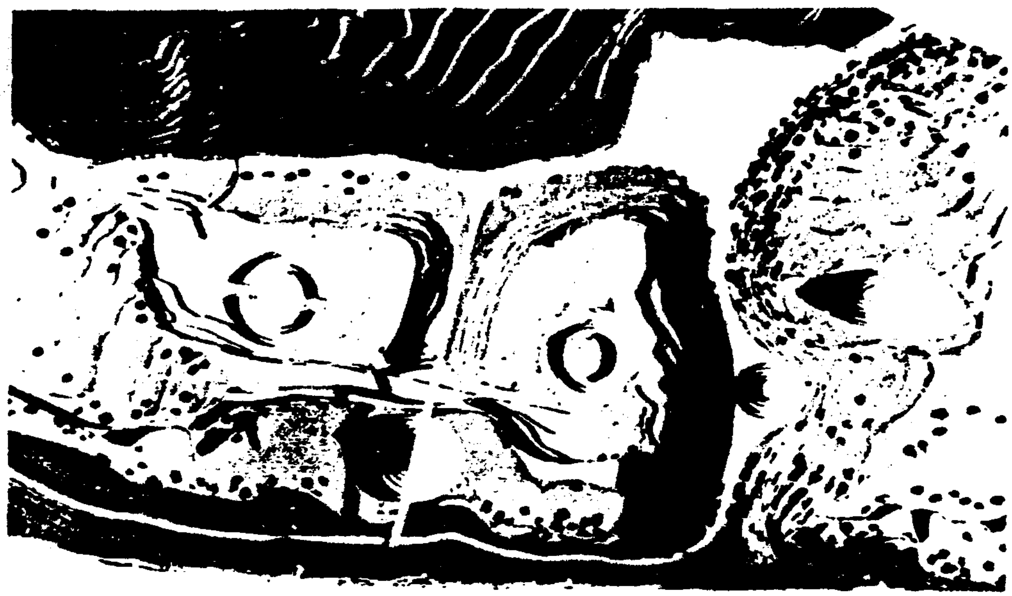
Source	Amount of Grant
Washington State Arts Commission	$4,000
Seattle Arts Commission	8,600
Port of Seattle	5,000
University of Washington	4,000
Lakeside Sand and Gravel	4,700
Buckeye Trust	48,900
Jewish Federation	5,000
National Endowment for the Arts	50,000
National Endowment for the Arts in Design	17,750
Bureau of Mines	35,000
Private contributors	3,110
King County Arts Commission	46,350
One-percent for Art (Public Works)	57,000
Total	$289,410

(2) Robert Morris - Reclamation Project, 1979, King County, Washington, 3.5 acres. Courtesy King County Arts Comm.

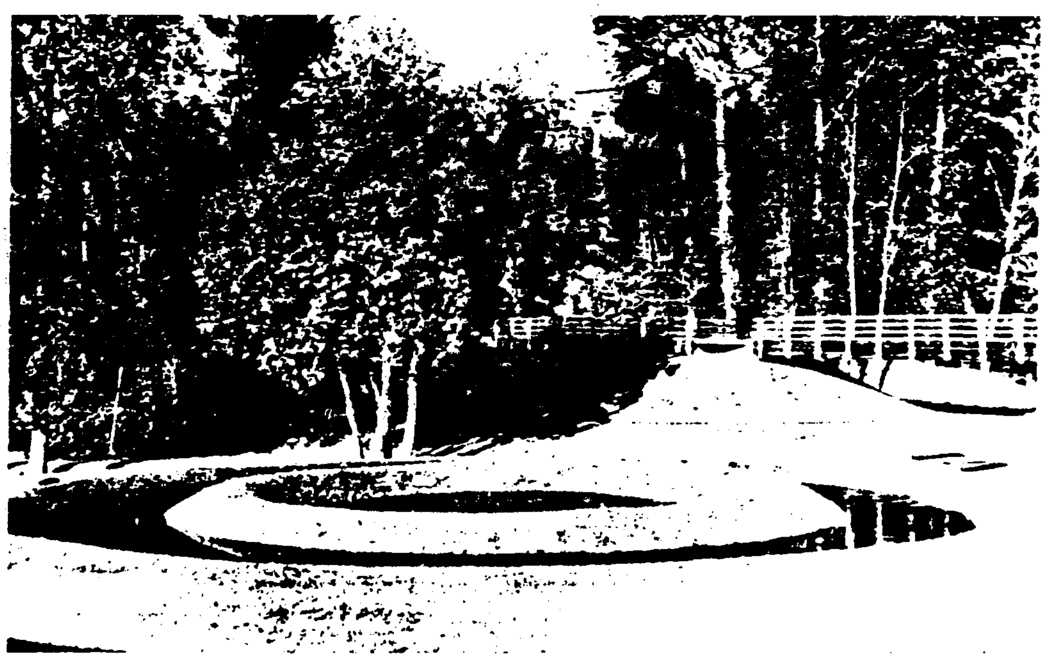


(3) Robert Morris - Reclamation Project, 1979, site plan, Courtesy King County Arts Commission.

Herbert Bayer produced an ingenious landscape in Kent, Washington, combining a park, sculpture and floodwater retention basin (Figure 4 & 5). Completed in eighteen monthe, the work was an instant and popular success and has become a progressive symbol for the city. The project was funded by the city of Kent, the National Endowment for the Arts, the Washington State Arts Commission, a Housing and Community Development block grant, the King County Arts Commission and private contributions.



(4) Herbert Bayer - Mill Creek Canyon Project, 1982, site model. Courtesy King County Arts Commission.

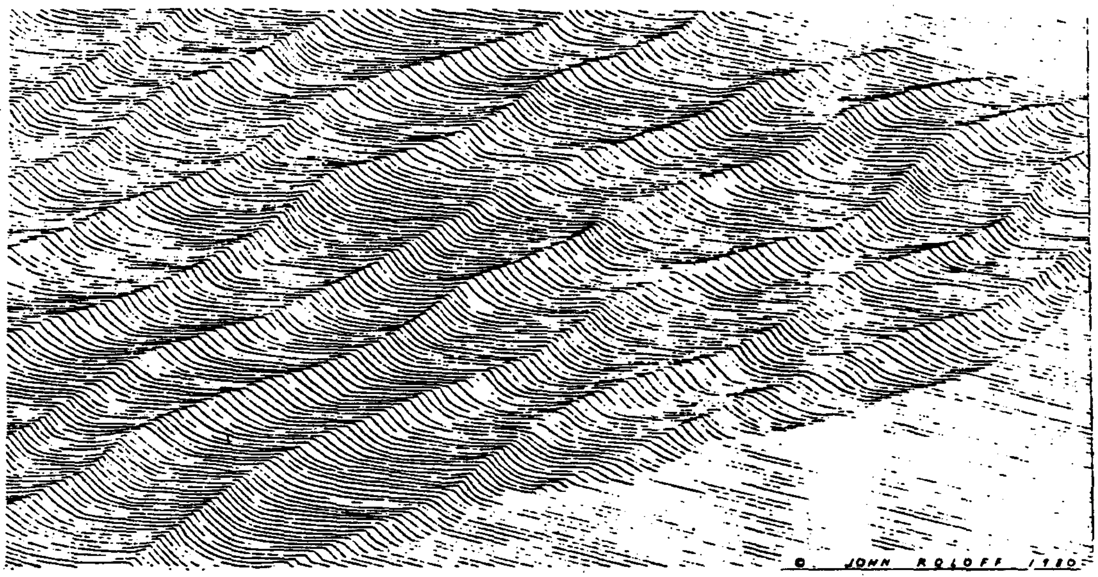


(5) Herbert Bayer - Mill Creek Canyon Project, 1982, Kent, Washington, 2.5 acres. Courtesy City of Kent.

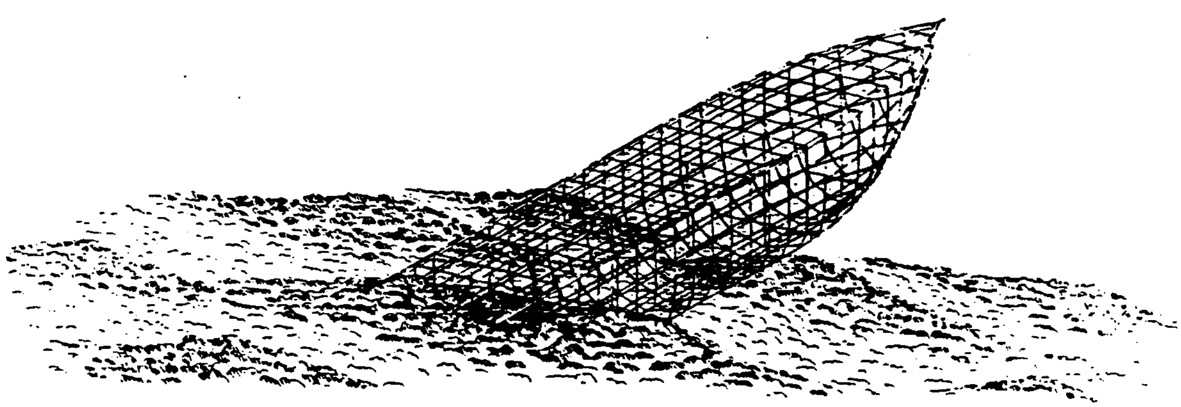
John Roloff has developed a series of intriguing ground contouring proposals for waste land. "Land Sea," 1980 (Figure 6) is designed to "resemble a water surface in a large swell oriented perpendicular to the prevailing wind." The surface would be revegetated.

Another Roloff idea applicable to mine reclamation or toxic sites is the construction of large sculpted greenhouses with self-contained irrigating systems to support plant life (Figure 7).

Roloff has recently begun work on two reclamation sites: a California Parks and Recreation Project in a landfill near Candlestick Park, and a dump site used by the University of Nevada, Reno.

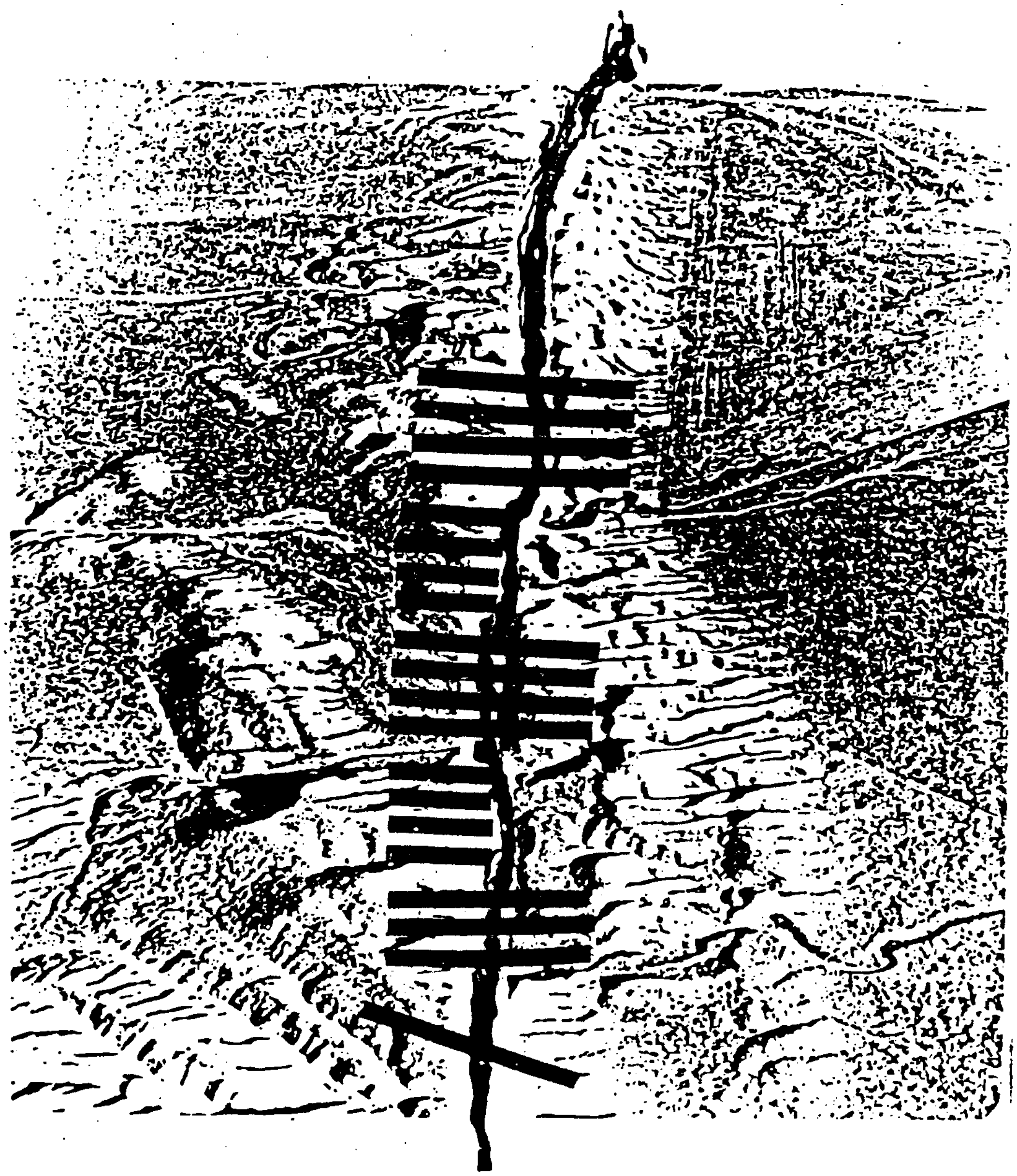


(6) John Roloff - "Land Sea," 1980, pen and ink. Courtesy the artist.



(7) John Roloff - "Sinking Ship," 1984, pen and ink. Courtesy the artist.

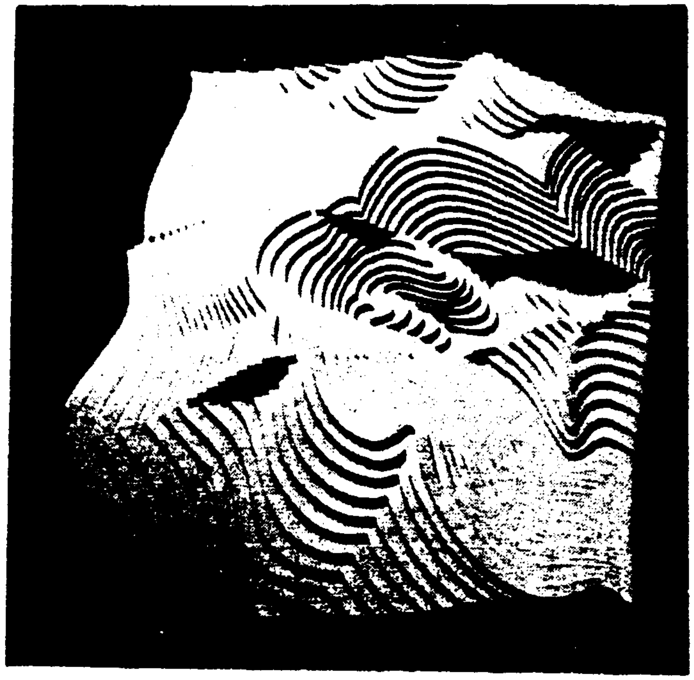
Gary Dwyer, Professor of Landscape Architecture at California Polytechnic State University has created many outdoor works. Dwyer's theory that environmental sculpture is a "biography or a storage battery for the energy of a site," is well demonstrated in Figure 8, a 1984 proposal for a sculpture across the San Andreas Fault.



(8) Gary Dwyer - Proposal for sculpture across the San Andreas Fault, 1984. Courtesy the artist. The horizontal forms represent the Chumash Indian word, who are you?" Movement of the fault, vertical line, will alter the sculpture.

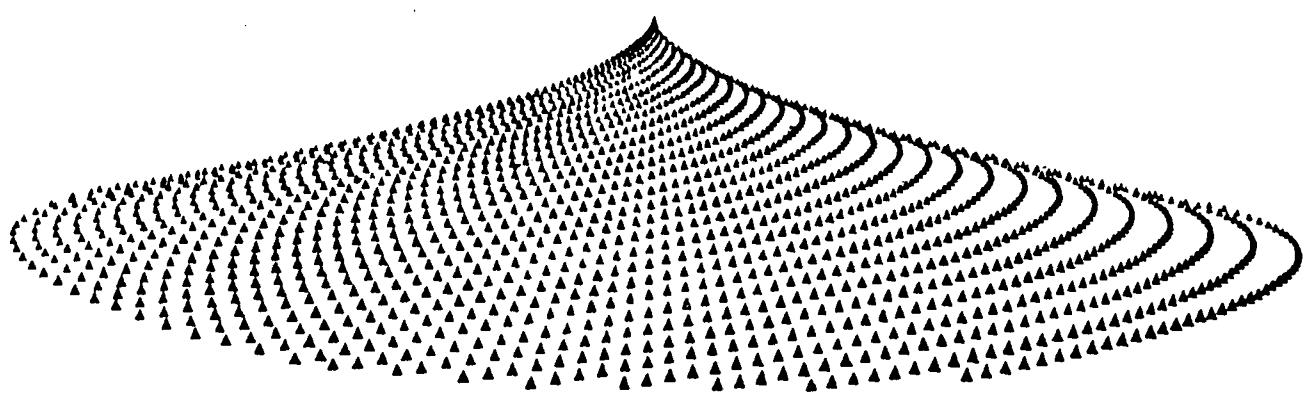
Athena Tacha, professor of art at Oberlin College, has developed a dazzling style of terracing that is illustrated in Figures 9 & 10. Tacha works in concrete and stone and has begun to add color to her terraced environments. "Time enters my sculpture at many levels," says Tacha. "Time as rhythm, as relative displacement in space, as evolution and change."

(9) Athena Tachs, Model for Step Sculpture, Courtesy the artist



(10) Athena Tacha - "Syncline," 1980, model
Courtesy the artist.

Agnes Denes is representative of a group of artists who use vegetation as sculptural elements of form, color and texture. "Tree Mountain", (Figure 11) a 1982 proposal, would create a large expanding spiral of indigenous trees on a sloping or terraced terrain. The result is a dramatic yet gentle landscape.



(11) Agnes Denes - "Tree Mountain," proposal, 1982, 10,000 trees over a 1.5 mile area. Courtesy Joyce P. Schwartz Gallery.

Zigi Ben-Haim demonstrates a different artistic strategy. By creating a dominant visual focal point on a site, the aesthetic impact of the site itself is diminished. His "Legion of Titans," Figure 12, "is constructed of the debris and residue of both nature and man." The sculpture arrears as strange and mysterious totems that both attract and frighten the viewer.

(12) Zigi Ben-Haim - "Legion of Titans," 1983, Tel-Hai, Isreal, 34'x8', concrete, steel, paint & fiberglass, Courtesy the artist.

Christo, in his inimitable style, has repeatedly demonstrated that massive art projects can prevail over public outcry, complicated permit requirements, environmentalists' objections and the minute probing of the world press. It is intriguing to imagine a Christo project covering a tailings pond or waste heap.

In all, there are about one hundred artists working in fields that relate to land reclamation. This is but a tiny cross-section of their creative reservoir of ideas.

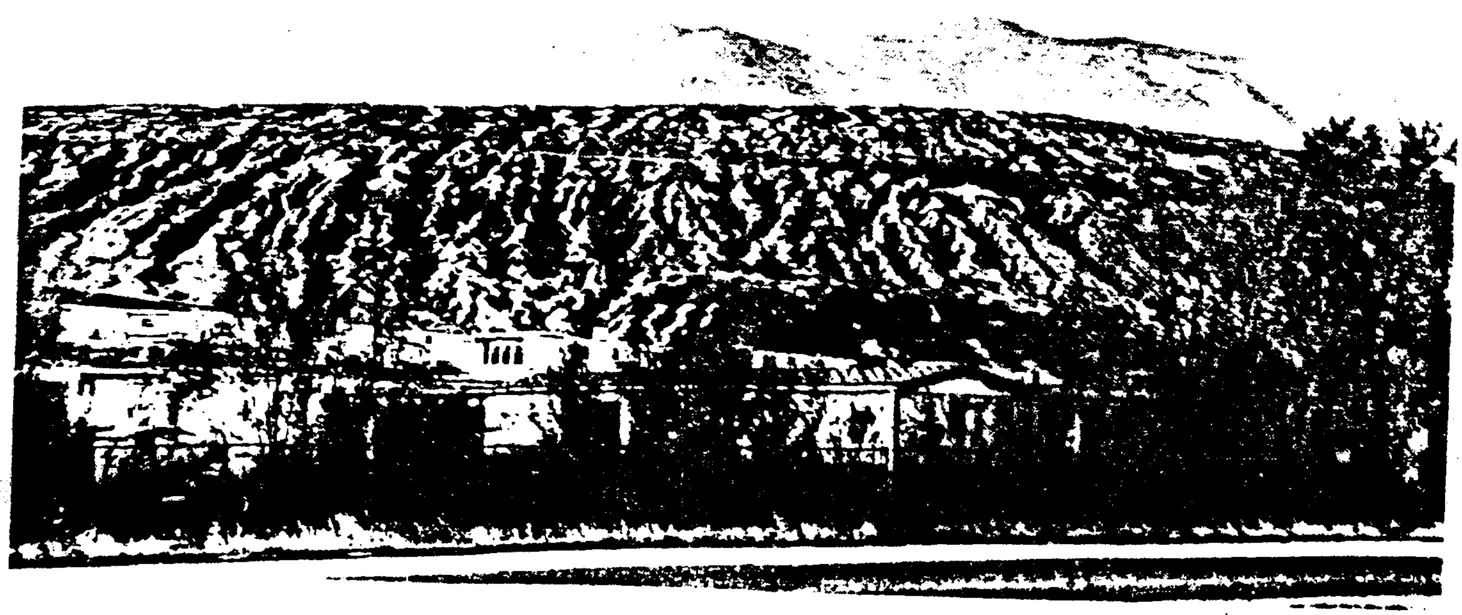
COLORADO SITES

During the last two years, I have had the opportunity to evaluate the aesthetic impact and potential of a range of waste sites and earth scars in Colorado (6). As a general rule, sites that are large, ugly, prominent, dangerous or depressing cry out most for aesthetic help.

At any specific site, the artist must consider his medium - the physical and chemical properties of the material, environmental and technical restraints, applicable reclamation law, site history, etc. Then, artistic considerations, e.g., size, shape, color, texture, light, visual impact, views and setting, can be addressed.

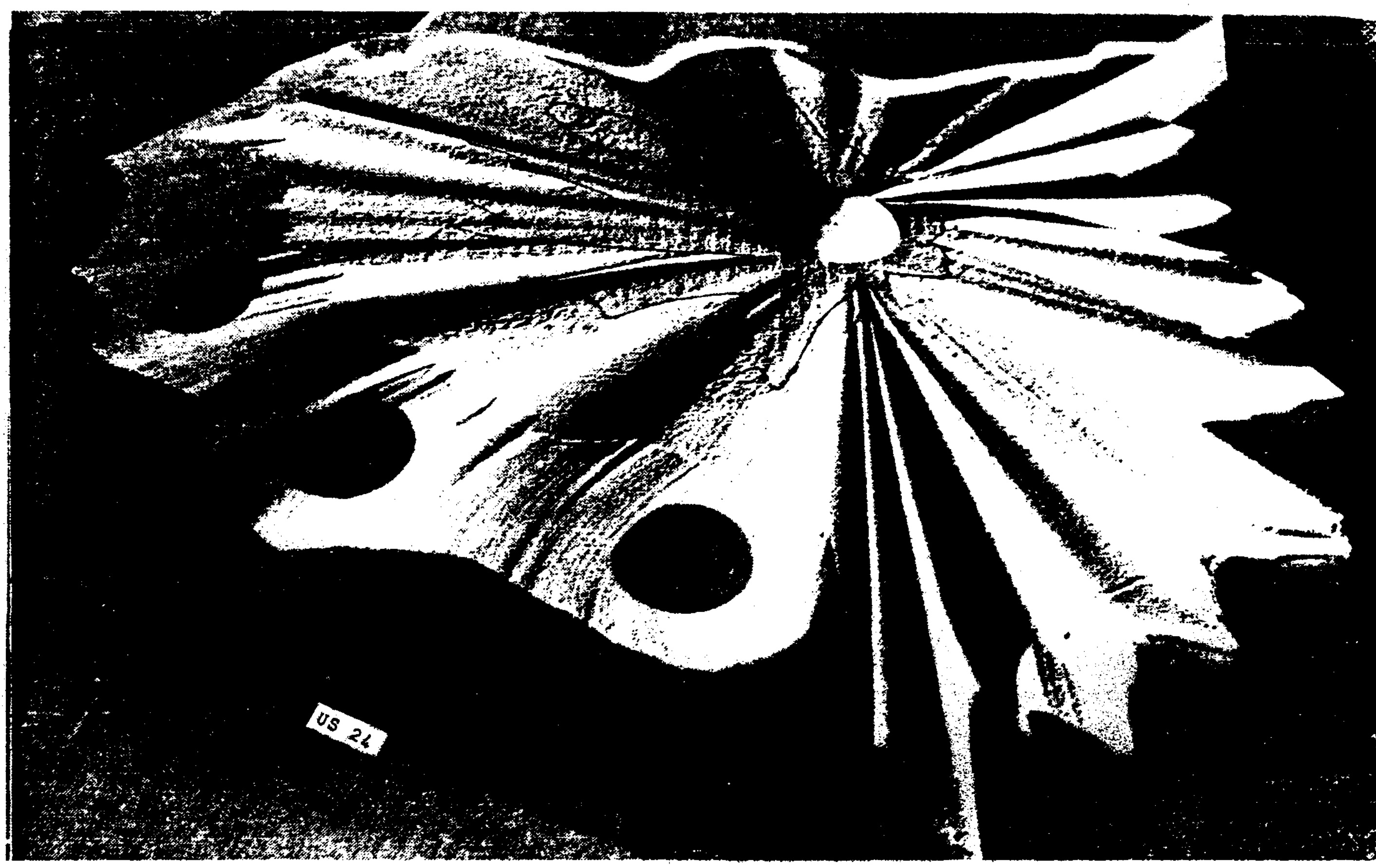
The following examples are conceptual models for specific sites that demonstrate the feasibility of aesthetic treatment.

The old Golden Cycle mill is a massive 175 acres of gold tailings located ½ mile from downtown Colorado Springs, CO, at the junction of two major highways. The finely milled tailings are heavily eroded with minimal natural revegetation. A dominant feature of the amorphous shape is a 150 foot high outslope along highway US 24. (Figure 13)



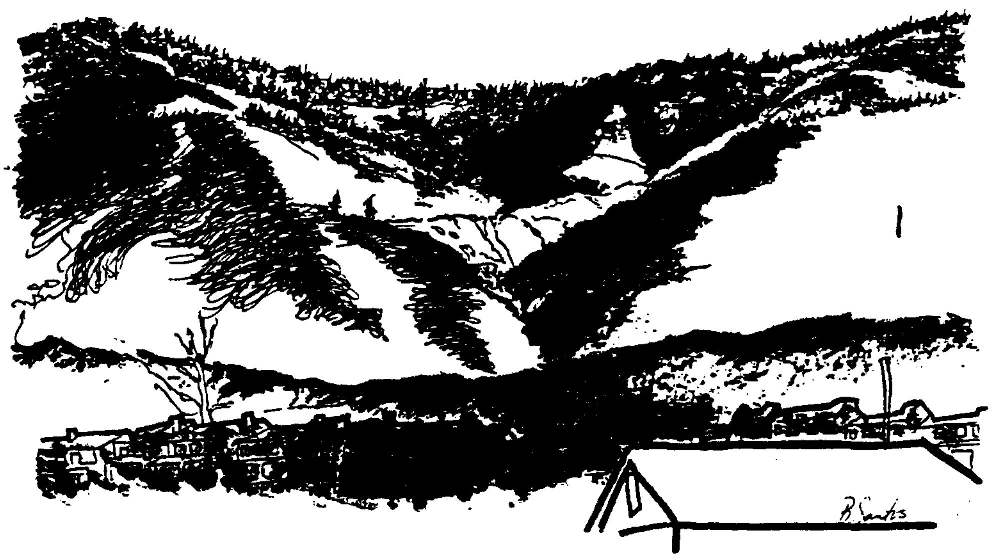
(13) North outslope of Golden Cycle mill tailings, US 24 in foreground, Rampart Range in background, facing south.

Colorado Springs' emerging development as the nerve center for space exploration prompted the design shown in Figure 14; a recontouring of the site as a park and space museum. This would be accomplished by a cut and fill operation over the existing tailings; the outslope would be reshaped and accented with circular floral displays; the spherical museum is at the apex of the design; parking is on the south; after recontouring, the site would be covered with a protective layer of reck and/or plastic and would be revegetated.

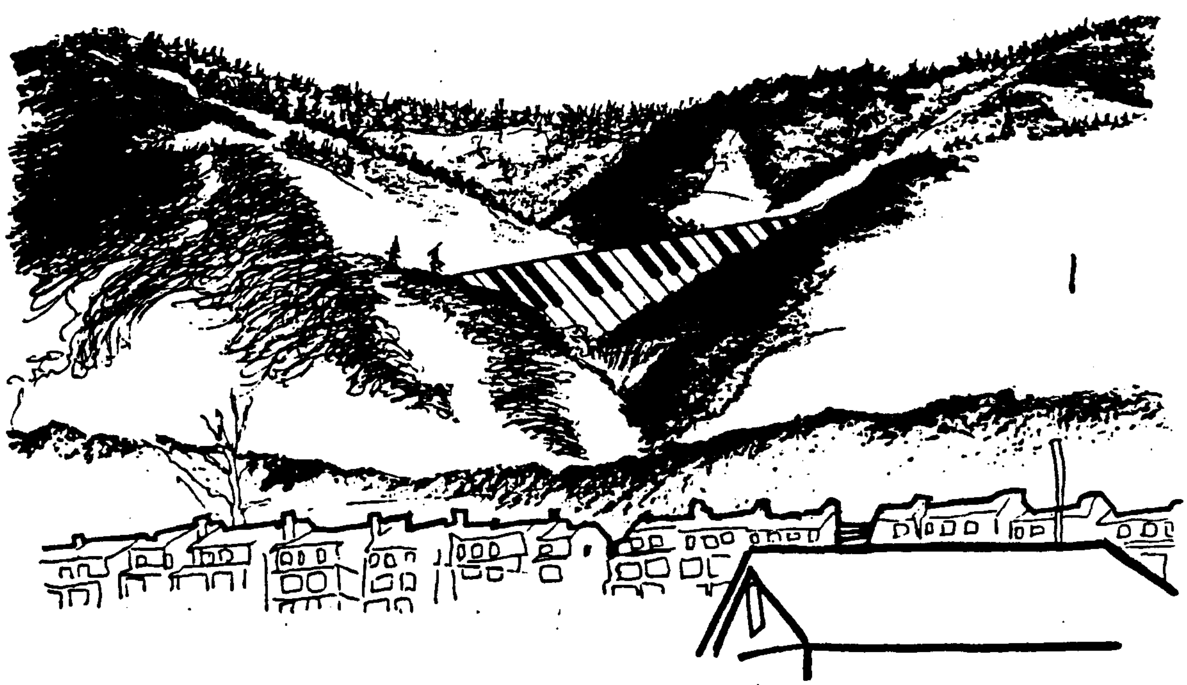


(14) Model for park/museum, styrofoam, scale, 1" = 200', see text for explanation, facing south.

The J.C. Johnson mine dump on Smuggler Mountain above Aspen, CO is visually prominent and offers interesting design possibilities (Figure 15). The dump could be altered to resemble a piano keyboard as in Figure 16. Black and white "keys " could be constructed with inert rock (rip-rap), contrasting vegetation or cements. A large scale sculpture overlooking Aspen could be a valuable community symbol and asset.

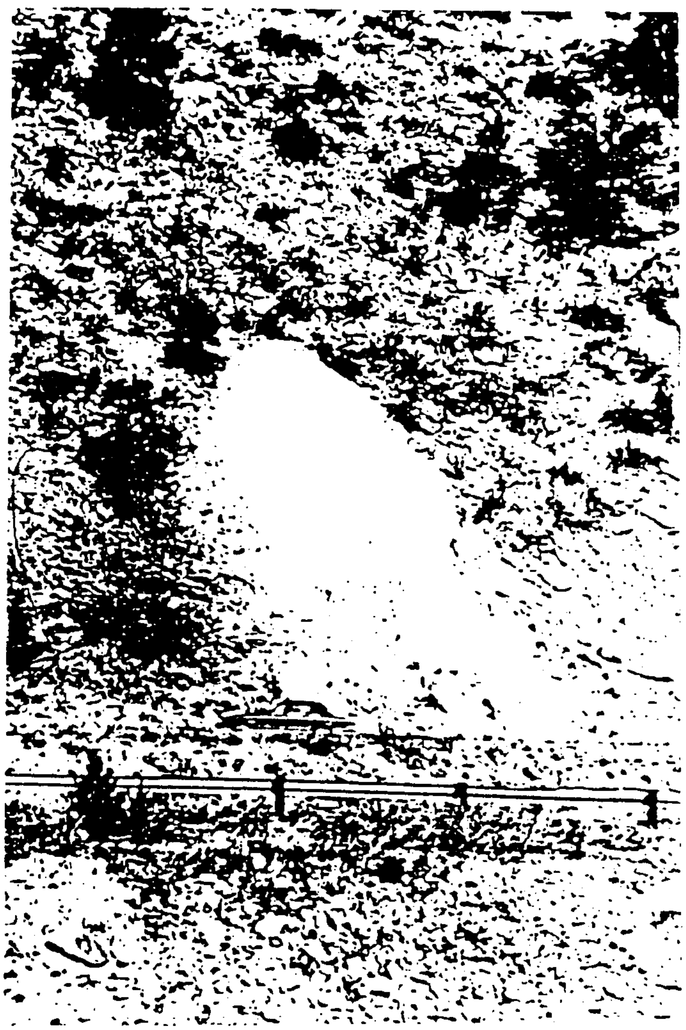


(15) Location of J.C.Johnson mine dump, pen and ink, Beth Santos, 1985, facing north.



(16) Proposed treatment, see text for explanation.

There are thousands of prospecting dumps in Colorado. Many are located on steep mountain slopes and are highly visable. Here is one example, a small dump along the I-70 corridor west of Idaho Springs, reshaped and revegetated to resemble a meteor impact (Figures 17 & 18).



(17) Mine dump along I-70

(18) Recontouring proposal, 1985, pen and ink.

(19) Coal spoils near Florence, CO., pen and ink,
Beth Santos, 1985.

Figure 19 shows a typically shaped spoils pile, in this case coal spoils near Florence, Colorado. The pile is steep, sterile, acid and ugly. A recontouring plan is sketched in figure 20 with more gentle slopes and visual interest. The site would be revegetated.

(20) Recontouring of spoils pile, collage, 1985.

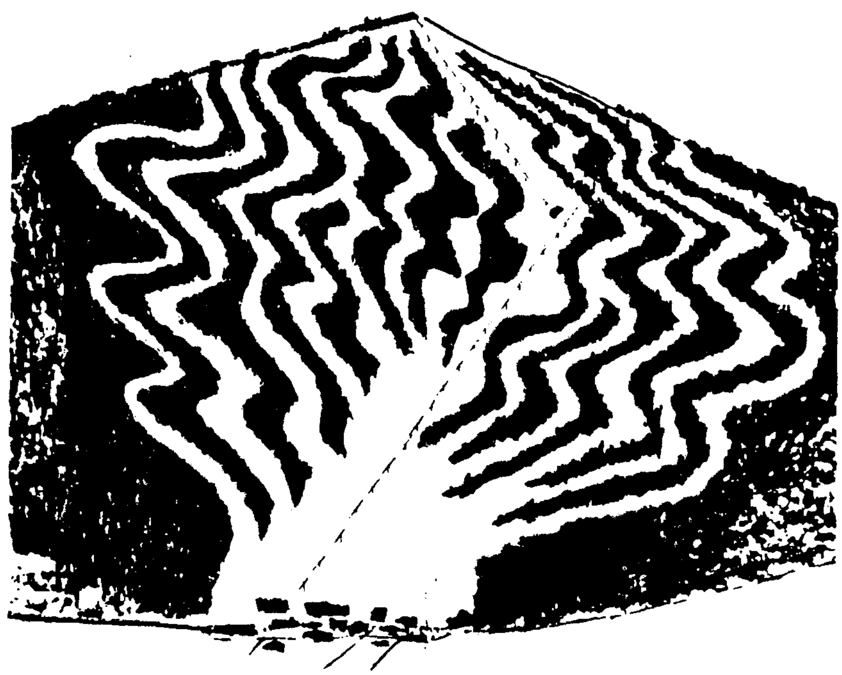
A 1984 proposal for the Argo Mill gold tailings in Idaho Springs, CO (Figure 21) was devised to utilize, as much as possible, the existing tailings configuration and minimize earthmoving costs.

(21) Model for the Argo Mill, plastiline, scale 1" = 75', 1984.

The next example is a model for a topographical face. I had no specific site or material in mind, but perhaps it can find a home somewhere. (Figure 22)

(22) Topographical Face, carved paper, 10"x10", 1985.

Ski slopes are often highly visable scars that dominate mountain views. Within the site-specific limitations of ski mountain terrain, and with full consideration of the recreational and safety mandates of slope construction, sculptures could be fashioned from the configurations of the ski runs themselves. Figure 23 is a group of sketches that illustrate this idea.



(23) Sketches for ski slope sculptures, pen and ink, 1985.

CONCLUSION

Two thousand years ago, Plotinus observed that "the principle that bestows beauty is perceived at first glance, something which the soul names as from some ancient knowledge, and recognizing it, welcomes it, enters into union with it. But let the soul fall in with the ugly, and at once it shrinks within itself, denies the thing, turns away from it, not accordant, resenting it."

For those of you with difficult or ugly reclamation sites that could benefit from aesthetic treatment, I urge you to involve the artist as designer with your reclamation team, and do so at the outset of planning.

The examples presented here demonstrate the broad potential for augmenting standard reclamation practice with creative solutions. The advantages can be considerable. Certainly communities adjacent to waste sites will obtain an improved visual environment, new potential for tourism and enhanced community image; industrial interests can reap much needed public relations benefits from their environmental concern; reclamation scientists and technicians will enjoy the challange of creating showpiece projects; regulatory agencies can support innovative alternatives to recycling the land.

Environmental art and land reclamation are cousins of the same consciousness. Converting waste land into art is a powerful expression of that consciousness.

LITERATURE CITED

1. Lippard, Lucy R., Overlay - Contemporary Art and the Art of Prehistory, Pantheon Books, New York, 1983

2. Beardsley, John, Earthworks and Beyond - Contemporary Art in the Landscape, Abbeville Press, New York, 1984

3. Kluesing, Cherie L., Reclamation Works, for the Abandoned Land Reclamation Council, Springfield, Ill., 1982

4. Sonfist, Alan, Ed., Art in the Land, E.P. Dutton, Inc., New York, 1983

5. Holt, Nancy, Ed., The Writings of Robert Smithson, New York University Press, 1979

6. Klite, Paul, Reclamation Art, for the Colorado Mined Land Reclamation Division and the Colorado Council on the Arts and Humanities, 1985 (copies are available from either agency.)

REHABILITATION OF ALPINE HIKING TRAILS IN THE NATIONAL PARKS OF CANADA

David Walker
Walker & Associates
R.R. #1 South
Edmonton, Alberta, Canada T6H 4N6

and

Gail Harrison
Parks Canada
220-4th Ave. S.E.
Calgary, Alberta, Canada T2P 3H8

INTRODUCTION

Increased use of the National Parks System over the past decades has placed the managers of "heritage natural resources" in a difficult position. The Parks Canada objective is:

> "to protect for all time those places which are significant examples of Canada's natural and cultural heritage and also to encourage public understanding, appreciation, and enjoyment of this heritage in ways which leave it unimpaired" (Parks Canada 1979).

To accomplish this dual mandate of both preserving and encouraging the use of the National Parks, planning and management of parks must consider the implications of facility development as well as the necessity to minimize the impact. Alpine hiking trails are an excellent example of the conflict that can arise- people enjoying the pleasures of an unspoiled wilderness all too frequently end up destroying the very thing they came to see. Parks Canada must pursue the delicate task of finding a balance.

THE PROBLEMS

Willard and Marr (1971) studied the recovery of alpine tundra under protection after trampling damage from hikers in Rocky Mountain National Park. They reported that trampling by visitors kills plants and initiates erosion processes. Some areas severely damaged by only a few seasons of human activity will require hundreds of years, possibly even a thousand, to rebuild a natural and persistent ecosystem (Willard and Marr 1971). In Olympic National Park, Bell and Bliss (1973) found that plant cover and production were rapidly reduced in even one season of light use. Also, different plant communities had different sensitivities to disturbance and plans for human use should incorporate this kind of information.

The use of alpine hiking trails in the National Parks of Canada's Rocky Mountain region has increased significantly in the past decade. New access to alpine areas has been created by the construction of gondola lifts and the opening of ski resorts for summer use. Some trails have seriously deteriorated as the traffic flow increased, particularly in wet areas and areas with late-lying snowbeds. Loss of the vegetative cover has exposed the soil and trails have become impassable because of mud or because soil erosion exposed a rough and treacherous bed of rocks. Hikers frequently take short-cuts or walk beside the old trail and in doing so have created "braids" in the trail which also eventually deteriorate with use. Solutions to the problem are (1) close the trail, (2) relocate the trail, if possible, or (3) rehabilitate the trail by upgrading the quality of the hiking surface and revegetating the damaged sections.

This paper will focus on Parks Canada's efforts toward improving the rehabilitation of alpine hiking trails. The additional parameter of continued visitor use must be considered for successful rehabilitation to occur. The work will be illustrated by the rehabilitation of three high use trails in the alpine zone of Banff National Park and Jasper National Park. On each trail, a different combination of rehabilitation techniques and visitor education/ information was used.

THE SOLUTIONS

Planning and Post-Rehabilitation Monitoring

Information vital to the planning of the trail reconstruction and rehabilitation work is collected before the commencement of design work. If several routes are in existence, the most heavily used alternative is identified by trail counters or visual observation. If the alternative is environmentally acceptable, the hiking surface is upgraded and the others closed and revegetated.

Also important is the number of people anticipated to use the trail as well as the proportion of people who will actually travel the entire distance. This depends on the terrain, altitude, exposure to the climate, length of season, frequency of bad weather, and category of visitor- avid backpacker or casual day-user.

Monitoring of the trail after rehabilitation is equally important. Visitor useage patterns may change as a result of the work and the program must allow for post-construction adjustments. Off-trail damage caused by hikers walking around late-lying snow banks can be minimized by closing the trail until all the snow has melted.

Public Awareness

A recognition of the fact that attempts to rehabilitate a damaged hiking trail will ultimately fail unless the conditions which created the damage are altered has resulted in a policy of emphasizing the presence of rehabilitation efforts. Signs at the trail head now inform hikers that rehabilitation work is in progress. Signs are placed at strategic locations requesting visitors to "stay on the trail". Information on what and how it is being done to repair damaged areas are provided to alert visitors of the implications of off-trail travel.

Barriers are also used. A short 2 m fence will not stop visitors from stepping over or around a barrier but it serves as a strong reminder that off-trail travel is not acceptable.

Drainage

Hiking trails which cross natural drainages can alter the normal flow pattern of water from snowmelt and subsurface discharge. On organic soils, the impact of the hikers' weight pounds the trail into a "U" shaped trough which intercepts and channels water onto the trail surface. Water on the trail can erode significant amounts of soil and render the trail difficult to travel.

Cross drainages are an essential part of trail rehabilitation. Low profile swales lined with rock are constructed at the intersection of the trail and natural drainages. Heavy water flows are accommodated by constructing open ditches braced with treated timbers and also lined along the bottom with rock. The downslope angle of the trail drainage is critical to avoid the accumulation of sediment and subsequent costly maintenance. Drainages are set at 9-11° (16-19%) when lined with rock. The discharge location and energy dissipation at the outflow is integral to the overall design.

Salvage of Material

Every effort is now made to preserve all soil and vegetative material which becomes surplus when a hiking trail is widened or a new trail is constructed. The salvage and transplanting of sod of alpine vegetation has proven to be a very successful technique. Sod is cut and removed by manual labor. Helicopters have been used to relocate sod when distances are too far for manual removal.

Care must be taken to match habitats when moving sod even short distances along a moisture gradient or from a snowbed to an exposed location. Prompt replacement of the sod to the new location is also necessary for good success. If stored for more than approximately one week, the edges of the sod pieces may dessicate to the extent that the vegetation will not recover. Burlap fabric which provides shading and allows some air movement is better for preserving moisture in sod than is clear plastic sheeting which can cause extreme temperatures to develop.

The relocation of local shrubs has also proven to be effective in assisting in the closure of trails to public access. Transplants of low stature shrubs planted for several meters along an old route become a "living sign" to arouse the awareness of visitors that the route is no longer the trail.

Topsoiling

Topsoil replacement has been used for sites where soil erosion losses have been significant. Helicopters are used to move topsoil to inaccessible areas. The introduction of undesireable exotic species is a concern in the National Parks. To avoid this problem at one site, a manufacturer of commercial potting soil was approached and a custom blend similar to the alpine soil was formulated. The commercial potting soil was highly organic in formula, had been sterilized to remove weed seeds, and was packaged in 20 kg plastic bags. The technique has proven to be successful. The low-density formula minimized the weight and hence transportation costs. The plastic packaging was easy to handle and was stockpiled on site in a dry state until required.

Mulching

The technique of mulching has been used with some success. Under most circumstances, cold soil temperatures are a limiting factor for plant growth at alpine elevations and most organic mulches aggravate this problem by insulating the soil surface and thereby lowering the soil temperature. One product however, a roll-out, rice-paper mulch increases soil temperature 1-2°C by preventing heat loss through advection and by creating a "greenhouse effect" (Walker 1981, Takyi 1980). The matting also serves to alert hikers that efforts to revegetate the site are underway. Most people have a natural inclination to avoid walking on a newly seeded lawn but it can only be exploited if the area is readily identifiable- not easy when it takes 3-5 years for plants to fully develop in the alpine.

Rigorous guidelines for installation of the paper mulch must be followed in order for the benefits of the product to be realized. The mulch fabric must be laid as closely to the soil surface as possible and the fabric must not flap even in a heavy wind. A layer of air between the fabric and the soil becomes a layer of insulation which will lower the soil temperature. Excessive movement of the fabric will quickly destroy any seedlings which protrude through the weave of the paper strips.

A roll-out excelsior (aspen wood) mulch has been applied in situations where soil moisture is more limiting to plant growth than low soil temperature. The technique has had some success on wind-swept ridges and slopes with a southerly exposure.

Seed Material

All revegetation at alpine elevations is done with native species. The source of grass seed is the result of research funded by Parks Canada beginning in the mid-seventies. In conjunction with the Alberta government, Parks Canada co-sponsored a native grass breeding program at the University of Alberta. The objectives of the research were to select and develop superior strains of native alpine grass species which were not only effective in revegetating difficult sites but were also feasible to produce on a commercial scale. An extensive program of species evaluation was carried out between 1976 and 1983. Selections from the program are now grown by contract for use within the parks.

Shrub Material

Several alpine shrub species are readily propagated by seed including white mountain avens *(Dryas octopetala)* and alpine bearberry *(Arctostaphylos rubra)*. Others have been successfully propagated by standard techniques of rooting hardwood cuttings. The propagation of alpine woody species by softwood cutting is a two stage process. First small specimens of a juvenile age are dug, potted, and placed in a growth chamber. The plants are maintained at a higher than normal temperature (18-22°) for an extended growing season (6-8 months) with frequent applications of fertilizer. The growing conditions force the normally low-growing alpine plants to become tall and lank. These stock plants produce excellent cuttings for softwood propagation.

Material produced for outplanting are grown at a much slower rate to encourage a natural growth habit. Plants are thoroughly hardened off prior to transplanting. The procedure has been successfully applied to a number of alpine species including moss campion *(Silene acaulis)*, yellow and purple mountain-heaths *(Phyllodoce glanduliflora and empetriformis)*, wooly everlasting *(Antennaria lanata)*, snow willow *(Salix nivalis)*, arctic willow *(Salix arctica)*, and purple saxifrage *(Saxifrage oppositifolia)*, and stonecrop *(Sedum lanceolatum)* .

REFERENCES

Bell, K.L. and L.C. Bliss. 1973. Alpine disturbance studies: Olympic National Park, USA.. Biological Conservation 5(1):25-32

Harrison, G. 1979. Impact, Inventory and Rehabilitation Plan, Sunshine Ski Area. Western Regional Office, Parks Canada.

Parks Canada. 1979. Parks Canada Policy. 69 pp.

Parks Canada. 1983. Sunshine Summer Use Plan. Western Regional Office, Parks Canada. 84 pp.

Takyi, S.K. 1980. Influence of roll-out mats and ridging on the establishment of plant cover on an unamended coal spoil. Progress Report for 1979. ENR Report No. 152. Alberta Energy and Natural Resources. 36 pp.

Westhauer, A., D. Graham, N. Holguin. 1984. Sunshine Meadows Summer Use Monitoring Program. Banff Warden Service, Parks Canada. 113 pp.

Willard, B.E. and J.W. Marr. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biological Conservation 3(3):181-190

Walker, D.G. 1981. Lake Louise Ski Area Rehabilitation Plan. Prepared for Village Lake Louise Ltd. 77 pp.

Walker, D.G. 1984. Rehabilitation Plan, Parker Ridge Trail, Banff National Park. Prepared for Western Regional Office, Parks Canada. 60 pp.

CASE HISTORIES

Whistlers Mountain Trail

Location:	13 km southwest of Jasper townsite, Jasper National Park Access by gondola
Elevation:	2,256 to 2,465 meters (treeline at 2,000 m)
Traffic:	150,000 visitors/annum Length: 3.0 km 50% hike the entire trail in good weather, 15% in bad
Public Awareness:	(1) Trail head information sign (2) Trail direction and closure signs (3) Roll-out mulch applied at trail closures (5) Boardwalk development at trail head
Mulching:	(1) Roll-out paper mulch on wet/moist sites (2) Roll-out excelsior mulch on windswept ridges
Fertilizer:	(1) Wet areas 88 kg-N/ha,11 kg-P/ha,22kg-K/ha,11kg-S/ha (2) Dry areas 77 kg-N/ha,22 kg-P/ha,17kg-K/ha,11kg-S/ha

Seed Material:

(1) Snow-free areas	(%/wt)	(2) Snowbed areas	(%/wt)
alpine wheatgrass	15	tufted hairgrass	11
spike trisetum	13	alpine fescue	37
interior bluegrass	62	alpine timothy	43
alpine bluegrass	10	alpine bluegrass	9

Shrub Material:

Name		% survival after 2.0 yrs
snow willow	*(Salix nivalis)*	44.1
arctic willow	*(Salix arctica)*	70.2
moss campion	*(Silene acaulis)*	90.6
stonecrop	*(Sedum lanceolatum)*	69.8

Transplants (2,000) planted by auger after snowmelt in early July.

Parker Ridge Trail

Location:	9 km south of Columbia Icefields, Jasper National Park			
Elevation:	2,035 to 2,271 meters (treeline at 2,150 m)			
Traffic:	6,000 visitors/annum	Length:1.5 km, Access from highway		
Public Awareness:	(1) Trail head information sign (2) Trail closure signs at short-cuts (3) Barriers at major trail closures (H 0.5 m, L 2-4 m) (4) Shrubs transplanted at trail closures (5) Roll-out paper mulch applied at trail closures (6) Deadfall and large rocks placed at trail closures			
Drainage:	(1) Rock lined swales at minor watercourses (2) Open ditches, timber braces, rock lined			
Material Salvage:	(1) Soil salvaged, replaced on eroded short-cuts (2) Sod cut from upgraded trail, replaced on old trail (3) Local shrubs relocated to closed trails			
Topsoiling:	(1) Commercial potting soil, custom blended local conditions (2) Sterilized and packaged 20 kg plastic bags, total 60 m^3 (3) Transport to site by helicopter			
Mulching:	(1) Roll-out paper mulch on exposed sites			
Fertilizer:	(1) 100 kg/ha of 11-55-0 at time of seeding (2) 150 kg/ha of 46-0-0 annually/ for 3 years/ spring applied			
Seed Material:	(1) Alpine Mix	(%/wt)	(2) Subalpine Mix	(%/wt)
	alpine fescue	32	tufted hairgrass	4
	spike trisetum	15	bearded wheatgrass	18
	interior bluegrass	15	streambank wheatgrass	18
	alpine bluegrass	17	northern wheatgrass	18
	alpine timothy	3	June grass	21
	alpine wheatgrass	18	Cusick's bluegrass	21
Results After 1 Year:	seedlings/m2	1037	seedlings/m2	846
	cover (%)	12	cover (%)	10
Shrub Material:	(1) Propagation in progress/ transplanting scheduled for 1986 (2) Arcitic willow, Snow willow, moss campion			

Sunshine Village Trail System

Location:	17 km southwest of Banff townsite, Banff National Park, Alberta and Assiniboina Provincial Park, British Columbia Sunshine Village Ski Area Access by Gondola
Elevation:	2,200 to 2,350 meters (treeline at 2,200 m)
Traffic:	1,000 visitors/annum pre- gondola use Length: 18 km 30,000 visitors/annum post-gondola use
Public Awareness:	(1) Trail head information sign (2) Ski company operated interpretive program with • information brochures • trail information staff • guided tours • trailside interpretive signs • staffed interpretive centre (3) Trail closure signs
Drainage:	(1) Rock lined swales at minor drainages (2) Metal culverts at major drainages
Material Salvage:	(1) Soil salvaged, replaced on eroded braids (2) Sod cut from upgraded trail, replaced on old trail (3) Transport of soil and sod by helicopter
Fertilizer:	(1) 100 kg/ha of 11-55-0 at time of seeding (2) 150 kg/ha of 46-0-0 annually/ for 3 years/ spring application

Seed Material:

Alpine Mix	(%/wt)
alpine bluegrass	20
spike trisetum	15
alpine timothy	10
Cusick's bluegrass	25
slender wheatgrass	30
seed rate	50 kg/ha

Behaviour of Alpine plants and high altitude revegetation research

by

Krystyna M. Urbanska

Geobotanical Department, Swiss Federal Institute of Technology
Zürichbergstrasse 38, CH-8044 Zürich, Switzerland

Introduction

The ever-increasing human impact resulted in disturbances in high altitude ecosystems. Winter sport areas in Alpine countries where artificially made ski-runs frequently are situated well above timberline, are particularly exposed to damage, de-stabilized and erosion-endangered surfaces being frequently large.
The need for revegetation of those areas has been recognized. However, the actual revegetation research is seldom, if at all, carried out and the current revegetation practices above timberline in the Swiss Alps do not take into account genetical and ecological factors operating in fragile ecosystems of high altitudes. It is regrettable because only the revegetation projects with a sound scientific background can result in optimum long-term returns.

The very essential factor in revegetation above timberline is a suitable plant material. I argued elsewhere(Urbanska 1986) that plants able to withstand the selective pressures in high altitude sites, represent the sole choice. Alpine plants are adapted to grow and reproduce during a short vegetation season in rather cold temperatures(see e. g. Bliss 1962, 1971, 1980, Billings 1974, Courtin 1968, Hadley and Bliss 1964, Landolt 1983, 1984, Urbanska 1985, 1986, Urbanska and Schütz, in press). The present paper deals with these two aspects of behaviour, particularly relevant to the success of revegetation in high altitude sites. The data from alpine and subnival vegetation belt discussed here were gathered, for the most part, in our long-term study on behaviour of plants inhabiting various alpine substrata. Some results have been previously published; unless otherwise specified, the details presented refer to the author's unpublished results both from the wild as well as greenhouse and experimental garden.

Before the actual paper is presented, two points have to be made:

1. The term "Alpine" with the capital "A" is used to denominate taxa native to the Alps. Precisely speaking, the present paper deals with Alpine alpine plants; the second term has an ecological meaning and refers to taxa occurring above timberline in any part of the world. Both terms are used in further parts of the paper.

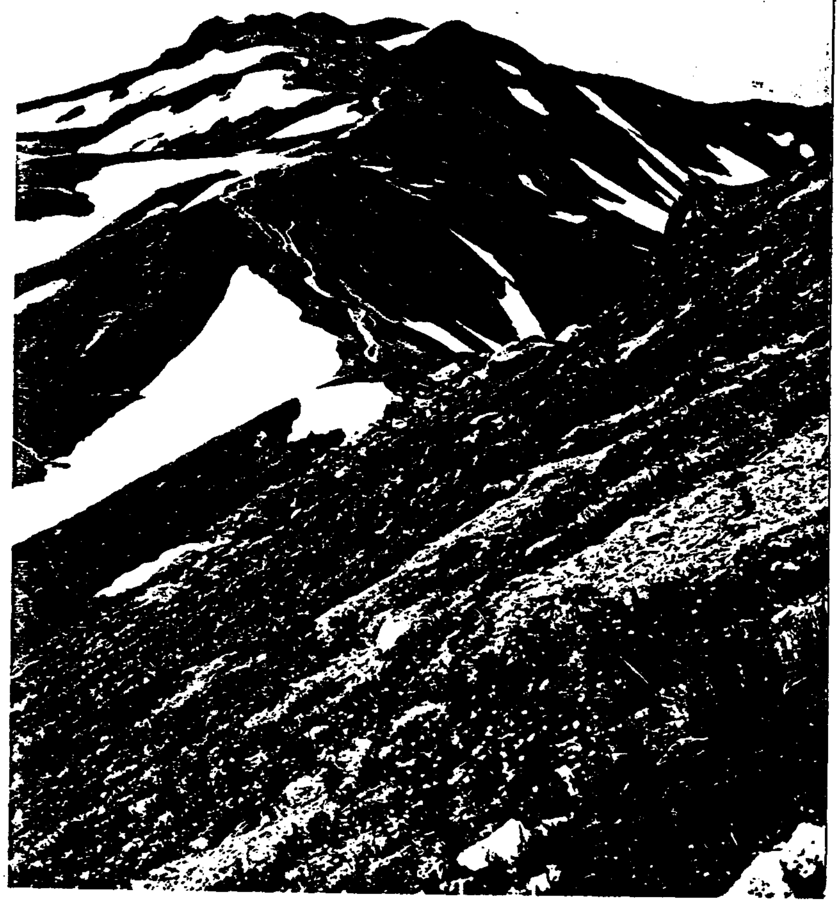


Fig. 1. High altitude landscape in the research area of the Geobotanical Department, SFIT Zürich: the ridge Wannengrat-Chörbschhorn, 2514-2650 m. a. s. l., siliceous substratum(paraschists and gneiss). Vegetation in foreground is dominated by _Agrostis Schraderiana_. Photograph taken by H. Bolzern on July 15, 1984.

2. The term "high altitude(s)" used here is obviously relative. The al-

titude bracket our studies are carried out within corresponds to some 2300-2850 m. a. s. l., which represents a rough equivalent of 7500-9350 ft. In the surroundings of Davos, Grisons(E Switzerland, central part of the Alpine chain) where our research area is situated, these altitudes represent a true alpine landscape (Fig. 1). On the other hand, the timberline in e. g. canton of Wallis stands higher(2400 m. a. s. l., Landolt 1983, 1984). Compared to e. g. Central Rocky Mts, the altitudes in Switzerland do not seem very impressive but the ecological situation is clear, plant life conditions being exceedingly rigorous in some sites.

Growth patterns

Bar very few taxa, growth in plants inhabiting alpine and subnival vegetation belt can be characterized as slow and low, the representative life form being a herbaceous perennial with relatively large underground biomass at more advanced developmental stages. In some taxa from extreme sites e. g. scree slopes, the very high potential for the root system growth is observable already at the seedling phase(Fig. 2); in others, the differences between aerial and subterranean parts may be not very distinct at early life phases, as indicated by experimental studies of Fossati(1980), Schütz(1983 and unpubl.) or Weilemann(1980, 1981, Fig. 3).

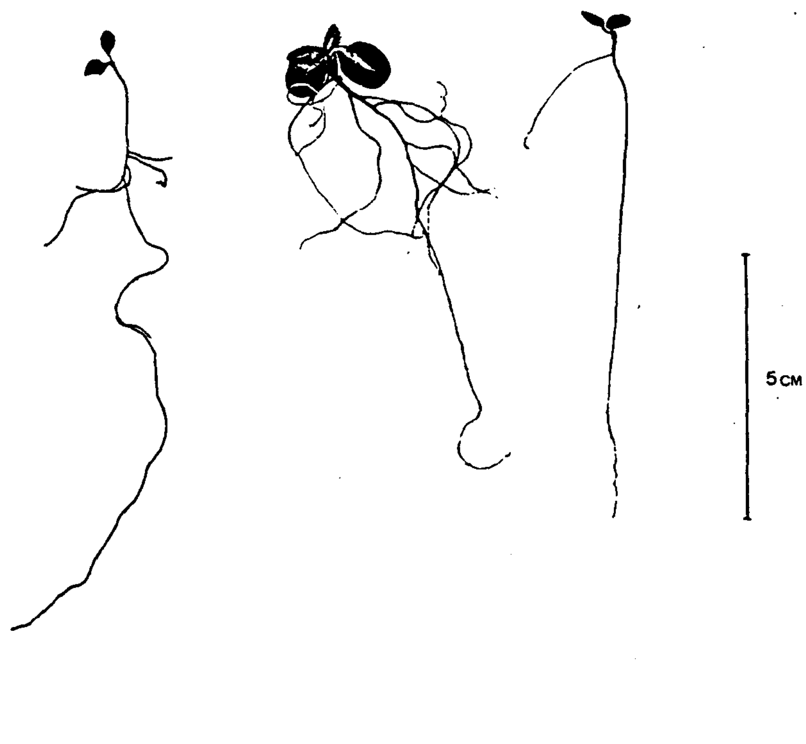


Fig. 2. Xerox silhouettes of 30-35 days old seedlings. l.to r.: <u>Biscutella levigata</u>(after Gasser 1981), <u>Cirsium spinosissimum</u> and <u>Doronicum grandiflorum</u>(unpublished data of Elmer). Climatic chamber experiments.

Fig. 3. Early life phases in Trifolium alpinum: xerox silhouettes of seedlings and young plants. Greenhouse experiment of Weilenmann(1981).

Numerous alpine plants manifest clonal growth resulting sometimes in rather complex structures. To illustrate the diverse behavioural patterns, some taxa studied in our research programme have been selected. For instance, Biscutella levigata(mustard family) produces secondary rosettes not only from lateral buds but also from root suckers developed in some distance from the mother rosette(Gasser 1981, 1983, 1986). Clonal system in Doronicum grandiflorum(composite family) is supported by a strong rhizome that may undergo fragmentation, especially in non-stabilized scree slopes(Schütz unpubl., Somson 1984); a similar patterns occurs in Ranunculus montanus s. str.(buttercup family) inhabiting scree and/or talus slopes(Dickenmann 1980, 1982). Geum reptans(rose family), very successful in some pioneer sites, produces numerous aboveground stolons with terminal rosettes that have to remain connected with the mother rosette for a rather long time if they are to survive(Urbanska and Schütz, unpubl.).

The formation of tussocks in alpine grasses and graminoids is obviously well-known. It is perhaps less known that clones in some taxa of this group not only consist of tillers but also are reinforced by other structures. For instance, Poa cenisia produces both extravaginal tillers and long underground stolons. On the other hand, Trisetum distichophyllum and Agrostis Schraderiana do not develope compact tiller groups but have well-defined, slender stolons that are resistent to an intermittent debris surface cover and render the large clonal system easily adaptable to changes occurring in unstabilized scree or talus slopes(Fig. 4). Tiller groups in Carex rupestris are held together by underground stolons, whereas the compact clones in C. firma are supported by strong, short rhizomes(see Hess et al. 1967).

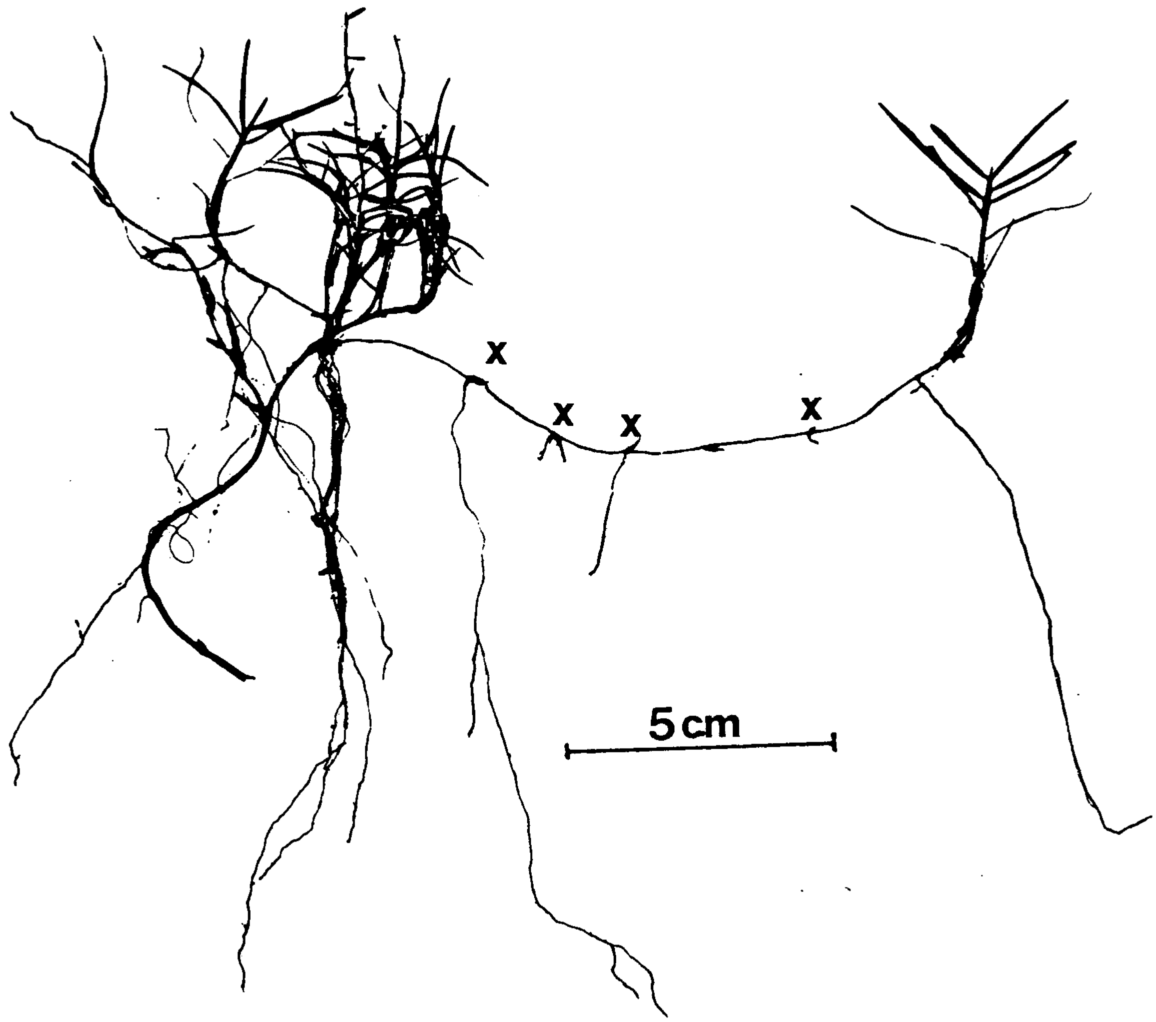


Fig. 4. Trisetum distichophyllum: a small fragment of the extensive clonal system. x = tillers and roots sprouting from the stolon nodes.

It goes without saying that not only the field observations on clonal systems of alpine plants but also experimental studies on growth and regeneration of high altitude taxa are indispensable for a better assessment of plant potential in revegetation trials. This aspect of the high altitude revegetation research is exceedingly important, for two reasons:

1. In particularly endangered surfaces, revegetation by planting is frequently carried out(see e. g. Miller and Miller 1978). Above timberline, however, direct transplantations should positively be avoided; the concept of repairing damage in one site by inflicting damages upon another one does not make any sense. On the other hand, our recent experimental results demonstrate that some Alpine grasses can easily be cloned from single tillers. In Festuca pumila for instance, a small tussock of about 15 cm in diameter consists of about 300 tillers; the recovery percentage is 95-100% and the recovery time from a single tiller to a developed clonal module of several tillers is six weeks-two months(Hefti unpubl.). It should be noted that 300 clonal modules are sufficient for revegetation

of a surface of about 16 m^2; the environment-conscious method of the single-tiller-cloning is to be strongly recommended indeed.

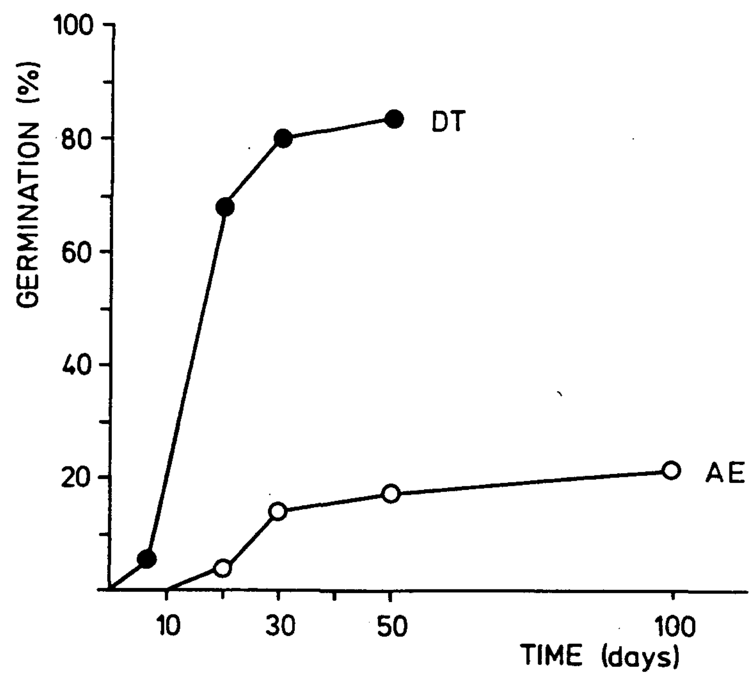
2. Cloning apparently has a strong invigorating effect; our results suggest that in some taxa not only the vegetative growth but also the formation of reproductive structures is enhanced(Urbanska unpubl, Hefti unpubl.). The latter aspect calls for a special attention.

Reproductive behaviour

Reproduction in alpine plants follows diverse patterns, both sexual and asexual processes being involved. Of a particular interest is the multifarious asexual reproduction that, on the one hand, results in the seed formation(agamospermy) and, on the other hand, comprises vivipary, formation of bulbils as well as the actual fragmentation of clones with the subsequent appearance of physiologically independent modules(Urbanska 1985).

The experimental clone fragmentation by separation of single tillers was just discussed; in the wild, larger clonal parts are usually separated as the result of soil disturbance. It seems that this kind of asexual reproduction may frequently occur in unstable or disturbed sites; however, the recovery potential in many taxa is not exactly known and should be included in revegetation research.

Germinating behaviour and seedling establishment in plants inhabiting high altitude sites in the Alps were discussed in another paper(Urbanska and Schütz, in press) to which the reader is referred for more detailed information. For the present contribution, we have selected some aspects of the reproduction by seed and also vivipary which seems to be important for the Alpine revegetation research.



Doronicum grandiflorum: germinating behaviour in seed originating from two alpine populations in the same area at about 2500 m. a. s. l. DT = Ducantal; AE = Aelpli. Unpublished data of G. Elmer and M. Schütz.

Seed output in alpine plants depends on environmental conditions and dramatic variation from year to year is well-known(see e. g. Fossati 1980, Urbanska 1985). Not only the quantity of developed seeds but also their quality may vary from site to site and even from one population sector to another(Fig. 5). Breeding behaviour of a given taxon plays an important rôle in the seed production: autonomously agamospermous and/or autogamous taxa possibly have a better chance than predominantly outbreeding plants dependent on mating partners. However, the successful seed production at high altitudes is influenced by climatic conditions not only at the onset of the seed-setting but also at later phases. The condition of the mother plant represents another important factor as a seed is largely the maternal investment(Westoby and Rice 1982).

Our recent observations indicate that not only the very production of seeds but also their germinating behaviour may be modified by ecological conditions accompanying the seed development. In late summer 1984, some plants have been brought from our Alpine research area to the experimental garden of the Geobotanical Department in Zürich(400 m. a. s. l.) and planted in a cold frame for overwintering; in the following year, seed production and the germinating behaviour were studied both in the material from the garden as well as in samples collected in the original sites above timberline. In three taxa studied, germination rates were higher in the garden-grown seeds than in those harvested in the alpine populations(Urbanska and Schütz, in press). Particularly interesting proved to be Trisetum spicatum that not only produced in the garden numerous well-germinating seeds(Fig. 6) but also some viviparous tillers.

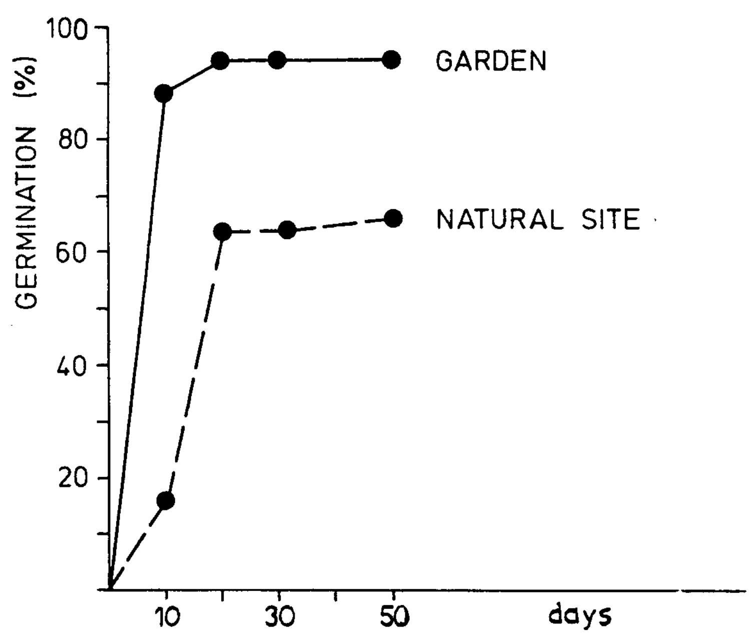


Fig. 6. Germinating behaviour in Trisetum spicatum: seeds from the same alpine population harvested in the experimental garden and those collected in the wild. Climatic chamber trial. From Urbanska and Schütz, in press.

Seed dormancy occurring in plants inhabiting high altitude sites in the Alps represents a rather complex phenomenon(Urbanska and Schütz, in press). It is interesting that scarification is frequently more effective than the cold treatment(see e. g. Fossati 1976, 1980, Schütz 1983 and unpubl, Urbanska et al. 1979, Weilenmann 1980, 1981, Zuur-Isler 1981, 1982). In this respect, behavioural patterns in Alpine plants are comparable to those reported from other mountains(see e. g. Amen 1966). A suitable pretreatment of the seed material prior to the sowing proved advantageous in our field trials(Schütz unpubl, Urbanska 1986). Another aspect important for revegetation research in the Alps is an apparent influence of substratum upon germination of some high altitude taxa(see e. g. Schütz and Urbanska 1984, Gasser 1986); it has to be taken into account when the material for revegetation by sowing is being selected.
Seedling establishment represents a particularly hazard-exposed phase in life history of alpine plants. Conditions above timberline are not only harsh but also unpredictable and the importance of safe sites(Harper 1977) is primary. In commercial revegetation carried out above timberline, large amounts of fertilizer are applied to boost the growth of the lowland material used. It is necessary to remember, however, that alpine ecosystems do have a low-nutrient budget and some nutrients may be limiting, but the plants adapted to life in alpine and subnival vegetation belt evolved strategies to cope with these conditions. For this reason, safe sites in the alpine area may not necessarily be defined in the first place by a high nutrient content of the soil. On the other hand, low temperatures are normal at high altitudes but an excessive frost combined with wind that appreciably increases the chilling factor may have sublethal or lethal effects. The same can be said about drought, another important hazard in the alpine life. It seems that the safe sites above timberline have to be viewed not only in the perspective of possible advantages they have to offer(e. g. a suitable soil structure) but also in terms of protection they give to plants at their early life phases(Urbanska and Schütz, in press). Further studies in this subject are required.

Reproduction by vivipary represents a low-risk strategy(Urbanska 1985). Plantlets of viviparous grasses produce tillers of greater stature than those developed from seeds of closely related seed-bearing taxa(Harmer 1984). The nutrient capital of plantlets is larger than that in seeds (Harmer and Lee 1978) and they are photosynthetically active from the very first stages of development; those factors may confer competitive advantages and also may be expected to favour establishment in habitats subject to short vegetation season. According to Lee and Harmer(1980) vivipary can be considered as a reproductive strategy evolved in response to environmental stress.

As far as the Alpine flora is concerned, viviparous *Poa alpina* represents certainly one of the most successful taxa above timberline. Its propagule output is generally high and so are the propagule establishment rates (Zollikofer 1930, Bachmann 1980, Urbanska 1985). Preliminary results obtained on *Poa alpina* in our revegetation research programme are indeed encouraging. The propagule output in the small tussocks brought to the experimental garden proved to be exceedingly high and the single-propagule-cloning resulted in the 100% recovery; the obtained tillers manifested an agressive growth(Urbanska unpubl.). Out of the 200 clonal modules planted into ski-run surfaces upon acidic silicate and dolomite, all produced culms with new propagules within only six weeks and at the end of the field season some new propagules were apparently established within the trial plots(Hefti unpubl.). An average propagule output per culm in the field being 30, the exceedingly high reproductive potential in viviparous Poa alpina is clearly recognizable.

Demographic behaviour

Growth patterns and reproductive strategies strongly influence the demographic behaviour of Alpine plants. This influence is particularly pronounced in extreme ecological sites; recent data from alpine vegetation belt show that demographic parameters in a given taxon may vary not only from one substratum to another but even from one niche to another(Figs 7-9), both the quantitative aspects as well as the very occurrence of particular age-state variants(e. g. seedlings) being closely related to site conditions.

Demographic studies permit to assess the population dynamics and the eventual population turnover. For this reason, data on e. g. population size, density and/or distribution of age-state variants in natural sites represent very useful criteria for the selection of plant material used in revegetation trials and may have a high prognostic value in a long-term planning.

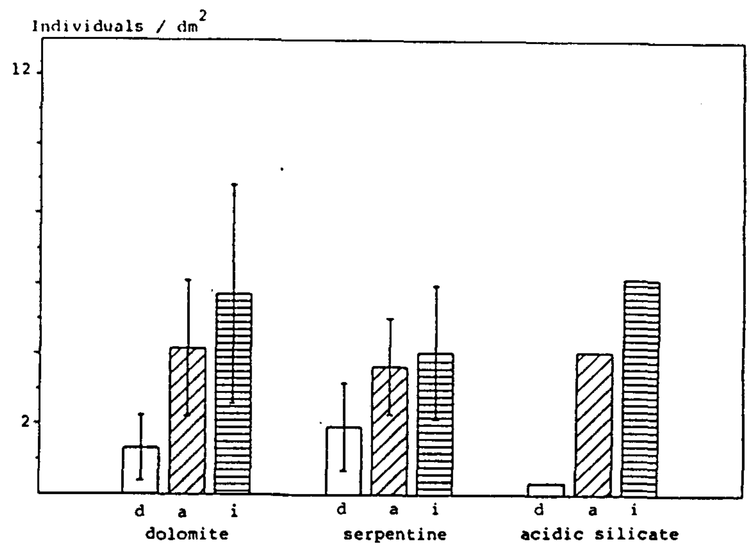
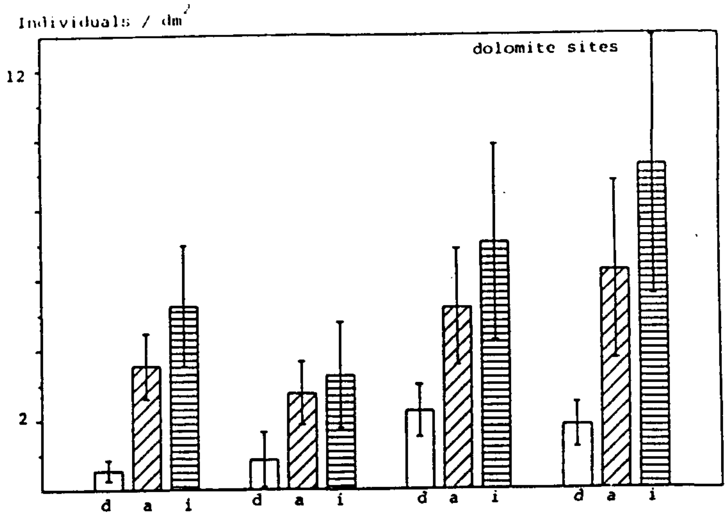
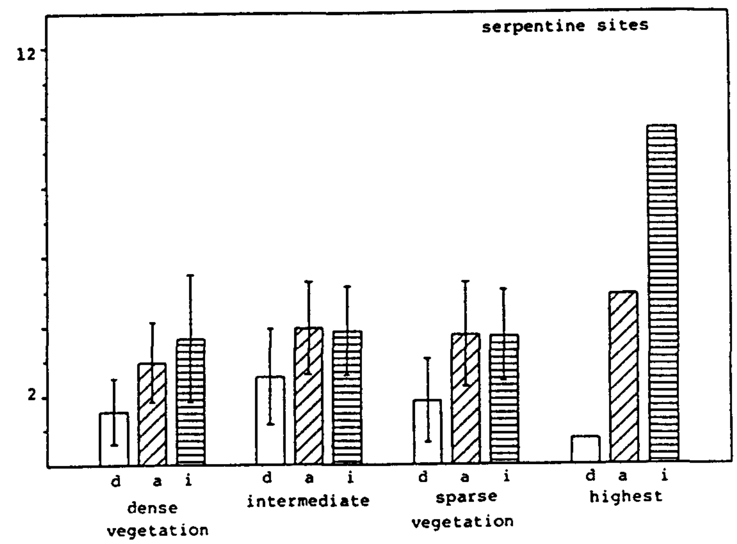


Fig. 7. Demographic studies in Biscutella levigata: global evaluations of density(d), abundance(a) and index of dispersion(i)(± S.D.) of seedlings, non-reproducing and reproducing rosettes on dolomite, serpentine and acidic silicate. Alpine vegetation belt, census of August 1983. After Gasser(1986).



8.



9.

Figs 8-9. Demographic studies in <u>Biscutella levigata</u>: global evaluations of density(d), abundance(a) and index of dispersion(i)(±S.D.) in various sites upon dolomite(8) and serpentine(9). Alpine vegetation belt, census of August 1983. After Gasser(1986).

Summing up

The data discussed in the present paper demonstrate that the knowledge of biological processes involved both in colonization of revegetated sites at high altitudes as well as in their actual exploitation is still largely deficient. We should like to stress this point especially in relation to the areas above timberline; the large progress made in the revegetation research in North America, essential for developing ecologically compatible revegetation practices, applies as yet mostly to subalpine and suprasubalpine vegetation belt.

As far as the Alps are concerned, revegetation research above timberline is rare and mostly focused upon successional stages in surfaces where lowland seeds were sown with unsatisfactory results(e. g. Meisterhans, in preparation). However, studies dealing with the actual selection of native plant materials and observations on soil and site dynamics are exceedingly important and an integrated scientific programme should be developed.

The principal problem emerging when revegetation by seeding with use of the native materials is considered is the availability of seeds. For the time being, there simply is no sufficient supply of any seed material adapted to the areas above timberline, let alone the particularly well-performing taxa. A repeated harvest in the wild is environment-damaging, not always reliable and admittedly expensive. Further studies should show if cultivation of selected alpine taxa at lower altitudes , especially reinforced by cloning, would ensure an increased and/or qualitatively better supply of alpine seeds without a recurrent damage to the natural populations. Our results suggest that a proper choice of material and a suitable pretreatment of seeds may result in their better germination than that in the case of a non-selective seeding; in this way, more effective results may be obtained with less material used.
The concept of safe site above timberline may have to be modified for each particular situation, but principally it should focuse upon surface stability and protection from drought and frost, an extensive application of fertilizer being open to further verification. As far as the Swiss Alps are concerned, protection from grazing animals should also be taken into consideration.
Revegetation by planting is time- and labour-consuming; it will have probably to be reserved for limited, especially endangered surfaces. On the other hand, it might assure a better success rate than revegetation by seeding. Planting combined with seeding might represent an optimum revegetation strategy and will be examined in our programme. Another interesting aspect represents revegetation by "seeding" of viviparous propagules, now studied by the present author.

The research programme outlined above obviously deals with only a part of the complex problem. Detailed studies on soil structure and stability, development of root system, long-term observations on performance and reproductive success, remain a wishful thinking - at least for the time being and as far as Switzerland is concerned. However, revegetation above timberline in the Swiss Alps still proceeds by a "trial and error" method. A serious revegetation research may in the long run reduce the number of trials and eliminate at least some errors; it is therefore urgently needed.

Acknowledgements

Sincere thanks of the author are addressed to graduate and undergraduate students, laboratory technicians at the Geobotanical Department and all volunteers who helped with revegetation of our experimental plots above timberline. The cooperation of the personnel of the cable car Jakobshorn and those of Schatzalp-Strela(Davos) is gratefully acknowledged. The American Excelsior kindly put at our disposal some curlex matting, very helpful in our safe site-oriented trials. Some of the research projects referred to in the paper were financed by Swiss National Science Foundation; we are thankful for this support. Special thanks are due to Prof. Dr. E. Landolt(Geobotanical Department) who critically read the manuscript.

References

Amen R. 1966. The extent and role of dormancy in alpine plants. Quart. Rev. Biol. 41, 271-281.

Bachmann M. A. 1980. Oekologie und Breeding System bei Poa alpina L. Mittl. Bot. Mus. Univ. Zürich No. 318, 1-200.

Billings W. D. 1974. Arctic and alpine vegetation: plant adaptations to cold summer climates. in: Ives J. D. and Barry R. G.(eds). Arctic and Alpine Environments, p. 403-443.

Bliss L. C. 1962. Adaptations of arctic and alpine plants to environmental conditions. Arctic 15, 117-144.

Bliss L. C. 1971. Arctic and alpine life cycles. Ann. Rev. Ecol. Syst. 2, 405-438.

Bliss L. C. 1980. Physiology and life cycles of arctic-alpine plants. Proc. High Altit. Reveg. Workshop No. 4, Colorado Univ. Inf. Ser. 42, 65-78.

Courtin G. M. 1968. Evapotranspiration and energy budget of two alpine microenvironments, Mt. Washington, N. H. Ph.D. Thesis, Univ. Illinois, Urbana.

Dickenmann R. 1980. Microdifferentiation patterns in Ranunculus montanus Willd. Ber. Geobot. Inst. ETH 47, 46-49.

Dickenmann R. 1982. Genetisch-ökologische Untersuchungen an Ranunculus montanus Willd. aus der alpinen Stufe von Davos(Graubünden). Veröff. Geobot. Inst. ETH 78.

Fossati A. 1976. Die Keimung von Hochgebirgspflanzen. Diploma Thesis Geobot. Inst. ETH.

Fossati A.1980. Keimverhalten und frühe Entwicklungsphasen einiger Alpenpflanzen. Veröff. Geobot. Inst. ETH. 73.

Gasser M. 1981. Differenzierungsmuster von Pflanzenarten, die auf verschiedenen Gesteinunterlagen wachsen. Diploma Thesis Geobot. Inst.ETH.

Gasser M. 1983. Zum demographischen Verhalten von Biscutella levigata L. Ber. Geobot. Inst. ETH 50, 67-85.

Gasser M. 1986. Genetic-ecological investigations in Biscutella levigata L. Veröff. Geobot. Inst. ETH. 85.

Hadley E. B. and Bliss L. C. 1964. Energy relations of Mt. Washington alpine plants. Ecol. Monogr. 34, 331-357.

Harmer R. 1984. Vegetative proliferation and vivipary in Scottisch grasses. Trans. Bot. Soc. Edinb. 44, 261-268.

Harmer R. and Lee J. A. 1978. The germination and viability of Festuca vivipara(L.)SM plantlets. N. Phytol. 81, 745-751.

Harper J. L. 1977. Population biology of plants. Academic Press N. York.

Hess H. E., Landolt E. and Hirzel R. 1967. Flora der Schweiz. Vol. I. Birkhäuser Verl.

Landolt E. 1983. Probleme der Höhenstufen in den Alpen. Bot. Helv. 93, 255-268.

Landolt E. 1984. Unsere Alpenflora. SAC Verl.

Lee J. A. and Harmer R. 1980. Vivipary a reproductive strategy in response to environmental stress? Oikos 35, 254-265.

Miller J. W. and Miller M. M. 1978. Revegetation of impacted subalpine plant communities in the North Cascades. Nat. Park Service Report.

Schütz M. 1983. Keimverhalten und frühe Lebensphasen alpiner Pflanzen von Silikat- und Kalkschuttstandorten. Diploma Thesis Geobot.Inst.ETH.

Schütz M. and Urbanska K. M. 1984. Germinating behaviour and growth potential in Taraxacum alpinum (2n=32) from the Swiss Alps. Ber. Geobot. Inst. ETH 51, 118-131.

Somson P. 1984. Structure des organes hypogés de quelques espèces lithophiles pyrénéennes en relation avec la dynamiques des pierriers. Ber. Geobot. Inst. ETH 51, 78-117.

Urbanska K. M. 1985. Some life history strategies and population structure in asexually reproducing plants. Bot. Helv. 95, 81-97.

Urbanska K. M. 1986. High altitude revegetation research in Switzerland - problems and perspectives. Veröff. Geobot. Inst. ETH 87.

Urbanska K. M. and Schütz M. Reproduction by seed in alpine plants and revegetation research above timberline. Bot. Helv., in press.

Urbanska K. M., Schwank O. and Fossati A. 1979. Variation within Lotus corniculatus L. s. l. from Switzerland. II. Reproductive behaviour of L. alpinus (DC) Schleicher. Ber. Geobot. Inst. ETH 46, 62-85.

Weilenmann K. 1980. Bedeutung von Keim- und Jungpflanzenphase für alpine Taxa verschiedener Standorte. Diploma Thesis Geobot. Inst. ETH.

Weilenmann K. 1981- Bedeutung von Keim- und Junfpflanzenphase für alpine Taxa verschiedenenr Standorte. Ber. Geobot. Inst. ETH 48, 68-119.

Westoby M. and Rice B. 1982. Evolution of the seed plants and inclusive fitness of plant tissues. Evolution 36, 713-724.

Zollikofer C. 1930. Zur Fortpflanzung von Poa alpina L. Jahrb. St. Gall. Naturw. Ges. 65, 99-117.

Zuur-Isler D. 1981. Zum Keimverhalten von alpiner Pflanzen auf Serpentinböden. Diploma Thesis Geobot. Inst. ETH.

Zuur-Isler D. 1982. Germinating behaviour and early life phases of some species from alpine serpentine soils. Ber. Geobot. Inst.ETH 49,76-107.

SECONDARY SUCCESSION PATTERNS IN A DISTURBED SAGEBRUSH COMMUNITY IN NORTHWEST COLORADO

Edward F. Redente and Mario E. Biondini
Range Science Department
Colorado State University

ABSTRACT

The relationship between secondary succession, soil disturbance, and soil biological activity were studied on a sagebrush community in the Piceance Basin of northwest Colorado. Four levels of soil disturbance were imposed following vegetation removal: (1) topsoil left in place; (2) topsoil ripped to a depth of 30 cm; (3) topsoil and subsoil were removed to a depth of 1 m, mixed and replaced; and (4) topsoil and subsoil were removed to a depth of 2 m and replaced in a reverse order. Plant species composition, dehydrogenase and phosphatase enzymatic activity, mycorrhizal inoculum potential (MIP), and percent organic matter were the variables measured.

Treatment 4 drastically altered the pattern of vegetation succession. Treatments 2, 3, and 4 started with Russian thistle (_Salsola iberica_) as the dominant species but six years later, Treatments 3, and to lesser extent 2, were similar to the species composition of Treatment 1, dominated by perennial grasses and perennial forbs. Treatment 4 developed a shrub-dominated community. Both dehydrogenase enzymatic activity and MIP increased with the change from Russian thistle to a vegetation dominated by either perennial grasses and forbs or shrubs. The intensity of disturbance

in Treatments 2, 3, and 4 resulted in drastic reductions of dehydrogenase activity and MIP, but in six years they recovered to levels comparable to Treatment 1. Phosphatase enzyme activity and organic matter were unrelated to species composition but related to treatment and time elapsed. In both cases a significant decrease was observed throughout the six-year period.

INTRODUCTION

Succession theory has played a central role in plant ecology for more than 80 years. Early views caused succession to be defined as a community or species replacement driven exclusively by autogenic environmental modification (Weaver and Clements, 1938). Most recently new theories have been developed that relate succession to tolerance and inhibition factors, species life-history characteristics, and population processes.

Most succession studies have been confined to the vegetation part of the ecosystem. Only recently the interrelationship between plant succession and soil biological activity has begun to be studied. Parkinson (1979), in a literature review of reclamation succession, noted the lack of information which relates plant succession to type and levels of disturbance and soil biological activity.

The present study was designed to address two main objectives: (1) to determine how various forms and intensities of soil disturbance can affect soil biological activity and rate of vegetation succession; and (2) to determine the degree of relationship between soil biological activity and species composition during succession.

MATERIALS AND METHODS

The study site was located in the Piceance Basin of northwest Colorado at an elevation of 2020 m. Sagebrush-grassland was the dominant vegetation type before disturbance and big sagebrush (*Artemisia tridentata tridentata*) comprised 60-80% of the canopy cover. Western wheatgrass (*Agropyron smithii*), streambank wheatgrass (*A. riparium*), prairie junegrass (*Koeleria cristata*), Indian ricegrass (*Oryzopsis hymenoides*), needle-and-thread grass (*Stipa comata*), and scarlet globemallow (*Sphaeralcea coccinea*) were major understory species. Soil texture ranged from loam to clay loam with the combined A and B horizons 30-60 cm deep. The pH was 8.0, electrical conductivity (EC) averaged 0.5 mmhos/cm, nitrate-nitrogen was 5 ppm (water extract), and phosphorus was 2.3 ppm (ammonium bicarbonate extract) in the first 15 cm of soil. Annual precipitation is 250-300 mm, approximately one half received as snow (Redente et al., 1984).

The study was initiated in the summer of 1976. Treatments consisted of four levels of soil disturbance following vegetation removal:

Treatment 1: Minimal disturbance to topsoil (A and B horizons).

Treatment 2: Topsoil ripped to a depth of 30 cm.

Treatment 3: Topsoil and subsoil (C horizon) were removed to a depth of 1 m. The material was mixed together and replaced.

Treatment 4: Two layers of 1 m of soil were removed and replaced in a reverse order with the second layer placed on the surface.

The experiment was arranged in a randomized block design with two replications per treatment. The plots were 6 x 8 m with a 1.5-m buffer zone between plots. The vegetation variable measured was plant canopy cover. The plots were sampled once a year, at the end of the growing season, with ten 0.25 m^2 (25 x 100 cm) permanent quadrats randomly located within each plot. Cover values were then utilized to calculate species composition (as percent relative cover).

Measurements of soil organic matter, potential dehydrogenase and phosphatase enzymatic activity, and mycorrhizal inoculum potential (MIP) were utilized as indices of soil biological activity (Klein et al., 1982; Reeves et al., 1982). Organic matter was chosen in the present study as a general index of the soil reserve nutrient status. Soil enzymatic activities are a far better index of soil biological activity than microbial counts since little is known about the activities of individual microbial species (Kuprevich and Shcherbakova, 1966). Dehydrogenase enzymes participate in the oxidation of carbohydrates and require the presence of NAD and NADP as co-factors. Dehydrogenases in soils are only found in intact functioning microorganisms and as such their level of activity can be used as an index of the capacity to process carbon by the microflora (Skujins, 1978). The majority of phosphatase enzymes in the soil are contributed by soil heterotrophic microorganisms even though some can exist as free enzymes (Speir and Ross, 1978). Their activity level, then, can be an indicator of the availability of free (not part of the plant material) carbon and nutrients in the soil. It has been shown that mycorrhizal fungi are crucial in the functioning of many climax species in a variety of ecosystems. Their presence or absence then can be a determinant factor in the control of successional patterns (Langford and Buell, 1969; Reeves et al., 1979, 1982).

Three soil samples from a depth of 5-10 cm were randomly collected from each plot at the time of the vegetation sampling. Dehydrogenase and phosphatase enzymatic activities and soil organic matter were measured according to Hersman and Klein (1979). The dehydrogenase activity values presented in this study represent the 'potential' activities, i.e., the maximum capacity of the soil microflora to process carbon. The assays were carried out with the addition of 0.5 ml of a 1% glucose solution in place of distilled water. Mycorrhizal infectivity of the soil was measured as percentage infection in corn bioassay plants as described by Moorman and Reeves (1979).

RESULTS

Vegetation Successional Patterns

The main patterns of vegetation succession in this study were given by the changes through time of: (1) perennial grasses, (2) perennial forbs, (3) annual forbs, and (4) shrubs. The general pattern followed by perennial grasses was an increase in percent relative cover (PRC) as time elapsed and an inverse relationship between perennial grass composition and the severity of the treatment (Table 1). The grass PRC in Treatment 1 increased from 49% in 1977 to 62% in 1982. The vegetation of Treatments 2 and 3 began with a very low grass PRC but made a substantial gain in the six-year period. In contrast, the vegetation of Treatment 4 had a low grass PRC throughout the six-year period. The grass component of Treatment 4 increased from 0.04% in 1977 to only 5% in 1982.

Table 1. Percent relative cover for the dominant species in each treatment for years 1, 4, 5, and 6 of succession.[a]

		Treatment 1				Treatment 2				Treatment 3				Treatment 4			
		Year of Succession				Year of Succession				Year of Succession				Year of Succession			
Common Name	Scientific Name	1	4	5	6	1	4	5	6	1	4	5	6	1	4	5	6
GRASSES																	
Streambank wheatgrass	Agropyron riparium	2.73	6.75	29.87	26.24	2.61	3.59	21.90	19.62	0.001	0.001	10.18	21.95	0.001	0.001	0.47	0.68
Western wheatgrass	Agropyron smithii	0.34	18.19	4.54	8.78	7.52	5.16	4.92	2.10	0.03	0.21	4.17	7.62	0.001	0.001	0.09	0.001
Prairie junegrass	Koeleria cristata	17.05	11.93	18.29	9.32	2.61	1.60	2.72	6.29	0.001	0.001	0.001	0.51	0.001	0.001	0.001	0.68
Indian ricegrass	Oryzopsis hymenoides	1.02	1.47	3.82	3.62	1.20	2.21	4.58	3.05	0.07	0.47	6.01	3.76	0.04	0.21	4.03	2.83
Needle-and-thread grass	Stipa comata	6.62	6.60	4.01	14.12	0.05	0.74	4.67	6.95	0.34	1.11	0.001	9.96	0.00	0.00	0.00	1.25
Other grasses[b]		21.28	4.89	3.42	0.07	0.27	0.00	0.00	0.00	0.83	2.76	0.00	0.00	0.00	0.00	0.28	0.00
TOTAL GRASSES		49.04	49.83	63.95	62.15	14.27	13.30	38.79	38.07	1.27	4.55	20.36	43.80	0.04	0.21	4.87	5.44
PERENNIAL FORBS																	
Scarlet globemallow	Sphaeralcea coccinea	26.74	28.36	22.37	22.81	11.87	17.77	32.51	9.62	1.01	2.11	3.98	4.07	1.48	2.16	4.31	3.17
Wild daisy	Erigeron engelmannii	0.41	0.001	0.53	0.27	0.05	0.21	1.78	2.57	0.00	0.00	0.00	0.00	0.00	0.001	0.75	1.93
Cushion phlox	Phlox muscoides	6.34	3.81	5.92	8.33	1.14	1.44	3.74	7.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lobeleaf groundsel	Senecio multilobatus	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.10	0.001	3.69	3.15	0.00	0.06	2.34	6.12
Holyleaf clover	Trifolium gymnocarpon	0.41	0.20	2.89	1.18	0.33	0.19	1.61	1.24	0.03	0.001	0.29	0.00	0.00	0.00	0.00	0.00
Other perennial forbs		0.00	0.00	0.33	0.00	0.00	0.00	0.52	0.10	0.00	0.02	9.31	18.04	0.00	2.28	4.39	0.57
TOTAL PERENNIAL FORBS		33.90	32.37	28.82	32.86	13.39	19.61	40.16	21.05	1.14	2.13	17.27	25.31	1.48	4.50	11.79	11.79
ANNUAL FORBS																	
Russian thistle	Salsola iberica	11.73	13.40	1.58	0.09	66.12	62.20	6.03	2.29	91.56	91.38	54.70	21.04	92.62	90.82	47.85	6.57
OTHER ANNUAL FORBS		2.90	3.60	1.00	2.45	0.00	0.00	0.00	0.00	0.00	0.00	4.01	0.00	0.00	0.00	0.00	0.00
SHRUBS																	
Big sagebrush	Artemisia tridentata	0.14	0.15	0.20	0.63	0.11	0.13	0.42	1.81	0.00	0.00	0.97	1.73	0.23	0.21	6.55	12.12
Rubber rabbitbrush	Chrysothamnus nauseosus	0.00	0.00	0.00	0.00	2.45	2.71	10.61	24.00	0.00	0.00	0.00	0.00	0.80	4.12	16.67	25.93
Green rabbitbrush	Chrysothamnus viscidiflorus	1.36	0.49	0.33	0.45	0.27	0.53	2.12	1.33	0.00	0.00	0.00	0.00	2.09	0.06	5.90	10.08
Broom snakeweed	Gutierrezia sarothrae	0.82	0.05	0.53	1.09	2.72	1.36	1.87	10.57	5.91	1.32	2.13	7.52	2.28	0.02	4.87	26.73
TOTAL SHRUBS		2.32	0.69	0.73	2.17	5.55	4.73	15.02	37.71	5.91	1.32	3.10	9.25	5.40	4.41	33.99	74.86

[a] Table taken from Biondini et al. 1985.

[b] In 1977 there was an invasion of Agropyron desertorum from an adjacent study on one of the replications of Treatment 1. That is the reason for the high values of the 'Other grasses' category in Treatment 1 of year 1.

The general pattern followed by perennial forbs was an increase in PRC as time elapsed, and an inverse relationship between perennial forb PRC and the severity of the treatment (Table 1). Perennial forb PRC in Treatment 1 was virtually unchanged in the six-year period. The vegetation of Treatments 2 and 3 started with a low perennial forb component but as time elapsed they changed in the director of Treatment 1. Perennial forb PRC also increased with time in Treatment 4 even though it remained below the level of the other three treatments.

Russian thistle was a major species in the initial stages of succession. Its contribution to species composition of Treatments 3 and 4 was very high in the first year of succession (Table 1). Russian thistle PRC decreased sharply with time in all treatments in contrast to grasses and perennial forbs. The only treatment with a sizable Russian thistle component after six years was Treatment 3 with a PRC of 21%.

Shrubs were the main group of species to differentiate Treatments 1, 2, and 3 from 4. Shrub PRC on Treatments 1 and 3 never surpassed 10% throughout the six-year period (Table 1). Treatment 2 showed a steady increase in shrub PRC (Table 1). The biggest increase, from 5% to 75% in shrub PRC was observed in Treatment 4.

The major trends in the PRC of the species groups described above support the hypothesis that high levels of soil disturbance can alter the direction of secondary succession (as defined by species composition).

Soil Biological Activity

Dehydrogenase enzymatic activity was positively related to the establishment of perennial grasses and shrubs and negatively related to

Russian thistle composition (Figs. 1 and 2). Low values of dehydrogenase activities coincided with stands dominated by Russian thistle. Treatments 2, 3, and 4 started with dehydrogenase activities of 8.45, 3.82, and 4.25 μg formazan g^{-1} 24 hr^{-1} while Treatment 1 had values of 12.16 μg formazan g^{-1} 24 hr^{-1} (Table 2). An increase in dehydrogenase activity was observed as succession proceeded and perennial species became established. This increase was independent of whether the vegetation was changing toward a grass-forb-dominated community (Treatment 1, 2 and to a certain extent 3) or a shrub-dominated community (Treatment 4). The four treatments did not differ significantly ($p \cong 0.15$) in dehydrogenase enzymatic activity in year 6 of succession regardless of the severity of the soil disturbance (Table 2).

Mycorrhizal inoculum potential followed a pattern similar to dehydrogenase activity. It has a significant relationship with both perennial grasses and shrubs and Russian thistle (Figs. 1 and 2). Low level of MIP coincided with the dominance of Russian thistle. In Treatments 3 and 4, where Russian thistle comprised more than 90% of the species composition, MIP values were 13% and 11.5% in the first year of succession (Table 2). Treatment 2 had a MIP value of 44.5% while Treatment 1 had a value of 55.0% and Treatments 1 and 2 were significantly different from Treatments 3 and 4 ($p \cong 0.032$) in the first year of succession. The MIP values increased with succession independently of whether the vegetation was changing toward a grass-forb- or shrub-dominated community. The severity of the treatment did not have an effect on MIP values after six years of succession. In 1982

Table 2. Levels of dehydrogenase and phosphatase enzymatic activities, mycorrhizal infection potentials, and organic matter in each treatment for Years 1, 4, 5, and 6 of succession.

	Treatment 1				Treatment 2				Treatment 3				Treatment 4			
	Year of Succession				Year of Succession				Year of Succession				Year of Succession			
Soil Parameters	1	4	5	6	1	4	5	6	1	4	5	6	1	4	5	6
Organic matter (%)	2.81	1.34	1.47	1.12	2.80	1.38	1.38	1.19	1.97	0.81	0.94	0.90	1.31	0.40	0.44	0.54
Dehydrogenase activity (μg formazan g^{-1} 24 h^{-1})	12.16	25.78	27.37	30.62	8.45	21.52	26.15	26.98	3.82	8.59	20.04	22.53	4.25	6.88	22.47	23.82
Phosphatase activity (μg PNP g^{-1} h^{-1})	89.4	114.98	87.51	71.45	199.00	110.53	73.54	71.39	190.06	63.86	42.14	50.15	111.60	41.83	29.95	31.92
Mycorrhizal infection potential (%)	55.00	66.50	66.50	67.00	44.50	52.50	59.50	67.50	13.00	11.00	31.00	36.00	11.50	20.00	22.50	69.00

[a] Table taken from Biondini et al. (1985).

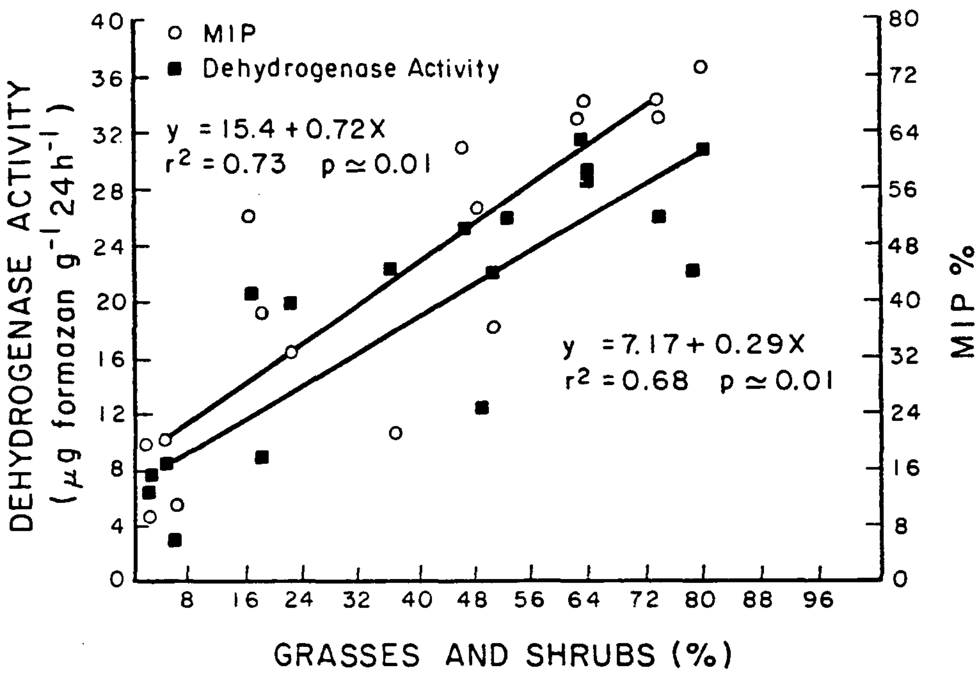


Figure 1. Dehydrogenase activity and mycorrhizal infection potential (MIP) in relation to the species composition of perennial grasses and shrubs. Taken from Biondini et al. (1985).

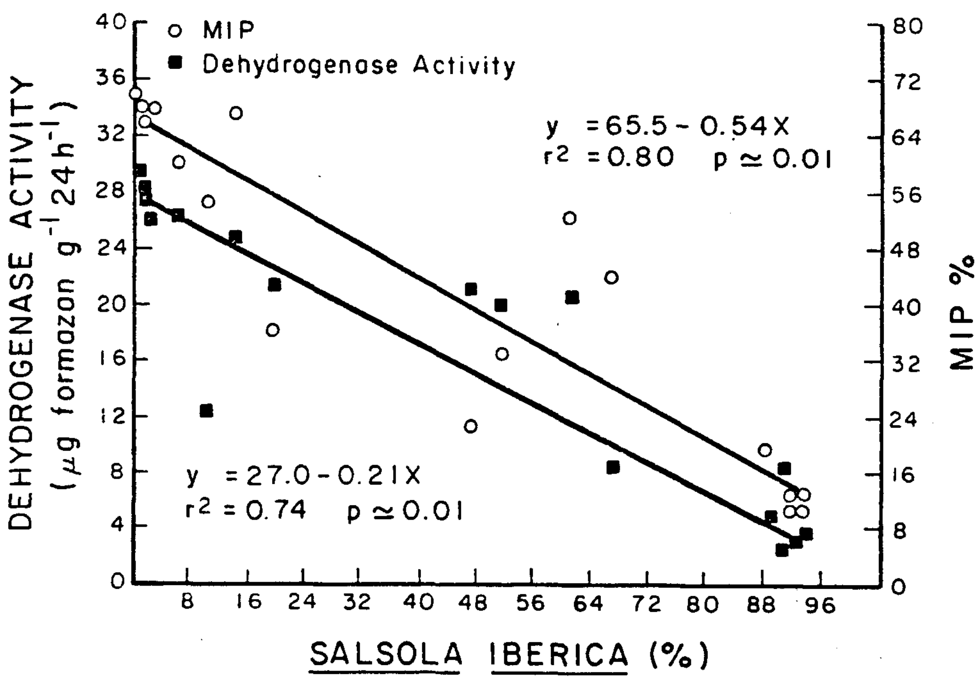


Figure 2. Dehydrogenase activity and mycorrhizal infection potential (MIP) in relation to the compositon of Russian thistle (*Salsola iberica*). Taken from Biondini et al. (1985).

MIP values for Treatments 1, 2 and 4 were not significantly different ($p \cong 0.20$) (Table 2). Treatment 3 was significantly different from Treatments 1, 2, and 4 ($p \cong 0.05$).

Phosphatase enzymatic activity and percent organic matter were not related to vegetation composition. They were, however, negatively correlated to time elapsed in the succession (Figure 3a). Phosphatase enzymatic activity decreased from an average (across all treatments) of 147.65 μg PNP g^{-1} hr^{-1} in 1977 to 56.22 μg PNP g^{-1} hr^{-1} in 1982. Likewise, organic matter decreased from an average (across all treatments) of 2.22% g^{-1} dry soil in 1977 to 0.93% g^{-1} dry soil in 1982. The severity of the treatment proved to have a significant and lasting effect on these two parameters. Six years after disturbance, Treatments 3 and 4 had lower phosphatase enyzmatic activity than 1 and 2 ($p \cong 0.05$) (Table 2). Organic matter in Treatments 1 and 2 was consistently higher than in 3 and 4 both in 1977 ($p \cong 0.05$) and 1982 ($p \cong 0.052$) (Table 2). Phosphatase enzymatic activity and percent organic matter were linearly correlated (Fig. 3b).

DISCUSSION

The general pattern of succession for Treatments 2, 3 and 4 consisted of an initial stage in which Russian thistle was the dominant species followed by a shift toward a grass-forb-dominated community in Treatments 2 and 3 and a shrub-dominated community in 4. In Treatment 1, the lower level of soil disturbance allowed only for a reduced invasion by Russian thistle. The species composition of Treatment 1 remained relatively unchanged

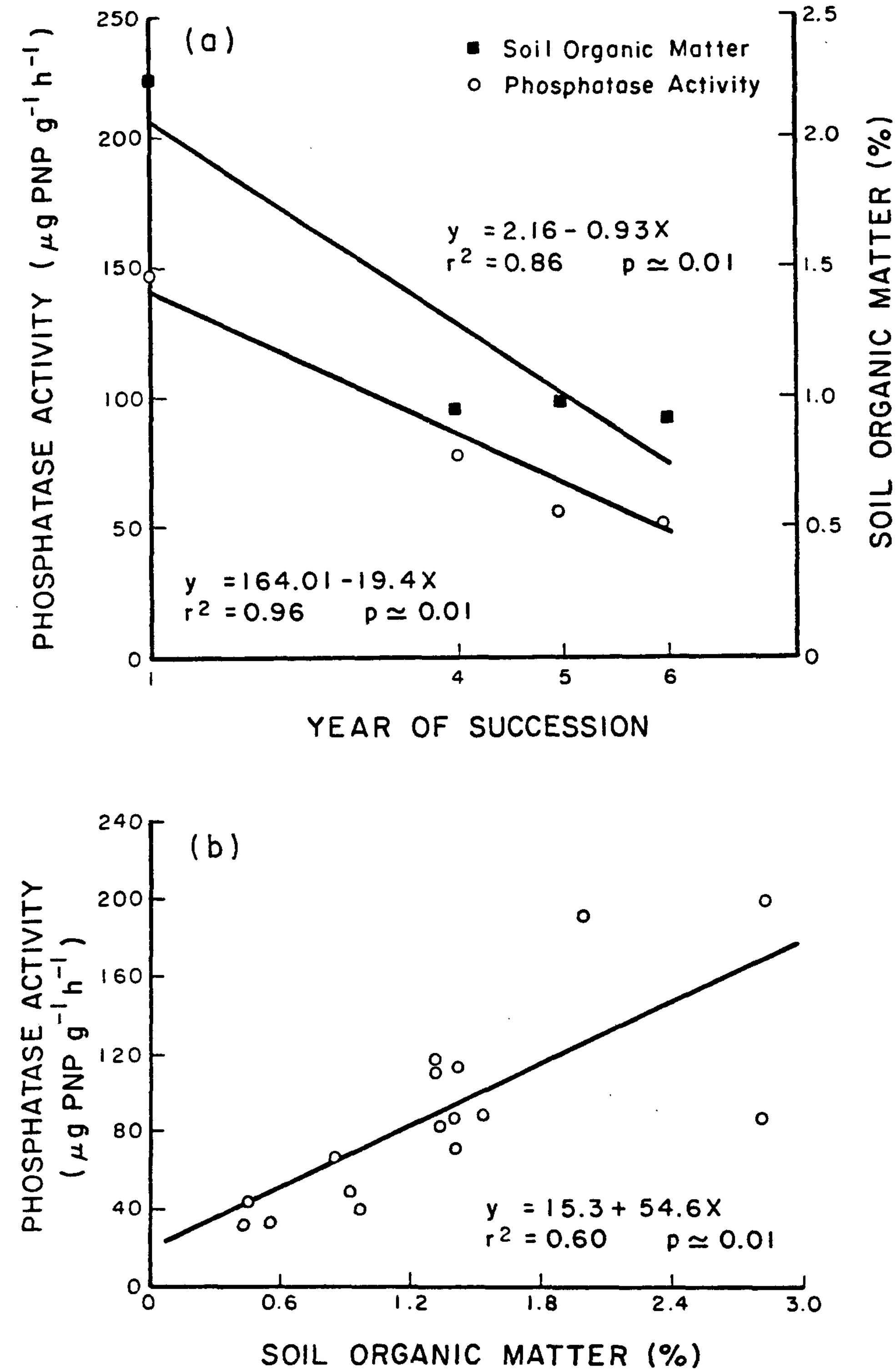


Figure 3. Phosphatase enzymatic activity and soil organic matter dynamics. (a) Average phosphatase activity and soil organic matter as related to successional time; (b) relationship between soil organic matter and phosphatase activity. Taken from Biondini et al. (1985).

throughout the six-year period, showing only a small trade-off between Russian thistle and perennial grasses.

Considering belowground processes, dehydrogenase enzymatic activity and MIP increased their levels with the advance of succession and were correlated to the shift in dominance from Russian thistle to perennial grasses and shrubs (Figs. 1 and 2). Phosphatase enzymatic activity and soil organic matter (which can give an indication of the availability of free nutrients and carbon in the soil) sharply decreased as time advanced. This decline may be an indication that as succession advanced, nutrient flow tightened (more nutrients immobilized in the plant biomass) and that the grasses and forbs that dominated Treatments 1, 2, and 3 or the shrubs that dominated Treatment 4 were more able to exploit these conditions. We speculate that the capacity of the latter successional species to exploit conditions of low nutrient availability may be related to a successional shift in the microflora composition from predominantly heterotrophic microorganisms that depend on free nutrients in the soil to plant dependent microorganisms which function in the rhizosphere.

Both rhizosphere microorganisms as well as mycorrhizal fungi have been shown to increase the capacity of plants to acquire nutrients under conditions of nutrient stress (Alexander, 1977; St. John and Coleman, 1983). This requires the diversion of fixed carbon toward the maintenance of a rhizosphere population. In the initial stages of secondary succession, conditions of nutrient abundance generally occur as a consequence of breakdown of organic matter previously tied up in plant material (Gorhman et al. 1979). Therefore we theorize that under these conditions it is not a profitable strategy for plants to divert part of their fixed carbon to maintain an extensive rhizosphere microflora population. With the advance of succession, however, more nutrients become immobilized in plant materials and less, in our view, are available in mineral forms, resulting in a nutrient stress of the plants. At this point, we theorize, it becomes a profitable strategy for plants to divert part of their fixed carbon to maintain a rhizosphere population in order to increase their capacity to acquire nutrients. It is within this general context that we view our hypothesized shift in the microflora composition from one predominantly comprised of free soil microorganisms to one with a higher composition of rhizosphere microorganisms.

Microbial activity in the free soil and the availability of a carbon source are correlated with the level of phosphatase enzymatic activity (Speir and Ross, 1978). A tight nutrient cycle and a reduction in free soil heterotrophic microorganisms would be consistent with the observed decline in phosphatase activity and organic matter. Cundell (1977) found evidence that in semi-arid areas the rhizosphere of grasses and shrubs is a very favorable place for microorganism development. The observed increases in dehydrogenase activity and MIP could then be explained by an increase in the rhizosphere microorganisms induced by an improvement in the rhizosphere environment with the shift from annual forbs to native perennial grasses and shrubs. It could also explain the relationship found between dehydrogenase activity and MIP and species composition.

One factor that was not anticipated was the rapid recovery of dehydrogenase activity and MIP under conditions of extreme soil disturbance (such as Treatment 4). This recovery in dehydrogenase activity and MIP was particularly unexpected in Treatment 4 where the horizons were reversed and parent material became the topsoil. This operation, on the other hand, could have been responsible for the ultimate dominance of shrubs in this treatment and the poor performance of perennial grasses and forbs. Shrubs, with their deep root system, are more adapted to soils with a coarse structure and precipitation that takes place either out of the growing season or consists of large but infrequent events (Neil and Tueller, 1971). These two conditions were met in the study. The reversed horizons resulted in a new "topsoil" with a very rocky surface. Fifty percent of the rainfall in the Piceance Basin occurs in the winter. The very low level of grass and perennial forb establishment in these plots (Table 1) also could have enhanced the probability of shrub establishment by a reduction in competition. The establishment of shrubs then could have created adequate rhizosphere conditions for microbial and mycorrhizae development. This could explain in part the rapid recovery of dehydrogenase activity and MIP (according to Reeves et al. (1979) the four shrubs in question (Table 1) are mycorrhizal).

Another unexpected result was the fact that enough viable spores of vesicular-arbuscular mycorrhizae were still present to reinfest plants after four years without an adequate host. Recent research by Schmidt and Reeves (1983) advances the proposition that Russian thistle, even though not a mycorrhizal plant, can create conditions around the roots (such as some carbohydrate exudates) to allow the fungi spores to remain viable until an adequate host develops.

In the present experiment dehydrogenase enzyme activity potentials after six years of succession averaged 25.99 μg formazan g^{-1} 24 hr^{-1} while native undisturbed vegetation had values of 19.05 μg formazan g^{-1} 24 hr^{-1} (Klein et al., 1982). This difference was consistent with Titlyanova's (1982) analysis of vegetation succession in the Siberian steppe. She found that the activity of the microbiocenosis was maximized at the intermediate seral stages and declined as vegetation approached climax.

One aspect of the results was in direct contradiction to most of the literature. Organic matter has been widely reported to increase with succession (Bard, 1952; Davidson, 1965; Zedler and Zedler, 1969; Chertov and Razunovskii, 1980; Aweto, 1981; Shavkat et al., 1982). In this experiment, however, a decline in soil organic matter was observed in all treatments (Table 2). The levels of soil organic matter in Treatments 1 and 2 after six years were comparable to the ones observed in the native undisturbed vegetation, 1.12% (Klein et al., 1982). After six years soil organic matter was still below the native vegetation levels, however, in Treatments 3 and 4. A plausible explanation for this result could be a lag in the re-establishment of an equilibrium between inputs and outputs in the carbon cycle. We theorize that the release of CO_2 via the decomposition of organic matter (incorporated in the soil by the disturbance) was higher than the corresponding inputs of new organic matter by the plants. This resulted in a negative balance, and as such, a reduction of soil organic matter occurred through time.

ACKNOWLEDGEMENTS

This study was funded by the United States Department of Energy under Contract No. DE-AC02-76EV04018.

LITERATURE CITED

Alexander, Martin. 1977. Introduction to Soil Microbiology. John Wiley and Sons, New York.

Aweto, A.O. 1981. Secondary succession and soil fertility restoration in southwestern Nigeria: 2. Soil fertility restoration. J. Ecol. 69:609-614.

Bard, G.E. 1952. Secondary succession on the Piedmont of New Jersey. Ecol. Monogr. 22:195-216.

Chertov, O.G. and S.M. Razumovskii. 1980. Ecological trends in soil forming processes. Zh. Obshch. Biol. 41:386-396.

Cundell, A.M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30:299-305.

Davidson, R.L. 1965. An experimental study of succession in the Transvaal Highveld. pp. 113-125 in D.S. Davis, D. DeMeillon, J.S. Harrington, and M. Valk (eds.), Ecological Studies in Southern Africa. W. Junk, The Hague.

Gorham, E., P.M. Vitousek, and W.A. Reiners. 1979. The regulation of chemical budgets over the course of terrestrial ecosystem succession. Rev. Ecol. Syst. 10:53-84.

Hersman, L.E and D.A. Klein. 1979. Evaluation of retorted oil shale effects on the microbiological characteristics of surface soil used in land reclamation and revegetation processes. J. Environ. Qual. 8:524-529.

Klein, D.A., D.L. Sorensen, and W. Metzger. 1982. Soil microorganisms and management of retorted shale reclamation. pp. 27-44 in E.F. Redente and C.W. Cook (eds.), Revegetation Studies on Oil Shale Related Disturbances in Colorado. DOE Research Report No. EV-04018-6, Department of Range Science, Colorado State University, Fort Collins.

Kuprevich, V.F. and T.A. Shcherbakova. 1966. Soil Enzymes (translated from the Russian by the Indian National Scientific Documentation Center, Delhi, for the U.S. Department of Agriculture). National Technical Information Service, Springfield, VA. 392 pp.

Langford, A.N., and K.F. Buell. 1969. Interpretation, identity and stability in the plant association. pp. 83-135 in J.B. Cragg (ed.), Advances in Ecological Research, Vol. 6. Academic Press, New York.

Moorman, T., and F.B. Reeves. 1979. The role of endomycorrhizae in revegetation practices in the semiarid west: II. A bioassay to determine the effect of land disturbance endomycorrhizae populations. Am. J. Bot. 66:14-18.

Niel, E.W., and P.T. Tueller. 1971. Special approaches to studies of competition and succession in shrub communities. pp. 165-171 in Wildland Shrubs, Their Biology and Utilization. Intermt. For. Range Exp. Stn., USDA For. Serv. Gen. Tech. Rept. INT-1, 1972.

Parkinson, D. 1979. Microbes, mycorrhizae and mine spoil. pp. 623-642. M.K. Wali (ed.), Ecology and Coal Resource Development, Vol. 2. Pergamon Press, New York.

Redente, E.F., T.B. Doerr, C.E. Grygiel, and M.E. Biondini. 1984. Vegetation establishment and succession on disturbed soils in northwestern Colorado. Recl. Reveg. Res. 3:153-165.

Reeves, F.B., R. Reinsvold, J. Saboloni, and A. Park. 1982. Importance of mycorrhizal fungi in regulating disturbed soils and retorted shale. pp. 45-65 in E.F. Redente and C.W. Cook (eds.), Revegetation Studies on Oil Shale Related Disturbances in Colorado. DOE Research Rept. No. EV-04018-6. Department of Range Science, Colorado State University, Fort Collins.

Reeves, F.B., D. Wagner, T. Moorman, and J. Kiel. 1979. The role of endomycorrhizae in revegetation practices in the semiarid West: I. A comparison of incidence of mycorrhizae in severely disturbed vs. natural environment. Am. J. Bot. 66:6-13.

Schmidt, S., and F.B. Reeves. 1983 Effect of the non-mycorrhizal plant Salsola kali L. (Chenopodiaceae) on vesicular-arbuscular mycorrhizal (VAM) fungi. Am. J. Bot. 77:1035-1039.

Shavkat, S., S.D. Khan, and J.A. Gadir. 1982. The vegetation dynamics of calcareous hills around Karachi, Pakistan, Pak. J. Bot. 13:17-38.

Skujins, J. 1978. History of abiotic soil enzyme research. pp. 1-49 in R.G. Burns (ed.), Soil Enzymes. Academic Press, London, England

Speir, T.W., and D.J. Ross. 1978. Soil phosphatase and sulfatase. pp. 197-250. in R.G. Burns (ed.), Soil Enzymes. Academic Press, London, England.

St. John, T.V., and D.C. Coleman. 1983. The role of mycorrhizae in plant ecology. Can. J. Bot. 61;1005-1014.

Titlyanova, A.A. 1982. Ecosystem succession and biological turnover. Vegetatio 50:43-51.

Weaver, J.E., and F.E. Clements. 1938. Plant Ecology. McGraw-Hill, New York. 601 pp.

Zedler, J., and P. Zedler. 1969. Association of species and their relationship to microtopography within old fields. Ecology 50:432-442.

RESULTS OF WOODY SPECIES TEST PLOTS ESTABLISHED ON A MINE EXPLORATION SITE IN ALASKA

Stephen G. Long; Cedar Creek Associates, Inc.
Fort Collins, Colorado

Scott L. Ellis; ERT
Fort Collins, Colorado

ABSTRACT

Four species of containerized tree seedlings, and hardwood cuttings of nine shrub and tree species were planted in two types of overburden, and in 18 inches of topsoil over overburden on a coal exploration site near Anchorage, Alaska. After two years, it was found that 98 percent of all tree seedlings survived. Lodgepole pine (Pinus contorta) showed extensive chlorosis symptoms. Balsam poplar (Populus balsamifera) showed the most vigorous growth. After one growing season, 72 percent of the hardwood cuttings survived. Greatest mortality was recorded for species that were partially leafed out at the time cuttings were taken [early blueberry (Vaccinium ovalifolium) and high bushcranberry (Viburnum edule)]. Willow showed greater than 90 percent survival. Seedling and cutting survival was very similar on all the substrates, slope angles, and planting seasons tested. This lack of difference is attributed to the overall favorable growing conditions which were cool and continuously moist. Both of these methods for reestablishing woody species appear suitable for this site.

INTRODUCTION

This paper describes the results of revegetation studies conducted on the site of a proposed surface coal mine in southern Alaska. These studies were initiated to validate the reclamation plan filed with the mine permit application. The following sections outline the specific objectives of these studies and an evaluation of woody cutting and tree seedling survival and growth 1 and 2 years after planting. The conclusions identify the major factors that appear responsible for the observed survival levels.

STUDY AREA

The revegetation study plots are located on the Diamond Shamrock Chuitna Mine project lease area within the Beluga Coal Field. The lease area lies on the north side of Cook Inlet approximately 80 airline miles west of Anchorage. The study site is located at an elevation of 1,300 feet (ft) on a gently sloping plateau that extends outward from the flank of Mount Spurr, a recently active volcano. Upland areas consist of a mantle of loess mixed with volcanic ash which overlies very gravelly, poorly sorted glacial till and weakly consolidated sedimentary beds. These sedimentary beds contain thin beds of sub-bituminous coal.

The climate at the site is transitional between maritime and continental. Heavy snow fall occurs from November through March;

rainfall maximums occur in September and October. Rainfall minimums occur in May and June. Average annual precipitation is approximately 40 inches and the average annual air temperature is 36 degrees.

The vegetation communities consist of a white spruce-paper birch woodland on upland sites, thin-leaf alder thickets on steep moist slopes, and willows and marshlands along stream drainages. Moose, and black and brown bear are important large mammals that occupy these habitats. Several salmon species spawn in the small streams that drain the lease area.

STUDY OBJECTIVES

Alaska mining regulations (Alaska Division of Mining) and fish and wildlife management agencies (Alaska Department of Fish and Game) suggest that long term revegetation goals should be to reestablish wildlife habitat at least as useful and productive as the premining environment. To obtain site-specific information on methods and plant materials suitable for achieving this goal, a revegetation field study was designed to answer the following research questions.

- Can woody wildlife browse species be established on mine disturbances using on-site hardwood cuttings as a source?
- Can containerized tree seedlings be established on mine disturbances?
- What is the relative survival and growth of cuttings and seedlings on topsoil replaced over overburden as compared to overburden alone?
- What is the relative survival and growth of hardwood cuttings on sites with relatively high soil moisture (drainageways) as compared to elevated, drier sites?
- What is the relative survival and growth of tree seedlings planted during different seasons (spring and fall), on different overburden substrates, and on different slope angles?

STUDY DESIGN

Mining at the proposed Diamond Chuitna mine will be conducted in two primary coal seams. The upper of these is designated the "Red" seam while the lower is named the "Blue" seam. Diamond Shamrock's test mining program has exposed both seams where they outcrop along the upper slopes of a small valley.

Plot blocks to test tree seedling survival and growth were constructed of excavated Blue overburden, excavated Red overburden, and of excavated Red overburden covered with 18 inches of endemic topsoil. Plot blocks constructed on excavated Blue and Red overburden consisted of a 3H:1V sloping plot block and a level plot block. These plot blocks were designated "Blue 3H:1V" "Blue Level", "Red 3H:1V", and "Red Level".

One level plot block, designated "Topsoil Level", was constructed on the excavated Red overburden covered with topsoil test site.

Two test plots were constructed for each of the overburden material types and the Red overburden/topsoil combination to test tree and shrub cutting survival and growth. Each set of test plots consisted of one plot constructed adjacent to the level tree plot block (upland position) and one plot constructed in a drainage way (lowland position). These plots were named according to the seedbed material in which planting took place and the landscape position (e.g., Blue Level Cutting-Dry, Topsoil Level Cutting-Wet, etc.).

An explanation of study variables incorporated into this test plot design is provided below.

Seedbed Material

Table 1 presents a summary of key physical and chemical characteristics of the overburden and topsoil seedbed materials from samples collected in 1985 following a summer fertilization. The primary difference between Red and Blue seam overburden is the much higher sand content of the Blue material. The Red overburden plots showed elevated levels of manganese and cadmium. The topsoil showed elevated levels of cadmium. The Red overburden plot showed much higher levels of total nitrogen. This is the result of high levels of ammonia (NH_4), possibly a consequence of fertilization. Topsoil shows much higher organic matter levels as would be expected. There is little difference in pH levels among test plot materials. This is noticeably different from "background" conditions where topsoil normally exhibits much lower (3.5 to 4.0) pH levels.

Slope

A wide range of slopes would likely result from grading during revegetation. Therefore, study plots were constructed on level and 3H:1V slopes for each of the two overburden types. It was not possible to construct level plots during the fall 1983 planting season because of adverse site conditions. No 3H:1V topsoil/overburden plots were constructed because of insufficient space. Tree seedlings were planted on both 3H:1V and level plot blocks to test the effects of slope. No cuttings were planted due to space limitations.

Season

A major study objective was to determine whether a fall planting season for tree seedlings is feasible in this part of Alaska. Though both a spring and fall planting season are recognized, it is generally thought that spring planting will result in the highest survival rates. Tree seedlings were planted on the excavated Red and Blue overburden plot blocks in September 1983 and June 1984 to test the affect of planting season.

Seedbed Moisture Content

The range in seedbed moisture adaptation is not well documented for the nine species of hardwood cuttings considered for revegetation testing. Therefore, two plots representing upland (dry) and lowland

TABLE 1

PHYSICAL AND CHEMICAL CHARACTERISTICS OF OVERBURDEN AND TOPSOIL USED
TO CONSTRUCT DIAMOND CHUITNA REVEGETATION STUDY PLOTS
(FALL 1985 - FOLLOWING A SUMMER FERTILIZATION)

Substrate	Sample Depth (in)	pH	Total N (ppm)	P (ppm)	K (ppm)	% Sand	% Silt	% Clay	% Organic Matter	Suspect Levels of Metal ions
Red Overburden	0-6	5.58	43.1	24.1	118	45.2	30.2	24.6	4.71	Mn (45.88 mg/g); Cd (1.4 ppm)
Red Overburden	6-18	5.62	10.0	10.5	79	46.2	29.8	24.0	5.24	Mn (49.88 mg/g); Cd (1.38 ppm)
Blue Overburden	0-6	5.84	9.3	24.3	54	79.2	12.8	8.0	2.59	None
Blue Overburden	6-18	5.94	5.9	18.9	42	77.2	14.8	8.0	1.73	None
Topsoil	0-6	5.43	14.0	6.1	71	47.2	37.8	15.0	8.63	Cd (1.58 ppm)
Topsoil	6-18	5.62	2.1	2.9	69	40.4	41.6	18.0	9.62	Cd (1.07 ppm)

(wet) seedbed moisture conditions were established for the Red and Blue excavated overburden materials as well as the Red overburden/topsoil combination. Cuttings only were planted in these plots. The "dry" plots were subject to moisture accumulation from rainfall only. The "wet" plots received moisture from rainfall and runoff from surrounding areas resulting in very moist to saturated seedbed conditions throughout the growing season.

Species

Four species of containerized tree seedlings were provided by the Alaska Forest Service for the purposes of this study. Hardwood cuttings of 9 species were collected in the vicinity of the test plots during the late spring of 1985. Table 2 lists the species of seedlings and cuttings used for testing in this study. All species occur within the study area or were recommended for testing due to growth requirements and characteristics.

TABLE 2

SEEDLING AND CUTTING SPECIES PLANTED

Tree Seedlings

- white spruce (*Picea glauca*)
- lodgepole pine (*Pinus contorta*)
- paper birch (*Betula papyrifera*)
- balsam poplar (*Populus balsamifera*)

Tree and Shrub Cuttings

- feltleaf willow (*Salix alaxensis*)
- grayleaf willow (*Salix glauca*)
- diamondleaf willow (*Salix planifolia*)
- tall blueberry willow (*Salix novae - angliae*)
- low blueberry willow (*Salix myrtilifolia*)
- Barclay willow (*Salix barclayi*)
- balsam poplar (*Populus balsamifera*)
- early blueberry (*Vaccinium ovalifolium*)
- high bushcranberry (*Viburnum edule*)

MATERIALS AND METHODS

Tree Planting

Ten tree seedlings of four tree species (Table 2) each were planted during the fall of 1983 and spring of 1984 on the Blue 3H:1V and Red 3H:1V plot blocks. Ten tree seedlings of the four tree species each were planted on the Blue Level, Red Level, and Topsoil Level plot blocks during the spring of 1984. All seedlings were 1/0 stock. Each tree seedling was planted by hand in prepared holes within the plots. The hole for each seedling was dug large enough to accommodate the root mass without bending. After placing the seedling in the hole, the hole was backfilled and the backfill tamped to provide support for the seedling. The planting was then watered to eliminate air spaces in the backfill. (Watering was eliminated when the backfill material was at or near saturation). A small depression was formed around the base of each seedling to aid in moisture concentration and the depression was mulched with wood chips. Fertilization and seedbed preparation for tree planting sites occurred during fertilization and seedbed preparation of adjacent herbaceous plots. Fertilizer was applied in amounts concurrent with recommendations resultant from seedbed material sample analysis and worked into the soil by raking. A supplemental application of fertilizer was applied in the summer of 1985. Seedbed preparation consisted of cultivation with shovels followed by raking. The area to which seedlings were planted was broadcast seeded to a native grass and forb seed mixture. Seeding of the tree planting sites was completed for the purposes of surface stabilization and to provide competition to tree seedlings similar to that potentially occurring under reclamation conditions.

Tree Seedling Survival and Growth Monitoring

For both spring and fall plantings, mortality determinations were made. Notes were also taken regarding chlorosis, apparent stress, fungi or insect damage, or mechanical injury. Annual new growth was measured in cm for each species as follows.

Pinus contorta - The longest basal side-shoot was measured and the number of side shoots recorded.

Picea glauca - New growth was measured at the apex of the stem. (New growth was separated from old growth on the basis of stem color and texture.)

Betula papyrifera - The longest new-growth branch was measured and the length recorded. (New growth originates from the previous year's ringed node).

Populus balsamifera - The longest new-growth branch was measured and the length recorded. (New growth was identified by deep red stem coloration).

Tree and Shrub Cutting Planting

Cuttings were planted on the level Red and Blue overburden plots, and the Red overburden topsoil plot. Cuttings were planted in two microtopographic sites within each plot block as previously noted.

Plot preparation was completed for all cutting plots in the following manner. The plot site was located and plot boundaries staked. The seedbed was prepared for cutting planting. The Red Level Cutting-Dry and Topsoil Level Cutting-Dry plot seedbeds were prepared with shovels. The Cutting-Wet plots for these seedbed material types were prepared with cultivators due to excessive seedbed wetness. The Blue pit plots were prepared with a pick due to compaction. The plots were then fertilized. With the exception of the Red Level Cutting-Wet plot, which would not have benefited from raking due to seedbed material saturation, all cutting plots were raked to incorporate the fertilizer into the seecbed. Cuttings were then planted.

Cuttings were taken from species stands in the immediate vicinity of the test pits. One- and two-year old wood was used for all cuttings with the exception of Salix alaxensis horizontal plantings. All proximal cuts were made immediately below a node. Side branches and approximately 75 percent of the leaf mass were trimmed from the cutting. The portion of the cutting to be planted below the soil surface was dusted with "Rootone" (IBA). The cutting was planted vertically to a depth three quarters of the cutting length. Efforts were made to collect cuttings from as many different parent plants as possible. Ten individuals of each species were planted in each plot.

Wood used for Salix alaxensis "horizontal" plantings was primarily one- and two-year old wood though somewhat older materials were occasionally included if such wood was healthy and viable. To complete these plantings, a shallow 10-foot long trench was excavated in the plot. Cuttings dusted with "Rootone" were laid end-to-end along the bottom of the trench and the trench was backfilled. The surface of the backfill was then firmed by walking over the trench. Cuttings were buried, on the average, within approximately one inch of the spoil/soil surface.

Photos documenting the condition of each cutting plot were taken following planting.

Tree and Shrub Cutting Survival and Growth Monitoring

The height of each surviving cutting was measured during the data collection field trip conducted in August and September of 1985. Measurement in cm was made in a line plumb from the greatest height of the cutting to the soil surface. An estimate of cutting stress was made by examining the condition of leaves and noting evidence of die-back.

Success of the Salix alaxensis horizontal plantings was determined by counting the number of individual shoots breaking the seedbed surface along each 10-foot buried planting.

RESULTS

1984 Tree Seedling Measurements

Tree seedlings planted during the fall 1983 and spring 1984 planting seasons showed a very high survival rate of 99 percent when measured during the fall of 1984. Of the 280 seedlings planted, only one seedling each of Populus balsamifera (mechanical damage), Picea glauca and Pinus contorta were lost. All Betula papyrifera seedlings survived. Both conifer seedling mortalities occurred in the Red 3H:1V fall planting.

TABLE 3

TREE SEEDLING SURVIVAL DATA (1985)

Plot Designation/ Species	Number Planted	Number Surviving	New Growth 1985 (cm)	Number Exhibiting Chlorosis (C) Slight Chlorosis (SC), Stress (S), Slight Stress (SS)	Remarks
Blue 3H:1V (Spring)					
Populus balsamifera	10	9	6.1		1 lost in minor slump
Betula papyrifera	10	10	4.7	1-S, 8-SS, 1-SC	
Picea glauca	10	10	5.8	5-C, 2-SC	
Pinus contorta	10	10	3.4	1-SS, 8-SC	
Blue 3H:1V (Fall)					
P. balsamifera	10	8	16.1		1 lost in minor slump; 1 lost to mechanical damage (1984)
B. papyrifera	10	10	3.6	2-S, 1-SC	
P. glauca	10	10	4.4	2-C, 4-SC	
P. contorta	10	9	3.0	4-C, 3-SC	
Blue Level #2 (Spring)					
P. balsamifera	10	10	6.8	2-SS	
B. papyrifera	10	10	14.7	1-S, 3-SS	
P. glauca	10	10	7.1	5-SC	
P. contorta	10	10	5.3	6-SC	
Red 3H:1V (Spring)					
P. balsamifera	10	10	12.8		
B. papyrifera	10	10	6.0	4-C, 4-SC	
P. glauca	10	10	6.4		
P. contorta	10	10	1.8	2-C, 7-SC	
Red 3H:1V (Fall)					
P. balsamifera	10	10	11.6	5-SS, 1-SC	
B. papyrifera	10	10	5.8	3-S, 1-SS, 2-SC	
P. glauca	10	9	5.4	1-C, 1-SC	1 lost to mechanical damage
P. contorta	10	9	4.4	4-C, 2-SC	
Red Level #2 (Spring)					
P. balsamifera	10	10	11.3		
B. papyrifera	10	10	7.2		
P. glauca	10	10	9.6		
P. contorta	10	10	2.7	2-S, 7-C, 1-SC	
Topsoil Level (Spring)					
P. balsamifera	10	10	12.4		
B. papyrifera	10	10	6.0	1-S, 5-SS, 1-SC	
P. glauca	10	10	7.7	1-SC	
P. contorta	10	10	2.7	5-C, 2-SC	
TOTAL	280	274 (98%)	NA	10(4%)-S, 25(9%)-SS, 34(12%)-C, 52(19%)-SC	

Chlorosis and stress affected a number of seedlings. Forty-nine (18 percent) seedlings exhibited chlorosis. Of this number, P. glauca, P. contorta, and B. papyrifera accounted for 18, 17 and 14 affected seedlings, respectively. No seedlings of P. balsamifera exhibited this condition. Additionally, nine (3 percent) P. contorta seedlings showed slight chlorosis. Deciduous species showed greater signs of plant stress than coniferous species where stress was noted. Overall, 25 seedlings exhibited apparent stress. P. balsamifera and P. glauca accounted for 21 and 4 affected seedlings, respectively.

1985 Tree Seedling Measurements

Tree seedlings planted in 1983 and 1984 showed a survival rate of 98 percent when measured in 1985 (Table 3). Discounting losses to mechanical damage, only one Pinus contorta seedling failed to survive through the second growing season. Fewer numbers of seedlings were observed in 1985 to be fully stressed or chlorotic although greater numbers of seedlings were slightly stressed or chlorotic than in 1984.

Populus balsamifera was least affected by stress or chlorosis and had the highest average new growth of all seedlings planted. This species appears to perform least well on the Red spoil seedbed material.

B. papyrifera had the second highest new growth average at 6.9 cm. Though a majority of seedlings appeared stressed or chlorotic, over two-thirds of these affected seedlings were in the slightly stressed or slightly chlorotic category. There was no correlation between affected seedlings and any test treatment. Greatest growth occurred on the Blue spoil seedbed material.

Of the two conifer species planted, Picea glauca appeared to be the most vigorous. The majority of chlorotic seedlings occurred in Blue spoil plantings. Average annual new growth was comparable to that of B. papyrifera at 6.6 cm. This species appears to do best on the Red spoil seedbed material and under a spring planting regime.

Pinus contorta appears to be the least vigorous of all species planted. Approximately 79 percent of the planted seedlings were affected by some level of stress or chlorosis when measured in 1985. Vigor does not appear to be correlated with any particular test treatment. This species had the lowest average annual new growth (3.3 cm) of all species planted. Greatest growth was attained on the Blue Level plot.

In terms of seedling response to seedbed materials, there was no preference with regard to seedling survival rate. The Red spoil material had the fewest number of seedlings affected by any level of stress or chlorosis. In 1984, Red spoil had the highest number of stressed and chlorotic seedlings. Seedlings on Blue spoil material had the highest average new growth, followed by topsoil and Red spoil materials which did not differ appreciably. A slight preference for the Red spoil material by seedlings is indicated but the extent to which this preference affects seedling growth and vigor is minimal.

With respect to planting seasons, the 1985 data show few growth differences between spring or fall planting seasons. Two P. contorta seedlings under a fall planting regime failed to survive through the second growing season. All spring-planted seedlings survived. Considering stress and chlorosis, fall-planted seedlings were somewhat more vigorous than spring-planted seedlings, although greater numbers of fully stressed or chlorotic seedlings occurred on fall plots. Differences between planting seasons, in terms of average new growth, were minimal. Average new growth means calculated over all species ranged from 5.0 cm to 6.8 cm.

Slope did appear to affect seedling vigor following the second growing season. Greater numbers of seedlings were affected by some level of stress or chlorosis on 3H:1V slopes than on level plots. These data generally agree with results of the 1984 data analysis. New growth means computed over all species in 1985 indicated a preference for level slopes. The response to slope differences was most noticeable on Blue spoil comparisons whereas slope differences affected new growth to a minor degree on Red Spoil.

1985 Shrub and Tree Cutting Measurements

Of 540 cuttings planted, 391 (72 percent) survived the first growing season indicating that this revegetation technique has good potential for use at the proposed mine site (Table 4). Thirty percent of the surviving cuttings suffered from some level of stress.

With respect to seedbed material comparisons, some preference was shown for spoil materials though differences in survival rates were modest. The topsoil seedbed material had noticeably higher numbers of stressed cuttings.

Comparatively higher success rates were found to be associated with more abundant moisture conditions. Differences in numbers of stressed or slightly stressed cuttings between moisture conditions were negligible. These results indicate that the potential of this revegetation technique can be maximized on disturbed lands with provisions for moisture enhancement or accumulation.

Individual species showed a wide range of adaptability to this revegetation technique. Those species showing the lowest survival rates and generally the lowest plant vigor include Vaccinium ovalifolium, Viburnum edule, and Populus balsamifera. The poor showing of these species may be the result of collecting cuttings too late in the spring. Each of these species was relatively advanced phenologically and some cuttings were in flower. Normally, cuttings taken this late in the season are not well suited to planting. It is assumed that late collection was the cause, at least in part, of the low survival rates and seedling vigor of these species. The majority of the survivors of these three species were found on wet plots indicating that the survival rate of late-collected cuttings might be enhanced by planting in areas with abundant moisture.

TABLE 4

CUTTING SURVIVAL DATA AFTER ONE GROWING SEASON ON
DIAMOND CHUITNA REVEGETATION PLOTS

Plot Designation/Species	Number Planted	Number Surviving	Number Exhibiting Stress (S) Slight Stress (SS)	Remarks
Blue Level Cutting-Dry				
Salix alaxensis	10	8		
Populus balsamifera	10	5	1-SS,1-S	
Salix planifolia	10	7	1-SS	
Salix glauca	10	10		
Salix barclayi	10	10	1-SS, 1-S	
Salix novae-angliae	10	10	2-SS	
Vaccinium ovalifolium	10	3	3-S	1 lost to mechanical damage
Salix myrtilifolia	10	9	1-SS	
Viburnum edule	10	2	2-S	
Blue Level Cutting - Wet				
S. alaxensis	10	10		
P. balsamifera	10	4	1-SS, 3-S	
S. planifolia	10	9		
S. glauca	10	10	2-SS	
S. barclayi	10	10	3-SS, 2-S	
S. novae-angliae	10	10	2-S	
V. ovalifolium	10	3	1-SS, 2-S	
S. myrtilifolia	10	9		
V. edule	10	6	4-S	
Red Level Cutting - Dry				
S. alaxensis	10	0		
P. balsamifera	10	7	2-SS, 4-S	
S. planifolia	10	9	2-SS, 3-S	
S. glauca	10	8		
S. barclayi	10	10		
S. novae-angliae	10	9	4-SS, 1-S	
V. ovalifolium	10	0		
S. myrtilifolia	10	9		
V. edule	10	6	6-S	
Red Level Cutting - Wet				
S. alaxensis	10	7		
P. balsamifera	10	8	1-S	1 lost to mechanical damage
S. planifolia	10	10		
S. glauca	10	10		
S. barclayi	10	10	4-SS, 1-S	
S. novae-angliae	10	9	3-SS, 1-S	
V. ovalifolium	10	4	3-S	2 lost to mechanical damage
S. myrtilifolia	10	10	1-S	
V. edule	10	5	2-S	
Topsoil Level Cutting - Dry				
S. alaxensis	10	5	1-S	
P. balsamifera	10	2		
S. planifolia	10	10	5-S	
S. glauca	10	10		
S. barclayi	10	7	1-SS, 1-S	
S. novae-angliae	10	8	3-S	
V. ovalifolium	10	0		
S. myrtilifolia	10	8	5-S	
V. edule	10	1		
Topsoil Level Cutting - Wet				
S. alaxensis	10	9	1-S	
P. balsamifera	10	6	1-SS, 3-S	
S. planifolia	10	10	5-SS, 1-S	
S. glauca	10	10	1-SS, 1-S	
S. barclayi	10	10	3-S	
S. novae-angliae	10	10	5-SS	
V. ovalifolium	10	7	7-S	
S. myrtilifolia	10	10	1-SS, 1-S	
V. edule	10	2		
TOTAL	540	391 (72%)	43 (11%)-SS, 75 (19%)-S	

Salix alaxensis, also adversely affected by a late cutting season, showed a modest (65 percent) survival rate. Surviving cuttings were very vigorous. This species did best on wet plots and on the Blue spoil and topsoil seedbed materials.

The remaining five cutting species showed high survival rates ranging from 92 to 97 percent. Though some seedbed material or moisture regime preferences are indicated for maximum results, these species show a wide adaptability to potential environmental conditions. None of these highly successful species were phenologically advanced at the time cuttings were collected further supporting the premise of the need for proper cutting collection timing.

Salix planifolia (92 percent survival) appears to be slightly better adapted to wet cutting plots. S. barclayi, (95 percent survival) conversely, exhibited a minor preference for drier test plots. Survival rate and, to a great degree, vigor of S. myrtilifolia (92 percent survival), S. novae-angliae (93 percent survival) and S. glauca (97 percent survival) did not appear to be influenced by either seedbed material or moisture regime.

The results of the horizontal plantings of S. alaxensis were disappointing (Table 5). It was believed this species would respond well to this type of planting. The greatest success was recorded on Blue spoil where shoots were produced on both wet and dry plots. The topsoil-wet plot was the only other plot to produce any shoots. The reasons for these results are unclear though planting methodology and cutting stock age may have contributed to the less-than-expected number of shoots. It is believed that this technique has potential for revegetation at the proposed mine site and should be further tested under actual revegetation conditions.

TABLE 5

SHOOTS DEVELOPED FROM 10 FT HORIZONTAL SALIX ALAXENSIS PLANTINGS ON DIAMOND CHUITNA REVEGETATION PLOTS

Plot Designation	Number of Shoots
Blue Level Cutting - Dry	22
Blue Level Cutting - Wet	12
Red Level Cutting - Dry	0
Red Level Cutting - Wet	0
Topsoil Level Cutting - Dry	0
Topsoil Level Cutting - Wet	10

DISCUSSION

The preliminary results (2 years) of this study indicate that the performance of the species tested is generally consistent with that obtained by other Alaskan researchers. Willows root very readily under a variety of conditions, making them useful as a source of rooted cuttings that can be grown in the nursery and then outplanted, or as hardwood, unrooted cuttings that can be planted on surface mine disturbances (Holloway and Zasada 1979; Miller et al. 1983; Zasada, Holloway, and Densmore 1978; Densmore and Zasada 1978). Tests with balsam poplar indicate that this species can be successfully propagated with both hardwood and softwood cuttings (Holloway and Zasada 1978, Miller et al. 1978). Other researchers have had moderate to excellent success in rooting highbush cranberry and limited success with rooting hardwood and softwood cuttings of blueberry (Vaccinium uliginosum) (Holloway and Zasada 1979).

Based on these results, a very high rate of survival can be expected from seedlings and rooted cuttings that are containerized prior to transplanting. On-site hardwood cuttings also show promise. The relatively continuous cool, cloudy conditions near Cook Inlet greatly reduces the evapotranspiration rates and consequently reduces the moisture stress on hardwood cuttings. Continuously wet soil moisture conditons appear to enhance survival, but are not essential for adequate survival under these site conditions.

All tree species tested with the exception of lodgepole pine appear well adapted to the Diamond Chuitna lease area conditions. The high level of chlorosis observed in lodgepole suggest that nutrient stress may limit the vigor of this species. Rapid leaching of nutrients from the well-drained substrates used in this study, as well as the absence of a mycorhizal associate for the pine may be factors that affect lodgepole pine growth.

CONCLUSIONS

- Very high rates (98 percent, 1 to 2 years) of tree seedling survival were observed during this study. This survival is attributed to the cool, moist site conditions prevalent throughout the growing season. Lodgepole pine appears least adapted to site conditions.

- Relatively high rates (72 percent) of hardwood cutting survival were also observed. Mortality was observed primarily in species that were leafing out at the time cuttings were taken (highbush cranberry, early blueberry, balsam poplar). On-site willow species showed greater than 90 percent survival, with the exception of feltleaf willow, which was leafed out at the time cuttings were taken.

- Cuttings must be taken prior to species leafing-out or breaking buds to attain the highest survival rates.

- There was very little differential survival or growth response to the different seedbed material, slope, and season of planting treatments applied. The favorable growing conditions and high levels of soil moisture throughout the growing season appear to limit the relative effects of the variables tested.

- Higher seedbed moisture conditions enhance the survival of tree and shrub cuttings.

- Seedling and cutting planting utilizing the species tested shows promise for revegetating the proposed mine site or other disturbed areas with similar site characteristics.

LITERATURE CITED

Densmore, R. and J. C. Zasada. 1978. Rooting potential of Alaskan willow cuttings. Canadian Journal of Forestry Research. 8:477-479.

Holloway, P. and J. Zasada. 1979. Vegetative propagation of 11 common Alaskan woody materials. PNW-334. U.S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Portland, OR. 12 pp.

Miller, C. R., R. Parkerson, J. Zasada, A. Epps, and J. A. Smith. (Eds) 1983. A revegetative guide for Alaska. Cooperative Extension Service. University of Alaska. Anchorage, AK. 88 p.

Zasada, J. C., P. Holloway, and R. Densmore. 1978. Consideration for the use of hardwood stem cuttings in surface management programs. Pp 148-157. In Evans, M.N. (Eds.). Proceedings of the Symposium on Surface Protection through Prevention of Damage (Surface Management). Anchorage: Bureau of Land Management. 296 pp.

ACKNOWLEDGEMENTS

The authors wish to thank the management and staff of the Diamond Alaska Coal Company for their continued support of and interest in advancements in reclamation technology.

CONSTRUCTING SKI TERRAIN IN COLORADO IN THE 1980'S

JIM GREGG
U.S. Forest Service
Dillon, Colorado

Ski terrain development has evolved from minor tree clearing to major alteration of mountains. With this change refinements in construction methods and rehabilitation approaches have occured. This paper will briefly highlight some of the concepts being used on ski trails in Colorado in the 1980's.

Factors which make ski terrain construction different in the 80's are:

- Financing is hard to come by. Decisions on "go" or "no go" are often on short notice from large parent companies. Turn around time for the investment must be as soon as possible leading to the "fast track" approach.

- Much of the ideal natural ski terrain has already been developed in our state. "Ideal" means close to population centers and base areas, natural snowfall, northerly aspect,and terrain which appeals to the majority of skiers. New technology however, has shed a different light on just what might be skiable. High speed, high capacity lifts can move skiers to more isolated terrain. Snowmaking can make southfacing slopes skiable. New developments in construction equipment has allowed areas to be worked which previously were avoided.

- Exposure to liability problems due to alteration of the natural environment must be considered in all construction.

- In order to remain competetive in the marketplace, ski areas like to offer something newer, bigger, or better each year. Cost per acre is not always looked at as much as the effect of the total project.

- Successful high altitude revegetation techniques have made it possible to work more terrain.

These factors produce additional challenges in the land management rehabilitation fields. The areas briefly addressed herein can guide planning and construction processes so a minimum impact on the land will occur and reasonable dollar amounts can be spent to produce the desired product.

WATER MANAGEMENT

Water Management on ski slopes is far more critical in the 1980's than in the past. Degragation of the water quality due to ski terrain construction is unacceptable. This is supported by numerous regulations at the Federal, state, and many times, local level. In addition, the skiing customer demands a perfect snow surface, free of icy spots. In the past, the ideal solution was to avoid all wet areas in laying out ski terrain. Today, crossing through, or into wet areas may be necessary to open up more skiable terrain.

Hydrological Assessment

Prior to opening up expansion areas or doing major work on an existing ski mountain a hydrological assessment can give the area planner the total picture of what water problems might be encountered. The assessment gives a prcatical on-the-ground orientation to:

- Reducing peak flows and channel damage.
- Reducing mass wasting.
- Minimimzing surface erosion.
- Maintaining existing environmental flows.

The following outlines a possible formula for a ski area Hydrological Assessment.

A. Delineate subdrainages greater than 400 acres.

   1. Compute areas and percent vegetated with timber overstory.

B. Map all surface water channels (any channel clear of vegetation for 40 out of 50 feet) including culvert runouts, trail rills, etc.

   1. Denote natural channels vs. new channels, waterbars, ditches.
   2. Channel confluences; show cross-section, gradient, integrity index, stable vs. unstable.
   3. Locate and map all culverts.
      a. Size, type, functional rating

C. Complete overview analysis of areas using on-ground review (sample) and aerial photo interpretation.

D. Denote subsurface systems.

   1. Potable water systems.
   2. Snowmaking systems.
   3. Sewage and wastewater systems.
   4. French drains, other subsurface drains.

Information may be available from existing documents. Information must include current use (gpm, cfs, acre/ft, etc), potential capacities (developable), and design capacities of existing and proposed systems.

E. Wetland Inventory

   1. Map all areas to meet Executive Order 11990, and Army Corp of engineer criteria for 404 permit determination. Include mapping of all spring type water sources.

F. Data Inventory

   1. List all data sources which could support hydrological analysis of proposed developments. General data sources include: snowfall records, meterological records and snowmaking records, specific cumulative impacts, fisheries, etc.

2. Develop summary statistics, extreme values, annual mean, duration of record.

G. Map and list all existing water rights, ownership, use agreement, diversions, augmentation plans which have been approved or currently proposed. Include maintenance routine done throughout the year on existing development.

H. Locate and map all recent, unvegetated slide areas greater than 5 cubic yards.

Based on the information provided by the assessment, opportunities and impacts relating to water management can be evaluated in light of the development objectives. This information when considered with geology and soils limitations can give insight on anticipated impacts, risks and costs. The hydrologic assessment provides a basic guideline as to how to approach the next phases of construction.

<u>Pre-Construction Erosion Control</u>

To take on any project in this day and age without a pre-construction erosion control plan is taking on unnecessary risk and exposure. With the information gained from the hydrological assessment, a strategy for erosion control prior to construction can be developed. The Erosion Control Plan should be a site specific/station by station accounting of erosion control measures. A blanket statement that erosion control will be carried out is no plan at all. Specific teams or individuals need to be assigned to the erosion control program. These individuals or teams also need to be able to react when a sudden storm or mishap occurs. The following is a Pre-Construction Erosion Control Checklist which can be used in various projects typically encountered in ski area construction.

PRE-CONSTRUCTION EROSION CONTROL CHECKLIST

		CONSTRUCTION OPERATION											
		1. Tree Removal	2. Culvert Installation	3. Snowmaking	4. Building Construction	5. Temporary Road	6. Permanent Road	7. Stump Removal	8. Terrain Enhancement	9. Contour Grading	10. Lift Construction	11. Parking Lots	12. Utility Installation
CONTROL MEASURES PRIOR TO OR CONCURRENT WITH CONSTRUCTION	A. SEDIMENT BASINS												
	B. SAND BAGS												
	C. HAY CHECK DAMS												
	D. TEMPORARY CONCRETE BARRIERS												
	E. FILTER BARRIERS												
	F. TEMPORARY DIVERSION DIKES/DITCHES												
	G. BERMS												
	H. SLOPE DRAINS												
	I. VEGETATIVE BUFFERS												
	J. PLASTIC RUNDOWNS												
	K. RIP-RAP												
	L. CHEMICAL TREATMENT												
	M. TRASH PUMPS AND HOSES												

Active Drainages and Ski Terrain

Ski terrain that would avoid any major drainages or the small year-round stream would be ideal. The intensity of ski developments today ,however, often involve dealing with active streams, whether it be upgrading old existing runs to handle more skiers or expanding into new country.

The culvert option poses the greatest risk and initially is the most expensive. Some of the unique problems relating to culverts on ski terrain are as follows:

Sizing - Culverts should carry the 20 year flood with no headwater and the 50 year flood with maximum allowable headwater. For design discharge, formulas which consider only one factor should not be used without verification by one or more other methods. Suggested methods are: Soil Conservation Service method, local flood frequency curves, or U.S. Forest Service records. Realize that the cutting of new ski terrain, slope grooming changes, and snowmaking can effect flow figures. Multible runs of culverts should be sized large enough to allow cleanout (30 inches or more diameter). Culvert sizing should be such as to allow for freezing, especially where gradiants are under 5%. The following sources give basic guidelines for discharge design and sizing.

Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular No. 5, December 1965, Hydraulics Branch, Bridge Division, Office of Engineering, Federal Highway Commission, Washington, DC 20590. This document contains charts and information for properly sizing culverts, based on the design discharge (from hydrologic analyses), culvert slope, allowable headwater, culvert length, etc. The sizing information pertains to any type of culvert installation, not just roads/highways. It is a national standard used or referenced by most state and federal agencies.

A Guide to Hydrologic Analysis Using SCS Methods, Richard H. McCuen, Prentice-Hall, 1982. Simplified versions of Soil Conservation Service hydrologic analyses methods, particularly methods TR-55 and TR-20. Gives basic complex methods in Soil Conservation Service National Engineering Handbook 4.

Installation - All installation should be under the direction of a design engineer or other suitably qualified persons. The American Association of State Highway and Transportation Officials (AASHTO) sets structural, materal, and construction standards. Variations for ski terrain culverts which have long runs and no vehicular cross-over should be evaluated by a qualified engineer or designer.

Intake Design - Due to the fact intake failure cannot be monitored as close as on traveled roadways, secure intake design is a must. Trash collectors may be important, especially if recent disturbance has taken place above. Trash collectors should be located upstream from the actual culvert intake.

Backup or overflow systems may be appropriate where failure risks with culverts exist.

Half culverting or ski arch can involve minor rerouting but is usually simple to install. Early season use with half culvert is usually less in that more snow is needed to cover the culvert. Subsurface or "French" drains with filter fabric are also an available technique to handle sub-surface water problems. Effective subsurface drainage should have gradiants of 10% or more.

VEGETATIVE MANAGEMENT

When skiing began in Colorado, trees on a ski mountain were more or less obsticles that needed to be removed to produce the ski trail. Then it was realized that trees actually added an aestethic dimension to the skiing experience. The cutting patterns could also be varied in such a way to allow the ski runs on a mountainside to have a softer impact as viewed from nearby valleys. Finally, in the 1980's it has also been realized that trees, along with all other types of vegetation, hold a key to the long term viability of a ski mountain. Vegetation Management on ski areas can provide information on initial ski terrain layout and design plus, through management of the remaining stands, influence snow retention, tree wind firmness, insect and disease resistence, and fuels management.

Initial Terrain Layout

Along with the other basic resource inventories, information on the trees and other vegetation is important in locating new terrain. The type of tree stand should influence the style of cutting and the resulting ski experience. The objective in designing of ski terrain is to create a quality skiing experience in a natural appearing forest mosaic. Design, considering the tree stands, can often influence skier traffic flow and aid in skier ability level segregation.

Managing Vegetation After Ski Terrain Construction

Maintaining existing or remaining stands on a ski mountain involves special silvicultural treatments, especially adopted to the ski setting. Some examples involving unique vegetative treatments on ski terrain are as follws:

- Regeneration cuts that maintain stand fragment integrity, i.e. small patchcuts and non-uniform shelterwood.
- Use of snags to protect pockets of regeneration from skier traffic.
- Maintaining stocking levels to discourage ski traffic into avalanche or cliff areas.
- Using windfirm trees as windbreaks and visual screens for lifts, trails, and facilities.
- Trees can be used to influence rate and timing of runoff.
- Visibility for skiers on stormy days can be improved by special tree management considerations.
- Avalanche areas can be influenced by vegetation management to anchor the snowpack.

Other factors involving vegation management on ski terrain that are not normally encountered in regular forest setting are access, cost effiecency and marketability, and terrain restrictions. Refinements in management approaches to improve vegetation management on ski terrain should be oriented to timely on-the-ground accomplishment. Although full detail information regarding habitat typing, stand entry dates, and regeneration stocking is ideal, much can be accomplished through the application of basic sound silvicultural principles dictated by the management of the skiing experience.

CONSTRUCTING SKI TERRAIN

Demand for skiing is intense. Ski areas want to open early on little snow or manmade snow. This requires a smooth ballroom surface.

Throughout the season, increased skier numbers cause ski wear in areas necessatating further summer season terrain modifications. Ski terrain with sharp breakovers or steeper pitches is not the answer on a main ski artery which serves skiers of all ability levels.

Ski terrain construction, beyond that of flush cutting trees, can be described in three general categories.

Stump Removal

Having stumps removed from ski terrain improves groomability and early season skiing. Popping stumps ideally with a tilt type blade minimizes the amount of earth disturbed. Most of the disturbance comes from gathering up the popped stumps, moving them to a disposal area, and the actual disturbance at the disposal area. Disposal areas are either dug pits or benches, and depressions in which the stumps can be buried. Slope gradiant is the primary influence on amount of disturbance caused by stump removal. One must be sensitive to the tree type and density in evaluating methods of stump disposal and its impact.

Terrain with large stumps can mean additional disturbance to fill in the stump holes. With smaller stumps, or gentle terrain, often the holes can be smoothed over by track packing. Stump removal that produces some disturbance but basically leaves the original soil profile undisturbed can provide an excellant seed bed for revegetation. Soil erosion is also minimized when the basic soil capillary action is left undisturbed. On steeper gradients waterbars are usually needed.

More often than not, stump removal encroaches on "terrain enhancement", a second type of ground disturbance in ski terrain construction.

Terrain Enhancement

Terrain enhancement involves minor contour changes to the terrain in order to improve skiability. Spot fall line improvement could be termed terrain enhancement. The softening of breakovers and filling of depressions usually not more than 1-2 feet in isolated areas on ski terrain could be called terrain enhancement. The basic pitch of the fall line over all the run would not change.

Terrain enhancement leaves the orginally soil profile undisturbed in over 50% of the area. In disturbed areas, topsoil is saved and respread and the humus and duff is evident on the final surface.

Erosion risk increases when this type of construction is undertaken. Water barring is necessary.

Contour Grading

Of the three types of ski terrain construction, countour grading has the most impact. The actual ski terrain is usually worked to the point that it is a lesser degree of difficulty. Actual contours are changed and sidehills altered to the extent cuts and fills could be major. Obviously, the original soil profile is lost and water management and revegetation become major factors. Amounts of cuts and fills may be engineered unless proven experience exists. Toeing of fills is necessary on steeper gradients.

All ski area planners should be aware of these three basic types of terrain construction possibilities. The real challenge is in deciding how much of which is acceptable at any one time. All the variables that affect high altitude revegetation should be considered along with the accompanying risks. Time of year, aspect, growing season, soil type, water quality effect, skiability are a few of the factors to consider. A critical path of work should have higher risk projects completed early in the season to allow revegetation establishment. Seeding within 5 days of the disturbance must be standard operating procedure.

UTILITY INSTALLATION

Although not directly related to actual ski terrain construction, utilities can have a major effect. Utilities include buried communication, power, Natural gas, sewer and water. In addition, the impacts of snowmaking installations can easily be included in the category of utilities, even though the impacts of snowmaking are the most major. Utility installation programs can have major impact on a mountainside due to their straight up and down nature.

Proper and well-programed installation procedures hold the key to minimizing the adverse effect on the land. The best intentions of the best contractors usually fall short in installing utilities in our mountain environment in an ideal time frame.

Digging in rocky steep terrain which pushes equipment to the limit, challenges any contractor. Add to this, weather, access, trained manpower and one realizes that its more than a typical job. Contractor estimates of time periods to do various portions of the work are important.

Utility Routing

Many of the problems with mountainside utility installation can be avoided if careful routing considerations are made to avoid problem areas. When problem areas cannot be avoided, special drainage considerations will be necessary. "Short inventory" construction should be used to minimize open trench, and the amount of construction material/vehicles in these areas. Avoidence, or special consideration, is needed when existing mountain drainage systems are crossed over or under.

Timing of Installations

New ski terrain with new utilities should be approached as two seperate projects. Often the ski terrain unaffected by the utility installation can be revegetated and green by the time a major installation is complete. Any slope modification must be done prior to utility installation. This minimizes areas exposed without revegetation. Make sure drainage is away from any proposed trenching, even if it means temporary waterbar installation.

Once actual trenching begins, exposure to the sudden mountain thunderstorm is the greatest risk. All should be in order (i.e., pipes, cables, welders, cats) to minimize the time a trench is open. Blow out zones for any water accumulated should be planned. Sandbags or dikes in ditches should be used to check velocities and hold water. Actually exposure should be limited to a few days per section with laterals being done later, once the trench is filled. Open trenching should never be allowed over weekends or non-work days.

Access for Installation

Preplanning of a construction access system is imperative for the installation. Using flattened spoils as a work platform is ideal in that compaction is minimized on the original ground level. With snowmaking, station welding at the top or bottom of the mountain and pulling the pipes in long lengths is more ideal than on-site field welding in that spoils pile access can best be used.

Long Term Stabilization

The upper soil profiles can be graded to the opposite side of the trench from the spoils. This greatly aids future revegetation efforts and should be done no matter how marginal the soil type appears.

Concrete thrust blocks should be used at critical points along pipelines (snowmaking) based on specific soils, geological and topographical conditions. Locating these thrust blocks just above surface waterbars or appropriately near subsurface drainage will act as a daming effect, minimizing water running along pipes.

THE PRE-CONSTRUCTION CONFERENCE

The pre-construction conference involving the specific on-the-ground crews is strongly recommended in order to accomplish wider favor among all people involved with a project. The pre-construction conference can give an identification with all involved as to the real problems involved with high altitude revegetation. Clarification of design features, planned construction techniques, temporary erosion control features and access routes and methods and identification of environmentally sensitive areas should be discussed. A field walk-through is ideal.

CONCLUSION

This report has highlighted some of the "ground oriented" factors which need consideration in developing Colorado ski terrain in the 1980's. These factors add to sound established revegetation techniques and standards, and will provide excellent tools for a strong environmental operation and cost efficient production.

7TH HIGH ALTITUDE REVEGETATION WORKSHOP

Participant List

BEN ALBRECHTSEN
US FOREST SERVICE
324 25TH ST
OGDEN, UT 84401

G. MICHAEL ALDER
NPI
417 WAKARA WAY
SALT LAKE CITY, UT 84108

CATHERINE ALEXANDER
COLORADO STATE UNIV
DEPT. RANGE SCIENCE
FORT COLLINS, CO 80521

ROBERT ANDERSON
AAREC, INC
29774 HWY 257
WINDSOR, CO 80550

DANIEL A. ANDERSON
BEAR CREEK URANIUM
P.O. BOX 2654
CASPER, WY 82601

PATTI ANDREAS
HOMESTAKE MINING CO
P.O. BOX 1109
GUNNISON, CO 81230

GREG ASSMUS
U.S. FOREST SERVICE
100 US HWY 34
GRANBY, CO 80446

DAVID AUGUSIEWICZ
VAIL ASSOCIATION
P.O. BOX 7
VAIL, CO 81658

CHUCK AUSTIN
REVEGETATION EXCHANGE
P.O. BOX 157
LOUISVILLE, CO 80027

CRAIG AXTELL
NATL PARKS SERVICE
ROCKY MTN NATL PARK
ESTES PARK, CO 80517

DANA R. BARDSLEY
USDA FOREST SERVICE
605 SKYLINE DR
LARAMIE, WY 82070

D. MICHAEL BARKER
EXXON COMPANY USA
P.O. BOX 308
GRAND JUNCTION, CO 81502

TOM BARTLETT
CSU
DEPT OF RANGE SCIENCE
FORT COLLINS, CO 80523

DOUGLAS BARTO
PITTSBURG & MIDWAY CO
P.O. BOX 176
OAK CREEK, CO 80467

ARTHUR R. BAUER
USDA FOREST SERVICE
605 SKYLINE DR
LARAMIE, WY 82070

RONALD BAUER
USDA FOREST SERVICE
P.O. BOX 25127
LAKEWOOD, CO 80225

LARRY BEAN
BUREAU OF RECLAMATION
2597 B 3/4 RD
GRAND JUNCTION, CO 81502

WILLIAM BEAVERS
NATL PARK SERVICE
3670 SILVER PLUME LN
BOULDER, CO 80303

JOHN BECKLEY
US FOREST SERVICE
100 US HWY 34
GRANBY, CO 80446

DAN BELL
SUMMIT COUNTY
P.O. BOX 68
BRECKENRIDGE, CO 80424

DIANA BENDER
UNOCAL
P.O. BOX 76
PARACHUTE, CO 81635

WILLIAM BERG
USDA-ARS
2000 18TH
WOODWARD, OK 73801

MELANIE BETHEL
COLORADO MTN COLLEGE
129 CHESTNUT APT #3
LEADVILLE, CO 80461

CYNTHIA BLACK
NM-MINING & MIN DIV
525 CAMINO DE LOS MARQUEZ
SANTE FE, NM 87501

JOSEPH BLAIS
CF&I STEEL CORP
P.O. BOX 316
PUEBLO, CO 81002

DON BOGART
DIVISION OF WILDLIFE
317 W PROSPECT ST
FT. COLLINS, CO 80526

DAVID BOON
DEPT OF ENVIR QUAL
8402 3RD ST
WELLINGTON, CO 80549

CINDY BOSCO
DEPT OF ENV QUAL
122 W 25TH
CHEYENNE, WY 82002

BARBARA BOWERMAN
USDOI OFC OF SURFACE MIN
1020 15TH ST
DENVER, CO 80202

R.L. BRAMMER
UNOCAL
BOX 76
PARACHUTE, CO 81635

JEFF BRIGGS
MTN STATES FORESTRY
P.O. BOX 205
GARDNER, CO 81040

BRAD BROOKS
COPPER MOUNTAIN INC
JUNCTION HWY 91 & I-70
COPPER MOUNTAIN, CO 80443

LARRY F. BROWN
BROWN & ASSOCIATES
P.O. BOX 698
IDAHO SPRINGS, CO 80452

BARBARA BRUNK
ROCKY MT CONSULTANTS
500 COFFMAN ST
LONGMONT, CO 80501

ROGER BUCK
NATL PARK SERVICE
P.O. BOX 25287
DENVER, CO 80225

DAVID BUCKNER
CAMP, DRESSER, & MCKEE
2300 FIFTEENTH ST #400
DENVER, CO 80202

ROBERT BUMP
BUREAU OF LAND MGMT
P.O. BOX 202
DILLON, MT 59725

CATHERINE BUMP
USDA FOREST SERVICE
P.O. BOX 1258
DILLON, MT 59725

PAUL BUTLER
US FOREST SERVICE
P.O. BOX 31
KEMMERER, WY 83101

BETH CALLAWAY
CRESTED BUTTE MTN RES
P.O. BOX A
CRESTED BUTTE, CO 81225

BOB CARLSON
STATE PARKS & REC
1313 SHERMAN #618
DENVER, CO 80203

JACK CARLSON
USDA SOIL CONSERVATION
511 NW BROADWAY RM 547
PORTLAND, OR 97209

RICK CASON
RANDALL & BLAKE INC
4901 S WINDERMERE
LITTLETON, CO 80120

NOLA CHAVEZ
NATL PARK SERVICE
ROCKY MTN NATL PARK
ESTES PARK, CO 80517

ELIZABETH CHENOWETH
WESTERN STATES RECLAM
7650 W 120TH AVE #3
BROOMFIELD, CO 80020

DAVID CHENOWETH
WESTERN STATES RECLAM
7650 W 120TH AVE #3
BROOMFIELD, CO 80020

DARRIN CISAR
COLO MTN COLLEGE
P.O. BOX 11
LEADVILLE, CO 80461

TOM CLARK
WEYERHAEUSER CO
WSC-3
TACOMA, WA 98477

THOMAS COLBERT
INTERMOUNTAIN SOILS
1873 S BELLAIRE ST
DENVER, CO 80222

BOB CONNER
ORGANIC EARTH SCIENCE
P.O. BOX 262F
LONGMONT, CO 80501

AMY CONNERTON
COLORADO MTN COLLEGE
P.O. BOX 78
LEADVILLE, CO 80461

MATHEW CROSS
RANGE DEPT - CSU
3898 S BANNOCK
ENGLEWOOD, CO 80110

TERRY S. CROWNER
PITTSBURG & MIDWAY CO
P.O. BOX 176
OAK CREEK, CO 80467

L. DEAN CULWELL
WESTECH
P.O. BOX 6045
HELENA, MT 59604

RICHARD DADDOW
USDA FOREST SERVICE
P.O. BOX 2140
CODY, WY 82414

CHARLES DEANGELIS
GRASS GROWERS INC
424 COTTAGE PL
PLAINFIELD, NJ 07060

DALE A. DEMING
MAGMA COPPER CORP
P.O. BOX M
SAN MANUEL, AZ 85631

CONNIE DENNEY
COLO MTN COLLEGE
P.O. BOX 17
LEADVILLE, CO 80461

EDWARD DEPUIT
UNIV OF WY-RANGE MGMT
UNIV STATION-PO BOX 3354
LARAMIE, WY 82070

HOWARD DOYLE
COPPER MTN INC
JUNCTION HWY 91 & I-70
COPPER MOUNTAIN, CO 80443

ROBERT DROBISH
WY RECREATION COMMISSION
122 W 25TH ST
CHEYENNE, WY 82002

JANET DROTAR
3701 W 68th AVE
APT #A201
WESTMINSTER, CO 80030

ALAN DUMP
COLORADO MTN COLLEGE
P.O. BOX 1849
LEADVILLE, CO 80461

KATHLEEN DWIRE
UT STATE UNIV
312 1/2 CANYON RD #A
LOGAN, UT 84321

JILL EASLEY
COLO DEPT HWYS
4201 E ARKANSAS #309
DENVER, CO 80222

JULIE ETRA
US FOREST SERVICE
P.O. BOX 8465
S LAKE TAHOE, CA 95731

CLORINDA FALVEY
CMC-STUDENT
815 HAZEL ST #1-A
LEADVILLE, CO 80461

CAMILLE FARRELL
COLORADO MINED LAND REC
1313 SHERMAN ST #423
DENVER, CO 80203

GREG FENCHEL
UPPER CO ENVIR PLANT
P.O. BOX 448
MEEKER, CO 81641

DOUG FREADWAY
PINON MESA NATIVE SEED
P.O. BOX 34
GLADE PARK, CO 81523

ROGER FUNSTON
605 WILDERNESS DR
GILLETTE, WY 82716

KENNETH GENZ
US FOREST SERVICE
1500 FRANKLIN WAY
SPARKS, NV 89431

LEE PAT GOCHNOUR
ST JOE AMERICAN CORP
N 111 VISTA #3F
SPOKANE, WA 99212

JOHN GRAVES
NATIVE SEEDERS
6324 LARIMER CTY LINE RD
WINDSOR, CO 80550

JIM GREGG
US FOREST SERVICE-DILLON
P.O. BOX 498
SILVERTHORNE, CO 80498

BOB EASTER
A.R. EASTER INC
900 S QUINCE BLDG B819
DENVER, CO 80231

MARGARET EWING
COLORADO USFS
240 W PROSPECT
FORT COLLINS, CO 80526

DAVID FARMER
CSFS
P.O. BOX Y
WOODLAND PARK, CO 80863

C. KIRK FAUGHT
UNIV OF WY
265 N CEDAR
LARAMIE, WY 82070

SUSAN FLEAK
COLORADO MTN COLLEGE
P.O. BOX 20 CMC
LEADVILLE, CO 80461

MICHAEL FUNKE
NATL PARK SERVICES
755 PARFET-PO BOX 25287
DENVER, CO 80225

LISA GEESEY
DEPT OF ENV QUAL-LAND
122 W 25TH
CHEYENNE, WY 82002

ERNEST GILLINGHAM
BUREAU OF LAND MGMT
219 E DOUGLAS-PO BOX 311
CANON CITY, CO 81212

TERRY GOODRICH
NATL PARK SERVICE
P.O. BOX 25287
DENVER, CO 80225

TODD GREEN
COPPER MTN RESORT
P.O. BOX 3001
COPPER MOUNTAIN CO 80443

KARL GRUBBE
405 N WHITCOMB
FORT COLLINS, CO 80521

MICHAEL GUILLAUME
P.O. BOX 1085
PINEDALE, WY 82941

LEW HAMMER
REVEGETATION EXCHANGE
P.O. BOX 157
LOUISVILLE, CO 80027

JERRY B. HARMAN
BUREAU OF LAND MGMT
2020 ARAPAHOE ST
DENVER, CO 80205

MICHAEL HAUSMAN
PPS PACKAGING CO
P.O. BOX 56
FOWLER, CA 93625

ED HAYWOOD
PLANTS OF THE SOUTHWEST
116 ELENA #3
SANTA FE, NM 87501

MICHAEL HIEL
MT DEPT OF STATE LAND
CAPITOL STATION
HELENA, MT 59601

J. DAVID HOLM
CO-DEPT OF NAT RES
1313 SHERMAN-423 CENT BLD
DENVER, CO 80203

RICK HUGHES
COLORADO YAMPA COAL CO
29588 ROUTT CTY RD #27
OAK CREEK, CO 80467

CHARLES JACKSON
AMAX-HENDERSON MINE
P.O. BOX 68
EMPIRE, CO 80438

PHIL JOHNSON
ECON INC.
2685 AIRPORT WAY
HELENA, MT 59601

DAVID JOHNSON
W. RESOURCE DEVELOPMENT
711 WALNUT ST.
BOULDER, CO 80302

ALAN HALL
NM-MINING & MIN DIV
525 CAMINO DE LOS MARQUEZ
SANTE FE, NM 87501

MIKE HARDING
NORTH AMERICAN GREEN
14649 HWY 41 N
EVANSVILLE, IN 47711

WENDELL G. HASSELL
SOIL CONSERVATION SER
7866 MARSHALL ST
ARVADA, CO 80003

CRAIG HAYNES
BUREAU OF LAND MGMT
P.O. BOX 1361
MEEKER, CO 81641

JIM HERRON
CO-DEPT OF NAT RES
1313 SHERMAN-423 CENT BLD
DENVER, CO 80203

DARWIN HOEFT
USDA
P.O. BOX 200
CUSTER, SD 57730

DENISE HOWARD
304 PETERSON ST
FT. COLLINS, CO 80524

J. LEIGH HUNT
CSU
405 N. WHITCOMB
FT. COLLINS, CO 80521

KAY JAMES
WALDEN COAL CO.
P.O. BOX 229
BOULDER, CO 80306

CLYDE JOHNSON
BUREAU OF LAND MGMT.
701 CAMINO DEL RIO
DURANGO, CO 81301

WILLIAM JOHNSON
USDA FOREST SERVICE
P.O. BOX 7916
ASPEN, CO 81612

ALAN JUNCKER
NORTH AMERICAN GREEN
14649 HWY 41 NORTH
EVANSVILLE, IN 47711

DEBORAH KEAMMERER
STOECKER-KEAMMERER & ASSOC
5858 WOODBOURNE HOLLOW RD
BOULDER, CO 80301

KYM KELLEY
KELLEY EROSION CONTROL
P.O. BOX 1115
S LAKE TAHOE, CA 95705

LARRY KLINE
USDOI OFC OF SURFACE MIN
1020 15TH ST
DENVER, CO 80202

MICHAEL KLISH
BUREAU OF LAND MGMT
2315 DOGWOOD CT
GRAND JUNCTION, CO 81506

CRAIG KNOCK
K & K HYDRO TURF
P.O. BOX 2269
GILLETTE, WY 82716

LOREN KROENKE
ROUTT NATL FOREST
29587 W US 40
STEAMBOAT SPGS CO 80487

TOM LAHTI
P.O. BOX 1828
CHEYENNE, WY 82001

JIM LANCE
COLO DEPT OF HIGHWAYS
P.O. BOX 2107
GRAND JUNCTION, CO 81502

LISA LARSEN
WESTECH
P.O. BOX 6045
HELENA, MT 59604

CURT LEET
BLM
P.O. BOX 2153
MEEKER, CO 81641

WARREN KEAMMERER
STOECKER-KEAMMERER & ASSOC
5858 WOODBOURNE HOLLOW RD
BOULDER, CO 80301

RICHARD KEIGLEY
NATL PARKS SERVICE
ROCKY MTN NATL PARK
ESTES PARK, CO 80517

KENNETH KLCO
GENSTAR GYPSUM CO
BOX 80
COALDALE, CO 81222

HENRY KLINGMAN
TRICON AG VOGELSANGSTR #7
P.O. BOX 144 CH-8033
ZURICH, SWITZERLAND

PAUL KLITE
1450 LOGAN ST
DENVER, CO 80203

PAUL KRABACHER
MLRD
2882 CABOOSE AVE
GRAND JUNCTION, CO 81503

DAVID KRUSE
US ARMY CORPS OF ENG
650 CAPITAL MALL
SACRAMENTO, CA 95814

MIKE LAMB
WINTER PARK SKI AREA
P.O. BOX 36
WINTER PARK, CO 80482

LYNN LANNING
WYOMING HIGHWAY DEPT
P.O. BOX 1708
CHEYENNE, WY 82002

MICHAEL LEAK
STATE PARK & REC
1313 SHERMAN #618
DENVER, CO 80203

TONY LEONARD
AMERICAN EXCELSIOR
P.O. BOX 5067
ARLINGTON, TX 76011

STEPHEN LONG
CEDAR CREEK ASSOC INC
616 COOK DR
FORT COLLINS, CO 80521

GARY LYNCH
MTN DEPT OF STATE LAND
CAPITOL STATION
HELENA, MT 59620

CARL MADISON
BUREAU OF LAND MGMT
2465 S TOWNSEND
MONTROSE, CO 81401

JOHN MCCARTY
COLO HIGHWAY DEPT
P.O. BOX 1221
GLENWOOD SPGS, CO 81602

JEFF MEYER
THORNE ECOLOGICAL INST
4860 RIVERBEND RD
BOULDER, CO 80301

DALE MILLER
INTER-FLUVE INC
408 N BOZEMAN
BOZEMAN, MT 59715

GARY W. MOATS
USDA FOREST SERVICE
605 SKYLINE DR
LARAMIE, WY 82070

MICHAEL MOLLICA
PLANNER, EAGLE COUNTY
P.O. BOX 179
EAGLE, CO 81631

J.M. MORRIS
AMERICAN EXCELSIOR
P.O. BOX 5067
ARLINGTON, TX 76011

GARY NOLLER
UPPER CO ENVIR PLANT
P.O. BOX 448
MEEKER, CO 81641

PETER O'BRIEN
MERISTEM NURSERY INC
P.O. BOX 698
REDWING, CO 81066

DALE LYLE
STREAM TEAM
408 E 22ND PL
LOVELAND, CO 80537

CARL MACKEY
402 W CHESTER
LAFAYETTE, CO 80026

JIM MARTIN
MIRAFI INC
P.O. BOX 240967
CHARLOTTE, NC 28224

FLOYD A. MCMULLEN
US OFFICE OF SURFACE
1150 S GLENCOE
DENVER, CO 80222

GARY R. MILES
NATL PARK SERVICE
P.O. BOX 25287
DENVER, CO 80225

ROBERT B. MILLER
WESTERN STATES HYDROSEED
5675 E GREENWOOD PL
DENVER, CO 80222

PETER MOLLER
COLORADO MTN COLLEGE
TIMBERLINE CAMPUS
LEADVILLE, CO 80461

ROBERT L. MOORE
THUNDER BASIN COAL CO
P.O. BOX 406
WRIGHT, WY 82732

RUTH MURAYAMA
SUMMIT COUNTY PLANNING
P.O. BOX 68
BRECKENRIDGE, CO 80424

BEN NORTHCUTT
MOUNTAIN WEST ENVIRON
P.O. BOX 2107
STEAMBOAT SPRGS, CO 80477

PATRICK O'SHEA
NAT ENV RECLAMATION
1057 SNEAD DR
TROY, MI 48098

DIANE O'SHEA
NAT ENV RECLAMATION
1057 SNEAD DR
TROY, MI 48098

PHIL OGLE
WYOMING DEQ-LAND QUAL
122 W. 25TH ST
CHEYENNE, WY 82002

DENNIS OOST
DESIGN WORKSHOP INC
719 E DURANT
ASPEN, CO 81611

RICHARD PARACHINI
CSU
RANGE SCIENCE DEPT
FT. COLLINS, CO 80523

JOHN PARKS
MONTANA STATE UNIV
RECLAMATION RESEARCH
BOZEMAN, MT 59717

GEORGE R. PERKINS
US FOREST SERVICE
BOX E
BEAVER, UT 84713

VERN PFANNENSTIEL
PEABODY COAL CO
10375 E HARVARD AVE
DENVER, CO 80231

MARK PHILLIPS
PHILLIPS SEEDING
11843 BILLINGS
LAFAYETTE, CO 80026

CHARLES J. POTTER
NATL PARK SERVICE
GLACIER NATL PARK
W GLACIER, MT 59936

ROBIN RALPHS
RANDALL & BLAKE INC
4901 S WINDERMERE
LITTLETON, CO 80120

JOHN RAWINSKI
RIO GRANDE NATL FOREST
1803 W HWY 160
MONTE VISTA, CO 81144

ED REDENTE
DEPT OF RANGE SCIENCE
CSU
FORT COLLINS, CO 80523

GEFF REED
COLORADO MTN COLLEGE
P.O. BOX 54
LEADVILLE, CO 80461

DAVID REED
CSU
500 W PROSPECT
FORT COLLINS, CO 80523

MICHAEL ANN REX
US FOREST SERVICE
100 US HWY 34
GRANBY, CO 80446

CRAIG RICHTER
COLORADO MTN COLLEGE
222 W 6TH ST
LEADVILLE, CO 80461

ROBERT RIDDLE
US FOREST SERVICE
P.O. BOX 31
KEMMERER, WY 83101

D.W. RILEY
ECI
390 S TAFT
LAKEWOOD, CO 80228

RON ROBERTS
MOBIL COAL PRODUCING
P.O. BOX 3021
GILLETTE, WY 82716

REGINA M. ROCHEFORT
MT RAINIER NATL PARK
TAHOMA WOODS, STAR RT
ASHFORD, WA 98304

T.R. ROHWEDER
MANVILLE CORP
7030 S NEWLAND CT
LITTLETON, CO 80123

ROY ROPER
BOESCH-FISHER ENGR
389 GLENMOOR RD
CANON CITY, CO 81212

KEVIN RYAN
SUMMITVILLE CSNLDT MIN
P.O. BOX 2-G
DEL NORTE, CO 81132

DAVID SAMMONS
ECI
390 S TAFT
LAKEWOOD, CO 80228

HERB SCHAAL
EDAW INC
240 E MOUNTAIN AVE
FORT COLLINS, CO 80524

MARK SCHUSTER
GRUBB & ELLIS CO
910 COVE WAY
DENVER, CO 80209

JANICE SEIBERT
AGRONOMY DEPT
CSU
FT. COLLINS, CO 80523

JIM SHARKOFF
COLORADO STATE UNIV
6504 LUNAR CT
FORT COLLINS, CO 80525

DAVID SHARP
SHARP BROS SEED CO
101 E 4TH ST RD
GREELEY, CO 80631

G.L. SHERWOOD
ROCKY MTN TREES & LAND
P.O. BOX 1336
CRESTED BUTTE, CO 81224

CLIFF SIMONTON
VAIL ASSOCIATION INC
P.O. BOX 7
VAIL, CO 81658

DIANA SMEDRA
COLO MTN COLLEGE
BOX 52
LEADVILLE, CO 80461

DEBRA SMITH
WALKER & ASSOC LTD
RR #1 S EDMONTON
ALBERTA, CANADA T6H4N6

BURNS SABEY
DEPT OF AGRONOMY
CSU
FORT COLLINS, CO 80523

ANDELL SAWDO
CRESTED BUTTE MTN RES
P.O. BOX 21
GUNNISON, CO 81230

STEVE SCHIESSWOHL
BUREAU OF RECLAMATION
P.O. BOX 1889
GRAND JUNCTION, CO 81502

STEVE SCOTT
BOWMAN CONSTN SUPPLY
2310 S SYRACUSE WAY
DENVER, CO 80231

CLAIRE SEMMER
COLO YAMPA COAL CO
P.O. BOX 881302
STEAMBOAT SPGS, CO 80488

DON SHARP
FINN CORP
9281 LESAINT
FAIRFIELD, OH 45014

HOLLAND SHEPERD
UTAH DIV OF OIL-GAS
355 W N TEMPLE
SALT LAKE CITY, UT 84180

HENRY SHOVIC
FOREST SERVICE
GALLATIN NF BOX 130
BOZEMAN, MT 59715

CHET SKILBRED
GLENROCK COAL CO
1026 55 RANCH RD
GLENROCK, WY 82637

TIM SMITH
COTTER CORP
12596 W BAYAUD AVE #350
LAKEWOOD, CO 80228

SCOTT SPACKEEN
NPI SEED DIVISION
1697 W 2100 NORTH
LEHI, UT 84043

ANDREW B. STAFFORD
BRIDGER COAL CO
P.O. BOX 2068
ROCK SPRINGS, WY 82901

SUZANNE STUTZMAN
NATL PARK SERVICE
P.O. BOX 25287
DENVER, CO 80225

TONY SVATOS
WHITE RIVER NATL FOREST
P.O. BOX 948
GLENWOOD SPGS, CO 81602

JOSEPH SWYERS
COLORADO MTN COLLEGE
P.O. BOX 480
LEADVILLE, CO 80461

MARC THEISEN
BOWMAN CONSTN SUPPLY
2310 S SYRACUSE WAY
DENVER, CO 80231

LEO K. THIESSEN
MANVILLE CORP
P.O. BOX 5108
DENVER, CO 80217

GARY THOR
DEPT OF AGRONOMY
CSU
FT. COLLINS, CO 80523

GARY THORSON
WY RECREATION COMMISSION
122 W 25TH ST
CHEYENNE, WY 82002

ANNA THURSTON
COLORADO GREEN ALCC
3895 UPHAM SUITE 150
WHEAT RIDGE, CO 80033

JEFF TODD
AMAK ENV AFFAIRS
1707 COLE BLVD
GOLDEN, CO 80401

AL TODD
US FOREST SERVICE
P.O. BOX 8465
S LAKE TAHOE, CA 95731

JOHN TOWNLEY
ORGANIC EARTH SCIENCE
P.O. BOX 262F
LONGMONT, CO 80501

RICHARD TRENHOLME
INTERMOUNTAIN SOILS
1873 S BELLAIRE ST
DENVER, CO 80222

MADHUKAR UPADHYA
UT STATE UNIV
P.O. 1406
LOGAN, UT 84322

KRYSTYNA URBANSKA
SWISS FED INST OF TECH
ZURICHBERGSTRASSE 38
ZURICH,SWITZERLAND CH8044

IVAN URNOVITZ
TEXAS OIL & GAS
1016 MAIN ST
LOUISVILLE, CO 80027

JANE VALERIUS
DEPT OF ENV QUALITY
210 LINCOLN ST
LANDER, WY 82520

BOB VILOTTI
ARKANSAS VALLEY SEEDS
4625 COLORADO BLVD
DENVER, CO 80216

RICHARD VINCENT
UNIV WY-GRAD STUDENT
810 1/2 S 11TH
LARAMIE, WY 82070

COLIN VOIGT
BUREAU OF LAND MGMT
P.O. BOX 1869
ROCK SPRINGS, WY 82901

MOHAN WALI
COLL OF ENVIRON SCI/FOR
STATE UNIV OF NEW YORK
SYRACUSE, NY 13210

DAVID WALKER
WALKER & ASSOC LTD
RR #1 S EDMONTON
ALBERTA, CANADA T6H4N6

SCOTT WANSTEDT
CSU
DEPT OF RANGE SCIENCE
FORT COLLINS, CO 80523

DAVID WESTERGARD
GRASS GROWERS INC
424 COTTAGE PL
PLAINFIELD, NJ 07060

DEBRA WHITALL
US FOREST SERVICE
P.O. BOX 8465
S LAKE TAHOE, CA 95731

ANTHONY WILLKOMM
COLO MTN COLLEGE
105 E 6TH ST
LEADVILLE, CO 80461

LARRY WOODS
AMERICAN EXCELSIOR
P.O. BOX 5067
ARLINGTON, TX 76011

SARAH WYNN
NATIONAL PARK SERVICE
DSC-TN6 P.O. BOX 25287
DENVER, CO 80225

BARBARA ZUCKER
COLORADO MTN COLLEGE
507 W 2ND ST
LEADVILLE, CO 80461

GORDON WARRINGTON
USFS BRIDGER-TETAN
P.O. BOX 1888
JACKSON, WY 83001

KAY WHISTON
UNIV OF WYOMING
1858 N 9TH #4
LARAMIE, WY 82070

SUSAN WHITE
NPI RECLAMATION CONST
417 WAKARA WAY
SALT LAKE, UT 84108

BILL WOLVIN
WINTER PARK SKI AREA
P.O. BOX 36
WINTER PARK, CO 80482

STONEY WRIGHT
AK PLANT MATL CTR
STAR RT. B - BOX 7440
PALMER, AK 99645

DIANE YATES
CRS SIRRINE
216 16TH ST MALL STE 1700
DENVER, CO 80202