

PROCEEDINGS:  
HIGH ALTITUDE REVEGETATION  
WORKSHOP NO. 8

Edited by

Warren R. Keammerer and Larry F. Brown

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**Proceedings**  
**HIGH ALTITUDE REVEGETATION WORKSHOP**  
**NO. 8**

Colorado State University  
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Edited By

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## High Altitude Revegetation Committee Background, Philosophy and Activities

One of the many requirements spawned by increased environmental awareness in the late 1960's was reclamation of disturbed lands. This requirement accelerated research in the field of revegetation. Much was known and much was being learned, but knowledge of high altitude and latitude revegetation was particularly lacking. And, in the early 1970's, no organization existed to serve as a clearinghouse to gather and disseminate the body of existing and developing information.

Jim Brown (Climax Molybdenum Company), and Bill Berg and Robin Cuany (CSU Agronomy Department) recognized this need and, with the financial backing of the Climax Molybdenum Company, organized a workshop on the subject. The first High Altitude Revegetation Workshop was held at CSU in the spring of 1974. Greater than anticipated attendance at the conference clearly demonstrated the need for continued effort, and the High Altitude Revegetation Committee was formed.

### Philosophy

The HAR Committee is comprised of volunteers from the mining and ski industries, revegetation/reclamation materials suppliers, consultants, various governmental agencies, and universities. *The objective of the Committee is simply the dissemination of information relating to high altitude revegetation.* In the early, more lucrative years, the HARC received enough in contributions to support a graduate research assistant. As more austere times developed, that level of funding disappeared.

The Committee usually meets once each year to select sites to be toured on summer field trips, and to plan the biannual conference. The Committee has also advised various agencies involved in reclamation. A small portion of the Committee secretary's salary is provided for time expended in the mailing of notices and maintaining some semblance of organization to sponsored activities. All remaining fees are expended directly on the conferences, publication of the proceedings, and field trips. Funds are held by CSU as an Agronomy Department account.

The organization is informal. Any interested person is welcome to participate in the activities. There are no membership drives or annual dues. As such, there is no formal mechanism for the participants needs and desires to be heard. Committee decisions on topics, speakers, etc., attempt to reflect and anticipate needs and wants, but The Committee cannot respond directly to desires unless they are communicated to us. We need and solicit input. Addresses and phone numbers of Committee members are listed elsewhere

in these Proceedings. Please contact any of us with any suggestions you might have. By collecting and pigeonholing ideas through the months, the Committee can organize an entire conference in one sitting.

## Activities

Since 1974, the HAR Committee has sponsored biannual conferences and annual field trips to unique mountainous revegetation project and research sites. All Conferences have been held at Fort Collins, Colorado, in conjunction with CSU, except the 1980 conference which was held at the Colorado School of Mines in Golden, Colorado. Summer Field Tours have been conducted at the following sites:

<u>Area Toured</u>	<u>Sites Toured</u>
1974	Vail/Climax, CO - Vail Ski Area, AMAX Climax Molybdenum Mine
1975	Empire, CO - AMAX Urad Molybdenum Mine, Winter Park Ski Area, Rollins Pass Gas Pipeline
1976	Idaho Springs/Silverthorne, CO - US highway 40 construction, Keystone Ski Area
1977	Aspen/Redstone, CO - Snowmass Ski Area, CF&I Pitkin Iron Mine, Mid-Continent Coal Redstone Mine
1978	Estes Park, CO - Rocky Mountain National Park
1979	Silverton/Durango, CO - Purgatory Ski Area, Standard Metals Sunnyside Mine, Bayfield Range Experiment Program
1980	Vail/Climax, CO - I-70 Vail Pass highway construction revegetation and Ten Mile Creek channelization, Copper Mountain Ski Area, AMAX Climax Molybdenum Mine
1981	Crested Butte/Gunnison, CO - AMAX Mt. Emmons Molybdenum Project, Western State College, Homestake Pitch (Uranium) Mine, CF&I Monarch Limestone Quarry
1982	Steamboat Springs, CO - Mt. Werner Ski Area, Howelson Hill Ski Jump, Colorado Yampa Energy Coal Mine, P&M Edna Coal Mine
1983	Rifle/Meeker, CO - CSU Intensive Test Plots, C-B Oil Shale Project, Upper Colorado Environmental Plant Center, Colony Oil Shale Project
1984	Salida, CO & Questa, NM - Domtar Gypsum Coaldale Quarry, ARCO CO <sub>2</sub> Gas Project, Molycorp Molybdenum Mine, Red River Ski Area
1985	Cooke City, MT - USFS Beartooth Plateau Research Sites, Bridger Plant Materials Center
1986	Leadville, CO - Peru Creek Passive Mine drainage treatment, California Gulch/Yak Tunnel Superfund Site, Colorado Mountain College
1987	Glenwood Springs/Aspen, CO - I-70 Glenwood Canyon construction, Aspen Ski Area
1988	Telluride/Ouray/Silverton, CO - Ridgeway Reservoir, Telluride Mt. Village Resort, Idarado Mine, Sunnyside Mine, July 28-29, 1988

## PREFACE

The 8th biannual High Altitude Revegetation Workshop was held at the University Park Holiday Inn, Fort Collins, Colorado. As always, the Workshop was organized by the High Altitude Revegetation Committee in conjunction with the Colorado State University Agronomy Department. The Workshop was well attended. In these times of mining decline, skiing stagnation, and highway construction budgetary constraint, it is encouraging that so many agencies and companies continue to seek better ways of revegetating disturbed lands.

Organizing a two day conference is a difficult undertaking made relatively easy by sharing responsibilities among members of the HAR Committee. Some of the duties, such as chairing a session, were more obvious than other duties. Individuals performing less obvious functions not listed in the Table of Contents were:

- Charles Jackson prepared the manuscript specifications;
- Tom Colbert saw to it that notification of the conference was published in related trade journals;
- Ben Northcutt served as liaison with the Governor's office;
- Warren and Debbie Keammerer solicited and collected donations for the coffee breaks and cocktail hour;
- Jeff Pecka escorted our Switzerland connection, Krystyna Urbanska;
- Pattie Andreas arranged for the Homestake Mine Movie "The Rebirth of Whitewood Creek";
- Ray Brown made the initial contact with the keynote speaker, Jim MacMahon;
- Larry Brown arranged for the banquet speaker, Robert Brown;
- Marc Theisen was in charge of the exhibits;
- Jeff Todd and others worked to update and improve the mailing list; and,
- Rob Clark arranged for the manufacture and sale of the HAR caps.
- Of special note, it must be pointed out that Gary Thor served as the overall Conference Coordinator. In so doing, he prepared the brochure, arranged and managed the mailings and registration with the Conference Services Office at CSU, collected and put out the abstracts of the papers, and made all the necessary arrangements with The Holiday Inn.

However, as always, the most important contributors to the conference were the speakers. These Proceedings are their product, and we express our gratitude to them.

Editors

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# RESTORATION AND STUDIES OF SUCCESSION

## AND COMMUNITY ARCHITECTURE

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### ABSTRACT

The reclamation of mined lands is usually accomplished by applying principles of management derived from experience with agricultural practices. This approach emphasizes the application of fertilizer and irrigation to sites which have been seeded by machinery which regularly disperses seed. These practices have been applied across a wide variety of sites from various climatic zones.

An argument will be developed that the strict adherence to agriculturally based practices may overlook a series of methodologies which are based on ecological principles and which may be better tailored to specific sites.

The arguments presented suggest that since various successional processes seem to vary in their importance from one biome to another, and since reclamation is considered to be a form of "managed succession", that attention to specific limiting processes, on a biome by biome basis may produce more effective reclamation scenarios.

Included in the discussion will be two general areas of interest. First it will be argued that plant communities have characteristic dispersion patterns and that these patterns may change from early to later successional stages. Assuming this to be the case, replicating the later successional patterns, during reclamation, may speed recovery. Specifically, plants in "correct" arrays may require no irrigation nor fertilization, because their spatial array enhances water and nutrient availability by capturing mobile organic and inorganic material in their environment.

A second series of arguments will be offered which suggest that the general form, or architecture, of the plant components of the community are more influential in determining the presence or absence of native animals than is the specific species array of plants. If true, this phenomenon suggests a very different series of management alternatives than those which are mandated by current law.

In addition to these two general theses, the problem of dealing with various scales of biological influence will be discussed in a management context.

Many of the topics covered will be addressed with examples from reclamation of arid lands in western North America. These examples will be used, because as recently as the mid-1970's a National Academy of Science Committee suggested that mined land in areas with less than 10 inches of precipitation per year would be difficult or impossible to reclaim.

## IDARADO SUPERFUND TRIAL: RECLAMATION THROUGH THE COURTS

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### INTRODUCTION

In December, 1983, the State of Colorado sued the Idarado Mining Company and its parent, Newmont Mining Corporation, in Federal Court under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. § 9601, et seq. ("Superfund"). Although initially the State sought recovery only for natural resource damages--as distinct from costs for reclamation and remediation--the case soon evolved into one to determine how to reclaim the Idarado Mine site. At the same time, Colorado instituted suits against several other mining companies, raising similar issues for their properties. Some of these cases have been settled. Some are still pending. The Idarado case has had a four-month trial on remediation issues. When the court's decision issues on that phase, it will be followed by a trial on natural resources damages issues which in turn will be followed by a trial to resolve the issue of who, besides Idarado, is liable for this site.

This case has great significance for mining companies and those involved in assisting mining companies in reclamation of their property. If the procedures and substantive policies which the State followed in the Idarado case become the norm, reclamation in Colorado is going to be a highly adversarial and very expensive process. Whether the solutions which emerge will be technically superior to those developed in the past remains to be seen.

### THE IDARADO MINE--LOCATION AND DESCRIPTION

The Idarado Mine is located in Southwestern Colorado between Telluride in the Upper San Miguel Valley and Red Mountain Creek, several miles above Ouray. The area of the Idarado Mine site has been mined since the last century. Typical of most Colorado mining districts, many different, small mines operated through various boom and bust cycles. At one time, the high country above Telluride was the site of many small mines and even a town--the Town of Tomboy. The remnants of these old operations are still to be seen and are in fact a major tourist attraction during the summer months.

Idarado Mining Company was formed in the late 1930's. Several companies had property interests in the area but were unable to mine those economically. Idarado consolidated a number of these smaller, uneconomic properties into a single entity. As established, the Idarado Mining Company operated very successfully from the late 1930's into the mid-to-late 1970's. At that point, Idarado ceased operations due to low metals prices.

Reclamation issues at the site were typical of those which would exist at any Colorado mining site. Idarado owned engineered tailings ponds in both the Red Mountain Creek and San Miguel valleys. There was drainage from the mine itself, again in both the Red Mountain Creek and the San Miguel River valleys. Additionally, there was drainage in the high country both from old mine portals and from snow melt which flowed onto and through old waste and tailings piles remaining from earlier generations of miners. Studies of groundwater in the San Miguel Valley immediately adjacent to the Idarado tailings ponds indicated elevated levels of metals. Additionally, over a period of years there had been complaints of blowing dust from the Idarado tailings pond and questions of soil contamination in the Telluride area. All of these issues were addressed in the Superfund trial.

#### IDARADO RECLAMATION ISSUES

##### 1. Choice of Forum: The Courtroom.

The first and perhaps the most disturbing issue raised by the Idarado case was the decision by the State to pursue reclamation through the courts. The State made no effort to address reclamation concerns in any type of administrative or negotiation process with Idarado prior to filing its lawsuit. Although it would suggest that it was compelled to file its action by a statute of limitations which may have been running on natural resource damages claims, the State made no effort to make use of normal administrative procedures even after the case was filed. Rather, it was content to have the courtroom process run its course, with negotiation coming into play only very late in the game and after the parties' positions had hardened.

##### 2. Choice of Weapons: Superfund.

Another very significant aspect of this case was the State's decision to proceed under CERCLA, the Federal Superfund law, rather than under Colorado's Mined Reclamation Act and other statutes. The Superfund law evolved from and is plainly directed to situations such as the Love Canal

hazardous waste site near Buffalo, New York, and major hazardous substance spills. It is doubtful that it was ever intended to be used, especially as a first cut, to develop a reclamation plan for the closure of a mining operation. Nevertheless, that is precisely what Colorado did at Idarado.

Superfund is an extraordinarily powerful law. As applied by the State, the statute includes four concepts of significance for mine reclamation. First, liability is established by any release of a hazardous substance into the environment, without regard either to the amount of that substance released or to the harm it caused. Under the statute, the metals which would be found in ordinary mine drainage, tailings piles, and probably waste piles would constitute a hazardous substance. The State asserted that if any amount of those substances is released into the air, ground, water, or soils, the releasing party is liable for all costs incurred by the State to remedy that problem. Those costs include the costs of technical consultants and lawyers for litigation, as well as the costs of reclamation itself.

The second concept under Superfund is that the State believes that remedial plans should be standards driven and not engineering driven. Traditionally, most approaches to mine reclamation have come from the viewpoint of developing reasonable engineering solutions to on site problems. The approach has been to look at the site and determine what would be reasonable in terms of standards in the industry, seriousness of the problem, engineering feasibility, and cost. The State takes a different approach under Superfund. It defines standards it wishes to have met in groundwater, surface water, soils, the air or environmental media and then requires a party to implement whatever engineering solutions may be required to meet those standards.

The third significant concept under Superfund is its approach to costs. It is the State's belief that cost is not an issue under Superfund. Traditionally, any approach to problems of reclamation have used a concept of cost benefit, which weighs the benefits achieved from particular actions in light of what it may cost to achieve those. The State rejects this approach under CERCLA. Rather, it uses a concept of "cost effectiveness," which first determines what will be "effective" to protect its notion of the public health, welfare and the environment--without any consideration of cost. Only after it has defined "effective" solutions will it balance costs to determine which of those is most effective and the least expensive. Plainly, the failure to evaluate reclamation from a cost-benefit perspective will, if it becomes State-wide policy, increase the cost of mine reclamation many fold.

The last concept is the use of the legal theory of joint and several liability. This concept was developed in law to address situations where an individual was injured and the acts of several individuals contributed to that injury in circumstances which made it difficult or impossible for the injured person to allocate specific injuries to specific causes. In that situation, the doctrine developed which allowed the injured person to assert his claim against all the persons responsible, have each of them held liable for the full amount of the injury, and leave it to those responsible to determine allocation of responsibility among themselves. The State has taken this in the CERCLA context to hold one company responsible for cleaning up properties it never owned and never operated and, indeed, to address what is really a State problem--reclamation of old abandoned mine workings. The application of these issues in specific onsite contexts will be discussed below to demonstrate their significance to mine reclamation issues.

For those interested in a more detailed explanation of the statute, I have attached an outline of the statute and its application to the mining industry prepared by two of my partners.

### 3. Tailings Pond Reclamation.

There are several tailings ponds on each side of the Idarado Mine site. The State's litigated solution for reclaiming these tailings included consolidating the smaller piles on each side of the mine into the biggest tailings pile (which obviously would mean moving many tons of tailings in some cases of thousands of yards); stabilizing the consolidated ponds against a "probable maximum flood;" and capping the consolidated ponds with a six-foot thick cap comprised of a supposedly impermeable layer topped by an erosion layer, topped in turn by a growth medium. The total cost of tailings reclamation alone, for both sides of the mountain, reached \$21,000,000.

The State recognized that this represented a unique approach to tailings reclamation. It was not aware of any other place in which non-radioactive tailings had been reclaimed to this level. Apparently, both the consolidation and the capping requirement were driven in part by the State's approach to standards which mandated elimination of even the minimal seepage through the ponds which would occur were they recontoured and revegetated to ordinary levels, and also by its concept of permanence which demanded reclamation which would remain effective without even ordinary maintenance for many centuries. Obviously, the State's approach

would be effective to reclaim tailings ponds. The policy issue for the State is whether the minimal reduction in metals loading achieved would be worth the extra cost.

#### 4. Flood Standards.

The State insisted at Idarado that tailings ponds and other features be designed to the probable maximum flood standard. Again, this derived from the concept of permanence, i.e., that everything must be geared to stand "permanently." The State apparently reached this design standard for the mining facilities without regard for the fact that such a severe flood event would cause major damage to towns and other facilities located in the area--entirely apart from the effects of the tailings ponds. Few communities in mining areas have structures designed even to the 100-year flood standard. The tailings were not a threat to the Town, but still the standard was fixed--again without apparent regard for incremental costs or incremental benefits.

#### 5. Reclamation of Non-Idarado Properties.

On the Telluride side of the Idarado Mine, miners before Idarado had simply dumped their tailings into the San Miguel River or its tributaries. Over time, most of those washed down the river. In some places, as a result of dams built in earlier years, tailings had come to be deposited along the river banks. Idarado had never dumped tailings in the river but had always placed its tailings in engineered ponds. Nevertheless, the State sought to hold Idarado liable to clean up the deposits from the historic mines. The State espoused the "grain of sand" theory, i.e., if a grain of Idarado tailings may have become lodged with the older tailings whether as a result of minor erosion or snowmelt runoff from its tailings ponds, Idarado would be responsible to clean up all the tailings.

An even more difficult situation existed on the Red Mountain side of the mine. Red Mountain Creek is severely degraded by acid drainage from portals, waste piles, and ponds. Idarado causes only a small portion of that--by all calculations under 10 percent. Total cleanup of Idarado's property, which Idarado was prepared to do, would have a negligible impact on Red Mountain Creek. The real problem on Red Mountain Creek is numerous other properties which were never owned or operated by Idarado but which discharge into the surface and groundwater systems. The State's theory was that, because Idarado drainage found its way into Red Mountain Creek, Idarado should be compelled to clean up the entire creek. If the owners of the other properties could not be found or had no money and therefore



could not be compelled to contribute to the costs of cleanup, that would be Idarado's problem, not the State's. The State estimated the cost for that cleanup at more than \$14,000,000.

#### CONCLUSION: DOES RECLAMATION BELONG IN THE COURTS?

The experience of this case answers the question with a strong negative. The costs of court proceedings are simply excessive. In the course of trial and pretrial preparation, the parties used technical consultants with expertise in surface and groundwater hydrology, mine reclamation, range science and soils, aquatic biology, aquatic toxicology, geochemistry, medicine and toxicology, air quality, blood lead analysis, urban pollution, metallurgical engineering, and other disciplines. In this case, the State of Colorado has already identified more than \$2,000,000 of technical consultant and legal costs which it has incurred in the case. The defendants' side incurred even higher costs than that. Obviously, the cause of reclamation is better served if that money is spent on the ground, rather than in the courts.

Additionally, the time involved for litigation grossly delays implementation of reclamation. This case started in December 1983. The first phase of the case will not be decided until mid-1988. If either side wishes to appeal the outcome of that, and if the most expeditious appellate process is followed, it could easily be another two years before a final decision issued just on the first phase of this case. On the other hand, if the other phases of the case need to be tried and decided for a consolidated appeal, that total additional time could easily be three to five years. Ten years could elapse from the time this case was first filed before significant reclamation work is accomplished at the site!

The last major difficulty with the courtroom process is that decision making is turned over to the legal process rather than to a technical process. Lawyers and judges are not trained as reclamation specialists. The adversarial process of a trial is not geared to developing sound scientific solutions to complex technical problems. Why then take reclamation issues to the court as a first step? Surely, the classic administrative process as previously followed in Colorado to address reclamation problems should be the starting point. The State and its miners should at least try to develop reclamation and closure plans through administrative processes and negotiation. Only if and when that process fails should the parties resort to the courtroom.

The unanswered question here is whether the Idarado case and the other Superfund cases which were filed by Colorado against mining sites are aberrational or are the norm. In the future, will the State address problems of reclamation by coming to its miners to talk reasonably to develop reasonable solutions? Or will it come to its miners only with an invitation to litigation, i.e., a summons and complaint? We do not know who will answer these questions. We can say that what the answers are will be critical to the future of Colorado mining.

**A PRIMER ON CERCLA FOR THE MINING INDUSTRY**

Alan J. Gilbert, Esq.  
Ronald M. Eddy, Esq.

## A PRIMER ON CERCLA FOR THE MINING INDUSTRY

The purpose of this outline is to provide a mine operator with a basic understanding of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. §§ 9601, et seq., as amended significantly in 1986 by the Superfund Amendments and Reauthorization Act (SARA), Pub. L. No. 99-799, 100 Stat. 1613. The outline is not exhaustive. Rather, it is intended to provide a miner with a comprehensive enough overview of the workings of CERCLA to understand the problems facing the industry, as well as the significant threats CERCLA poses to the assets of his mine and his company.

### I. INTRODUCTION.

- A. CERCLA has already affected mining dramatically throughout the country. It has furnished federal, state, and local governments with an extremely powerful tool with which to address virtually all environmental problems created by the mining industry. It has changed the way property transactions take place, the way joint ventures and other operating agreements are structured, and the economics of the industry.
- B. To restate the obvious, mines are at great risk from CERCLA's comprehensive approach because they disturb the ground, the surface and ground water, and the atmosphere.
- C. It is our thesis that the only way a miner wins under this statute is to avoid the process entirely. As described below, once a formal CERCLA action has begun the only sure thing is that lawyers and technical consultants profit. That is no way to run a mining company.

### II. OVERVIEW OF CERCLA.

#### A. Background.

- 1. CERCLA is a federal statute, enacted by Congress in 1980 to remedy the problem of inactive and abandoned hazardous substance sites.
- 2. Prior to CERCLA, no federal statute addressed such sites. The Resource Conservation and

Recovery Act, 42 U.S.C. § 6901, et seq. (RCRA), had been enacted in 1976, and was directed at the generation, transportation and treatment, storage, and disposal of hazardous waste. Nevertheless, RCRA had been interpreted not to apply to existing inactive or abandoned disposal facilities.

3. CERCLA was, in large part, a reaction to Love Canal and similar, highly publicized hazardous substance incidents.
4. When CERCLA was enacted, its ambiguous and poorly drafted provisions led to considerable litigation over basic issues. Those issues have virtually all been decided in favor the enforcing government, and against the defendant (the mining company for purposes of this outline). In addition, most of the relatively minor issues the government managed to lose in court were typically reversed by Congress in the 1986 SARA amendments.

### III. HOW CERCLA WORKS.

#### A. Who is liable under CERCLA?

1. CERCLA creates four separate groups of liable parties (Section 107).
  - a. A current owner or operator of a hazardous substance facility (defined as a place where hazardous substances have come to be located). If you own a mine with a tailings pond, you are liable.
  - b. The past owner or operator of a hazardous substance facility if, at the time of his ownership, hazardous substances were disposed of at the site. This definition reaches back to previous mining companies in a historic mining area, for example.
  - c. Persons who "arrange for disposal" of hazardous substances at a facility at which such substances already exist. This is the broadest class of liable persons under CERCLA. It includes third parties who use

tailings ponds as solid waste disposal areas, or others who arrange, through contractual or other means, for disposal of hazardous substances at a mine site. It also includes a mine which sends waste to a landfill -- liability is for the landfill cleanup in that instance.

- d. Transporters of hazardous substances to a hazardous substance facility.
2. CERCLA only contains very limited defenses: They include (1) an act of war, (2) an act of God, and (3) a third party defense.
    - a. A mining company cannot depend upon an act of war or an act of God to shield it from CERCLA liability.
    - b. The last CERCLA defense -- that an act of a third party not contractually related to the miner solely caused a release and the harm -- is much narrower than it first appears.
  3. "Hazardous substances" are very broadly defined. They include several base metals (lead, zinc, and cadmium, for example), as well as many common degreasing solvents used for many years at mine sites where equipment was serviced and cleaned.
  4. CERCLA is characterized by overlapping liability. There are typically many people financially responsible for one CERCLA site. In a historic mining area, for example, the current mining companies, as well as mining companies who have long since left, as well as people who used existing tailings ponds or waste piles as landfills for hazardous substances, are all potentially liable for cleanup of the site.
- B. To whom are these parties liable under CERCLA?
1. CERCLA creates a cause of action -- the ability to bring a court case -- for the federal government, state governments and Indian tribes, and private parties. As described below, these plaintiffs are the beneficiaries of varying degrees of CERCLA remedies.

2. The federal government has at least three choices under CERCLA.
    - a. It can clean a mining site, using federal funds (from the "Superfund"), and then sue any one of the responsible parties for recovery of those costs as well as natural resources damages (Sections 104 and 107).
    - b. EPA can issue an order to a responsible party, requiring that person to clean up the site (Section 106).
    - c. EPA can bring an action asking a federal court to enjoin a responsible party to clean up a site (Section 106).
  3. States and Indian tribes have similar rights under CERCLA.
    - a. In a fashion similar to the federal government, a state or an Indian tribe is empowered to spend its own money to clean a site, and then sue responsible parties for reimbursement as well as natural resources damages (Section 107).
  4. Private parties have the hardest time recovering under CERCLA.
    - a. A private party can spend his own money to clean a CERCLA site, and then bring an action against responsible parties for reimbursement (Section 107).
- C. What acts make one liable under CERCLA?
1. There are three elements to liability which must be proven by plaintiff in a Section 107 action for reimbursement and natural resources damages:
    - a. a release or threatened release
    - b. of a hazardous substance
    - c. which caused response costs to be incurred.

2. In a Section 106 action for injunctive relief, the federal government must show:
    - a. there may be
    - b. an imminent and substantial endangerment
    - c. to the public health or welfare or the environment
    - d. because of an actual or threatened
    - e. release of a hazardous substance
    - f. from a facility.
  3. The elements of CERCLA liability are very easily met in either instance. A federal district court judge in Denver recently remarked, only half jokingly, that the Indians would be liable under CERCLA for dropping arrow heads on the Colorado plains!
  4. Once these Section 107 elements are shown, the federal government and state and Indian tribe governing bodies can recover all costs which are "not inconsistent" with the National Contingency Plan (a set of procedural rules promulgated by EPA. 40 C.F.R. Part 300).
  5. Private parties bear a more difficult burden of proof of Section 107 reimbursement costs under the statute. They recover "necessary" costs "consistent with" the National Contingency Plan.
  6. Courts have interpreted the distinction between "not inconsistent" and "consistent" to mean that a defendant, a miner in this instance, bears the burden of proving inconsistency against the federal government, state government, or an Indian tribe. In contrast, a private party plaintiff bears the burden of proving his or her costs "consistent." The distinction may make a practical difference at trial, resulting in suits much more difficult for private parties.
- D. Many CERCLA liability issues have been decided against defendants.



1. Liability under CERCLA is "strict." That means that a plaintiff need only show that a defendant carried out the activities described above, and not that there was any breach of duty (fault or negligence) in those activities.
2. CERCLA is clearly retroactive. Lawful acts accomplished many years ago give rise to CERCLA liability now. Those caught in a change of the rules, the defendant miner, in particular, still must pay for cleanup. As an example, an entirely lawful thirty-year old tailings pond or waste pile can trigger current liability.
3. The government need not show direct causation between the activity of the mining company and the release.
  - a. For example, a mining company reusing an old tailings pond may have only put hazardous substance "A" into that pond in recent years. Assume the pond is leaking hazardous substance "B" as a result of earlier mining activities. The first company remains liable for the entire cleanup -- because it arranged for disposal of hazardous substance "A" at a hazardous substance facility -- despite the fact that there is absolutely no connection between the materials the company placed on the pond and the materials leaking from the pond.
4. Liability under CERCLA is "joint and several," unless a defendant can show that there is a reasonable basis for a judge to force a plaintiff to pursue relief separately against several parties.
  - a. This issue arises in historic mining areas, particularly, where entire drainage basins are pockmarked by old mines, and filled with the attendant waste piles and tailings ponds.
  - b. The government has in several instances attempted to make one company liable for the cleanup of the entire basin described,

regardless of the fact that the company had no connection with the waste piles, tailings ponds, and portals created by other companies.

- E. What remedies are available to the CERCLA plaintiff?
1. All plaintiffs are entitled to reimbursement of cleanup costs, so long as those costs are incurred consistent with the requirements of the National Contingency Plan.
  2. The federal government is, in appropriate circumstances, entitled to an injunction requiring the defendant miner to clean his facility (and, perhaps, the facilities of others).
  3. The state and federal governments, as well as Indian tribes, are entitled to recover damages for injury to natural resources. These damages are intended to compensate for injury remaining after cleanup has taken place. They can include things like restocking now-clean streams or replanting vegetation.
- F. How the CERCLA process works in practice.
1. The CERCLA process before the federal government, particularly, has evolved into a commonly understood set of procedures. They are set out below, with the understanding that this outline is just a generalized overview of the process. It may vary dramatically from site to site.
  2. The first step in the process is the discovery of a hazardous substance site by the government. The site can be, for example, a vacant field with barrels, a hazardous waste landfill, a mining site complete with tailings ponds, waste rock piles, and portal drainages, or the bottom of a harbor where sediments are contaminated with hazardous substances. The discovery can be from the newspapers, a disgruntled employee, another level of government, or other means.
  3. The government first performs a Preliminary

Assessment. This is an initial, cursory, "paper" investigation of the site.

4. If the Preliminary Assessment concludes that the site may be a problem, it is ranked on the Hazard Ranking System, a mathematical model which is intended to represent -- through a numeric score -- the danger of this site relative to all other sites ranked.
5. If the ranking is high enough, the site is placed on the National Priorities List, a list of problem areas across the country which is published regularly by EPA.
  - a. Several mines and mining areas are listed on the National Priorities List.
6. If its hazard ranking warrants, the site is the subject of a Remedial Investigation (RI). This study, and the resulting document are an intensive and expensive characterization of the site and its problems.
7. The next step in the process is creation of a Feasibility Study (FS). The Feasibility Study announces the standards the government intends to use for cleanup, and then evaluates a variety of cleanup alternatives, with attendant costs and environmental effects.
8. The next step in the process is the last agency step. It is the issuance of a Record of Decision (ROD), which announces the remedy selected by the government.
9. The next step is issuance of an order, commencement of a lawsuit, or the beginning of cleanup by the government.

#### IV. CERCLA ISSUES FOR THE MINING INDUSTRY.

- A. Acquisition of mining properties in historic mining areas.
  1. The acquisition of mining properties raises substantial CERCLA risks in many circumstances. When a mining company becomes the current "owner

or operator" of a site, it inherits liability for virtually every hazardous substance activity that took place earlier.

2. The attached memorandum, concerning "CERCLA Liability Associated with Acquisitions of Mining and Other Properties," describes risks associated with purchases, as well as some suggestions for the mining operator.
  3. As a practical matter, it is our opinion that there is virtually no defense to CERCLA liability in the mine purchase context.
- B. CERCLA creates more technical issues than it does legal issues. (As described above, most controversial legal points have already been resolved against defendants by the courts or by Congress.)
1. The mining company knows better than the government what the problem is at a site and how to fix it.
  2. The company's technical resources must be brought to bear in a useful way, or the government's remedy will not make sense.
- C. Standards for cleanup.
1. A major issue under CERCLA is how clean a site must be at the end of remediation to satisfy CERCLA's requirements.
  2. As a general rule, a cleanup under CERCLA must assure protection of human health and the environment, must be cost effective, and must provide a permanent solution. Each of these requirements is technically and legally controversial.
    - a. The government requires all remedies to protect public health and the environment first, and only then looks to cost-effectiveness.
  3. This issue has been translated, first through the National Contingency Plan and then through the SARA amendments, to a consideration of what

standards should be used to measure cleanup, and where those standards should be measured in the environment. Applicable and relevant and appropriate requirements (ARARs) are to be chosen, and then applied at an appropriate place, to measure CERCLA cleanups.

- a. "Applicable" requirements are those federal requirements which would be legally applicable if the response action in issue had not been taken pursuant to CERCLA. They include things like water pollution standards for point source discharges, air pollution standards for incinerators, and the like. The actual permits are not required, but their technical requirements are folded into the CERCLA process.
  - b. The more difficult issue is the choice of "relevant and appropriate" requirements. These are federal requirements which, while not applicable, are designed to apply to problems sufficiently similar to those encountered at the site that their application is appropriate.
  - c. No one knows how to pick relevant and appropriate requirements. As an example, should federal water quality criteria be used as "appropriate and relevant" in a stream that supports catfish when the particular criteria was designed to protect a different kind of fish, such a trout?
4. EPA has split ARARs into three categories. These include action-specific requirements (like sludge disposal requirements), location-specific requirements (such as historic protection laws), and chemical-specific requirements (such as a technology-based standard for lead under the Clean Water Act).
  5. State standards, too, can be applied in a CERCLA action if they are brought to the federal governments' attention and are routinely used by the state. Federal and state relations have been strained recently over differences of opinion in this area. The latest example is the

controversy over the cleanup of the Rocky Mountain Arsenal near Denver, Colorado.

6. The point of measurement of an ARAR is critical. The difference between measuring for heavy metals in the ground at the boundary of a tailings pond, for example, as opposed to the confluence of any groundwater and a nearby stream, can mean the difference in many millions of dollars of cleanup costs.
7. The determination of standards is a case-by-case determination. It is the single most important issue in the CERCLA cleanup process.
8. Decisions concerning appropriate cleanup standards are, virtually always, matters of technical judgment.
9. Example: mine site, point and non-point sources of heavy metal entering surface and groundwaters, located in a highly mineralized area where mining has occurred for more than 100 years.
  - a. What concentrations of heavy metals should be used as the "goal" of the remediation? Where should they be measured?
    - (1) If federal water quality criteria are used, as suggested in SARA, the miner will be faced with extremely stringent levels.
    - (2) Those levels can be lower than metals levels that occur in neighboring streams unaffected by mining activities.
    - (3) Must the remedial measures adopted ensure that the metal levels are met at all times, or can they fluctuate above and below the ARAR level? How does one account for seasonal fluctuations in metals concentrations?
    - (4) Where should metals concentrations be measured? If measurement point is right next to a tailings pond or under

the pond, for example, extreme remediation may be required. If the measuring point allows for some dilution instream or in the ground, the expense of cleanup may be considerably less.

- (5) Even if instream values exceed ARARs, does it matter from an environmental standpoint? How does one take into account the fact that certain aquatic organisms can easily acclimate to concentrations of metals well above federal criteria levels?
10. How does one assure a "permanent" remedy, as required by statute? Permanence is difficult to define in practice. Nothing lasts forever. Given the fact that cost-effectiveness is another remedy standard to be met in CERCLA, can permanence and cost effectiveness both be satisfied at once?
- a. The "permanence" problem becomes very practical very quickly. By requiring EPA to assure that any remedy is permanent, the Agency is forced to examine very minor risks at the front end of the remedy process. That translates into very expensive, theoretical remedies, as the Agency tries to protect against all eventualities. In contrast, the typical construction process, normal at most mines, is to try a sensible, less expensive remedy first, and add patches if it does not work.
  - b. Does permanence require removal of materials from a site? If it does, cleanup is going to be extremely expensive.
    - (1) As an example, EPA estimates that the cleanup of Lowry Landfill near Denver, Colorado, would take 25 years and cost approximately \$3 billion if total removal is chosen. That will not leave much money in the economy of Denver. It also presumably will not leave many responsible companies operating. The

same problem can be true in a mining context.

- c. How does one argue with EPA, on a technical level or otherwise, concerning permanence?
- D. The CERCLA process requires a company to follow unusual procedures to work successfully with the government. If they are not followed, the company's attempts will be ineffective.
1. The company will be forced to work within the Remedial Investigation/Feasibility Study framework if the government is taking a lead role.
    - a. It must provide comments as part of the administrative process and on the government's schedule. The government's experts must be rebutted in writing, but, more importantly, the company must offer new ideas concerning more appropriate remediation.
    - b. The activities of the company must be directed first at convincing EPA, but must always address the possibility that a judge will be reviewing the matter to make a final decision.
    - c. It is very difficult to have significant impact on the process until the remedial design phase. By then, however, many of the significant issues may be already decided.
  2. The federal government is moving -- apparently -- toward a more cooperative technical process. EPA is willing, up to a point, to listen to your experts.
- E. EPA will be afforded a great degree of deference in its remedial decisions by a reviewing court, if matters get that far. That can be a very significant problem.
1. EPA has little experience in the actual construction of remediation at mine sites. Your



in-house people will become very frustrated very quickly.

2. The federal agency is plagued by rapid turnover. Once you have trained a lawyer and a project manager on the fine points of mining and construction, they leave to take jobs in private industry.
3. EPA uses outside contractors heavily. It is typically very difficult to communicate with the government's consultants, a group whose mission is to please the Agency, not to make mining sense or economic sense.

F. What kind of expertise do you need if you have a CERCLA problem?

1. You are going to need a lawyer familiar with the CERCLA process to guide you. Your comments to the government, if made at the wrong time, for example, will be useless.
2. You will need technical experts. You will need people that know their job, can explain their technical judgments clearly, and have a high frustration threshold. These people will be at the center of your defense efforts.
  - a. They will be required to critique the government's scientific data and conclusions.
  - b. They will be required to offer common sense opinions on the best way to address the cleanup issues.
  - c. They must be people who can translate abstract science into case-by-case solutions.
  - d. They must be able to deal with technical uncertainty, make a decision on a reasoned basis, and move on.
  - e. You need someone in charge of your technical program who can develop a coherent overall approach to your problems.

G. Frustrations with the CERCLA process are normal.

1. The miner must be prepared for the tremendous frustrations of being involved in a Superfund action.
  - a. Dealing with the government can be frustrating on many levels. It is difficult to address technical issues when it is difficult to talk to the government's contractors. It is likewise difficult to address technical issues with an Agency project manager who is in experienced.
  - b. Lawyers on both sides get in the way of technical judgments (sometimes for good reasons, sometimes not).
  - c. Consistent with its "permanence" mandate under CERCLA, the government approaches remediation with virtually no regard for the costs involved. It will be up to you to raise that issue. As a federal judge stated recently, the government likes to fly first class so long as someone else is paying the bill.
  - d. You must be prepared to accept a "wrong" solution which is better than the first "wrong" solution proposed.
  - e. Upper level management will not understand the process, why money is being spent at such an alarming rate, and the ultimate expense of cleanup. A little education -- in the form of first-hand experience with the government or its lawyers -- usually does wonders.

## MINED LAND RECLAMATION IN SOUTH DAKOTA

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### ABSTRACT

Mining activities have increased greatly in recent years in the Black Hills area. The value of non-fuel mineral production increased 33 percent from 1983 to 1987 and earnings from metallic mining increased 20 percent in that same period. This increased activity has forced a clash of values and ideals in the state.

Unlike most western mining areas, the Black Hills are fairly heavily populated. Furthermore, as the highest mountains between the Rockies and Atlantic Ocean, the Black Hills have unique historic and scenic value. The Hills provide many recreational opportunities and are the site of vacation homes for people from a five state area. Pressure to preserve this environment is strong.

Mining, on the other hand, is a major source of economic activity, providing a total payroll of \$65 million in the state annually with a projected increase of \$17 million by 1990. At a time when economic development is being stressed heavily as the paramount state objective, regulation of mining activities must be considered very carefully.

The mining task force and the Board of Minerals and Environment were faced with the assignment of balancing the sensitive natural and political environment of the Black Hills with increasing developmental pressure from mining interests. The task force responded by passing a new set of rules that permit mining but require fairly stringent reclamation measures. The general reclamation standards require physical reclamation to achieve "visually and functionally compatible contours." Although grading and backfilling may be required to achieve this standard, mining companies are relieved of this obligation to the extent they can demonstrate the physical, economic or aesthetic infeasibility of the effort.

## Reclamation of Abandoned Bentonite Mined Lands

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### INTRODUCTION

Lands disturbed by and abandoned after bentonite mining in the Northern Great Plains are difficult to reclaim because of adverse chemical and physical properties of the spoil material, the arid/semiarid climate of the area, and to some extent, the mining methods utilized. Ninety percent of the nation's supply of bentonite is mined in Montana, South Dakota and Wyoming. Wyoming alone accounted for 74% of the total U.S. production in 1979 (Ampian 1980). Large scale bentonite mining began in the region in the 1930's. However, few mined areas were reclaimed before the early 1970's, when most of the Northern Great Plains states passed reclamation laws. The National Academy of Sciences (1974) reported that in Montana more land was disturbed in 1973 by bentonite mining than by coal mining, and that more abandoned spoils had accumulated over the years from bentonite mining than from coal. Although these statements refer to Montana, they are indicative of the regional situation. Estimates of abandoned bentonite spoils in the region range from 16,000 to 26,000 hectares.

Bentonite is produced by the alteration of volcanic ash into clay minerals. Approximately 75 million years ago ash from volcanic eruptions in the Rocky Mountain Region was carried eastward by high-altitude winds and deposited in bodies of saline water in the western Great Plains. The resultant clay beds cover extensive areas and represent several periods of ash deposition. Because most of the clay beds were formed in a marine environment, soils/spoils associated with these deposits are generally high in soluble salts, especially sodium, resulting in a highly saline-sodic and dispersed system. The spoils are generally characterized by low to medium fertility, high pH, low water infiltration, high run-off potential and high bulk density.

Due to the irregular distribution of mineable, high grade, bentonite deposits; small (1 to 8 ha) shallow (15 m) pits tend to be interspersed with nonmined areas in discontinuous patterns over the landscape. This "extensive" rather than "intensive" land disturbance directly or indirectly affects large land areas, and can cause logistical problems in reclamation.

Natural revegetation and seeding of non-topsoiled, non-amended bentonite spoils has resulted in poor plant establishment (Sieg et al. 1983; Dollhopf and Bauman 1981); therefore, spoil modification is essential for successful revegetation of these lands.

Reclamation of abandoned bentonite spoils has met with limited success (Hemmer et al. 1977; Dollhopf and Bauman 1981; Bjugstad et al. 1981) unless organic amendments were utilized to enable greater water infiltration into the spoil and to reduce crusting. Dollhopf and Bauman (1981) evaluated the use of organic (sawmill wastes, manure and straw) and inorganic (gypsum, calcium chloride and sulfuric acid) amendments. The use of inorganic amendments in conjunction with straw mulch and irrigation resulted in poor to no plant establishment (Dollhopf and Bauman 1981). Dollhopf and Bauman (1981) also evaluated the effect of inorganic amendments on the hydraulic conductivity of spoil material. They found that although these materials increased the hydraulic conductivity of the spoil, the increase was not great enough to bring it above the 'very slow' permeability class,  $0.125 \text{ cm hr}^{-1}$  (Kohnke 1968).

These findings are not unexpected since, inorganic amendments alone would require several years to improve spoil physical characteristics through the replacement and leaching of sodium. To be effective, inorganic spoil amendments need to either be used in conjunction with other amendments that result in the immediate improvement of physical characteristics, thereby allowing water to infiltrate, or be applied to the spoil alone and allowed sufficient time to react before seeding. Hemmer, et al. (1977) and Dollhopf and Bauman (1981) reported improved seedling establishment on spoils amended with wood residue. Bjugstad et al. (1981) also reported greater growth of two woody shrubs and two forbs when the spoil was amended with perlite and vermiculite.

The purpose of this paper is to describe the development of a reclamation technology that has proven successful for revegetating abandoned bentonite spoils.

## TECHNOLOGY DEVELOPMENT

### Preliminary Evaluation

Field studies were initiated in 1979 on 1.5 ha of leveled abandoned bentonite spoils near Upton in northeastern Wyoming (Schuman and Sedbrook 1984). The long-term average annual precipitation of the area is 37 cm, which occurs mostly (22 cm) as spring and early summer rainfall. The average frost-free period is 165 days.

The study involved an initial evaluation of the feasibility of using wood residue as an amendment to effectively modify spoils and thereby aid revegetation. Wood residue rates of 0, 112, and 224 Mg  $\text{ha}^{-1}$ , nitrogen at 5.0 kg N  $\text{Mg}^{-1}$  of wood residue and phosphorus at 90 kg P  $\text{ha}^{-1}$  were incorporated into the leveled spoil to a depth of 30 cm. The plots were drill seeded in mid-June with a mixture of crested wheatgrass (Agropyron desertorum), thickspike wheatgrass (A. dasystachyum), western wheatgrass (A. smithii), streambank wheatgrass (A. riparium), fourwing saltbush (Atriplex canescens),

yellow sweetclover (Melilotus officinalis), black greasewood (Sarcobatus vermiculatus) and rubber rabbitbrush (Chrysothamnus nauseosus) at the rate of 18 kg pure live seed (PLS) ha<sup>-1</sup>.

Perennial grass aboveground biomass estimates were obtained in 1980-1983. Plant biomass averaged 12, 712 and 897 kg ha<sup>-1</sup> for the 0, 112, and 224 Mg ha<sup>-1</sup> wood levels, respectively, over the four years. No significant differences in biomass were observed between the 112 and 224 Mg ha<sup>-1</sup> treatments. Biomass of perennial grass species increased during the four years on the amended treatments. Wood residue amendment of the spoils resulted in greater water infiltration and storage and in reduced bulk density in the zone of incorporation. Results of this pilot study demonstrated the beneficial effects of wood residue on revegetating abandoned bentonite spoils; therefore, further refinement of the procedure was warranted.

### Technology Refinement

Approach - Refinement of wood residue and nitrogen fertilizer rates was needed to insure the most efficient treatment combination for adequate revegetation. Therefore in 1981 a second study was established about 1 km from the preliminary study site. The study design was a split plot type with a split block within the main treatment (wood residue). Four wood residue rates (0, 45, 90, and 135 Mg ha<sup>-1</sup>), four nitrogen fertilizer rates (0, 2.5, 5.0, and 7.5 kg N Mg<sup>-1</sup> of wood residue) and two seed mixtures (native and introduced species) were established on regraded abandoned bentonite spoils (Figure 1). Phosphorus was applied at the rate of 90 kg P ha<sup>-1</sup>.

Nitrogen fertilizer was applied on the basis of wood residue rate and not area to enable maintaining a uniform carbon:nitrogen ratio across treatments. Nitrogen fertilizer rates on the control plots, where no wood residue was applied, were the same as those applied to the 45 Mg ha<sup>-1</sup> treatment (0, 112, 224 and 336 kg N ha<sup>-1</sup>). The nitrogen rates selected were based on a preliminary greenhouse study conducted by Ludeman and Schuman (G.E. Schuman, 1979, personal communication). After application of wood residue and fertilizer amendments, the spoil was chiseled to 30 cm depth and disked to incorporate the amendments.

In October 1981, the plots were drill seeded with either the native or introduced grass species mixture. A native shrub, Nuttall saltbush (Atriplex nuttallii), was included in both grass mixtures. The native species mixture included: western wheatgrass, thickspike wheatgrass, slender wheatgrass (A. trachycaulum), streambank wheatgrass and green needlegrass (Stipa viridula). Grasses in the introduced species mixture included: crested wheatgrass, tall wheatgrass (A. elongatum), intermediate wheatgrass (A. intermedium), pubescent wheatgrass (A. trichophorum) and smooth brome (Bromus inermis). The seeding rate was 650 PLS m<sup>-2</sup>, with each grass species sown at the rate of 130 PLS m<sup>-2</sup>. Nuttall saltbush was seeded at the

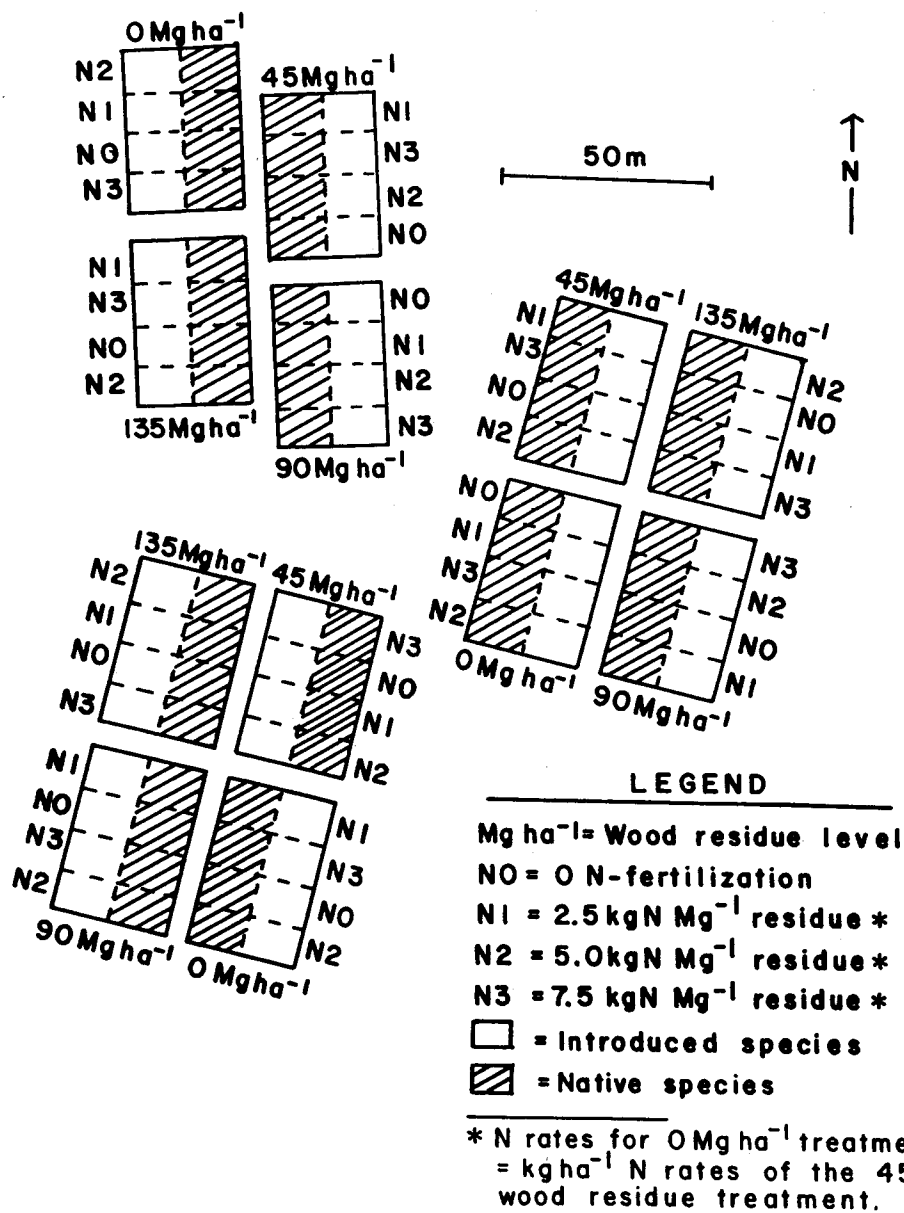


Figure 1. Field plot design of study with respect to wood residue, nitrogen fertilization and seed mixture treatments. (Smith, et al. 1985).

rate of 32 PLS m<sup>-2</sup>. Seedling emergence, seedling survival and seedling density data were obtained in 1982. Plant production data were obtained in 1983-86. Soil samples were taken each spring (1982-85) to evaluate the moisture and salinity status of the spoil. Wood residue decomposition was evaluated in 1984-86, utilizing a buried litter bag technique.

**Spoil Responses** - The high clay content and saline-sodic characteristics of the spoil (Table 1) resulted in a poor seedbed. One of the main benefits derived from the wood residue amendment of the spoil was increased water infiltration. This increased water infiltration resulted in greater water storage for vegetation establishment and the leaching of soluble salts. The data in Table 2 demonstrate the increased moisture in the spoil attributable to the wood residue. The 0-15 cm spoil depth exhibited the greatest increase in water content. However, the 15-30 cm depth also exhibited higher water content than the untreated spoil. No consistent soil water pattern was evident among treatments for the 30-45 cm depth. This lack of response below the depth of wood residue incorporation is not unexpected, since the untreated spoil has a very limited permeability. These data showed that the 90 and 135 Mg ha<sup>-1</sup> wood residue rates resulted in significantly greater water storage in the surface 30 cm of spoil than that observed for the 0 and 45 Mg ha<sup>-1</sup> rates. The observed increases in water content were likely the result of decreased bulk density, improved 'spoil structure' and increased water infiltration.

One benefit of increased water infiltration into the spoil was the leaching of soluble salts. The increased water movement into the spoil resulted in significant leaching of the soluble salts from the surface 15 cm of spoils (Figure 2) from 1981 to 1984. However, in 1985 a severe drought resulted in significant upward migration of salts as a result of upward water movement in response to evapo-transpiration. Even though upward salt migration occurred during the drought year, the electrical conductivity of the 0-15 cm depth did not exceed the 1982 level. It is anticipated that with normal or above normal precipitation, leaching of soluble salts will continue. Leaching was also a function of wood residue rate (Figure 3); however, the only significant differences were in the 0-15 cm spoil depth.

The incorporation of wood residue into the spoil has definitely increased water infiltration, resulting in leaching of soluble salts from the surface 15 cm of the spoil. However, further examination of the soluble cation data has shown an increase in the sodium-adsorption-ratio (SAR) of the spoil profile over time in residue amended plots, ( $SAR = Na^+ / [(Ca^{++} + Mg^{++})/2]^{1/2}$ ), where cation concentrations are expressed as meq/liter). The pool of soluble sodium (91% of soluble cations) is so large that as leaching occurs, the relative proportion of sodium compared to calcium and magnesium has become greater, thereby increasing the SAR (Figure 4). This observed increase in the SAR can have significant long-term effects



Table 1. Physical and chemical characteristics of pretreatment bentonite spoil samples, 1981. (Smith et al. 1985).

Parameter	Mean and standard error*	
<u>Particle-size separates, %</u>		
Sand	10.8±	0.8
Silt	29.6±	0.8
Clay	56.6±	1.1
NO <sub>3</sub> -N, mg kg <sup>-1</sup>	7.7±	0.4
NH <sub>4</sub> -N, mg kg <sup>-1</sup>	2.6±	0.1
Kjeldahl-N, mg kg <sup>-1</sup>	751.1±	5.8
P, mg kg <sup>-1</sup>	8.1±	0.3
C, g kg <sup>-1</sup>	10 ±	1
pH	6.8±	0.1
EC <sub>se</sub> , dSm <sup>-1</sup>	13.4±	1.1
<u>Soluble cations, mg kg<sup>-1</sup></u>		
Ca	187.9±	9.2
Mg	73.6±	4.2
Na	3613.7±	101.3
K	32.0±	0.8
Sodium adsorption ratio (SAR)	63.1±	1.2

\*Particle-size separates obtained from five observations, all other parameters are a mean of 144 samples.

Table 2. Mean soil-water content across nitrogen fertilizer treatments, for four wood residue levels, at three sample depths, 1982-1985, (Belden 1987 and Smith 1984).

Wood Residue Mg/ha	Sample Depth (cm)		
	0-15	15-30	30-45
	-----§-----		
		<u>1982</u>	
0	15.3	13.9	14.0
45	16.7	13.7	12.7
90	23.9	17.0	12.9
135	24.9	18.3	14.0
		<u>1983</u>	
0	14.9	13.9	13.4
45	17.4	13.6	12.7
90	19.6	16.3	13.5
135	19.6	16.8	13.7
		<u>1984</u>	
0	14.5	14.5	14.3
45	15.9	13.2	13.5
90	16.3	15.4	14.7
135	18.1	16.3	15.5
		<u>1985</u>	
0	15.6	13.8	14.4
45	19.3	14.1	13.5
90	26.1	16.0	14.1
135	29.1	17.3	14.9

lsd<sub>05</sub> = 2.6 to compare soil-water between wood residue levels within a sample depth and year; 2.4 to compare soil-water between sample depths within a wood residue level and year; 2.3 to compare soil-water between years within a wood residue level and sample depth.

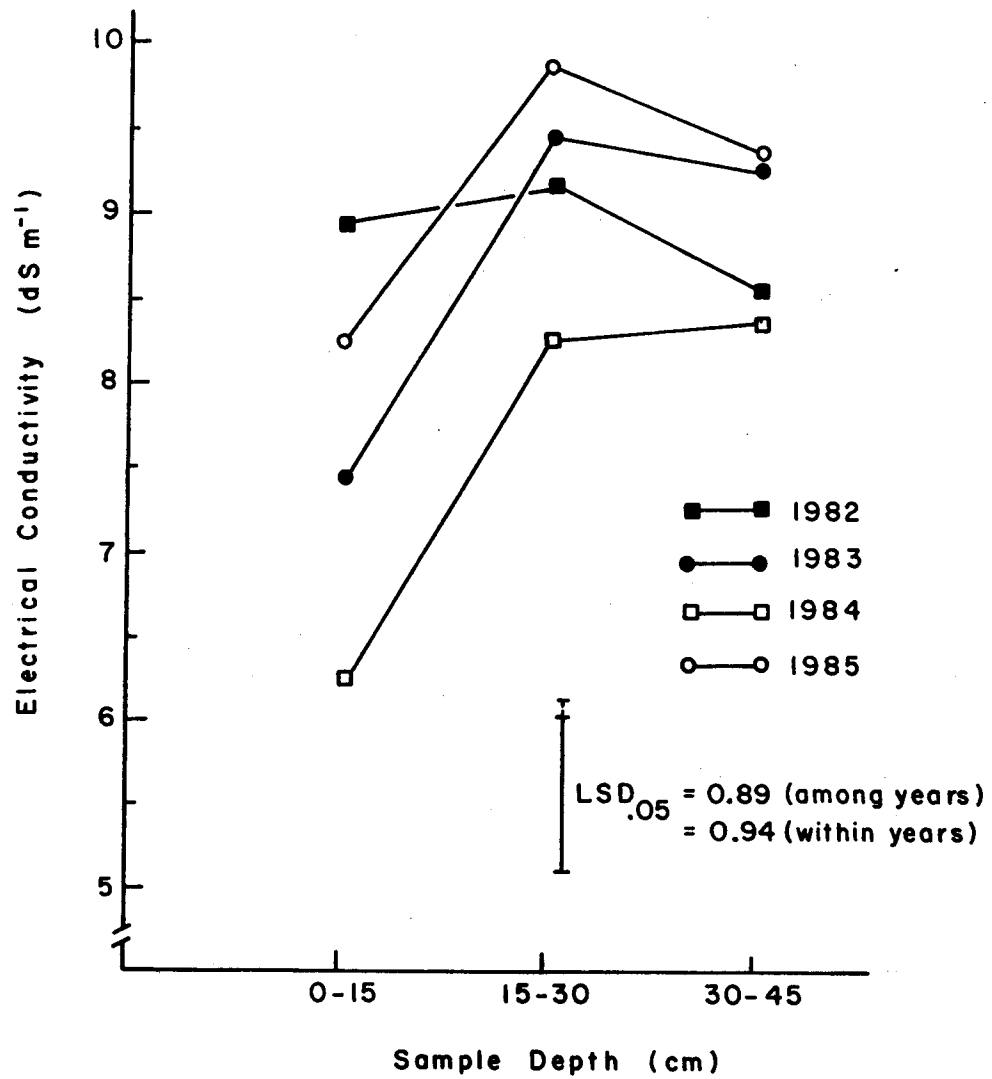


Figure 2. Mean electrical conductivity across wood residue and nitrogen fertilizer treatments, for 1982-1985 at three sample depths. (Belden 1987)

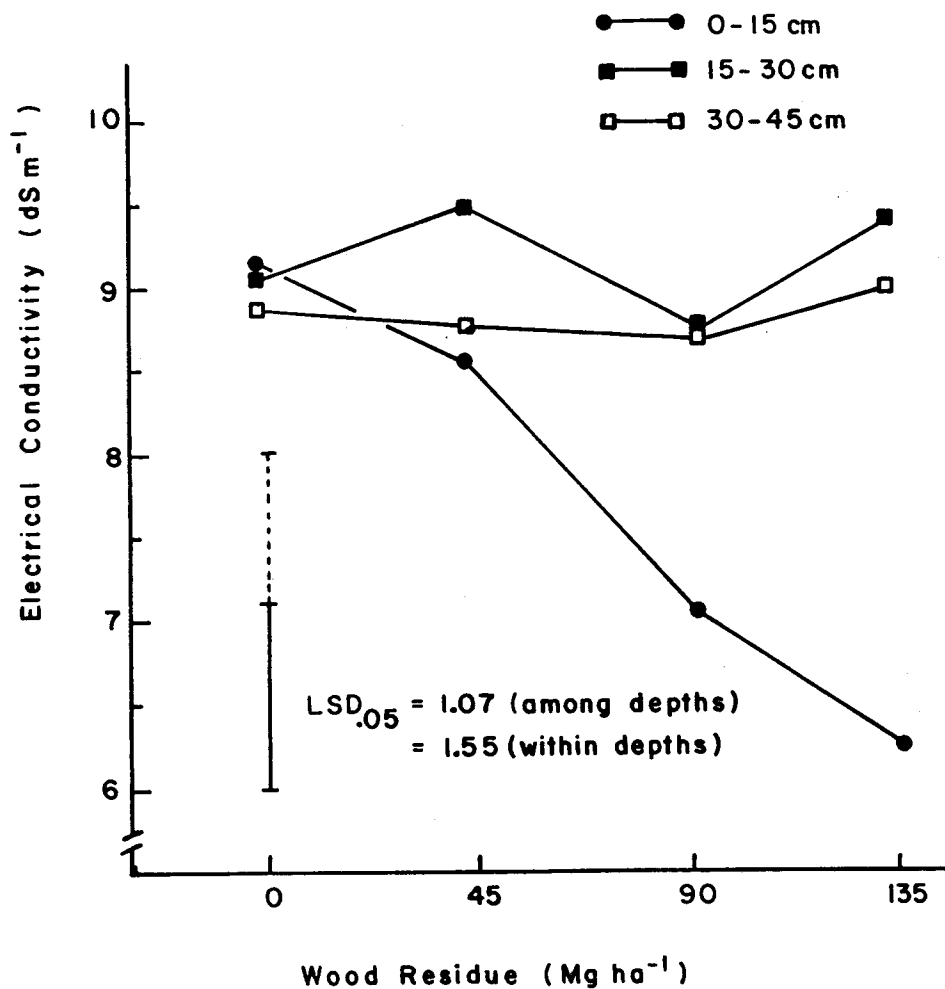


Figure 3. Mean electrical conductivity across nitrogen fertilizer treatments and years, at three sample depths, for four wood residue levels. (Belden 1987)

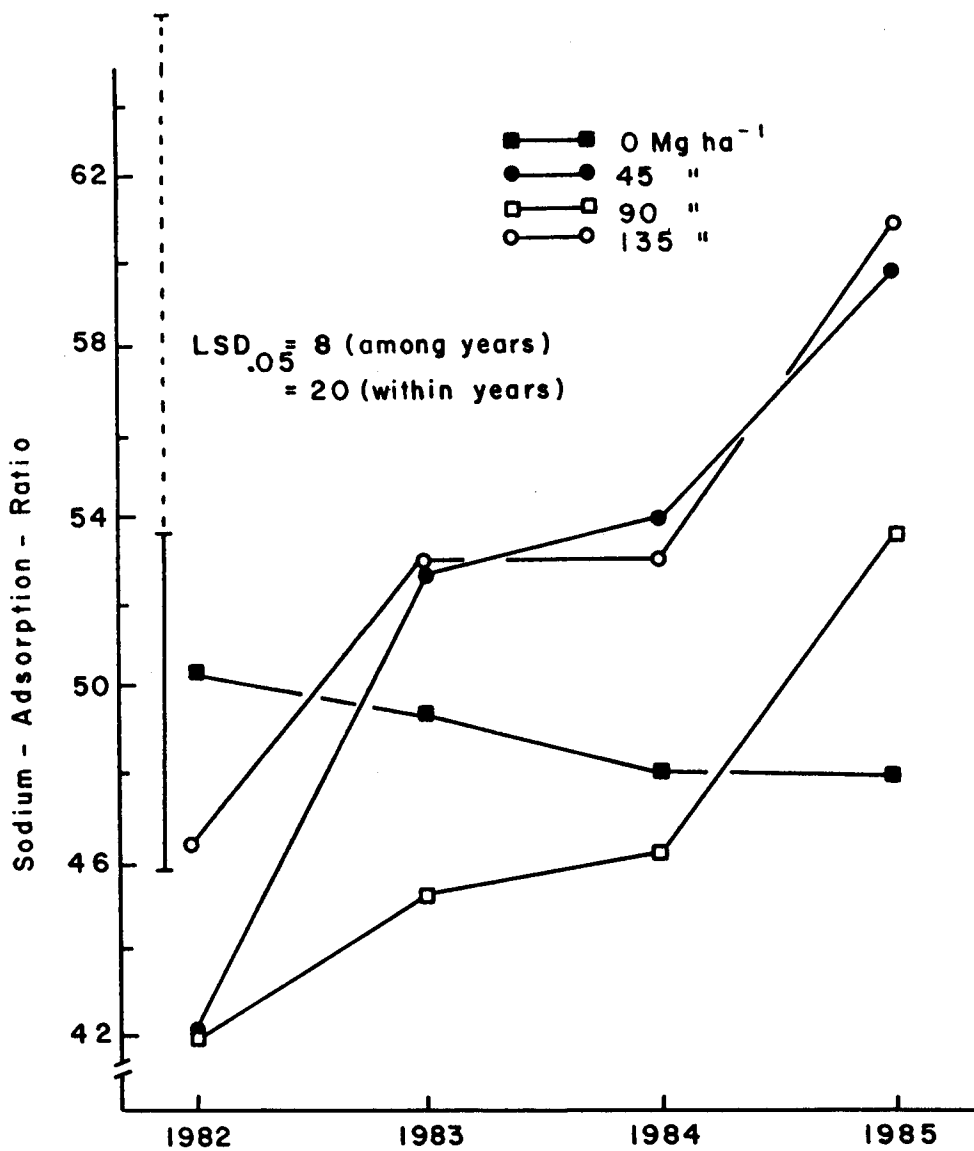


Figure 4. Mean sodium-absorption-ratios across nitrogen fertilizer treatments and sample depths, at four wood residue levels, for 1982-1985. (Belden 1987)

on plant nutrition, soil physical qualities and subsequent maintenance of the vegetation. The increasing SAR indicates that chemical amendments are necessary, in addition to the wood residue, to insure long-term reclamation and revegetation success. Such chemical amendments may include calcium compounds such as gypsum or calcium chloride.

Vegetation Responses - Seedling density was significantly influenced by wood residue rate because of its effect on soil-water content, soil crusting and bulk density (Figure 5). Seedling density and survival were not different between the native and introduced species mixtures. Seedling density was significantly greater for the three nitrogen fertilizer treatments than for the treatment receiving no nitrogen. However, there were no differences in seedling density between the three nitrogen fertilizer levels.

Perennial grass aboveground biomass increased as wood residue rates increased, with the maximum production occurring at the 135 Mg ha<sup>-1</sup> wood residue level (Table 3). The data in Table 3 represent the average biomass of the native and introduced grass species mixtures, since in only two instances were there any significant differences between the seed mixtures. Grass biomass in 1985 was extremely low compared to previous years because of the extreme drought. Precipitation from August 1984 through June 1985 was approximately 60% of normal for the period. However normal precipitation occurred in late summer 1985 and the 1986 growing season, resulting in the improved production observed in 1986. Visual observations of the plant community in 1986 indicated that some plant mortality had occurred as a result of the 1985 drought; therefore, predrought production levels may not be reached for several years.

Perennial grass biomass also responded to nitrogen fertilizer rates in 1983 and 1984 with peak biomass occurring at the 2.5 and 5.0 kg N Mg<sup>-1</sup> of wood residue rates, respectively (Figure 6). In contrast, nitrogen fertilizer had no appreciable affect on the aboveground biomass in 1985 and 1986. The limited nitrogen fertilizer response in 1985 and 1986 was probably the result of the drought. It is important to have adequate nitrogen present for both plant growth and decomposition of the wood residue.

Species mixtures generally did not respond differently to the amendments. However, the native species mixture produced greater aboveground biomass at the 90 Mg ha<sup>-1</sup> wood residue rate in 1983 and 1984, whereas the introduced species mixture exhibited greater production in 1983 for the 135 Mg ha<sup>-1</sup> treatment.

Vegetation diversity for both seed mixtures peaked at residue rates lower than those required for maximum forage production (45 and 90 Mg ha<sup>-1</sup> for native and introduced species mixture, respectively) (Smith et al. 1986).

With the exception of tall wheatgrass, all successfully established grass species were rhizomatous. This indicates that sod-forming grasses are generally better suited than bunchgrasses

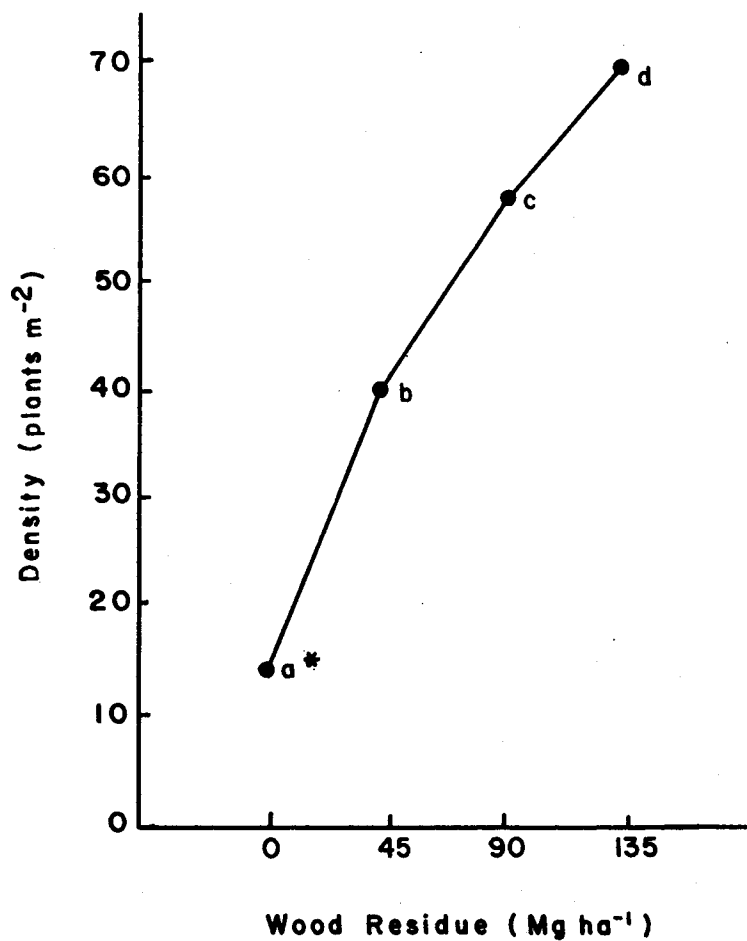


Figure 5. First-year density of seeded perennial grasses as related to wood residue level. Upton, WY, August 1982. (Smith 1984)

\*Each value represents the mean of 96 observations; values with the same lower case letter are not significantly different at the 5% level as evaluated by Duncan's Multiple Range Test.

Table 3. Perennial grass aboveground biomass (averaged across fertilizer N treatments) in response to wood residue rate, Upton, WY, 1983-1986. (Smith 1984, Belden 1987 and unpublished data)

Year	Wood Residue (Mg ha <sup>-1</sup> )			
	0	45	90	135
	kg ha <sup>-1</sup>			
1983	59	669	1748	2550
1984	80	361	1220	1956
1985	10	55	148	448
1986	15	116	324	886



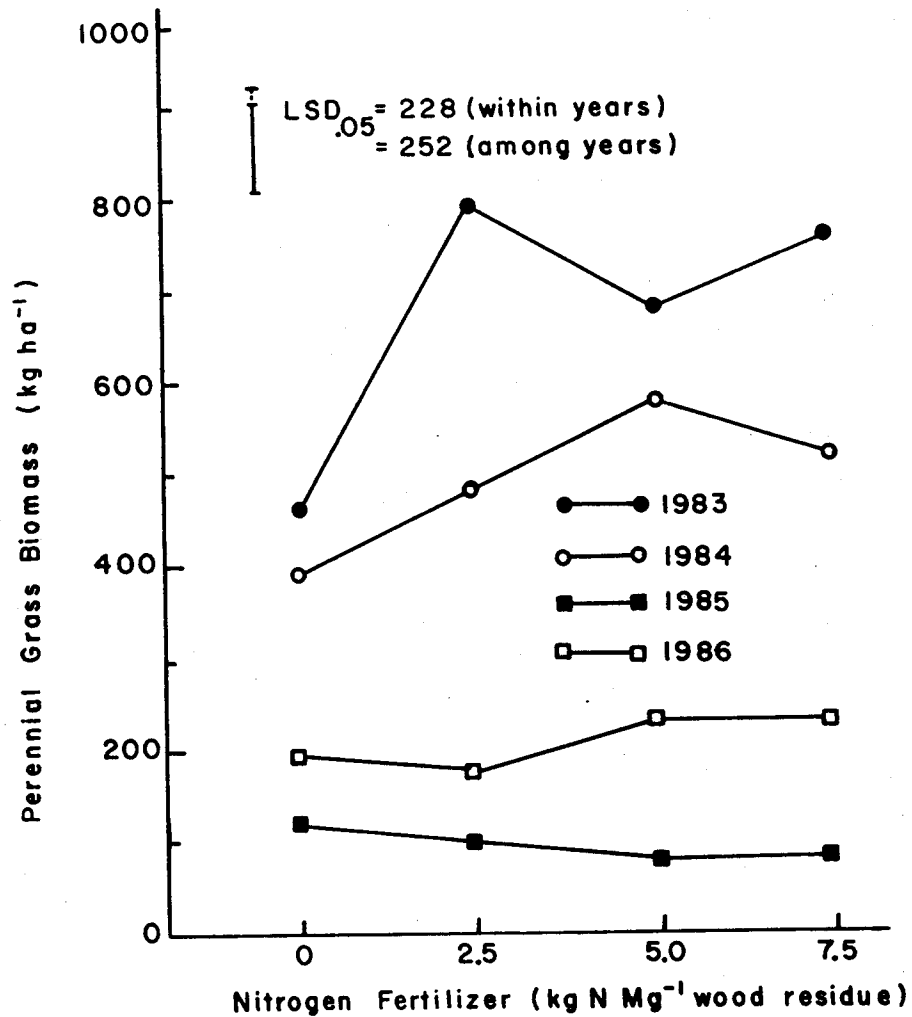


Figure 6. Mean perennial grass biomass across the 45, 90 and 135 Mg ha<sup>-1</sup> wood residue treatments and seed mixes, at four nitrogen fertilizer levels, for 1983-1986. (Belden 1987 and unpublished data) LSD values are for evaluating 1983-1985 data only.

for revegetation of bentonite spoils. The predominance of sod-forming grasses on dense clay soils in the region support this observation (Weaver and Albertson 1956). Rhizomes have been noted to exhibit physical resistance to breakage and the capacity for regrowth and/or increased production from rhizomes after breakage in a high clay soil (White and Lewis 1969). A more detailed discussion of individual species and community level responses was given by Smith et al. (1986).

This study has shown that plant species potentially useful and/or successful in revegetation of wood residue amended abandoned bentonite spoils should have at least some of the following characteristics: sod-forming morphology, drought and salt tolerance, adaptation to clay texture, and adaptation to a shallow, poorly drained spoil environment (Smith et al. 1986).

Wood Residue Decomposition - Decomposition of the wood residue increased with increasing nitrogen fertilizer levels (Figure 7). After 36 months, decomposition of the wood residue was 11.5, 15.1, 17.7 and 18.5% for the 0, 2.5, 5.0, and 7.5 kg N/Mg of wood residue treatments, respectively. These data support the hypothesis that decomposition occurs more rapidly at narrower carbon:nitrogen ratios, where nitrogen is less limiting to microorganisms. Decomposition generally increased with increasing wood residue rates during the 36 months, with the exception of the 23 and 36 month observations for the 90 Mg ha<sup>-1</sup> wood residue rate. Based on the rate of decomposition in the initial 36 months, most of the wood residue would decompose in 15 to 25 years, assuming a constant rate of decomposition. However, decomposition should progress more slowly in later years, because a greater proportion of the remaining material is lignin, which is very resistant to microbial degradation. This slower rate of wood residue decomposition is desirable since the residual residue will continue to enhance water infiltration, salt leaching, soil development and sustained plant growth.

#### SUMMARY

This paper has outlined the development of a reclamation technology for abandoned bentonite spoils, and has summarized the findings of research supporting this technology. Wood residue amendment improved the physical and chemical characteristics of the spoil, resulting in improved water infiltration and the concurrent establishment of a desirable, productive plant community. However, these studies have also pointed out the need for an inorganic amendment, such as gypsum, to be incorporated along with the wood residue and fertilizer to replace the sodium in the system and to prevent further deterioration of the spoil. It is important to understand that the inorganic amendment is complimentary to the wood residue and not a substitute for it. The wood residue is necessary

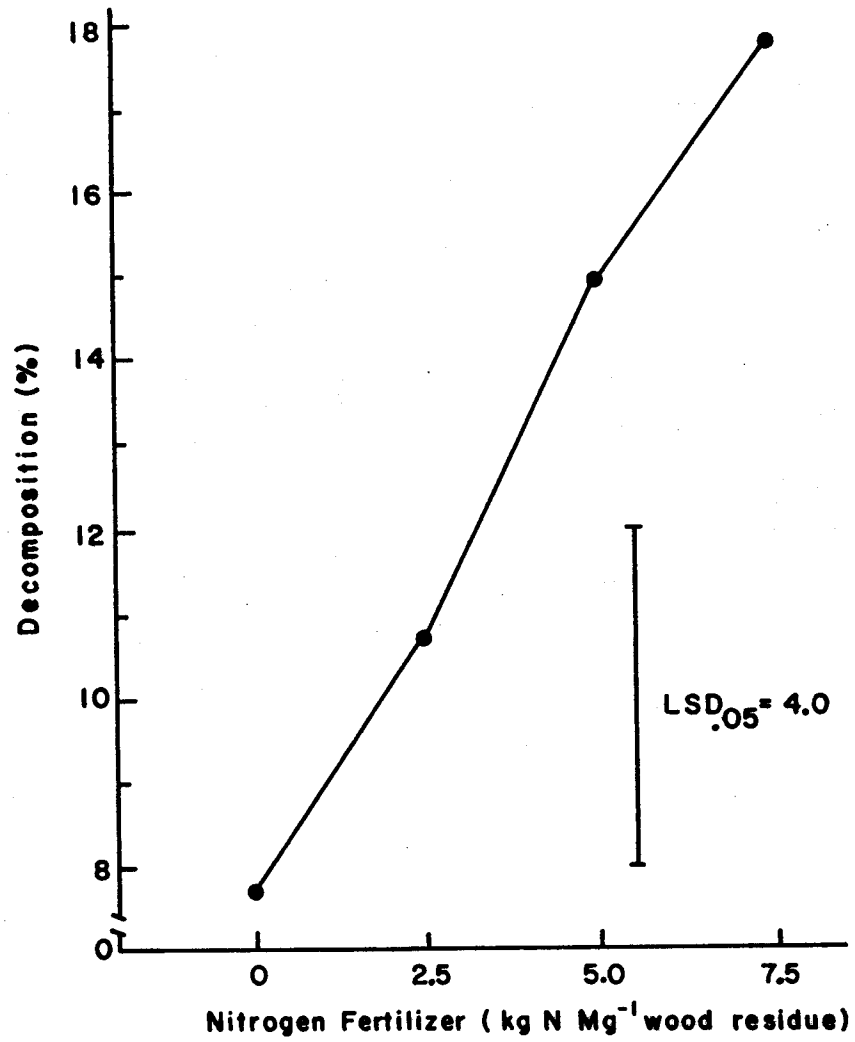


Figure 7. Mean percent wood residue decomposed across the 45, 90 and 135 Mg ha<sup>-1</sup> wood residue treatments and years, at four nitrogen fertilizer rates after 36 months.

for the immediate physical improvement of the spoil, enabling the initial establishment of a desirable plant community. Nitrogen fertilizer must also be incorporated with the wood residue to insure adequate nitrogen for both wood residue decomposition and plant growth. These studies have shown that  $5.0 \text{ kg N Mg}^{-1}$  of ponderosa pine wood residue is adequate to meet the needs of the plants and decomposition. Phosphorus fertilization should be based on inherent levels of phosphorus in the spoil.

Further evaluation of lands reclaimed using this technology would be desirable to evaluate their long-term stability under normal, premining land uses. The Abandoned Mined Lands Program of the Wyoming Department of Environmental Quality, Land Quality Division, has adopted this technology in the reclamation of approximately 6,000 ha of abandoned bentonite lands. They have selected an intermediate, average wood residue rate of  $68 \text{ Mg ha}^{-1}$ , fertilization at  $5.0 \text{ kg N Mg}^{-1}$  of wood residue, and an inorganic amendment (gypsum, calcium chloride or phospho-gypsum) at the rate necessary to reduce the inherent exchangeable-sodium-percentage to 10. A significant portion of the area scheduled for reclamation has been amended and seeded, with the program to be completed in 1990.

Use of wood residue as a bentonite spoil amendment is attractive for several reasons. Amended spoils become productive and reduce aesthetic and environmental concerns (both for the bentonite industry and sawmills), and result in a market for an otherwise unused by-product in the region.

Acknowledgment is given to Mr. Jack A. Smith and Mr. Scott E. Belden who participated fully in this research while pursuing Masters of Science degrees in Range Management and Soil Science, respectively (both are on the staff of the Land Quality Division, Wyoming Dept. of Environ. Quality). Dr. E.J. DePuit, Associate Professor, Range Management Dept., University of Wyoming is also acknowledged for his participation in the research. The Wyoming Department of Environmental Quality and Wyoming State Forestry Division are acknowledged for their assistance and partial funding of the research.

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## AN OVERVIEW OF URANIUM TAILINGS RECLAMATION

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### INTRODUCTION

The reclamation of uranium tailings impoundments has begun in earnest with the decline of the commercial use of uranium for electrical generation and the inception of the Department of Energy's (DOE) Uranium Mill Tailings Remedial Action Project. This reclamation is controlled by the Nuclear Regulatory Commission (NRC) under Public Law 95-604, the "Uranium Mill Tailings Radiation Control Act of 1978" (UMTRCA), enacted by Congress in November, 1978. Under this legislation the NRC was responsible for developing the regulations using standards set by the U.S. Environmental Protection Agency (EPA). The intent of the regulations is to assure that uranium tailings are managed and reclaimed in a manner that does not create unacceptable environmental or health impacts, or impose unnecessary burdens on future generations. The goal of UMTRCA is to assure long-term stabilization of the tailings and long-term control of the radioactive and nonradioactive constituents present. Because of the concern for long-term stability, the use of vegetation to stabilize the reclaimed sites is viewed less favorably by the NRC than the use of rock.

### REGULATORY REQUIREMENTS

From the beginning of the regulatory process, the objective has been to control the disposal and reclamation of uranium tailings to provide protection, primarily from the radioactivity present, for long periods of time, and to manage the risks posed by the tailings to the lowest possible levels.

The regulations developed by the NRC to control uranium mill tailings disposal and reclamation are set forth in 10 CRF 40, which incorporate EPA standards and provide a set of technical criteria (Appendix A of 10 CRF 40). It is important to note that the technical criteria do not provide design standards but set out performance objectives. The most important of these technical criteria with respect to reclamation are:

That reclamation be effective for up to 1000 years to the extent reasonable, and in any case, for at least 200 years,

The reclamation provide assurance that releases of radon-222 from the tailings to the atmosphere will not exceed an average

release rate over the entire site of 20 picocuries per square meter per second,

That reclamation provide isolation and stabilization of the tailings to prevent their misuse by man and dispersal by natural forces such as wind, rain, and flood water, and

That the long-term performance of the reclamation should be accomplished without reliance on ongoing maintenance long-term institutional control of the sites.

The performance objectives stated in the technical criteria provide the basis for determining how an acceptable reclamation plan should perform. Because there are no design criteria, site specific conditions can be taken into account in the design, theoretically resulting in better reclamation which is compatible with the site. But the long-term perspective embodied in the technical criteria require more stringent reclamation measures than have traditionally been imposed on mill tailings. The most apparent of these is the requirement to demonstrate long-term stability against surface erosion in the absence of any ongoing monitoring or maintenance. This precondition for acceptable reclamation design has caused the NRC to be skeptical of vegetative stabilization, and if vegetation is proposed, to extensively prove that this method of surface stabilization will satisfy the requirements of the technical criteria.

#### APPLICATION OF THE REGULATIONS TO RECLAMATION DESIGN

The fact that the regulations establish technical criteria and not design criteria result in a situation, which, on one hand allows flexibility to meet the specific constraints and needs of the site while on the other hand causes uncertainty about whether or not a design will be acceptable. The criteria represent performance and to some extent philosophical objectives for reclamation. The performance of reclamation plans can and are analyzed using a range of analytical techniques (Nelson et al. 1983 and Nelson et al., 1986). However, the accuracy of these techniques is limited, especially when predictions about performance far into the future are required. This condition causes uncertainty and requires that a high degree of subjective judgement be employed in the decision processes.

Uncertainty about the accuracy of the performance predicted using the techniques available requires that the regulator make subjective judgments about the risk or the consequences of failure and the increase in cost that is justified to reduce risk.

Because of the uncertainties associated with making predictions about performance far into the future and the desire to control risk at a very low level, the NRC requires that very conservative assumptions be used in the analyses of reclamation plan performance. This is manifested by a preference for rock over vegetation.



Extensive research has recently refined the design evaluation technology for rock and soil/rock matrix covers. Rock covers can now be designed with a relatively high degree of confidence that, with proper construction, will perform as well as the design evaluation predicts. In contrast, the evaluation of soil cover performance is somewhat limited by the technology available and requires extensive engineering judgement. Since an acceptable design methodology for soil covers has not yet been fully developed, the confidence level in implementing a soil cover is less than that which results from using a rock cover. However, if some level of monitoring and maintenance is allowed, the risk of using either rock or vegetation would become very small.

## RECLAMATION COVER DESIGN

Because of the control of radon gas emanation and prevention of release of tailings by wind or water erosion from a reclaimed uranium tailings site are two of the principle objectives of reclamation, a cover over the tailings is a requirement. The design of the cover can and does vary depending upon the site specific conditions. Control of radon gas emanation is achieved by covering the tailings using a variety of combinations of material thicknesses and types. The thickness of the cover is also determined by the need to demonstrate long-term stability against surface erosion. It is this requirement which brings into question which of the surface stabilization options are best suited to a site. These options range from the use of soil covers with very gentle slopes (in the range of 1/2 percent for the top surfaces and 5:1 to 10:1 for the embankments), to steeper slopes stabilized with rock or riprap.

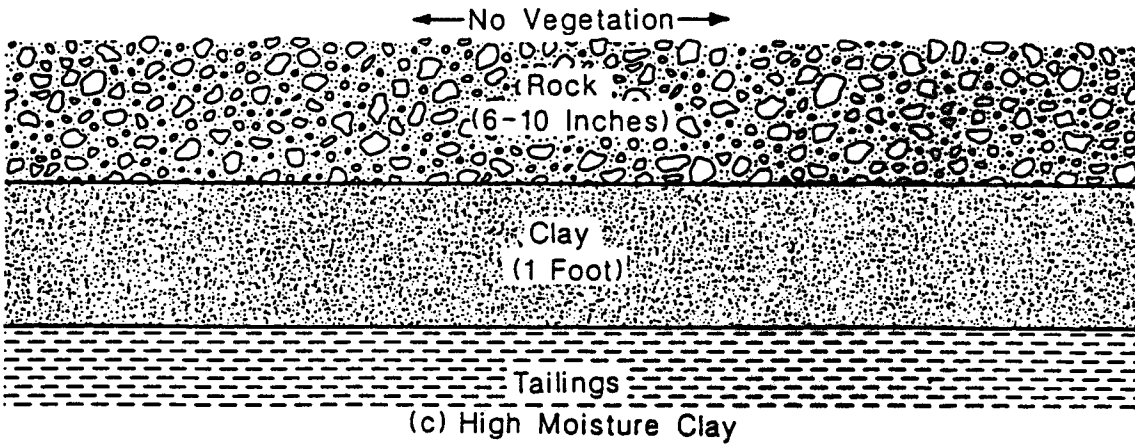
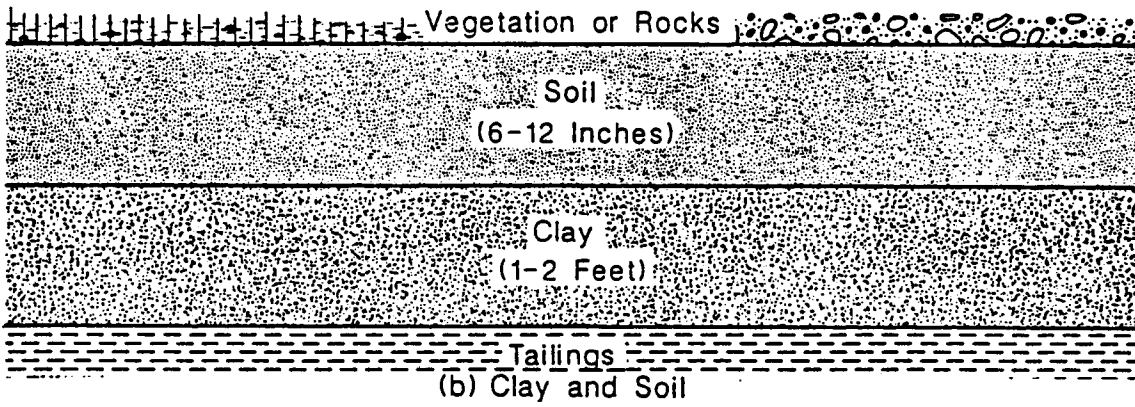
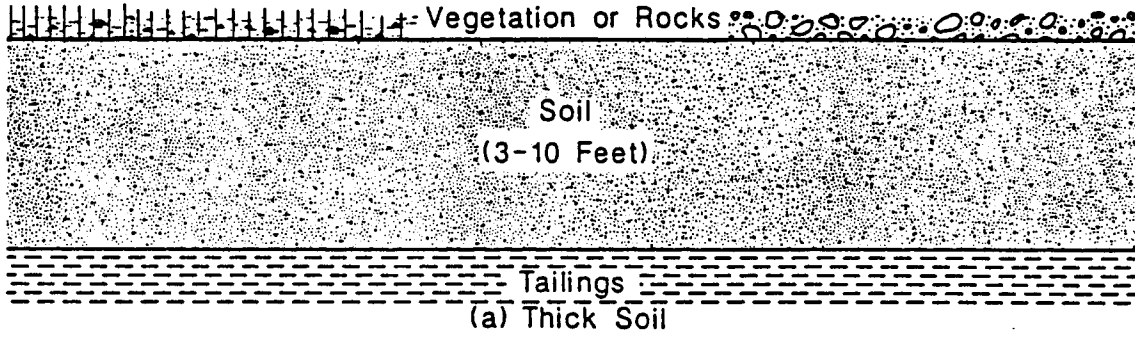
When the NRC first drafted their regulations they proposed that a minimum of 3 meters of cover was required to control radon gas and to assure the long term stability of the reclamation. At that time the proposed radon emanation limit was 2 pCi/m<sup>2</sup>/sec. Now that the radon control standard has been raised to 20 pCi/m<sup>2</sup>/sec, minimum cover thickness of 3 meters cannot be justified on that basis and the requirement for a minimum cover thickness no longer exists. In practice the cover design which is a combination of slope, material type, thickness and surface stabilization method, first based on the thickness needed to control radon at 20 pCi/m<sup>2</sup>/sec and then on the demonstration that it will provide the necessary long-term stability.

There are many combinations of surface configurations and surface stabilization alternatives that can be used to provide the necessary long-term erosional stability for the cover. The job of the designer is to evaluate the alternatives which best suits the site-specific conditions to identify the most economical and licensable cover design. Figure 1 illustrates some of these cover design alternatives.

### Licensability of a Cover Design

The cover design rests on the ability to demonstrate that it will control radon gas emanation and provide isolation of the tailings for a long period of time. It is clear that a cover protected against erosion

FIGURE 1  
TYPICAL COVER (RADON BARRIER) OPTIONS



with durable rock will be more licensable than a reclamation cover stabilized with vegetation. Using the performance analysis techniques available, both designs achieve the required level of protection and stability. While both cover designs may achieve the required performance, the cover stabilized with vegetation will receive a great deal more scrutiny by the NRC and a rigorous evaluation process will be required to demonstrate that it is acceptable.

#### COMPARISON OF RECLAMATION PLANS

Comparison of reclamation plans constructed and proposed for two different groups of uranium tailings sites, the inactive (Title I) and the active (Title II) sites provides a useful illustration of how the physical differences between sites translate into different reclamation designs and surface stabilization methods. The inactive sites are those uranium tailings sites where operations ceased many years ago and are now the responsibility of the federal government (under the control of the DOE) to reclaim. The active sites are those sites in operation or recently operated and owned by private industry. The regulations which control reclamation of both types of sites are the same. The differences in the plans that have been developed result principally from different site-specific conditions.

The major site condition that leads to different cover designs, as discussed by Shepherd and Abt (1988), is the presence of earthen embankments at most Title II sites and their absence at Title I sites. This is a result of different tailings impoundment construction techniques and regulations during the periods of impoundment operation.

This condition dramatically affects the potential for gully erosion to expose and release tailings from the site, one of the most important factors affecting reclaimed surface stability. The analysis generally used to determine if a cover provides the necessary long-term stability is to estimate the depth of gully intrusion and to determine if this amount of gully incision could expose and release tailings. The gully erosion potential is most critical on the relatively steep reclamation embankments.

For most Title I sites, where the embankments are constructed of tailings, a much more critical gully intrusion situation exists than at Title II sites, where embankments are constructed of earthen materials. These two embankment conditions are illustrated in Figure 2. Because of this condition, two basic cover options exist for Title I sites. One is to flatten the slopes slightly and construct the embankment cover using a relatively thin surface of non-eroding material, such as rock. The other option is to use a soil cover thick enough to prevent potential gully erosion from reaching the tailings. Figure 3 depicts these two options. For the first option a small amount of generally higher cost rock is required, as opposed to a larger amount of lower cost soil for option two. In option 2, much flatter reclaimed slopes are required to achieve the necessary cover thickness. The availability and cost of suitable rock compared to the cost of soil is the basis for determining which option is most appropriate for the site.

FIGURE 2  
TYPICAL EMBANKMENT CONDITIONS AT TITLE I AND TITLE II SITES  
(Adapted from Shepherd and Abt, 1988)

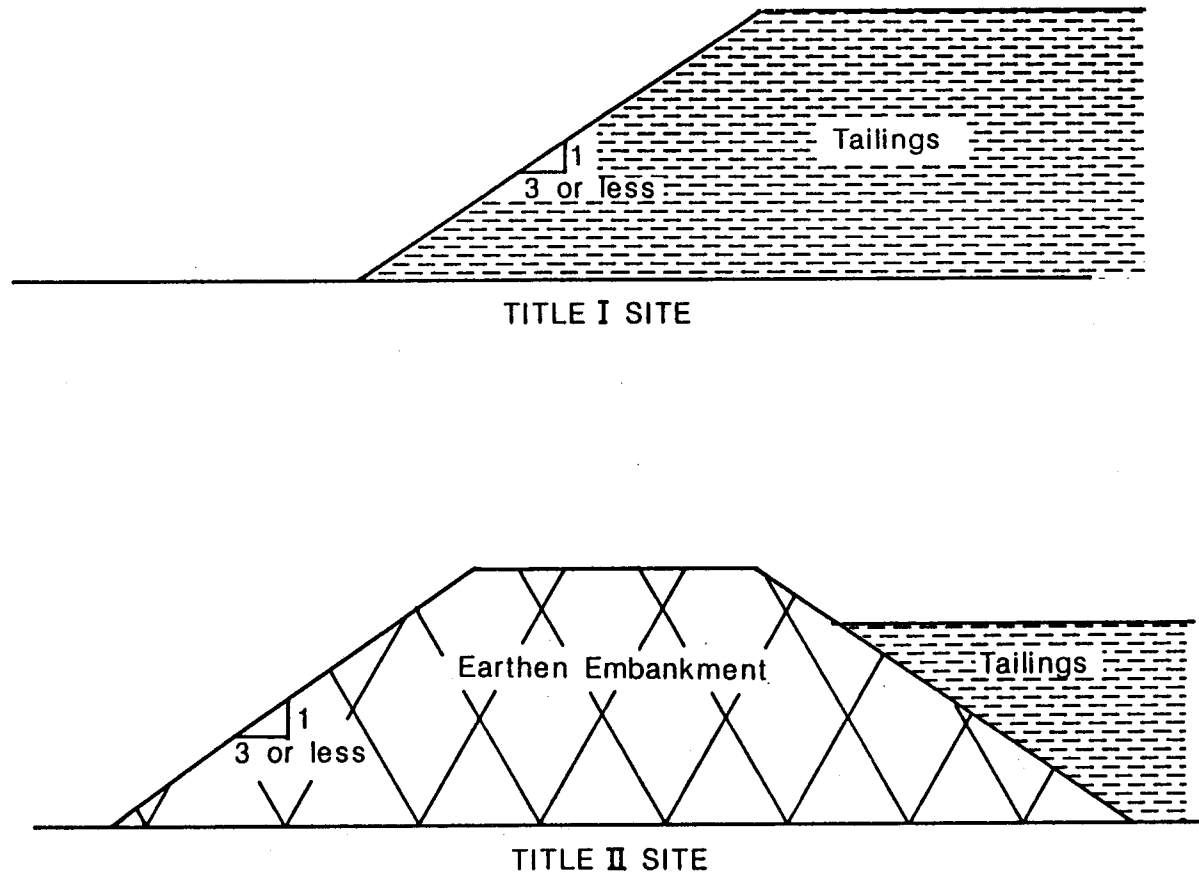
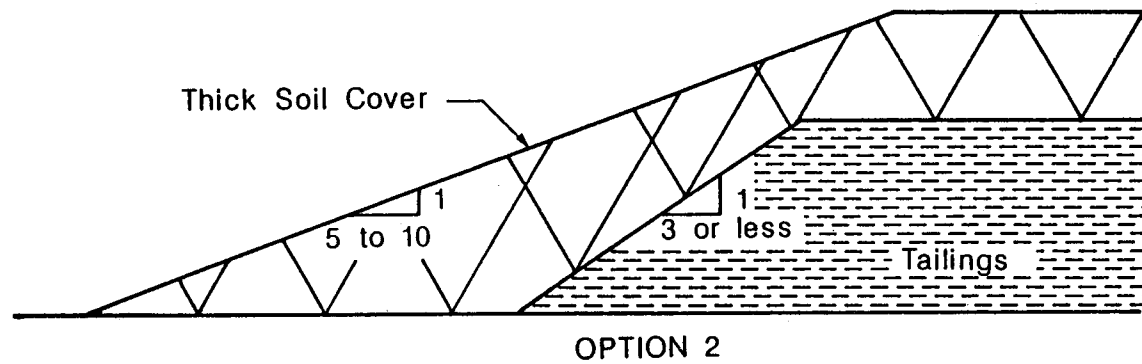
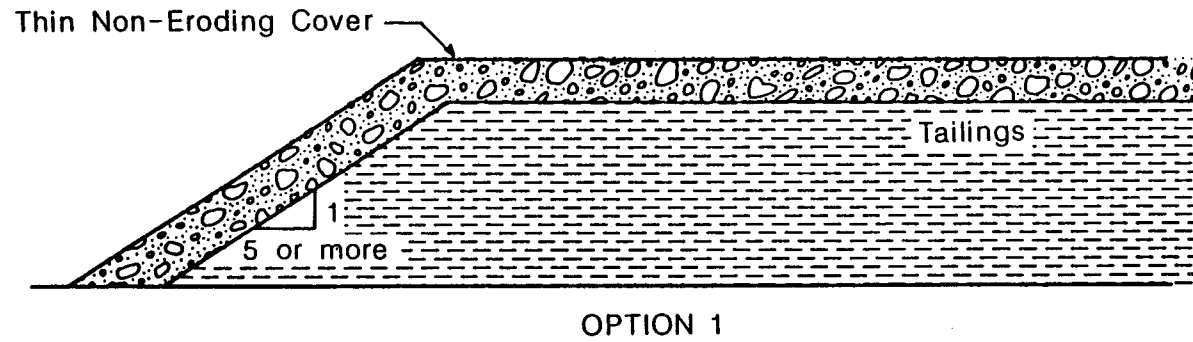


FIGURE 3  
BASIC EMBANKMENT COVER OPTIONS FOR TITLE I SITES  
(Adapted from Shepherd and Abt, 1988)



At Title II sites, however, the presence of earthen embankments means that no additional embankment thicknesses may be required to prevent potential gully erosion from exposing or releasing into tailings. As a result, modification of the existing embankments using relatively small amounts of soil can provide reclamation cover for the embankments.

The differences that exist in the design and stabilization methods employed for the top surfaces of the reclamation cover at Title I and Title II sites relate primarily to the cost and availability of alternative construction materials and not to specific site conditions.

The DOE has generally opted to use rock or rock/soil combinations at Title I sites to control surface erosion and provide stability. At the active sites the industry has generally proposed the use of soil covers stabilized with vegetation, with the surface configurations carefully designed to control runoff velocities below erosive limits. This approach is more in keeping with normal reclamation practices and is generally employed because it results in the most economical reclamation for the site.

#### ACCEPTABILITY OF VEGETATIVE STABILIZATION OF RECLAMATION COVERS

The acceptability of vegetative stabilization of the reclamation covers is an issue. While the NRC does not preclude the use of vegetative stabilization, the agency does not favor it and has much more confidence in the use of rock. The NRC's concern about vegetation is their uncertainty about its long-term performance. For vegetation to be acceptable for surface stabilization, the technical criteria call for a demonstration that over the long term it provide a full and self sustaining cover, but no clear definition of full and self sustaining is provided. It is clear that the NRC mistrusts the ability of vegetation to perform the required function.

Part of this mistrust is based on the precondition that no institutional control of the site will occur in the future and therefore, no maintenance will be performed to correct a problem before it becomes a serious failure. The validity of this concept for uranium tailings reclamation continues to be debated. An examination of the risks associated with uranium tailings and the adequacy of the regulations was undertaken by the National Research Council (1986). This examination concluded, among other things, that the objective to assure long term stability with no provision for some periodic inspection and maintenance was unrealistic. It is further concluded that when the risks associated with uranium tailings were viewed in the perspective of the wide variety of risks that face U.S. society, simple comparisons suggest that the health risks posed by uranium tailings are trivial for the average citizen. To what extent these considerations will influence regulatory policy about acceptable reclamation is still uncertain.

## DISCUSSION

The regulations set up and administered by the NRC to control the reclamation of uranium tailings disposal sites provide a flexible framework within which reclamation plans for these sites can be designed. This flexibility is an obvious benefit in that it allows site specific conditions to be effectively and efficiently addressed. However, because of the requirement to demonstrate stability of the reclamation for long time periods without relying on institutional control or maintenance to preserve the integrity of the site, very conservative designs are required. As a result, vegetative stabilization of the reclamation covers is not considered by the NRC to be the preferred surface stabilization option. The agency would prefer to have rock used for this purpose since a higher degree of confidence can be placed in its long-term performance.

Whether or not this position is justified based on technical performance considerations or that the reclamation design must demonstrate long-term stability without institutional control or maintenance, has not been finally determined in light of the actual risk posed by uranium tailings. As a result of the deliberation about the acceptability of vegetation to provide long-term surface stabilization, it is clear that significant opportunities exist for research and the development of evaluation techniques in this area.

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# REVEGETATION TECHNIQUES FOR TOXIC TAILING

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## INTRODUCTION

It has been estimated that over 15 billion metric tons of tailing has accumulated in the United States and that this waste product occupies more than 900 sq. km. (Barth 1986). Many of these impoundments are no longer in use, and unless properly reclaimed, these impoundments are a source of pollution that often reaches significant levels.

There are variety of reasons why many inactive tailing impoundments are not reclaimed. Some are scheduled for possible future use, others are held for secondary mineral recovery once mineral values increase to a profitable level, some are not reclaimed because technology is lacking for cost-effective reclamation, and others are simply abandoned.

Revegetation is generally a critical part of the reclamation process. A self-sustaining plant cover is a cost effective means of stabilizing tailing against wind and water erosion. Vegetation can transpire large quantities of water, thus reducing water entry into tailing and subsequent seepage from the impoundment. Vegetation is aesthetically pleasing and can disguise the unappealing visual impacts often presented by tailing impoundments. Finally, vegetation can also provide a resource for human and animal use.

Some inactive impoundments revegetate to some extent on their own, and others are revegetated during the reclamation process. However, problems are encountered when the tailing is toxic to vegetation. Because tailing is washed or ground rock that may or may not contain processing chemicals, it is generally poorly suited to support plant growth. It can be toxic to plant growth when excessive metals, hydrocarbons, salts, or processing chemicals are present.

As used in this paper, toxic tailing refers to tailing having chemical traits that either severely restrict plant growth or prevent plant growth. Revegetation of such phytotoxic tailing can be accomplished by either tailing modification or tailing isolation. Following is an evaluation of these two techniques to revegetate toxic tailing.

## MODIFICATION

When toxic tailing is encountered, the first response is often

aimed at modifying the tailing in some manner to make it suitable for plant growth. Because of the large area covered by many impoundments, the lack of on-site cover material, the environmental degradation associated with obtaining off-site cover material, and the cost of applying cover material, tailing modification is a reasonable first choice. Tailing can be modified via leaching, amendment application, and biological treatment, or by a combination of these treatments.

### Leaching

James and Mroost (1965) and James (1966) may have been the first to use leaching to remove toxic metals from tailing. Tailing from a South African gold mill was alkaline when first deposited, but quickly acidified due to the oxidation of pyrite. Acidification occurred to a depth of approximately 2 m, with a zone of maximum acidity occurring approximately 30 cm below the surface; pH values as low as 1.5 were detected. These authors found that the downward leaching of acids could be accelerated by application of water in the form of a fine mist; application rate of the water was equal to the infiltration rate of the tailing. Sufficient water was applied to drive the acids down into the alkaline body of the deposit, thus preventing reacidification of the surface via capillary rise. The vegetative cover subsequently established appeared to be self-sustaining. It was concluded that leaching acids from the tailing surface to a depth from which they will not return can be successful in detoxifying tailing, provided that most of the pyrite in the surface layers has been oxidized.

Working in a greenhouse, Hunter and Whiteman (1975) found that leaching metal mine tailing in Australia successfully removed soluble salts and heavy metals that appeared responsible for the lack of vegetation growing in tailing impoundments, some of which had been inactive for 20 years. Following leaching with water to removed soluble salts, plant yields increased by a factor of more than 40. This leaching also removed heavy metals, particularly zinc and to a lesser extent lead and copper. Metal removal was significantly more efficient if the leaching solution contained ammonium phosphate. These authors concluded that revegetation of this toxic tailing could take place if the tailing were first modified with fly ash to improve physical properties (especially infiltration and percolation rates), leached with water to remove salts and heavy metals, and then fertilized.

Nielson and Peterson (1972) found that leaching salts from toxic tailing (EC of 18 mmhos/cm) in Utah was not difficult under laboratory conditions. They found that leaching with 5 cm of water per 30 cm of tailing reduced the salinity to a level where plants were not significantly affected. When tailing was leached with 15 cm of water per 30 cm of tailing, salinity was essentially eliminated. Unfortunately, these results could not be directly applied to field conditions. Tailing deposition was such that layers of slimes and sands were created. This layering inhibited the vertical movement of water and reduced the effectiveness of leaching. However, in an impoundment

with a functioning tile drain, irrigation decreases subsurface (30 to 60 cm depth) salinity from approximately 9 mmhos/cm to approximately 4 mmhos/cm during a 15 month period. In an adjacent pond receiving the same treatment but lacking a functional tile drain, irrigation appeared to have no effect on salt content other than to cause salinity levels to fluctuate greatly from wet to dry periods.

Leaching has also been successful for highly saline processed oil shale (Berg et al. 1983). Following leaching with 100 cm of water during a field experiments, the bulk of the soluble salts were moved to depth below 90 cm. Soluble salts increased during the second growing season, especially in the upper 30 cm of shale, but decreased during the next season due to leaching by melting snow. Six years after leaching, the salinity levels in the surface 100 cm of shale were essentially the same as those measured immediately after leaching. Also working with retorted oil shale, Redente et al. (1985) found that leaching with 75 cm of water decreased the soluble salt content by 30% and increased aboveground biomass by 29% as compared to the unleached treatment.

The above information indicates that leaching to remove toxicants from tailing can be successful if the toxicants are in a form that can be moved by water, if they are not regenerated after leaching, if leaching depth is sufficient for plant growth and for prevention of upward toxicant migration during dry periods, if physical traits of the tailing are conducive to leaching, and if the impoundment has adequate internal drainage. In addition, sufficient water must be available for leaching and the environmental consequence of the leachate must be evaluated.

#### Amendment Application

A variety of organic and inorganic amendments are available for treating toxic tailing. Limestone is the most frequently used amendment when acid tailing is encountered. This amendment is relatively low cost, readily availability, and very effective at increasing pH. Other neutralizing agents, especially waste products including fly ash, scrubber waste, calcium silicate slags, fluidized bed combustion residue, caustic bauxite waste, sodium carbonate residue, ammonium bicarbonate, and dicalcium silicate have been used as neutralizing amendments for acid materials (Koch and Bell 1983; Jastrow et al. 1981; Dunn and Melis 1974; Plass 1982). However, such materials often require high application rates to be as effective as limestone, and some waste products may introduce unwanted trace elements that interfere with revegetation. When tailing pH is extremely low and well buffered, the amount of neutralizing agent required to remove toxicities may be extremely high and application rates in excess of 300 metric tons of limestone/hectare have been applied in experimental plots. Therefore, neutralization of tailing to eliminate toxicities and thus allow for revegetation may not be practical in some situations.

Once neutralized, reacidification via oxidation of residual pyrites

or via upward acid migration must be considered. Nielson and Peterson (1972) found that 140 metric tons per hectare of limestone was not sufficient to maintain the pH of copper tailing above 7 for more than 6 months. Subsequent field studies indicated that over 220 metric tons per hectare of limestone would be required to maintain the pH at a level suitable for revegetation. Berg et al. (1973) found that acid molybdenum tailing could be neutralized by liming, but continuing sulphide oxidation reduced pH, even when the application rate of lime was up to six times the base equivalent required for neutralization. They concluded that even higher lime application rates or maintenance liming would be required for long-term vegetative stabilization. Prior to successful revegetation, Chenik (1960) applied air-slaked lime to obtain a rapid rise in pH, and coarsely crushed limestone to give long-term pH control for pyritic tailing. Michelutti (1978) applied both fine and coarse limestone for short-term and long-term control of acidity in pyritic tailing. However, within 3 months after application, highly acid conditions had returned due to upward migration of acids during dry periods.

When tailing is extremely alkaline, acidifying agents may assist in reducing toxicities. Working with bauxite tailing where hydroxyl ion toxicity restricted plant growth, sulfuric acid (applied at a rate of 9.7 g/100 g tailing) reduced the pH from 9.3 to 6.9 after 10.5 weeks. Pyrite (applied at a rate of 10.0 g/100 g tailing) and sulfur (applied at a rate of 2.3 g/100 g tailing) were not as effective but still reduced pH by one unit during the experimental period. It appeared that the efficiency of pyrite and sulfur as acidulants could be increased by inoculation with appropriate microbes. Following leaching to remove excessive salts, all of the above treatments were considered appropriate to ameliorate bauxite tailing to a point where plant growth was possible.

Organic matter is a commonly used tailing amendment to increase cation exchange capacity, water-holding capacity, nutrient content, and nutrient retention. Numerous studies, such as that by Hortenstine and Rothwell (1972) and Verma et al. (1977), have documented the benefits to tailing revegetation efforts when organic matter is applied. Organic matter is also effective in reducing toxicities of both alkaline and acid tailing. Fuller et al. (1982) found that revegetating toxic alumina tailing in Alabama was successful when a 2 cm layer of sewage sludge was mixed with the surface 5 cm of tailing. In addition to adding nutrients, the sewage sludge reduced tailing pH from 12.1 to 10.2. The organic constituents in the sludge also had a significant aluminum complexing ability that reduced tailing toxicity. This complexing ability may have been enhanced by the greater solubility of organic matter at the high pH level of the tailing.

This complexing ability of organic matter also makes it a valuable amendment for reducing metal toxicities in acid tailing. Amendments such as sewage sludge, sawdust, straw, wood chips, food processing waste, calcitic papermill sludge, manure, composted municipal refuse,

wood chips, and tannery waste have been of value in reducing metal toxicities in a variety of acidic materials (Sopper and Kerr 1981; Plass 1982; Simson et al. 1981). For example, the author successfully revegetated acidic copper tailing by applying the equivalent of 14 metric tons of manure per hectare. Without this amendment plants were unable to become established in the tailing. Plass (1982) successfully revegetated acidic wastes (pH of 4.0) by applying 20 metric tons of organic matter per hectare. Numerous other examples could be cited, but the above examples should suffice. However, Bradshaw (1983) warned that oxidation of metal-saturated organic matter can free the complexed metals, and toxic conditions can return unless there is a steady supply of organic matter.

In some situations, a combination of a neutralizing agent and an organic amendment are superior to a neutralizing agent alone. Evaluating methods to revegetate highly acid waste, the author found that a combination of limestone (applied at 20 metric tons/ha) and sewage sludge (applied at 11 metric tons/ha) allowed for significantly more biomass production than limestone alone (applied at 20 metric tons/ha) or a combination of limestone applied at this rate and fly ash applied at a rate of 56 metric tons/ha.

#### Biological Treatment

Other than species selection, biological techniques to ameliorate toxic materials prior to revegetation are relatively new and largely unproven at this time, and limited to pyritic wastes. Application of bactericides inhibitory to iron oxidizing bacteria has the potential of reducing acid generation from pyritic waste (Shellhorn et al. 1985). According to the authors, the bactericide should remain active for a number of years to allow the development of beneficial heterotrophic bacteria, enzymes, and mycorrhizae that will establish a natural cycle mitigating acid generation.

A commonly used biological technique for revegetating toxic tailing is species selection. In some cases, toxicities can be avoided by selecting plant species tolerant to the chemical conditions presented by the tailing. Metaliferous plants often have high tolerances to certain metals and have been successfully used to revegetate mining waste toxic to essentially all other forms of plant life (Smith and Bradshaw 1972). However, food chain implications of vegetation high in metals should be considered before implementing this approach. Other plants are highly tolerant of salts and are valuable in revegetating saline or sodic tailing. Genetic engineering has the potential to develop subspecies tolerant of toxic conditions found in many tailing impoundments. However, implementation of this possible revegetation technique to circumvent tailing toxicities will require considerably more research and careful evaluation of all ecological implications.

## ISOLATION

When tailing cannot be amended to support plant growth, isolating the tailing from all or part of the plant rooting zone may be necessary. In some cases, especially when chemically induced physical conditions restrict plant growth, only a shallow isolating layer may be required. For example, a highly sodic waste that supported only a sparse community of perennial grasses received a surface covering consisting of 10 cm of soil (Barth 1984). Perennial grasses readily became established in the soil and utilized a portion of the underlying sodic waste as a rooting zone. Yields where soil depth was 10 cm were almost seven times the yields where soil was not applied to the sodic waste.

But in most situations, considerably more than a shallow layer of favorable material will be required for revegetation. Both Smith and Bradshaw (1972) and Michelutti (1974) found that when 10 cm of cover material was applied to toxic mining waste, initial revegetation was successful. However, erosion, upward migration of toxicants, and/or failure of plant roots to penetrate into the waste soon degraded the revegetated area. Therefore, both depth of material needed to support revegetation and control of upward toxicant movement must be considered when isolating toxic tailing from the plant rooting zone.

Upward movement of acidic or basic salts during tailing revegetation has been noted by James and Mrost (1965), Farmer and others (1976), Michelutti (1974), Barth and Martin (1981), Blight and Caldwell (1984), Galbraith et al. (1972), Smith and Bradshaw (1972), and others. Both laboratory and field investigations have shown that as toxicants move upward, plant roots are killed and the revegetation effort seriously jeopardized (Barth 1986). It appears that toxicants move upward during dry periods via capillary rise. As suggested by Merrill et al. (1983), upward movement via diffusion also can be important in some situations. The author has found toxicant movement from tailing into overlying soil in a wide variety of climates including arid climates in the West, humid climates in the East, and even in tropical climates.

Isolation of toxic tailing and control to upward toxicant movement can be accomplished by establishing a barrier to upward migration followed by application of a growth medium. Another technique involves depth isolation where depth of the material applied to tailing is sufficient to contain the toxicants and to allow for plant growth in uncontaminated material.

### Barrier Isolation

Both synthetic and natural materials can be used to form a barrier to upward toxicant movement. Once isolated in this manner, a growth medium is applied to the barrier and revegetation follows.

A variety of synthetic materials are available for barriers and

include polyvinyl chloride (PVC), chlorinated polyethylene (CPE), chlorosulfonated polyethylene (Hypalon), polychloroprene (Neoprene), isobutylene isoprene (butyl rubber), and related products that are flexible, chemically resistant, and highly impermeable. PVC is probably the best choice because this product is intended to be buried and therefore it costs considerably less than other materials formulated to withstand surface conditions. But even with the relatively low cost of PVC, the cost of purchasing and installing this material is very high. In addition, longevity is a problem. Most manufactures of synthetic materials estimate that such materials will loose their flexibility and functionality 30 to 50 years after being installed. Even during their functional life, such synthetic barriers are prone to fail due to freeze-thaw cracking, thermal stress, gas generation, biological degradation, creep failure, hydrostatic pressure, and differential settling of the underlying tailing. Because of the cost and limitations associated with synthetic barriers, their use in tailing reclamation is not recommended.

Sealants including plastic latexes, asphalt, hydraulic asphalt concrete, soil cement, cellular concrete, and soil asphalts have been used as liners and have potential for use a barriers in tailing reclamation. These materials have good weatherability, immunity to biological attack, puncture resistance, compatibility with chemicals often found in tailing, and the ability to be applied with minimal defects (Golder Associates 1984). However, such products are likely to find little application in tailing reclamation due to their high cost.

A flexible material with a very small particle size, a large surface area, and a high base exchange capacity may have utility in forming a barrier to upward toxicant movement. Sodium montmorillonite (bentonite) has been successfully used as a capping material to restrict water entry into underlying waste, but its use as a barrier to allow revegetation of toxic tailing has not been well documented. In a greenhouse experiment conducted by the author, a high clay material was used as a cap for toxic tailing. As a barrier to water penetration, the cap was only partially successful because the underlying tailing did not have sufficient stability to allow the clay to be highly compacted. However, the clay layer was successful at restricting upward movement of toxicants; when experiments with and without a clay barrier were compared, the clay barrier reduced upward toxicant movement by a factor of four. In this case, a ferruginous matrix was formed as the toxicants moved into the clay. This extremely hard crust may have restricted further upward movement, and by the end of the experiment this crust was very effective at reducing water entry into the underlying tailing. As was the case with synthetic barriers, a clay barrier is both expensive and difficult to install. Compaction of the barrier is necessary, and often tailing does not have the physical characteristics to allow this compaction to take place. Such barriers can fail due to drying of the clay, root penetration, differential settling of the tailing, gas generation, hydrostatic pressure, and other failure mechanisms. However, in some situations, especially where clay material is readily

available on site, a clay barrier may be useful in facilitating revegetation of toxic tailing.

Upward toxicant movement, or capillary rise, is dependent on continuity of small pores; if pore continuity is interrupted or if the pores are large, capillary rise of toxicants will not take place. Therefore, a capillary barrier consisting of large pores (such as that provided by coarse gravel) will prevent upward toxicant migration and will allow for revegetation of toxic tailing. This technique has been used in field situations for containment of a variety of tailing products. For example, Spires and Coortin (1974) used an 8 cm layer of crushed rock to prevent upward migration of metallic salts present in underlying tailing. Another experiment used 8 cm of 0.6 cm crushed slag to form a capillary barrier (Michelutti 1978). Other investigators found that a 15 cm layer of 2.5 cm washed gravel placed between processed oil shale and overlying soil prevented upward migration of salts (Frischknecht and Ferguson 1979). Also concerned about revegetating processed oil shale, Cook (1979) established a capillary barrier using 20 cm of coarse gravel overlain with 10 cm of fine gravel. The author established a capillary barrier that was based on the piping ratio of Cedergren (1977). Piping is the movement of fine particles into the pore spaces of underlying coarse particles, and use of the piping ratio will allow the selection of materials that maintain the large pores essential to the functioning of a capillary barrier. Using this ratio to select materials having proper particle size, a capillary barrier was established using 20 cm of coarse gravel placed on toxic tailing followed by a protective layer consisting of 20 cm of fine gravel. Soil was then placed on the fine gravel and the area revegetated. Following 8 years of monitoring, penetration of fine gravel into the underlying coarse gravel was less than 3 cm and within the limits predicted by the piping ratio. Thus, there was no contamination of the soil and the revegetation effort was successful. The major limitation of using a capillary barrier is the cost of obtaining and spreading the large quantities of sorted gravel that are required. As with the other types of barriers mentioned, longevity of the capillary barrier is often of concern.

Chemical absorptive barriers may have application to revegetating toxic tailing. Such materials as ground limestone, pulverized fuel ash, hydrous oxides of iron, fly ash, activated charcoal, activated alumina, and clay are among the products proposed to attenuate migrating toxicants (Bell et al. 1984; Chan et al. 1978; Fuller 1981). However, their applicability to facilitate revegetation of toxic tailing is not documented at the present time. In addition, large scale application of these products can be difficult and some products are expensive.

Barriers have additional limitations when placed on slopes, such as when revegetating impoundment dikes made of tailing. All of the above-mentioned barriers restrict water percolation. In certain situations, this could allow the material overlying the barrier to become saturated with water and slip.



## Depth Isolation

For a variety of reasons, it is often not feasible to install a barrier over toxic tailing. Another alternative can be referred to as depth isolation. The basic concept behind depth isolation of toxic tailing is to form a containment zone immediately above the tailing. Capillary movement will introduce toxicants into this zone, but the toxicants will not move out of this zone (and into overlying soil) due to the depth of the zone and the cyclic downward leaching of the toxicants.

A variety of materials can be used for the containment zone. Waste rock from mining operations, low quality overburden, alluvium, or other types of low-cost materials that have little or no value in other phases of reclamation can be used. Preferably, such materials should have traits including the absence of toxicants, coarse texture, high permeability, low clay content, and low water retention. The author successfully used waste rock from shaft development to form a containment zone. This material consisted of rocks up to 60 cm in diameter and sufficient fines to fill the voids between the rocks.

The containment zone must be of sufficient depth to contain the toxicants that move upward via capillary rise and diffusion. Unfortunately, height of rise for this type of situation cannot be predicted, and field experiments are usually necessary to establish the depth of the containment zone. A number of such field experiments have been conducted. Sandoval and Gould (1978) measured 15 cm of upward sodium migration from sodic spoil into overlying soil within 3 years in North Dakota. Investigations by Merrill et al. (1983) in North Dakota concluded that when silty loam and sandy loam soils were placed over high sodium spoil having a low hydraulic conductivity, 10 to 15 cm of upward sodium migration could be expected. Field plots in Montana and North Dakota found that sodium migration into overlying loam soil ranged from 7 to 14 cm when measured 4 years after plot construction (Barth 1984). Working in Montana, Dollhopf et al. (1985) found that after 7 years, significant quantities of sodium and other salts migrated 24 cm into sandy loam soil overlying sodic spoils. Berg et al. (1983) found that salts in processed shale migrated 28 cm into overlying soil within 1 year after soil application. However, 6 years after soil application, precipitation (which averaged 26 cm/year) had leached the salts back into the underlying shale. Anderson et al. (1985) presented data indicating 16 cm of upward salt migration from processed oil shale 5 years after application of 46 cm of silty loam soil. One year after application, Bell and Meecham (1979) measured 5 cm of upward salt migration in sandy loam soil placed over fine textured, highly saline alumina refinery waste (red mud). Stark and Redente (1986) found that soluble salts (especially sodium salts) in retorted oil shale migrated 5 to 10 cm into overlying soil 6 years after plot establishment. Working in Brazil, Williams (1987) collected data suggesting that salts from alumina tailing migrated 20 cm into overlying compacted subsoil 4 years after application.

The author monitored upward salt migration in a 60 cm deep waste rock containment zone placed on highly saline and sodic tailing. Salt migration was 16 cm when measured two years after plot establishment, and by 5 years after plot establishment, total upward migration averaged 23 cm. The rapid initial movement of salts followed by a decreasing rate of upward migration was consistent with data collected during long-term growth chamber experiments by the author. From 0 to 122 cm of soil was placed on top of the containment zone, but this variable had no effect on the rate or total height of upward salt migration. Roots grew into the containment zone and into that portion that was contaminated by upward migrating salts. Most of these roots appeared dead where salt concentrations were high, and when soil depth was shallow, some roots in the lower portion of the rooting zone grew parallel to the contaminated material. No detrimental effects to the plants were found when their roots penetrated into the contaminated material. However, when plant roots enter contaminated material and make contact with soluble tailing products, biological translocations and magnification of tailing products must be evaluated.

When isolation techniques are used to revegetate toxic tailing, the depth of soil (or growth medium) to be placed above the barrier or containment zone must be considered. In one situation studied by the author, excellent shrub and grass production was obtained when 60 cm of soil was applied to a containment zone. However, soil depth was not a variable in this research and the production of grasses and shrubs at other soil depths is not known. When the author used a capillary barrier, soil depth was a variable and following 8 years of data collection, grass production increased with soil depth until the sandy loam soil reached a depth of 50 cm; further increases in soil depth failed to increase grass production. However, the 20 cm fine gravel layer that protected the coarse gravel capillary barrier was utilized by grass roots, thus indicating that the growth medium should be 70 cm deep for grass production. Soil depth requirements for shrubs ranged from 60 cm (plus 20 cm of underlying fine gravel) to over 90 cm (the maximum depth tested), depending on the shrub species.

#### CONCLUSIONS

When revegetation of tailing impoundments is restricted or precluded because of toxicants, there are a number of methods to overcome this problem. In some situations, the tailing can be modified to support plant growth. Leaching to remove toxicants from the rooting zone can be successful if the toxicants are water soluble, if they are not regenerated, and if the leaching depth is sufficient to prevent toxicants from migrating into the rooting zone. A variety of amendments can ameliorate tailing toxicities. Limestone is an excellent amendment to treat metal toxicities due to acid conditions, and in some cases alkaline waste products can be used in place of limestone. Organic matter is very useful as a toxicant complexing agent in both acid and alkaline wastes. Selection of vegetation strains tolerant of the chemical environment of the tailing is of demonstrated benefit in some

situations.

When tailing modification is not possible, isolation is often used to allow revegetation to take place. Isolation can use a variety of synthetic, chemical, or natural barriers. However, all types of barriers are costly and longevity is of concern. Rather than a barrier, a containment zone of low value material appears to be a practical means of tailing isolation. Field research has shown that this containment zone should be from approximately 40 to 60 cm deep to contain the toxicants that will migrate into this zone. A growth medium is then applied to the containment zone.

It should be emphasized that revegetation is only one aspect of toxic tailing reclamation and if the revegetation process is to be successful, all aspects of reclamation must be thoroughly investigated and implemented.

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# SPECIES COLONIZATION STUDIES: CLIMAX MINE TAILING SITES

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## INTRODUCTION

The Climax Molybdenum Mine site is located at the top of Fremont Pass in the mountains of central Colorado. Elevation of the site ranges from approximately 10,500 to 11,500 feet. The site is characterized by a very short growing season, cool temperatures and the possibility of snow during any month of the year. Over the years of operation of the mine, millions of tons of processed ore tailing have been disposed of in ponds created in the high mountain valleys that occur adjacent to the mine site. For the most part, these tailing ponds do not support any vegetation except for narrow zones along the margins of the ponds.

The purpose of the vegetation colonization studies conducted in 1987 was to examine the tailing ponds, dams and adjacent areas to determine what species have naturally colonized these sites. By gaining insight into the species composition on these sites, it may be possible to optimize the design of revegetation plans for the tailing disposal areas.

In addition to the colonization studies, observations were also made of several revegetation test plots installed on the site in the early- and mid-1970's. The purpose of this work was to determine which species have survived on these plots, considering that they have received no attention over the last several years.

## METHODS

Reconnaissance of the tailing pond areas showed that there were a limited number of sites which been naturally colonized. Of these, seven sites were chosen for inclusion in the colonization studies. Each of the study sites was visited, and observations were made on the species composition. These observations were used to prepare species lists for each of the sites. Special attention was placed on identifying those species that were growing directly on tailing. On sites with tailing, observations were made regarding depth of tailing using a small soil auger. These observations assisted in understanding the nature of the substrate in which the plants were growing.

Observations made on the old test plots consisted of comparing the sites as they currently are with information presented in an earlier report regarding the status of the plants growing in the test plots (Barrau and Berg 1977).

## RESULTS AND DISCUSSION

Seven different areas were examined on the Climax site. These sites were selected because they supported at least minimal plant growth or because they were areas of specific interest. In all cases, plant growth on the tailing ponds is limited to very narrow bands at the pond margins. Plants do not grow out in the center of the ponds and most grow within ten meters of the pond margins.

### Observations on Plant Colonization

Area 1 - Disturbed Areas between the East Dump and Highway 91. This area consists of a small drainage between a large waste rock dump and some small patches of native vegetation along Highway 91. Most of the disturbed areas at this site occur along the drainage. The native vegetation along the highway consists of a subalpine willow shrubland type intermixed with a wet subalpine meadow type. In all, 29 species were observed in this area (Table 1). These plants were growing in a mix of tailing, coarse rock material, and very small amounts of organic soil. The primary component of the substrate was tailing. The major species on this site include water sedge (Carex aquatilis) and tufted hairgrass (Deschampsia caespitosa).

The sequence of vegetation development on this site appears to be related to the growth of rhizomatous species like water sedge. It appears that the sedges that were growing in the native subalpine wet meadow were able to vegetatively expand into the tailing. Once they expanded into the tailing the upper layer of the tailing began to accumulate organic matter as the yearly growth of sedges began to accumulate as surface litter. The growth of the sedges expanded to cover much of the tailing surface. At some time after the development of the sedge meadow, some other event occurred which caused the sedges to die. This event may have been deposition of additional tailing or possibly some type of drought conditions. Currently, the remains of the meadow can be seen as a patch of black plant bases that have not yet completely decomposed. At the edge of this patch, sedges are again expanding into the tailing. Vegetative expansion appears to play an important role in the colonization of the tailing material at this site.

Tufted hairgrass appears to have become established as seedlings. This species seems to be very tolerant of the acid conditions associated with sulfide ore wastes. On the Climax site, it is the most commonly encountered grass species on moist tailing sites. As conditions become drier, it does not do as well.

Area 2 - Robinson Tailing Pond Dam and Adjacent Areas. There are essentially no plants growing on the face of the Robinson tailing pond dam. There are several species that occur on the adjacent areas where there is a mix of tailing and soil. These areas are mostly tailing, however there is a small amount of soil mixed in. In all, 17 species were observed in these areas (Table 1).

The face of the dam is composed of pure tailing material which has a texture of fine sand and tends to be whitish-gray in color. The



Table 1. Species occurrences at each of eight study sites in areas adjacent to or near the Climax Mine tailing ponds and dams.

SPECIES	STUDY SITES							
	AREA 1	AREA 2	AREA 3	AREA 4	AREA 5	AREA 6	AREA 7	OLD MINE SPOILS
<b>NATIVE GRASSES AND GRASSLIKE PLANTS</b>								
<i>Agropyron scribneri</i>	X	X	X					
<i>Agropyron trachycaulum</i>		X		X	X		X	X
<i>Agrostis scabra</i>			X		X		X	
<i>Bromus ciliatus</i>					X			X
<i>Bromus marginatus</i>				X				
<i>Calamagrostis canadensis</i>	X		X					
<i>Calamagrostis stricta</i>							X	
<i>Carex aquatilis</i>	X	X	X					
<i>Carex ebenea</i>			X	X			X	
<i>Carex spp.</i>	X		X					
<i>Deschampsia caespitosa</i>	X	X	X	X	X			X
<i>Festuca arizonica</i>	X				X			
<i>Hordeum jubatum</i>					X			
<i>Juncus arcticus ssp. ater</i>		X						X
<i>Juncus interior</i>			X					
<i>Juncus mertensianus</i>	X	X	X					
<i>Juncus tenuis</i>	X							
<i>Juncus tracyi</i>		X						
<i>Luzula spicata</i>	X							
<i>Phleum commutatum</i>	X	X						
<i>Poa alpina</i>		X						
<i>Poa annua</i>							X	
<i>Poa fendleriana</i>			X					
<i>Poa secunda</i>			X					
<i>Trisetum spicatum</i>	X		X					X
<b>INTRODUCED GRASSES</b>								
<i>Agrostis alba</i>					X			
<i>Alopecurus pratensis</i>		X	X	X	X			
<i>Bromus inermis</i>	X				X	X		
<i>Dactylis glomerata</i>	X		X		X	X		
<i>Festuca rubra</i>					X			
<i>Phleum pratense</i>	X		X	X	X	X		X
<i>Poa pratensis</i>	X				X	X		
<b>FORBS</b>								
<i>Achillea lanulosa</i>	X	X	X	X	X		X	X
<i>Agoseris glauca</i>						X		
<i>Anaphalis margaritacea</i>			X					
<i>Antennaria parvifolia</i>	X							
<i>Arabis drummondii</i>	X							
<i>Cirsium arvense</i>					X			X
<i>Cirsium coloradense</i>								X

Table 1. (Cont'd) Species occurrences at each of eight study sites in areas adjacent to or near the Climax Mine tailing ponds and dams.

SPECIES	STUDY SITES							
	AREA 1	AREA 2	AREA 3	AREA 4	AREA 5	AREA 6	AREA 7	OLD MINE SPOILS
<i>Clementsia rhodantha</i>	X							
<i>Descurainia pinnata</i>								X
<i>Epilobium anagallidifolium</i>		X						
<i>Epilobium angustifolium</i>	X	X	X	X	X		X	X
<i>Equisetum arvense</i>		X	X					
<i>Eriogonum umbellatum</i>			X					X
<i>Fragaria americana</i>						X		X
<i>Heterotheca fulcrata</i>			X				X	X
<i>Ligularia bigelovii</i>		X						
<i>Ligularia taraxacoides</i>			X				X	
<i>Linaria vulgaris</i>					X		X	
<i>Lupinus argenteus</i>		X						
<i>Mertensia ciliata</i>	X							
<i>Mertensia lanceolata</i>					X			
<i>Oxytropis sericea</i>					X			
<i>Penstemon whippleanus</i>	X							
<i>Phacelia sericea</i>			X		X			
<i>Potentilla diversifolia</i>						X		
<i>Rumex salicifolius</i>	X	X	X	X	X		X	X
<i>Senecio atratus</i>			X					X
<i>Senecio eremophilus</i> var. <i>kingii</i>							X	
<i>Senecio triangularis</i>	X							
<i>Senecio wootoni</i>								X
<i>Solidago spathulata</i>							X	
<i>Spergularia rubra</i>		X	X					
<i>Taraxacum officinale</i>	X	X			X	X		
<i>Trifolium hybridum</i>	X							
<i>Trifolium repens</i>	X							
<i>Valeriana edulis</i>								X
<i>Veronica wormskjoldii</i>	X							
<b>SHRUBS</b>								
<i>Artemisia tridentata</i>								X
<i>Lonicera involucrata</i>								X
<i>Pentaphylloides floribunda</i>						X		
<i>Rubus idaeus</i>								X
<i>Salix brachycarpa</i>		X	X				X	
<i>Salix drummondiana</i>					X	X		
<i>Salix phylicifolia</i> ssp. <i>planifolia</i>	X		X					X
<b>TREES</b>								
<i>Picea engelmannii</i>			X		X	X		X
<i>Pinus contorta</i>					X		X	X

surfaces have been sprayed with a dust suppressant (Coherex) in order to keep the tailing material from blowing.

The major species in the upland areas adjacent to the dam include fireweed (Epilobium angustifolium) and slender wheatgrass (Agropyron trachycaulum). The areas where these species occur consist of tailing with small amounts of coarse rock and soil mixed in.

In the wet areas below the dam, the major species include field horsetail (Equisetum arvense), subalpine rush (Juncus mertensianus), baltic rush (Juncus arcticus ssp. ater), and Tracy rush (Juncus tracyi). These species tend to commonly occur on all vegetated wet areas on the margins of the tailing ponds and at the bases of the tailing dams.

Area 3 - Southern Edge of the Robinson Tailing Pond. This area consists of waste materials mixed with tailing at the edge of the pond and pure tailing material in the pond itself. In all, 29 species were observed in this area (Table 1). The species composition of the wet areas was comparable to that observed in Areas 1 and 2. Tufted hairgrass, water sedge and subalpine rush occurred as the major species. On the drier sites at the edge of the pond, the major species included tufted hairgrass and orchard grass (Dactylis glomerata). In the western part of this area there are tailing deposits on the side slopes. There are patches of water sedge underlain by a buried rich organic topsoil. There seems to be no difference between the substrate where the patches occur and the open areas between the patches. There are coarse cobbles below the buried topsoil. These sites are highly erodible and it appears that the patches of water sedge go through cycles of establishment and destruction similar to that which was seen in Area 1. On this site it appears that the cycles are related to erosion and deposition of the tailing.

The species composition on the drier upland areas at this site was comparable to that observed in Areas 1 and 2.

Area 4 - Area Immediately Downslope from the Manure and Lime Test Plots. This small area consists of a mixture of soil and tailing that has washed from the face of the Robinson dam. Mostly the plants are growing in tailing that has only thin veneer of soil material. Nine species were observed growing on this site (Table 1). All of these species were also found on other tailing/soil sites.

Area 5 - Mayflower Dam and Adjacent Areas. There is nothing growing on the face of the Mayflower Dam. The disturbed area at the base of the dam consists of a mixture of tailing, soil material and coarse rocks. In all, 25 species were observed in this area (Table 1). Saplings of both Engelmann spruce (Picea engelmannii) and lodgepole pine (Pinus contorta) were found in this area, however, they tended to occur on sites with more soil and less tailing. Most of the species in this area were also observed in the other areas that were examined. No plants were found growing in pure tailing in this area.

Area 6 - Margins of the Mayflower Tailing Pond. The species growing in the margins of the Mayflower tailing pond (Table 1) were all growing directly in tailing. The tailing at the site where the plants were growing was approximately 30-38 cm (12-15 inches) thick and was underlain by a buried topsoil. The plants may have been rooted in the

underlying soil as well as in the tailing. As the distance from the shoreline and the depth of tailing increased, the number of plants decreased dramatically. Several Engelmann spruce saplings were growing at this site. It appears that they were growing on the site before they were covered by the tailing. They have continued to survive but do not appear to be doing well.

Area 7 - Tenmile Dam and Adjacent Areas. There were no plants growing on the face of the Tenmile tailing pond dam. In general appearance it was similar to the Robinson and Mayflower dams. Also, there were no plants growing at the margins of the Tenmile tailing pond. Several areas were examined but no plants were seen other than those that were obviously growing in soil that had come up through the very edge of the pond.

The areas adjacent to the base of the Tenmile dam consisted of a mixture of tailing and soil materials, with tailing forming the bulk of the substrate. In all, 16 species were observed growing in this area (Table 1). Of these, the most interesting is a species of reedgrass (Calamagrostis stricta). This species usually is found in subalpine bogs and wet meadows. In this area, however, it was found growing directly in tailing on a mostly upland site. The species is strongly rhizomatous and had formed several dense clumps approximately 0.75 meters in diameter. The plants appeared to be doing quite well, and it appeared that the individual colonies were increasing in size. If individuals of this species can be established on the tailing ponds, they might increase vegetatively and help to stabilize the site.

Old Mine Areas in Kokomo and Searle Gulches. In order to get an idea of natural colonization on non-tailing areas, several areas in Kokomo and Searle Gulches were examined for species composition. These sites consisted of mine waste rock and mine tailing dumps. In all, 23 species were observed on these sites (Table 1). Species growing on old roads and cabin sites were not included in the list. Most of these species were also observed growing on the areas adjacent to the dams and tailing pond margins on the Climax site.

## Observations on Test Plots

1976 Mulch Study. Preliminary results from the 1976 mulch study were presented in Barrau and Berg (1977 pp. 62-67). These plots were seeded in late June 1976 and were then evaluated later in the growing season. Preliminary results were evaluated as being "good". Most of the willows cuttings that were planted had died, but the willows planted as clumps were all alive. The spruce sapling transplants were alive but some of them "looked poor".

In 1987, nearly everything on these plots had died. None of the willow cuttings survived, however two clumps of willows were still alive. The four spruces mentioned on page 66 of the Barrau and Berg (1977) report are still alive, however they are very chlorotic and do not appear to be doing well. None of the seeded grasses in replications I, II, and III of the mulch study survived. There are a few surviving plants growing in areas adjacent to the test plots. These areas were planted with the Climax mix at the same time the test plots were installed. Observed species include smooth brome (Bromopsis inermis),

Kentucky bluegrass (Poa pratensis), western yarrow (Achillea lanulosa), and sheep fescue (Festuca ovina). Smooth brome was the most prevalent of these species.

The causes for the decline of vegetation on these plots may be related to erosion. The tailing is very highly erodible, and it is possible that the vegetation on the plots was not capable of stopping the erosion process. It is also possible that the plants became physiologically stressed beyond their limits of tolerance and died. With the death of the plants came increased erosion of the plots. Either way the plot currently shows evidence of both sheet and rill erosion.

Lime Study Plots. The lime study plots were planted in late June, 1976. The study consisted of creating plots with four lime rates (2, 4, 6, and 8 tons per acre) and three replicates of each treatment. The plot was located at the base of the northwest corner of Dam No. 1 on the Robinson tailing pond. A description of the study and preliminary results are presented on pages 58-61 of Barrau and Berg (1977).

In 1987, there were still some patches of vegetation remaining on the lime test plots. The patches occurred in a regular pattern and strongly reflected the four treatments. In all cases, the remaining patches of vegetation were roughly in the centers of each of the treatment blocks. The size of the patches ranged from about 1.5 meters in diameter to less than 0.5 meters in diameter. The largest patches occurred in the 8 ton per acre treatments, the medium sized patches occurred in the 6 ton per acre treatments, and the smallest patches occurred in the 4 ton per acre treatments. There were no surviving plants in the 2 ton per acre treatments. Surviving species included smooth brome, Arizona fescue (Festuca arizonica), red fescue (Festuca rubra), sheep fescue, common dandelion (Taraxacum officinale), timothy (Phleum pratense), Kentucky bluegrass, and orchard grass. Of these, smooth brome and Arizona fescue were the most abundant.

Manure Study. The manure study plots were prepared in September, 1973 and were planted in early June, 1974. They are located adjacent to the lime study plots described above. The study consisted of evaluating four replications of five manure application rates (10, 20, 40, and 80 tons per acre of manure. A discussion of the study design and preliminary results are presented on pages 14-24 of Barrau and Berg (1977).

In 1987, the 80 tons per acre treatment was essentially the only one that had any remaining patches of vegetation. The other plots had a few scattered plants. The most prevalent species was smooth brome. Other observed species included a species of rockcress (Arabis drummondii), Arizona fescue, red fescue, sheep fescue, meadow foxtail (Alopecurus pratensis), common dandelion, western wallflower (Erysimum asperum), tansy mustard (Descurainia pinnata), western yarrow, and timothy.

Native Species Trials on Tailing. The native species trials study is described on pages 48-55 of Barrau and Berg (1977). Planting of the plots was completed in late July, 1976. The seeds used in this study were collected on the Climax site. The study consisted of testing four

different seed or woody plant mixes each replicated four times. The mixes consisted of:

- 1) Green gentian (Fraseria speciosa) seeds.
- 2) A mixture of native grass, sedge, and forb seeds.
- 3) Native willow cuttings.
- 4) Shrubby cinquefoil, willow, sage and spruce transplants.

In 1987, most of the plants that had grown in these plots were gone. One of the native grass, sedge and forb treatment plots still had a few surviving individuals. Observed species on this plot included smooth brome, meadow foxtail, Kentucky bluegrass, red fescue, and slender wheatgrass. All of the green gentian and willow cutting plots were bare. One of the woody transplant plots had two surviving willows and another had one surviving spruce and one surviving shrubby cinquefoil (Pentaphylloides floribunda).

Comments on the lime, manure and species trials plots. One of the main reasons for the decline of vegetation on these plots relates to erosion of the face of the Robinson tailing dam. The plots are located immediately below the dam, and over the last ten years there has been a considerable amount of tailing material that has washed from the dam and onto plots. Without this influence, it may be that there would be a greater number of surviving plants on the test plots.

1986 Test Plots. The 1986 test plots were installed on the western edge of the Robinson tailing pond south of the dam. These plots consist of field trials of four different treatments, and as such they are much larger than the test plots installed in the mid 1970's. All of the plots were treated with 10 tons per acre lime and 400 pounds per acre of fertilizer. The treatments consisted of:

- 1) Four inches of topsoil spread over tailing
- 2) Twenty tons per acre of sewage sludge over tailing
- 3) Four tons per acre of native hay over tailing
- 4) Four tons per acre of native hay and ten tons per acre of sewage sludge over tailing.

The summer of 1987 was the first growing season for the plots. The treatment with four inches of topsoil produced the best results. The addition of topsoil to the tailing was successful in creating a plant growth medium that was much more stable than the tailing alone. Walking across the tailing is much like walking on sand at the beach. The mixture of topsoil and tailing provided a substrate that was much firmer and seemed to provide a better medium for plant growth. The major species on the plot included annual rye (Secale cereale), cheatgrass (Bromus tectorum), timothy, and devil's shoestrings (Polygonum aviculare). Other observed species included common dandelion, Kentucky bluegrass, sheep fescue, tansy mustard, Canada bluegrass (Poa compressa), smooth brome, white clover (Trifolium repens), and a species of groundsel (Senecio atratus). There was at least some growth in each square meter of the plot. The results with this treatment look very promising.

The second best treatment was the one with twenty tons per acre of sewage sludge. The results with this treatment were not nearly as good as those obtained with the topsoil treatment. The individual plants were much more scattered than on the plot with topsoil. Major species included annual ryegrass, Kentucky bluegrass and timothy. Other observed species included tufted hairgrass and meadow foxtail. Contrary to the topsoil plot, the tailing substrate remained very soft even with the addition of the sewage sludge. The soft substrate may have contributed, in part, to the limited success with this treatment.

The third best treatment was the one with four tons per acre native hay and ten tons per acre sewage sludge. The vegetation on this plot was more sparse than that growing on the twenty tons of sewage sludge per acre treatment. The best results in this plot occurred on microsites where the native hay mulch had not blown away. Observed species included annual ryegrass, timothy, Kentucky bluegrass, meadow foxtail and tufted hairgrass.

The least successful treatment was the one with four tons per acre of native hay. Very few grass seedlings were noted. The places where seedlings were found were on microsites where the mulch had not been blown away. Observed species included annual ryegrass, tufted hairgrass and unidentifiable species of bluegrass and fescue. These latter two species were represented by only a few basal rosettes without any flowering culms.

The preliminary results from the 1986 test plots tend to reinforce the observations made on the naturally colonized sites. Sites with pure tailing tend to support very few plants, but sites that have a mix of soil and tailing have greater species diversity and plant cover.

#### SUMMARY

Colonization of the tailing ponds and adjacent areas has occurred to only a limited extent. Observations suggest that it would require long time periods (probably more than 100 years) for plants to become established on most of the tailing ponds as they currently occur. Unstable surface conditions caused by blowing tailing, low pH values, dry conditions in the upper soil layers and very poor nutrient status of the mill tailing create conditions that are very marginal for plant growth.

Observations suggest that with only slight modification, the tailing can support plant growth. On native sites with only a thin veneer of soil or soil mixed with coarser rock, a variety of species can become established. This is especially true of moist sites. Drier sites will also support a variety of species, however total cover tends to be reduced.

The test plots also show that with addition of manure and lime it is possible for the tailing to support plant growth. The value of adding only limited amenities can also be seen in the preliminary results of the 1986 test plots. Addition of only a thin veneer of topsoil produced noticeably better results than treatments without any topsoil.

Natural colonization of the tailing ponds at the Climax appears to be occurring at a very slow rate. Currently, plants grow only at the

margins of the ponds. While it appears that these plants are growing in the tailing, it is possible that some of them may have roots that extend into underlying buried topsoil or subsoil. This appears to be the case for saplings of coniferous trees and willows that occur at the margins of the ponds.

On pure unamended tailing, very few species occur. The following species include those that were most commonly encountered growing directly in tailings: water sedge, subalpine rush and tufted hairgrass. While observed in only one area, reedgrass (Calamagrostis stricta) appears to be a species that can grow on relatively dry sites composed of pure tailing.

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# ENVIRONMENTAL ASPECTS OF CYANIDE IN MINERAL PROCESSING

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## ABSTRACT

A background on the use of cyanide in the U. S. Mining Industry, definitions of terms, and areas requiring potential regulatory control will be reviewed. Current federal/state/local activities will be discussed along with a commentary on the propriety of these various efforts. Long-range impacts will be considered especially in the context of revegetation concerns.

We will attempt to integrate an account of studies recently completed or underway with perceived needs.

## BACKGROUND

The majority of the world's dry sodium cyanide is used for extracting gold and silver from their ores. Chart I illustrates orders of magnitude of this product use in the United States' mining industry.

### USES OF CYANIDE IN THE U.S. MINING INDUSTRY

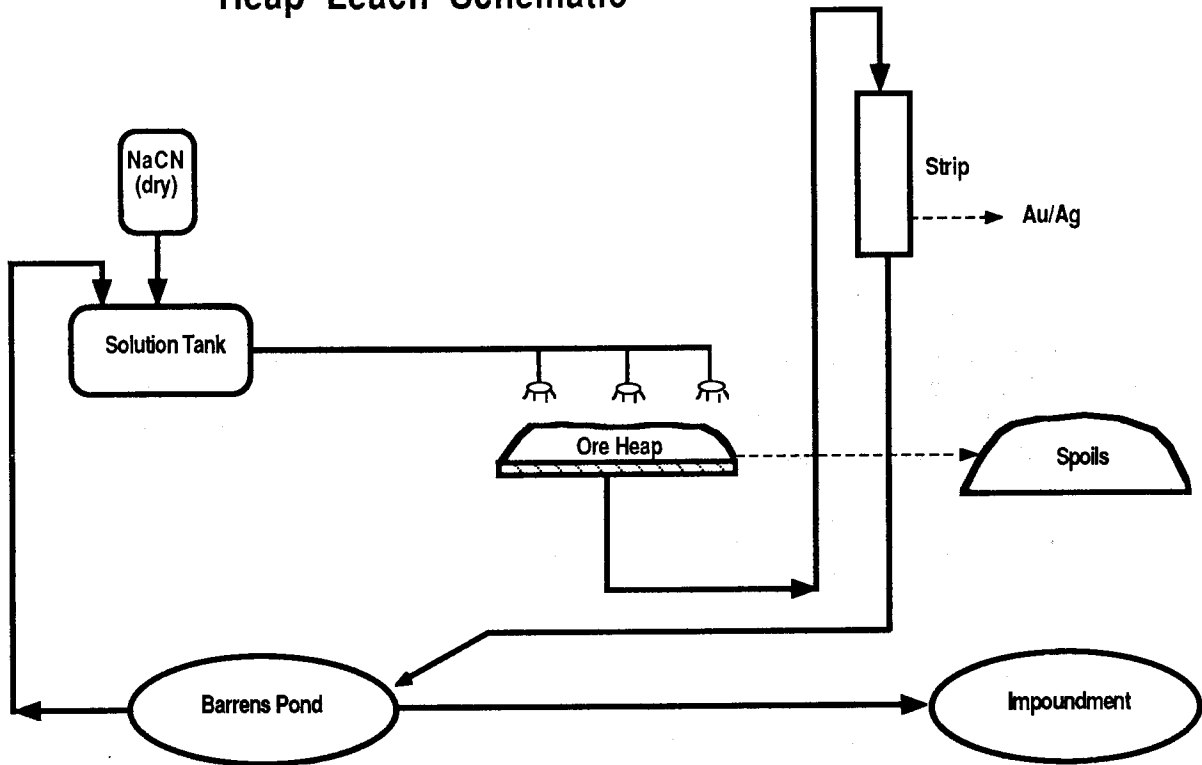
- o PRECIOUS METAL LEACHES                     $\geq 60$  M lb/yr  
(ABOUT 80% OF GOLD, 5% OF SILVER)
- o MOLYBDENUM/COPPER SEPARATIONS         $< 5$  M lb/yr \*
- o LEAD/ZINC SEPARATIONS                    $\ll 5$  M lb/yr \*

\* very low concentrations; dismissed as environmentally nonhazardous by environmental agencies.

### CHART I

The hydrometallurgy is accomplished either by traditional tank or vat leaching, or via the process developing over the last fifteen years, heap leaching, shown in the schematic diagram.

### Heap Leach Schematic



Since cyanide is a notoriously toxic substance, and since these operations consume vast quantities, concerns with the potential impact on the environment has been present since well before the advent of the environmental movement. It should be said at the outset the "track record" is surprisingly good: Cyanidation of gold ores has been commercial for ninety-five years, with most adverse environmental incidents the results of mishandling by people who knew better.

Current responsible practices, both mandatory and voluntary, continue to raise the damage-free record of use of this material, at least in North America. Our purpose today is to describe where perceived and actual threats may lie, what is known, and where continuing studies are addressing areas of ignorance.

## DEFINITIONS

The fabric of regulations, standards, etc. is sufficiently interwoven that definitions of the terms require a couple of lists.

### DEFINITIONS

#### FREE CYANIDE (CN<sub>F</sub>)

HCN, CN<sup>-</sup> ± Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>+2</sup>, Mg<sup>+2</sup>

#### WEAK-ACID-DISSOCIABLE CYANIDE (CN<sub>WAD</sub>)

CN<sub>F</sub> + Zn, Cd, Ag, Cu, Ni

#### TOTAL CYANIDE (CN<sub>T</sub>)

CN<sub>WAD</sub> + Fe, Co, Au, Pt

### CHART II

The key things to remember are that "free cyanides" are the most toxic substances, but we have poor tools to measure them at realistic levels of concern. Weak-acid-dissociables are less toxic, especially the last three, are more precisely detectable, and can be intentionally detoxified by oxidizing agents, the most common method for free cyanides as well. The balance of these complexes are very low order of toxicity, generally extremely difficult to destroy, and serve to obscure realistic regulations by causing some level of confusion on what "cyanide" really comprises.

## NATURAL DECONTAMINATION AND REGULATIONS

Chart III illustrates what happens to the vast majority of cyanide used in leaching operations.

### NATURAL DETOXIFICATION MODES

VOLATILIZATION	HCN ↑
BACTERIAL OXIDATION	CNO <sup>-</sup>
COMPLEXATION/IMMOBILIZATION	CuCN, Cu <sub>2</sub> Fe(CN) <sub>6</sub>
PLANT METABOLIZATION	CYANOGENIC GLUCOSIDES
UV PHOTOLYSIS	Fe(CN) <sub>6</sub> <sup>-4</sup> → HCN ↑

### CHART III

Although these methods have proved quite effective, a body of diverse standards has grown, in part because all cyanide is not used in isolated desert environments.

REGULATORY STANDARDS

POTABLE WATER	0.2 ppm CNf
AMBIENT FRESH WATER	5.2 ppb CNf
TLV (OSHA/MSHA) IN AIR	10 ppm
AIR QUALITY	1/40 TLV (Arbitrary)
SOLIDS CLASSIFIED AS HAZARDOUS	>1000 ppm CNf

PROPOSED

SOLIDS	20 ppm in leachate
--------	--------------------

SOME PERMITS

HEAP-LEACH DRAINAGE	0.2 ppm
---------------------	---------

TENTATIVE COMMUNITY EXPOSURE GUIDELINE

AMBIENT AIR	2 ppm
-------------	-------

CHART IV

A few observations are in order: Cyanide is an acute poison; survival of a dose rarely leads to after-effects. It is not cumulative, carcinogenic, or embryotoxic according to many tests conducted over many decades. It is far more toxic to fish than humans, which accounts for the difference between the first two lines.

Because of the ease with which the body detoxifies itself, it is somewhat bemusing to consider that the 100 mg estimated lethal dose would require one to consume instantaneously over 125 gallons of water at the regulatory limit. Bear in mind that cyanides are common in nature, many plants producing cyanogenic glucosides (peaches, almonds, some species of clover, lima beans, etc.). The body detoxifies the cyanides ingested from smoking a cigarette in less than five minutes.

One might speculate why it is appropriate to restrict heap-leach drainage to the potable-water standard, since few humans or animals will derive their water requirements from this source! In addition, studies underway show the extreme difficulty with which cyanides from the surface could reach groundwater without attenuation. As the capstone, and of particular interest to this group, is the fact that cyanide, as fixed nitrogen, is a plant nutrient.

## NEEDED ENVIRONMENTAL CONTROLS

Chart V is the author's attempt to assess real areas of concern.

### REGULATORY NEEDS

<u>CATEGORY</u>	<u>REQUIREMENT</u>
PONDS	ISOLATION UNTIL SAFE
LEACH-HEAP SPOILS	TOXIC DRAINAGE AVOIDANCE
TAILS	TOXIC DRAINAGE AVOIDANCE
DISCHARGE LIQUIDS	- STREAM STANDARDS - GROUND-WATER STANDARDS - LAND APPLICATION
<u>REVEGETATION:</u>	o CYANIDES AS FERTILIZERS o METAL-LEVEL MONITORING (if significant)

### CHART V

These requirements are primarily to safeguard fish and mammals, while nature takes its course. The impacts on vegetation would seem to be restricted to concerns with the effect of metals complexed with the cyanides, if significant. To try to place this in perspective, we are probably looking at concentrations at typical trace-element levels, reduced by the extreme weatherability of the solid cyanide complexes: the iron complexes, if shielded from ultraviolet, are stable in geological time under surface and near-surface conditions. Copper cyanide is so refractory that it is about four thousandths as toxic as free cyanide.

### CONTINUING EFFORTS

Chart VI lists a few efforts to continue quantification of what many are beginning to perceive as a problem unlikely to cause much damage. We continue to cite, as a data point, the absence of significant environmental damage, world-wide, from use of billions of pounds of cyanide over nine decades.

CURRENT STUDIES

SOIL ATTENUATION STUDY - R2C2 - SALT LAKE CITY  
(INDUSTRY/GOVT./PUBLIC INTEREST)

POND DETOXIFICATION STUDY - DU PONT CO.

SPOILS/TAILINGS HISTORY - PEI ASSOCIATES  
(FOR O.R.D. OF USEPA)

CHART VI

CYANIDE - THE  
MOST OVERSTUDIED  
POTENTIAL POLLUTANT?

CHART VII

REVEGETATION OF MINED LAND USING PROMAC® SYSTEMS BACTERICIDES  
Warren T. Maierhofer  
The BFGoodrich Company  
Akron, Ohio 44318

INTRODUCTION

Microorganisms, by direct and indirect mechanisms, catalyze the oxidation of metal sulfides found in base metal and coal mines, and play a significant role in the formation of acid mine drainage in ore stock piles, tailings, and waste rock. Elimination of these bacteria will inhibit acid formation and metals solubilization, thereby promoting revegetation. Acidity and resulting solubilization of metals cause revegetation efforts to fail frequently.

ProMac Systems of The BFGoodrich Company has developed and refined controlled release bactericides that inhibit acid generation at the source. These systems have proven to be an effective and economical means for reclaiming mined land and improving water quality.

Chemistry of Acid Formation

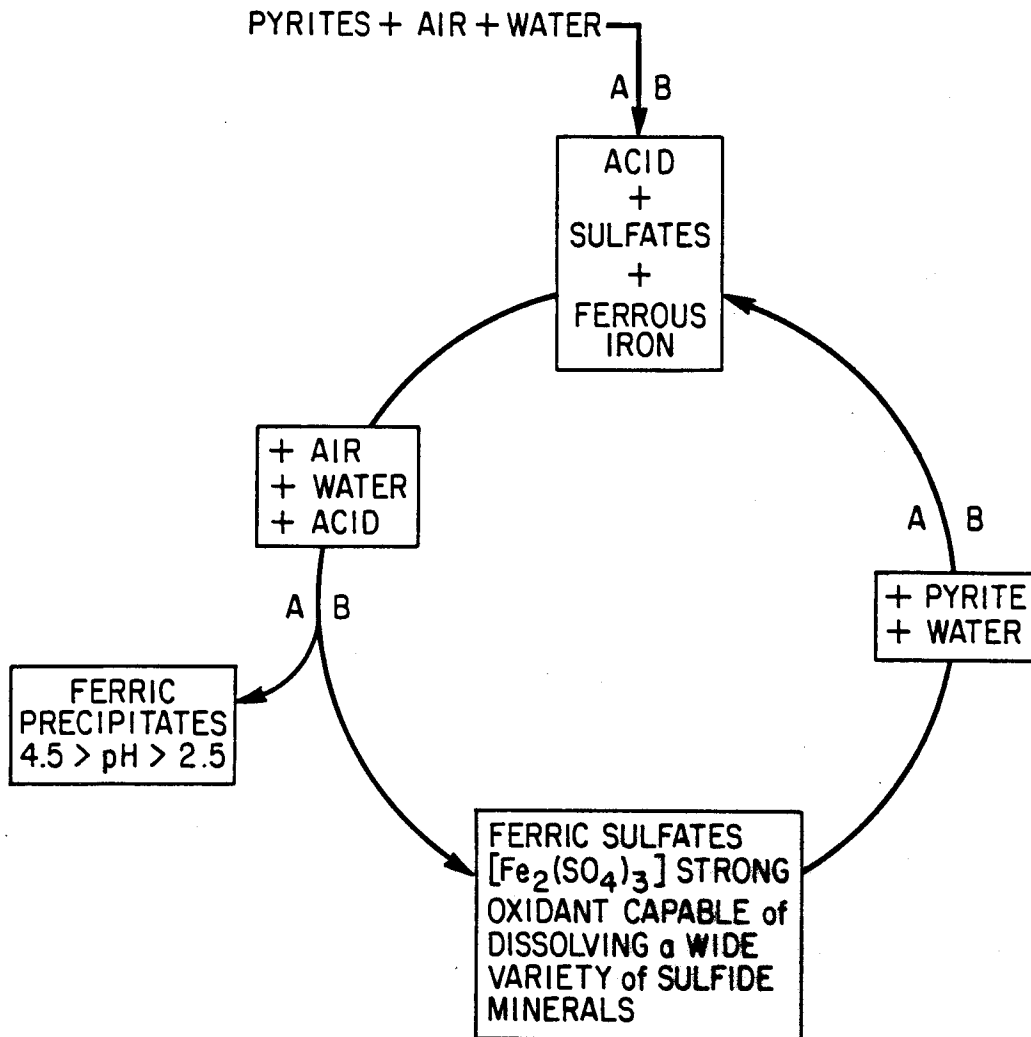
The stoichiometry of acid formation has been well described (Singer and Stumm, 1969 and 1970). Iron is released into solution and sulfuric acid is produced in a self-propagating cycle which is catalyzed by bacteria. As pH decreases, iron is alternatively oxidized and reduced in the cycle (Figure 1).

Ferric precipitates, commonly called "yellowboy," are formed in a specific pH range. At pH values less than 2.5, ferric iron is a strong lixiviant and powerful oxidant capable of dissolving a wide variety of sulfide minerals. Oxidation by ferric iron can proceed even in the absence of oxygen or viable bacteria deep within a dump (Hutchins, et al, 1986).

Acid Control Strategies

Numerous acid mine drainage (AMD) abatement methods have been investigated (Kim, et al, 1982). Kleinmann and Erickson (1986) found these techniques could be broadly categorized into two segments: (1) techniques that physically limit contact between the reactants, and (2) techniques that alter reaction rates. In the first category, these methods include compaction, run-off diversion, selective placement of pyritic materials, physical barriers, etc.; category number two includes alkaline or phosphate addition, and bacterial inhibition.

Generally, these techniques have enjoyed some degree of success and a combination of methods should be employed to insure favorable results; yet, it makes sense to concentrate efforts into areas where the greatest degree of control can be established.



A - ABIOTICALLY  
B - DIRECT BACTERIAL ACTION

Figure 1. Chemistry of Acid Formation



## Ingredients in Acid Formation

Water - Ultimately, rain and snow provide the system with a source of water which serves as reactant, reaction medium, and transporter of reactant and products (Lovell, 1970). Engineering, which is costly and not without speculation, can limit the movement of water across and through the expanse of a mine site; however, some precipitation will inevitably contact pyritic material.

Oxygen - Much work has been devoted to the control of AMD by restricting diffusion of atmospheric oxygen into spoil. If the concentration of oxygen contacting the pyrites can be sufficiently reduced, then the formation of acid will be limited.

Oxygen restriction is difficult to achieve in the field. Based on thermodynamic measures, it is necessary to reduce oxygen concentrations to an unattainable level of  $10^{-60}$  atmospheres (Barnes and Romberger, 1968) before pyrite oxidation reactions are stopped. Therefore, the sealing of waste dumps and mine portals with so-called impermeable caps may not adequately reduce oxygen availability.

Sulfides - The physical form of the sulfide mineral contributes to the degree of reaction. Smaller particles, because of their greater surface areas, tend to react more quickly. Also, less crystalline forms of sulfide minerals tend to be more reactive (Dixon, et al, 1982).

Bacteria - The relationship between bacteria and AMD was probably first considered in 1919 (Onysko, et al, 1984). It wasn't until the late forties that a specific microorganism was isolated (Temple and Koehler, 1954). Today, it is commonly accepted that a family of bacteria, typically represented by Thiobacillus ferrooxidans is the principle catalytic agent in the production of acid in mine environments. This bacterium is responsible for up to 95% of the acid generated in tailings, waste rock dumps, and coal refuse.

Chemical oxidation of ferrous iron is kinetically limited; however, T. ferrooxidans can increase the rate of reaction by a factor of greater than 1,000,000 (Singer and Stumm, 1970). Without these bacterial catalysts, the oxidizing rate of ferrous iron in natural systems is too slow to be of any consequence in acid formation.

T. ferrooxidans derives its energy by oxidizing ferrous iron and, to a lesser extent, elemental sulfur, thiosulfate, tetrathionate, and the sulfide moiety of various noniron minerals (Hutchins, et al, 1986). Indigenous to pyritic minesoils, T. ferrooxidans thrives in the presence of oxygen, water, and a soil with pH values below 5.0.

Research has shown the vulnerability of T. ferrooxidans to the various chemical compounds including food preservatives, organic acids, and anionic surfactants. Originally, bacterial inhibitors could

achieve a 50% reduction in acidity (Kleinmann and Erickson, 1986). BFGoodrich has since shown reductions as high as 98% (see Figure 6).

#### Summary

The mine operator is at the mercy of his geology, meteorology, and ambient conditions. Considering that alkaline and phosphorous additions are after-the-fact approaches to reclamation, the logical alternative for AMD abatement is bacterial inhibition. ProMac Systems bactericides weaken the grease-like coating of the bacterium that enables it to live in a hostile environment where pH may fall below 1.9 while the pH of the interior of the bacterium's cell is near neutral. The protective membrane around the cell becomes permeable and the acid penetrates the cell membrane and retards or destroys the organism (Tuttle, et al, 1977). This mechanism prevents T. ferrooxidans from developing a resistance to the active ingredients in ProMac.

#### PROMAC SYSTEMS

Anionic surfactants are some of the most effective compounds that can be used to inhibit the growth and activity of T. ferrooxidans; yet, without controlled release systems, these chemicals quickly biodegrade, adsorb to soil materials, and become diluted by runoff. Spray applications of bactericides can inhibit acid formation for three to six months, then treatment has to be repeated for effective control of acid formation in active ore piles.

The BFGoodrich Company has developed and refined long-term controlled release pellets blended with highly effective inhibitors. These polymer pellets slowly release ingredients that selectively inhibit Thiobacilli and promote the growth of beneficial heterotrophic bacteria to provide a soil environment conducive to plant growth.

Controlled release systems must be designed to function in varied environments. The chemical and physical environment plus hydrology and climate must be considered. Some specific factors which were taken into account during the development of the controlled release pellet for acid generation inhibition are reviewed in Table 1.

ProMac Systems function when water contacts and activates the controlled release pellets. A quantity of bactericide is carried with the incoming water to points of bacterial action on the pyrite surfaces. Here, the ingredients contact the bacteria and biooxidation is halted at the source (Sobek and Rastogi, 1986).

#### Climate and Altitude

Treatment with ProMac Systems bactericides is site specific and designed to function in a variety of climates from arid to tropical. Dosage rates using different pellet combinations are formulated to meet the conditions of climate. For example, arid regions that receive

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Table 1. Design Factors for ProMac Controlled Release Bactericides

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Chemical Environment

- moisture content, acidity, pyrite content

Physical Environment

- particle size distribution, soil cover, slope, accessibility, degree of vegetation, type of overburden material, age of material (state of acid production)

Hydrology

- percolation rates, runoff rates

Climate

- precipitation (average and events-form), temperature (average and extremes)
- 

little rainfall require quick releasing pellets while regions that receive an abundance of snow or rain require slow releasing pellets.

High altitude regions are often characterized by low temperatures, heavy snowfall, short growing seasons, and shallow soils. Regardless of temperature, bacteria are present in high altitude environments, although they may not be metabolically active. When temperatures fall below 0°C, water is no longer mobile and the controlled release pellets do not release bactericides. During periods of freeze, biotic oxidation does not occur and there is no need for bactericidal release since bacteria are not very active below 2°C (Ferroni, et al, 1986).

A study of T. ferrooxidans in subarctic British Columbia found that surface temperatures in the brief summer reached 15°C. In the low pH environment, T. ferrooxidans was quite capable of establishing populations sufficient to catalyze acid generation. Sulfate generation increased fivefold for every 10°C increase in temperature when bacteria were present, while sulfate generation only increased twofold in an abiotic environment with each temperature increase of 10°C (Halbert, et al, 1983).

#### THE NATURAL DYNAMIC CYCLE

Prior to mining, the soil environment and its biota have defenses against acid-generating bacteria and the acidic byproducts. Once the land is drastically disturbed and sulfides are exposed to water and oxygen, an acidic environment becomes established. Then, T. ferrooxidans populations will increase dramatically and acid production will be accelerated. The calcareous content of the soil will be overwhelmed and unable to neutralize all the acid formed.

ProMac Systems provides the soil environment with the time and conditions necessary to reestablish the natural system of checks and balances. Biotic oxidation is inhibited and there is low acidification of the site material. The pH is maintained at a level sufficient for the development of beneficial heterotrophic bacterial populations. These microorganisms increase the soil-moisture capacity and decompose organic matter, producing humic materials, principally polysaccharides, that aid the development of soil structure and enhance plant growth.

These factors aid the natural succession of vegetation. Soil bacteria produce growth factors and regulators that further stimulate growth. Organic acids, inhibitory to T. ferrooxidans, are produced and the beneficial effects of an increasing heterotrophic bacteria population begin. Vegetation produces plant residues that promote the growth of heterotrophs while the decomposition products of plant residue digestion by heterotrophic bacteria inhibit T. ferrooxidans. Nutrients and minerals are returned to the soil and are available for recycle and reuse, while a healthy root system competes for moisture and oxygen depriving it from the AMD bacteria.

Bactericides, if designed with longevity mechanisms, help nature return mined land to a stable form, similar to conditions existing prior to mining. Normally the acid production cycle can be broken in three to four years with ProMac Systems, while the controlled release pellets are designed with lives in excess of seven years.

After several completions around the Dynamic Cycle, (Figure 2), the heterotrophic bacteria out-number the AMD bacterial in overwhelmingly high ratios, about 1000 to 1. After more than seven years, the ProMac pellets become exhausted and the land is once again self-revitalizing.

#### THE BFGOODRICH APPROACH

Application rates for ProMac Systems are site specific. Diagnostic considerations (Table 2) are determined when field engineers conduct a site evaluation. The team will collect soil and water samples and make a complete audit of physical characteristics of the site.

Following the site evaluation, specific laboratory analyses are conducted on the site material. Work includes incubation and column leach tests which help determine the degree of bacterial activity, acid producing potential, and the combination of ProMac Systems products required to remedy the problem.

Once the diagnosis is complete, ProMac spray and pellets are applied onto graded material. The products are applied using standard reclamation equipment such as a hydroseeder, cyclone seeder, or drop spreader. Topsoiling and standard reclamation practices of liming, fertilizing, seeding and mulching follow the application.

**Key to Permanent Successful Reclamation:  
A NON-POLLUTING, STABLE, REVEGETATED LANDFORM**

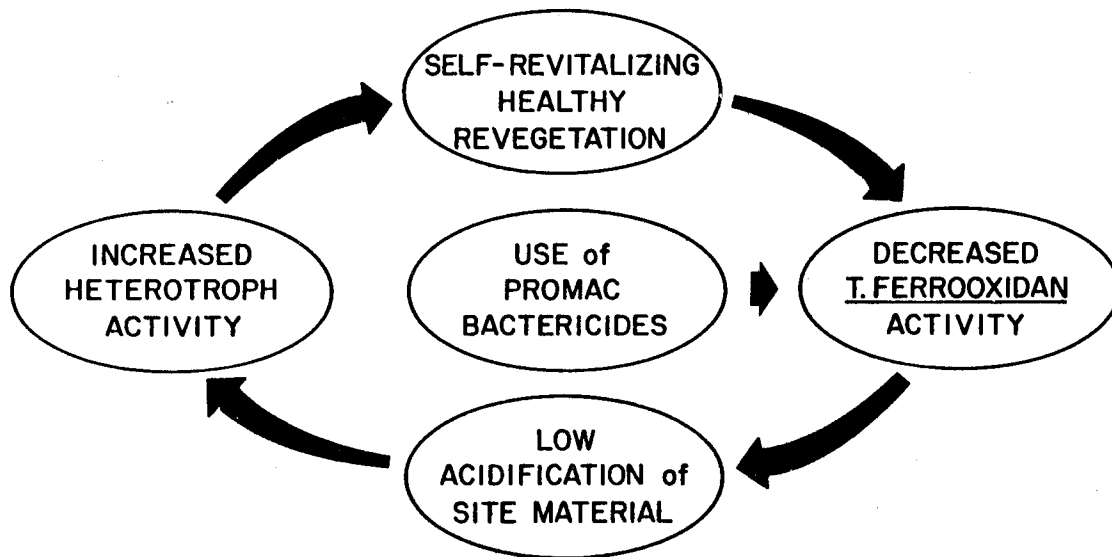


Figure 2. The Natural Dynamic Cycle

Table 2. Diagnostic Consideration

Site Material	<ul style="list-style-type: none"> <li>• Sulfur Forms</li> <li>• Neutralization Potential</li> <li>• Adsorption Capacity</li> <li>• Pyritic Content</li> <li>• Metals Content</li> <li>• Other Geology</li> </ul>
Site Topography	<ul style="list-style-type: none"> <li>• Grade</li> <li>• Permeability</li> <li>• Accessibility</li> </ul>
Hydrology	<ul style="list-style-type: none"> <li>• Drainage Patterns</li> <li>• Precipitation</li> <li>• Infiltration</li> </ul>

The final step is post-reclamation monitoring. BFGoodrich monitors the site, if desired, and performs follow-up site material and water analyses, and bacteriological studies.

## ECONOMICS

The utility of a technology, regardless of its promise and capability, must be judged by its economic viability. ProMac Systems is a proven commercial technology whose survival depends on its cost effectiveness and reliability to customers.

Three major market segments of the mining industry can benefit from the use of bactericides. They are: (1) active mining operations, (2) final reclamation at active operations, and (3) reclamation of abandoned mined land. The economics of each segment vary as each has different end goals.

Active operations are concerned with preventing future acid drainage problems while minimizing the costs of existing treatment. Goals for final reclamation are to reduce total reclamation costs, to prevent acid mine drainage from the site, to reduce or eliminate water treatment costs, and to minimize maintenance and monitoring. Also, the operator wishes to obtain acceptable vegetation to obtain bond release and future mining permits.

End goals for the reclamation of abandoned mine land vary slightly. Goals include minimizing health risks, preventing water pollution, controlling wind and water erosion, obtaining aesthetically acceptable vegetation, and minimizing maintenance and monitoring efforts and costs.

The cost of ProMac Systems treatment is site-specific. Treatment costs for reclamation can vary from \$1200 per acre for a 40-acre spoil area to \$4,000 per acre for a 5-acre, highly pyritic waste rock dump (Rastogi and Sobek, 1986). Bactericides offer several cost offsets. Liming can be drastically reduced because the system limits future acid generation. Lime requirements may be as high as 100 tons per acre without the system, while this requirement may be reduced to ten to twenty tons per acre with the system. Soil cover depth can be reduced to minimum depths, such as eight inches, which reduces reclamation costs associated with borrow areas or transportation costs of imported soil.

Bactericides promote healthy, lasting vegetation and protect against acid burnout. Maintenance costs associated with reseeding and fertilizing as well as erosion control also are reduced. Treatment costs of acid waters generated at these sites are substantially reduced, up to 98% (Rastogi, et al, 1987). Based on costs gathered from various sources, Table 3 shows the potential for cost savings with bactericide treatment. Bactericides may save up to 30% in upfront costs (Table 3) depending upon the site. Future savings which are somewhat intangible are not summarized.

The chemical spray may be used exclusively at active operations such as preparation facilities, product storage areas, snow disposal

areas, haul roads, pit operations, toxic backfill materials, tailing ponds, and inactive leach pads. Costs for a field spray vary from \$500 to \$900 per acre or \$.08 to \$.25 per ton of material processed.

Table 3. Cost of Site Reclamation in \$/Acre

Item	Standard Practice	With Bactericides
Site Grading	1,500 - 5,000	1,500 - 5,000
Lime	40 - 1,200	40 - 40
Soil Cover	2,000 - 8,000	1,000 - 2,000
Borrow Area	700 - 3,000	350 - 800
Seeding	300 - 400	300 - 400
Site Maintenance	700 - 2,000	200 - 700
Engineering	500 - 1,000	500 - 1,000
Bactericides		1,500 - 4,000
Bactericide Application		100 - 200
TOTAL	5,740 - 20,600	5,490 - 14,140
SAVINGS		0% - 30%

#### Case History

An abandoned refuse area, the Route 43 Site in southern Ohio (Figure 3), was studied before and after reclamation with first generation ProMac products. The site was divided into two sections, each about 3 acres, and treated in August 1984. The left half was treated with a combination of liquid spray and controlled release pellets after final contouring. Following the treatment, both sides were covered with 6-8 inches of topsoil followed by fertilizer, agricultural limestone, seed, and hay mulch. The right half serves as the control.

Heterotrophic microorganisms which include bacteria, fungi, algae, and protozoa promote revegetation. Their proliferation indicates the quality of the soil environment. Soil samples were analyzed annually.

Table 4 shows that the treated area has more heterotrophic bacteria than the control area and that heterotrophic populations are growing more rapidly in the cover soil. The study also showed that populations of the detrimental *T. ferrooxidans* increased more than 1000 times (Table 5) on both sides, but increased more slowly in the treated area (Bohac, et al, 1987).

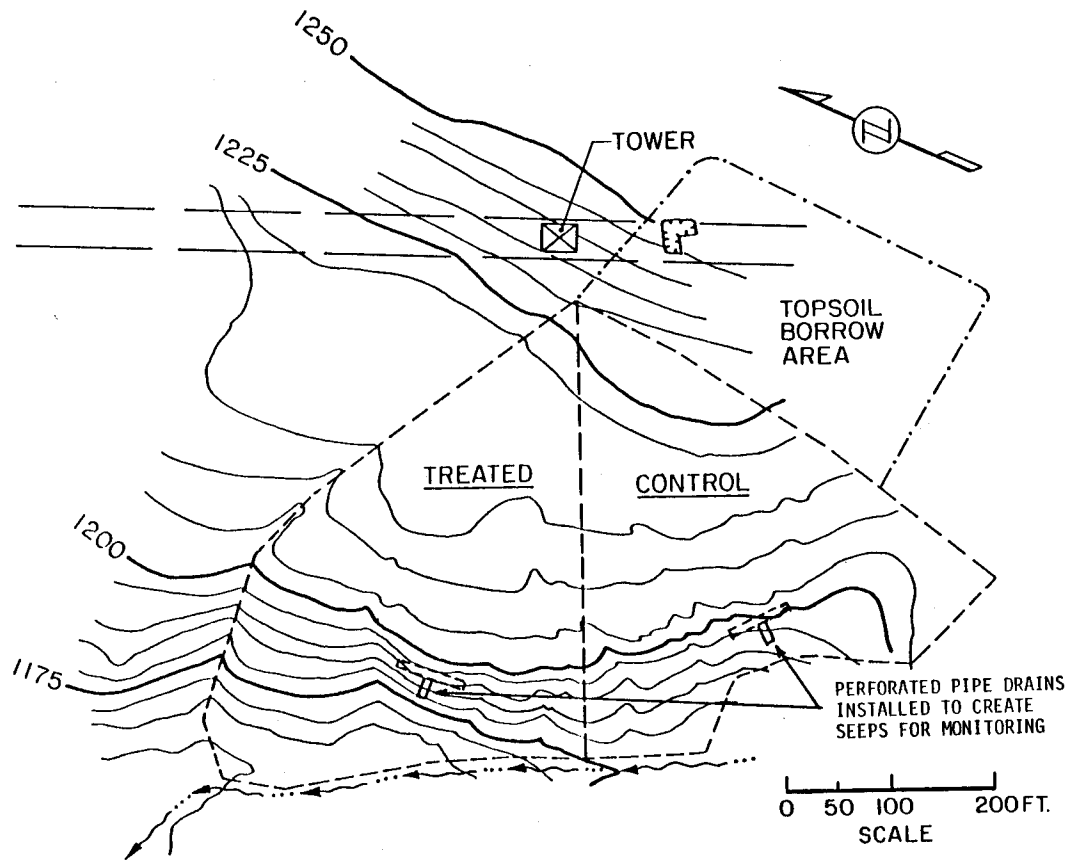


Figure 3. Route 43 Site, Southeast Ohio

Table 4. Heterotrophic Bacteria Populations Per Sample in Cover Soil

	Year		
	1985	1986	1987
Treated Area	$2.6 \times 10^5$	$1.7 \times 10^7$	$3.47 \times 10^7$
Control (Untreated) Area	$2.1 \times 10^4$	$3.8 \times 10^5$	$6.43 \times 10^5$

Table 5. *T. ferrooxidans* Population Per Sample in Refuse

	Year		
	1985	1986	1987
Treated Area	$1.30 \times 10^2$	$9.7 \times 10^3$	$5.61 \times 10^5$
Control (Untreated) Area	$1.34 \times 10^4$	$1.2 \times 10^4$	$1.76 \times 10^7$



Table 6. Ratio of T. ferrooxidans to Heterotrophic Bacteria in Soil-Refuse Interface Samples

	Year		
	1985	1986	1987
Treated Area	0.05	0.35	0.22
Control (Untreated) Area	7.00	1.01	1014.00

Today, the site supports healthy vegetation, while the control area has rapidly degraded. The treated area has denser vegetative cover and generates much less acid than the untreated area. The treated area supports volunteer legume growth which results in increased N<sub>2</sub> fixation and a higher heterotroph population.

What seems to be more important than specific population numbers (Figure 4), however, is the ratio between T. ferrooxidans and the heterotrophic bacteria (Table 6). While in the treated soil this ratio remained about the same, the control area showed a significant increase in this ratio. Figure 5 presents these results in an alternative format.

#### Seep Water Quality

Perforated pipe drains were installed at the Route 43 site on both the treated and control sides. In May of 1987, water samples collected from these drains were analyzed and the data is presented in Figure 6. After three years of reclamation, drastic differences in water quality are noted.

The control area seep produced acid water of a quality similar to naturally occurring seeps on the site prior to reclamation. Water from the seep located in the area treated with ProMac Systems products has low metals and low acid content and does not destroy vegetation.

Refuse moisture data from the Route 43 site also indicate the performance of ProMac Systems products (Figure 7). These data show the chemical parameters that reveal the effectiveness of the bactericide treatment. The treated area data continue to show consistently improving conditions and stability, while data from the control region show high acidity and solubilized metals and deteriorating conditions.

Interesting to note, aluminum content almost perfectly follows the acidity curve, indicating the direct relationship between acid and aluminum solubilization. Aluminum is a prime phytotoxin.

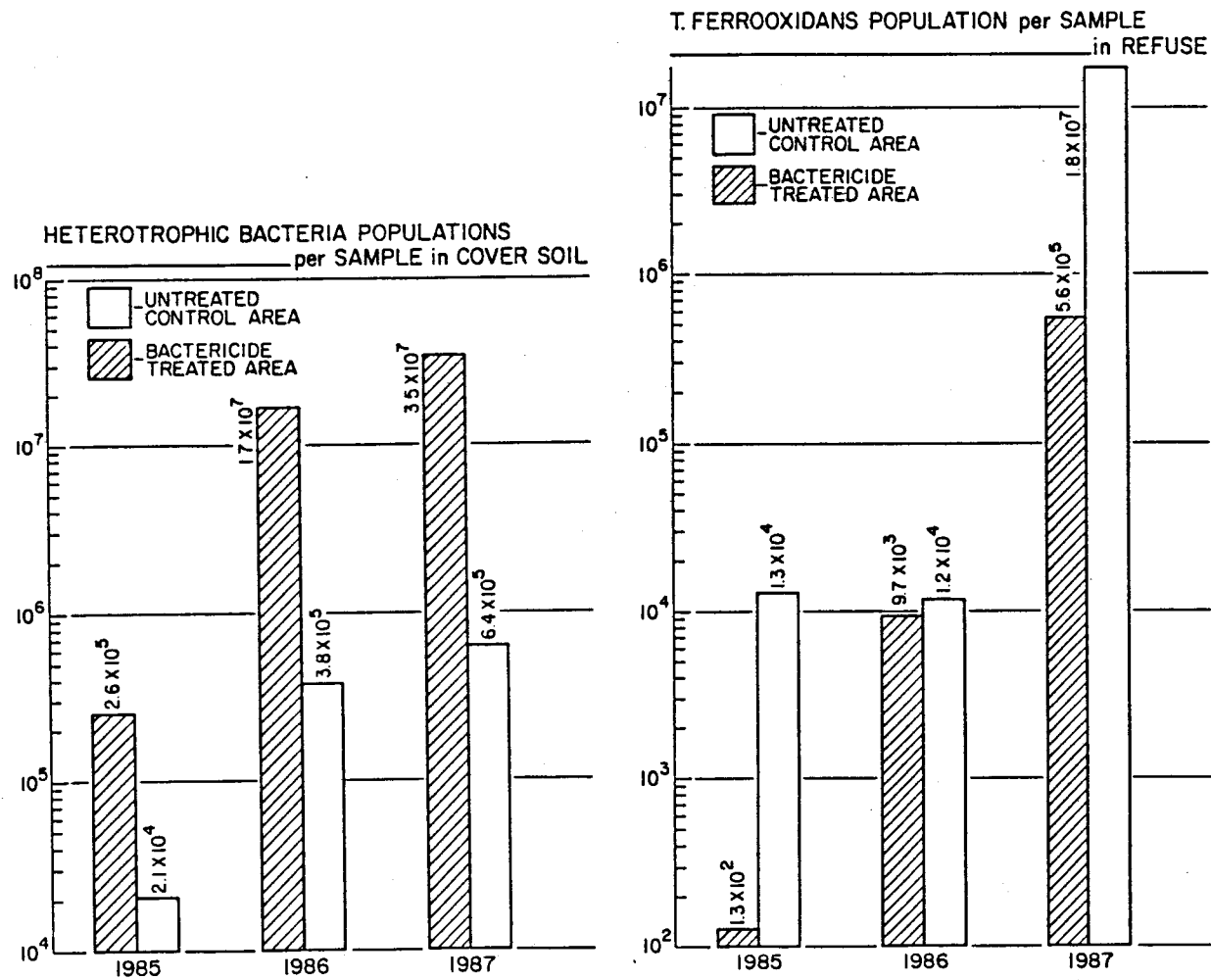


Figure 4. Bacterial Populations for 3 Years after Treatment of the Route 43 Site

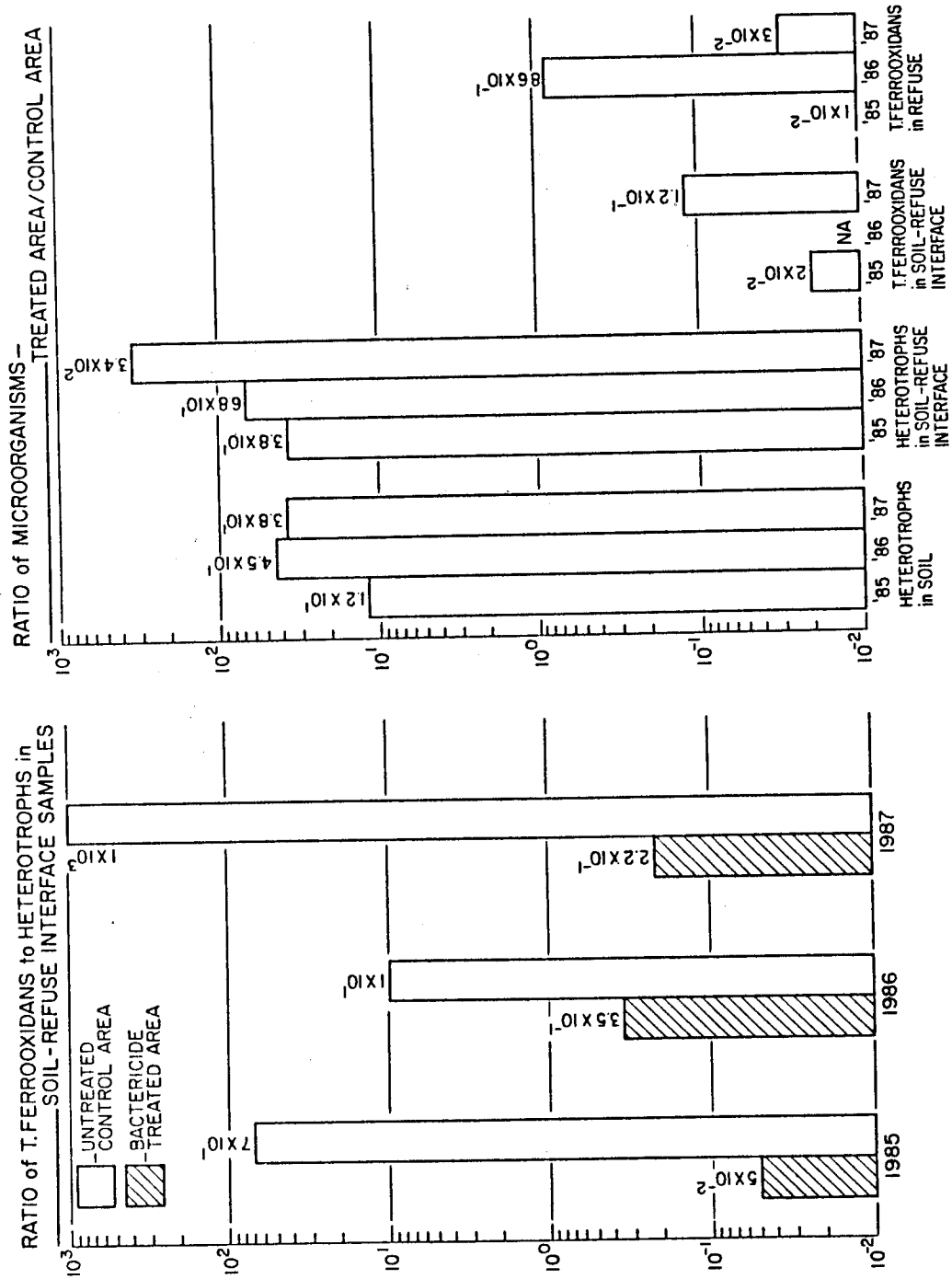


Figure 5. Microbial Ratio Data from the Route 43 Site



TREATED SIDE DRAIN

pH 5.9

Acidity	19 ppm	Sulfates	100 ppm
Al	0.5 ppm	Fe	<0.2 ppm
Mn	0.3 ppm	Cond.	590 $\mu$ mhos

NOTE: HIGH QUALITY VEGETATION



CONTROL SIDE DRAIN

pH 2.6

Acidity	844 ppm	Sulfates	2,040 ppm
Al	38.7 ppm	Fe	104 ppm
Mn	6.1 ppm	Cond.	2,910 $\mu$ mhos

NOTE: VEGETATION DESTROYED BY SEEP

Figure 6. Water Quality Data from Artificially Created Seeps 3 Years after Reclamation

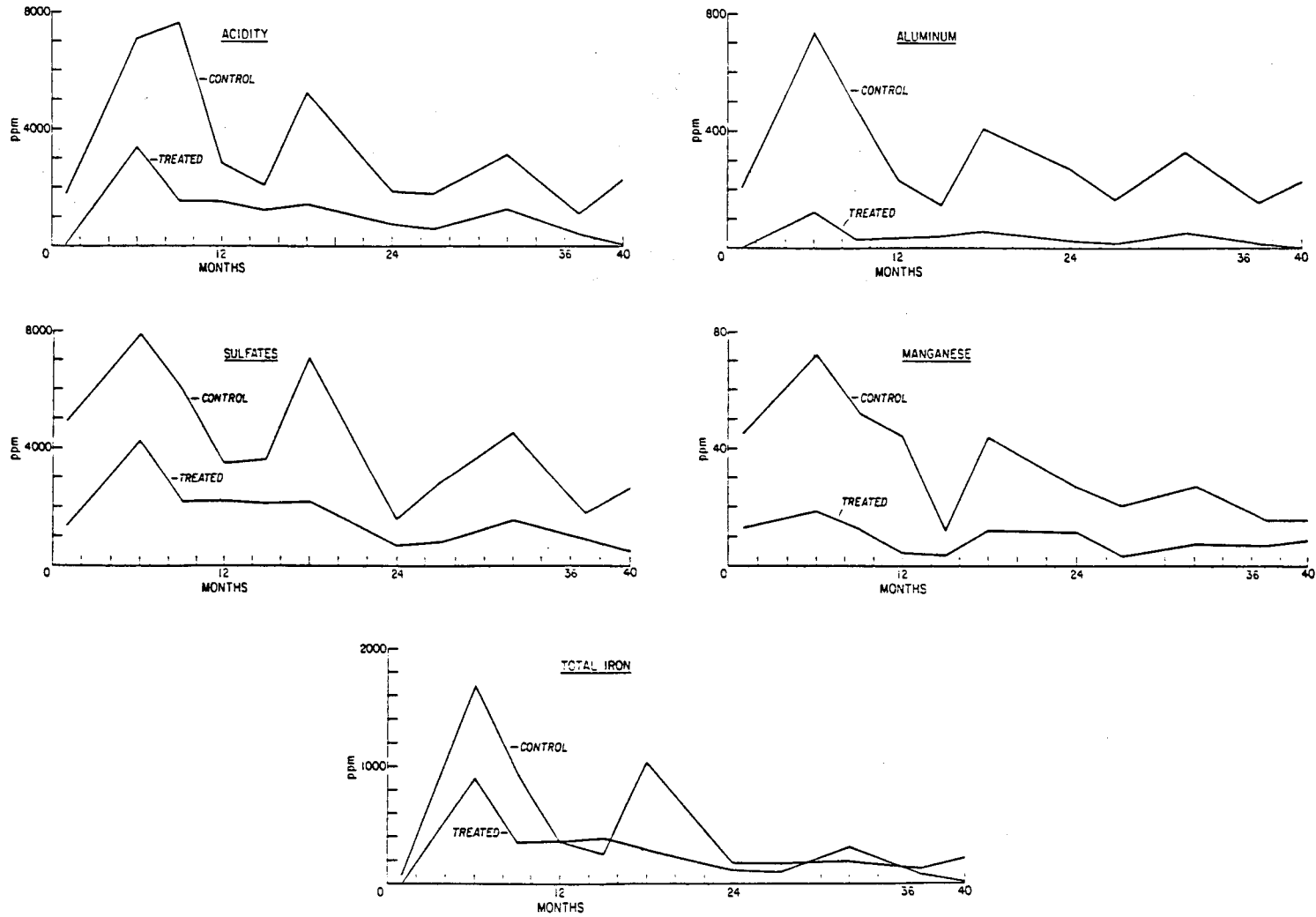


Figure 7. Refuse Moisture Data from Lysimeters 3 Years after the Route 43 Site was Treated

LABORATORY STUDIES WITH METAL MINING WASTES

Sulfur fractionation was performed on all three materials to determine pyritic sulfur and resultant ferrous iron contents. Table 7 contains the sulfur form data for each material where the levels of pyritic sulfur are in decreasing amounts. Also, the materials are listed in order of increased weathering.

Table 7. Sulfur Fraction Determination

	Pyritic Sulfur %	Sulfate Sulfur %	Organic Sulfur %	Total Sulfur %
Copper	47.500	0.400	0.810	48.700
Nickel	5.430	2.310	3.160	10.900
Uranium	0.321	0.992	0.017	1.330

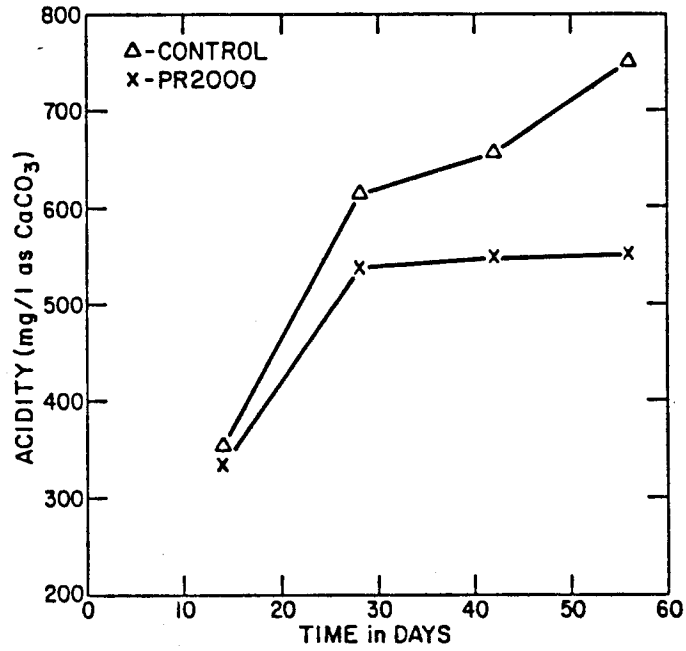
Figures 8 and 9 represent acidity data obtained from eight weeks of incubation testing for tailing samples of copper, uranium and nickel ores, respectively. As the data represent separate samples from each incubation period, the results are cumulative and must be compensated for by adjusting to a time zero baseline (Sobek, et al, 1986; Sobek, 1980).

Data trends established for copper (Figure 8) indicate that subsequent to four weeks of incubation, acid production was minimal. A final reduction in acidity at week eight of >50% averaged for the treated samples was obtained.

Induced leachates from uranium tailings (Figure 8) suggested an immediate response to the bactericide was obtained, evidenced by 70% reduction in acid production at the second week of incubation. However, trends established through week eight indicate a return towards control level acidity values. In contrast, results on nickel tailings (Figure 9) indicate no reduction in acid production by the treatment was obtained during the test period.

Acidified ferric ion solutions are effective lixiviants for many metals of sulfide and oxide ores. On this basis, the copper ore tailings possessing the highest pyritic sulfur level would be expected to produce the most acidity. Data presented in Figures 8-9 contradict this prediction, showing a significantly higher level of acidity for uranium ore samples. Nickel tailing leachates produced acidity levels at rates relative to uranium and copper tailings in agreement with pyritic sulfur analysis.

### COPPER TAILINGS



### URANIUM TAILINGS

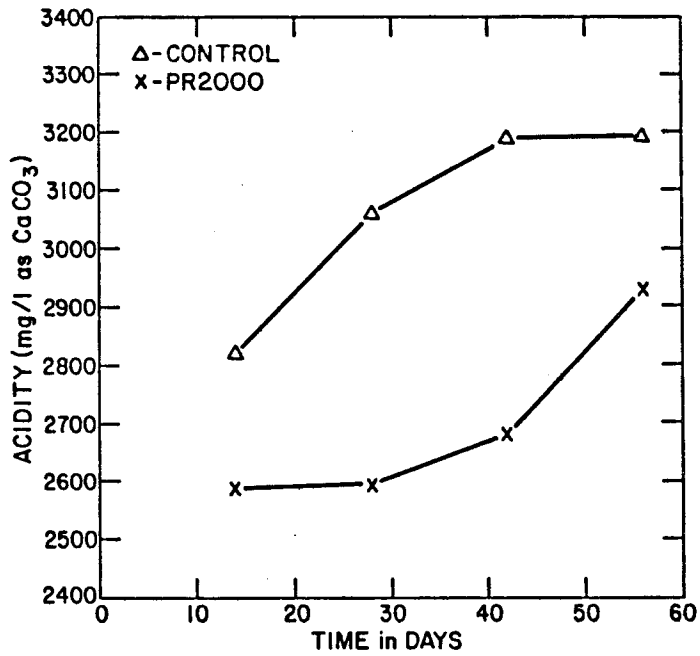


Figure 8. Acidity from Incubation of Copper & Uranium Tailings

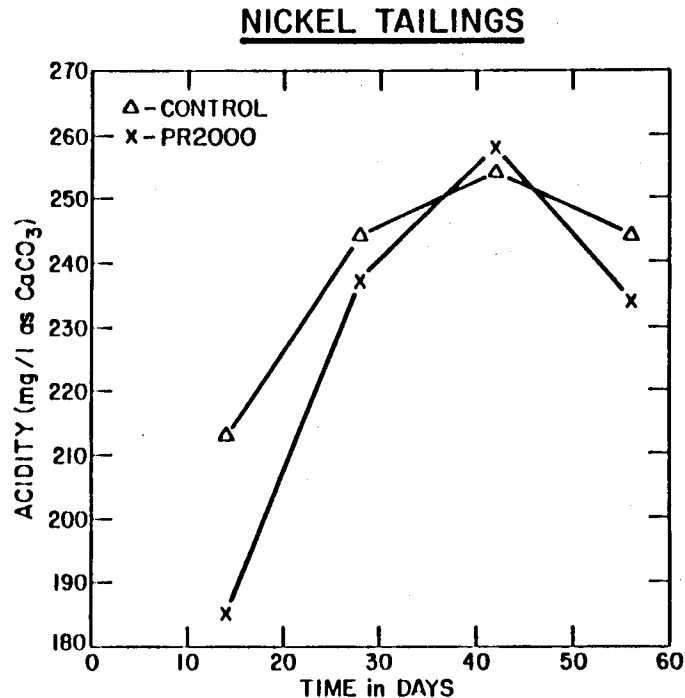


Figure 9. Acidity from Incubation of Nickel Tailings

Batch incubation data by itself shows that significant inhibition of iron-oxidation and subsequent pyrite oxidation and acid formation were witnessed only for copper ore tailings. The lack of a positive bacterial response for nickel leachates suggests that inorganic kinetics were governing the pyritic oxidation and the nickel tailings were not acidic enough for vigorous bacterial activity. However, uranium tailing leachates exhibiting strong positive bacterial responses produced minimal levels of acid inhibition during interim incubation periods. High baseline acidities for this material may generate potential acid hydrolysis of the bactericide solution producing limited effects.

#### FUTURE OF BACTERICIDES IN THE PREVENTION OF AMD

With the rebound of mining and an increased concern to restore mined land to its original condition, bactericides may become standard practice in reclamation. Indeed, Ohio, Illinois and Indiana have cited ProMac Systems in their reclamation specifications. Montana, West Virginia, California, Texas, and Pennsylvania are expected to follow suit.

Microbial based technologies have allowed the extraction of metals from low grade ores, thereby increasing the volume of waste associated with these operations. T. ferrooxidans is the most widely studied leaching microorganism of economic importance. Bactericide technology may hold the key to the disposal of such wastes.



In the near future bactericides could be used to control acid generation in leach pads which are temporarily inactive due to market fluctuations. Maintenance and water treatment efforts would be minimized during the shut-down until the economic situation changes, then the pad could be reactivated.

Presently, bogs, water treatment facilities, and a host of exotic technologies offer the only means for treating mine drainage from underground sources. In the future, bactericides may be used to prevent, rather than treat, deep mine acid waters. An effective means for delivering bactericides to deep mines needs to be established.

#### CONCLUSIONS

ProMac Systems involves the use of controlled release bactericide to reduce acid drainage problems and improve water quality as well as to reduce associated treatment costs in active mining, at preparation plants, in active coal piles, active refuse piles and mine tailings. The system requires a one-time application that sets up a recovery cycle to help nature permanently restore a site with healthy vegetation. By inhibiting acid-producing bacteria, ProMac Systems reduces acid formation and aluminum solubilization. It makes the environment conducive to growth of heterotrophs which are needed for healthy vegetation, which in turn produces humus and organic acids detrimental to the acid-producing bacteria. ProMac Systems products are biodegradable.

ProMac Systems has been registered by the U. S. Environmental Protection Agency under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) for use in controlling acid formation in minesoils.

Unlike many other abatement techniques, ProMac Systems is a preventative strategy designed to stop acid problems before they develop.

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## WETLAND-BASED TREATMENT STRATEGIES FOR ACID MINE DRAINAGE CONTROL

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### INTRODUCTION

There are over 10,000 abandoned mines in Colorado, many of which discharge drainage into nearby streams and rivers. Such discharge, along with leachate from mill tailings and mine waste rock dumps, contributes to one of the most widespread water quality problems in the State: high concentrations of heavy metals. In Colorado alone, nearly 3000 miles of streams and rivers have metal concentrations that exceed basic standards for aquatic life, agriculture, or domestic water supply. Much of the metal content of these waters is a natural consequence of surface and ground-water flow over and through mineralized rock. However, approximately 1400 stream miles have elevated metal concentrations that can be directly attributed to past mining activities. In several instances, this has attracted national attention. For example, there are eight mining sites in Colorado on the National Priority List for possible Superfund remedial action. Because of the widespread nature of this problem, there clearly is a need for low-cost, low-maintenance treatment alternatives to the relatively expensive treatment technology currently available.

One method that recently has become popular in coal mining regions of the eastern United States is the construction of wetland treatment impoundments. This method relies on natural biological and geochemical processes to remove metals from discharge that is allowed to flow through the system. They are generally constructed by excavating a shallow impoundment, filling the depression with organic mulch (peat, composted hay, ground forest products, and similar materials have been used), and planting aquatic vegetation. Other designs, such as creating a marshy meander belt have also been tried. Many of these systems have been shown to be effective in removing significant amounts of metals (Girts and Kleinmann, 1986, and Kleinmann 1985). The demonstrated success of these systems has generated sufficient interest among state and federal agencies in the West to investigate their potential in the mineral belts of the Rocky Mountains. In this paper, we describe some of the natural processes whereby metals are removed by wetlands, and discuss what we believe to be important considerations that need to be recognized in the development of this type of technology.

## METAL REMOVAL FROM WATERS BY WETLANDS

The metal removal capability of wetland environments, such as marshes, bogs and fens is well known, and in fact, some economic metal deposits are ancient wetlands (Atlas and Bartha, 1981). Several processes contribute to metal absorption by these systems. As chemical oxidation takes place, oxides and hydroxides of iron and other metals precipitate from surface flow and in ponds. These precipitates settle in quiet water or are filtered out as the water passes through the soils and around vegetation. Precipitation of metals is strongly pH-dependent, and because the pH of mine drainage often is low (usually from 2.5 to 5.5), ferric hydroxide will be the main precipitate, forming the characteristic yellow sediment in mine drainage known as "yellow boy". Most other metals remain soluble under such acid conditions. Under conditions of neutral or alkaline pH, precipitation of hydroxides is the dominant form of metal removal, which is one reason that conventional treatment techniques often specify the addition of lime. Under low-pH regimes in wetlands, other processes can become important in removing metal ions.

Wetland soils are typically high in organic content, and as a result, usually have a high cation exchange capacity compared to other soil types. This property gives wetland soils the ability to absorb relatively high amounts of metal ions by exchanging them with hydrogen ions bound to the structure of the organic molecules. The magnitude of the cation exchange capacity of wetland soils varies considerably, depending on the conditions of soil formation, the nature of ions already occupying exchange sites, and the percentage of the inorganic soil fraction. Values in the range of 0.1 to 1 meq/g dry soil seem to be typical of many sites in the Rocky Mountains. The ability of organic soils to adsorb metals by cation exchange diminishes as exchange sites become saturated with metals, or as the pH of the soil becomes more acidic. In any case, the quantity of metals held in the soils by adsorption to organic molecules is finite, and from our observations of wetland sites in the Front Range that receive metals from mineral seeps or mine drainage, probably represents less than 15 percent of the total soil metal content.

However, the value of organic adsorption should not be assessed in terms of cation exchange capacity alone. Metallo-organic complexes, when viewed over time periods of years to decades, probably represent a transitional phase in the eventual formation of more stable inorganic metal compounds. Without the retention capability of the organic soil fraction, most of the metals would flush through the system. Furthermore, some of the organic metal complexes may be labile forms that are more readily used by microorganisms.

Microorganisms constitute an important component of wetland ecosystems and have a significant influence on the geochemistry of metals (Mitsch and Gosselink, 1986). Bacteria, algae, and fungi can reduce dissolved metal ion concentrations either by direct accumulation of metals within their cellular structure or by producing changes in

pH, or by catalyzing redox reactions in the aqueous environment to facilitate precipitation of the metals from solution (Beveridge and Murray, 1976; Dugan, 1970). In aerobic soils, certain species of Thiobacillus oxidize iron and sulfur, while in anaerobic soils Desulfovibrio reduces sulfate to sulfides (Tuttle, et al, 1969). Other aspects of the importance of microbes to the concept of wetland treatment are discussed below.

Higher plants growing in the wetland also are important to the metal removal process, but mostly in an indirect manner. Vegetation stabilizes the soil, helps to filter out metal precipitates, and provides a source of energy and carbon to the microbial components of the ecosystem. Plant roots also may temporarily concentrate certain metals such as iron on their surface, perhaps in conjunction with microbial processes (Gambrell and Patrick, 1978). Plants do absorb metals through their roots, often concentrating the metals in root or shoot structures, but accumulation of metals in plant parts is of doubtful importance in long-term retention of metals by wetlands. Metals absorbed by plants are presumably leached out of dead plant parts during the decomposition process.

#### METAL ACCUMULATION IN NATURAL WETLANDS

There are many places in the Rocky Mountains where wetland ecosystems exist at natural mineral seeps or have invaded abandoned mining sites. If the concept of wetland treatment is valid for mountain environments, then we should be able to observe the accumulation of metals in the sediments of these wetland sites and detect an improvement of water quality. While there are few published data on metals in such environments, the result of recent surveys of high altitude fens in the Front Range suggest that such accumulation is taking place. A dramatic decrease in metals and an increase in pH was measured in surface waters flowing through a fen that receives drainage from the Shoe Basin Mine (Figure 1, Emerick and Howard, 1988). Analyses of soils from several wetland sites (Figure 2) demonstrate a range of metal accumulation, with the highest concentrations observed in fens receiving mine discharge (Cooper and Emerick, 1988). While the above surveys do not represent rigorous investigations of the wetland processes involved in metal accumulation, further study of these or similar sites may be instructive in determining appropriate design features of constructed wetland treatment systems. The fact that metals appear to be accumulated in relatively high concentrations fosters optimism that such sites may be regarded as natural models with features that could be emulated in the design of constructed systems.

#### THE DEVELOPMENT OF CONSTRUCTED WETLAND TREATMENT SYSTEMS

The notion of wetland treatment has become very popular among many mining companies in the East. As a result, over the past few years over two hundred systems have been built, often with little knowledge

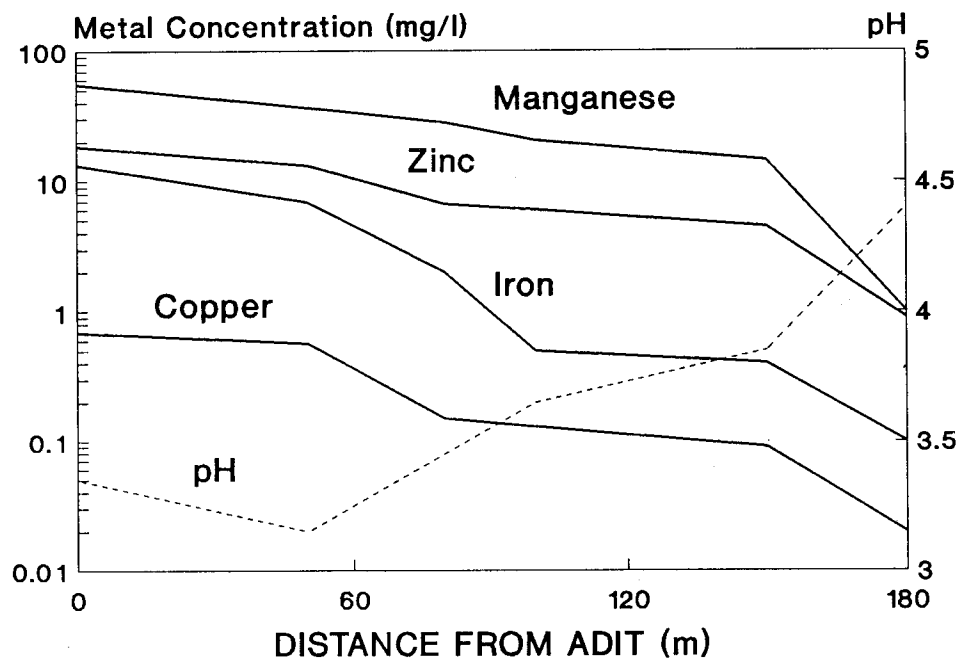


Figure 1. Concentrations of manganese, zinc, iron, and copper, and values of pH in surface waters flowing through a wetland receiving discharge from the Shoe Basin Mine adit. The site is located in the Peru Creek drainage approximately four miles southeast of Loveland Pass, Colorado. The discharge flows down a ditch for about 50 m before it reaches the margin of the wetland, which is a sedge fen, dominated by *Carex aquatilis*. The initial drop in pH observed in the figure is probably due to oxidation of ferrous iron.

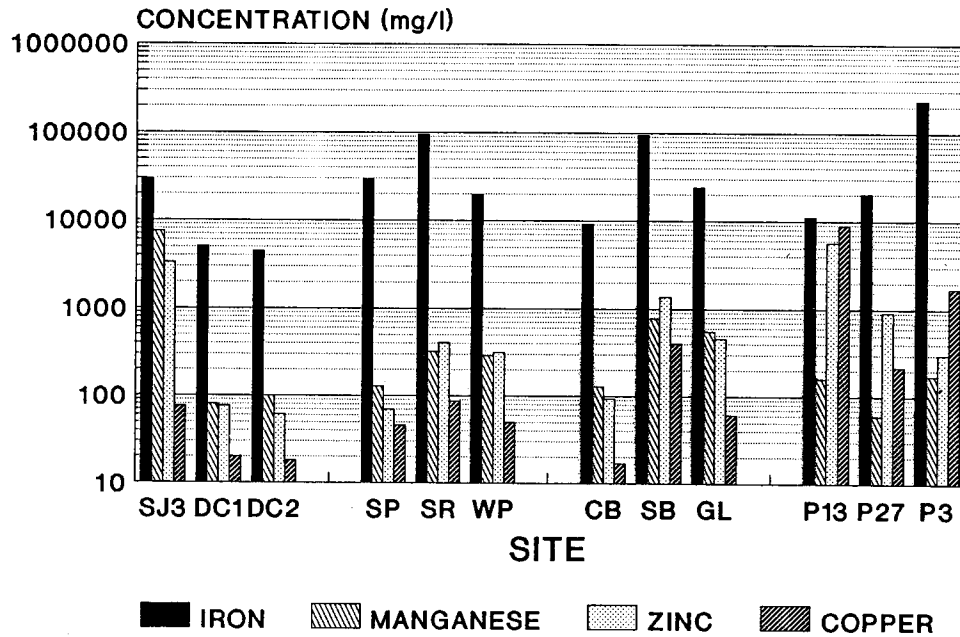


Figure 2. Concentrations of iron, manganese, zinc, and copper in wetland soils from selected sites along the upper Snake River and its tributaries near Montezuma, Colorado. Sites labeled SJ3, SB, P13, P27, and P3 are fens that receive mine drainage, or are contaminated by mill tailings. SP, SR, and GL receive water from natural mineral seeps, and DC1, DC2, and CB are relatively "clean" sites with no apparent affect from mineralized rock or waters.



or understanding of how or why they should work. Some systems have proven to be effective, but others have not. A beneficial side effect of this activity has been that workers at the Bureau of Mines in Pittsburgh have been able to evaluate many systems and are gaining an understanding of which designs seem to work best.

In the West, interest in these systems has been slow to develop and as a consequence few have been constructed. We don't have a large data base on which to compare successes and failures. As a result, we have focused on the theoretical basis of this type of water treatment, and have been conducting studies of specific components of wetland based treatment systems.

Perhaps one of the reasons for the slow growth of this technology in the west (other than the fact that many people aren't aware of this method) stems from the different environment of the Rocky Mountains compared to eastern regions, which has led to some uncertainty regarding the transferability of the technology. Mountain climates are cooler, and have shorter growing seasons. Biological and geochemical processes can be expected to proceed at slower rates than in warmer regions, implying that larger treatment areas would be needed. Terrain is often steep, with limited access, and narrow valley bottoms often don't offer much room for construction of wetland impoundments. In many of these situations, wetland treatment simply would not be practical. In spite of these limitations, the demonstrated potential of this treatment concept warrants consideration for western regions.

The primary objective of using a wetland for treating mine drainage is to precipitate the metals such that they will be immobilized. If we were to speculate on the most likely immobile forms for metals dissolved in mine drainage, it is reasonable to investigate how these metals occur in sediments that have undergone early diagenesis. The rationale is that the mineral forms for manganese, iron, and the other base metals in mature sediments represent the most thermodynamically stable phases for these elements. Some of the classic monographs on geochemistry (Mason and Moore, 1982; Krauskopf, 1979; Stumm and Morgan, 1981) and sedimentary petrology show that in sediments formed by chemical precipitation, the usual iron minerals are hematite ( $\text{Fe}_2\text{O}_3$ ), pyrite ( $\text{FeS}_2$ ), or siderite ( $\text{FeCO}_3$ ), and the usual manganese minerals are pyrolusite ( $\text{MnO}_2$ ) and rhodochrosite ( $\text{MnCO}_3$ ). The base metals (Cu, Zn, As, Ag, Cd, Au, Hg, and Pb) typically occur as sulfides, oxides, and carbonates.

Of particular importance is how these elements occur in lignites and coals since this would be the ultimate fate of a wetland over geologic time. In this case, the metals generally end up in inorganic forms such as pyrite and rhodochrosite and are not retained by the organic constituents (Valkovic, 1983).

The importance of these observations lies in determining the role of organic material in a wetland system. If the above observations do indeed point to sulfides, oxides, and carbonates being the most stable

forms of base metal precipitates, then immobile organic forms of these metals are intermediate products that will eventually decompose to inorganic precipitates. This also implies that the strategy for optimizing a wetland treatment system is to focus on the formation of inorganic precipitates and design the organic portions of the system to promote the formation of these products. An important research goal should be to determine how this can best be done.

Bacteria survive in nature by catalyzing chemical reactions that are far from equilibrium and can release significant amounts of energy upon reaction. Indeed, the formation of acid mine drainage is significantly promoted by bacteria that subsist on the energy released by the oxidation of pyrite (Krauskopf, 1979). In aerobic zones in a wetland, these same bacteria will promote the oxidation of iron and perhaps manganese to the more insoluble states. In the anaerobic zones, sulfate-reducing bacteria are active in the formation of  $H_2S$ . Bacterial decomposition of organic matter will, to some extent, cause the release of ammonia. Generation of hydrogen sulfide and ammonia has the effect of raising the pH of the system and promotes formation of inorganic precipitates, resulting in improved water quality. Thus, another important goal for the design of wetland treatment systems is to provide optimum conditions for the growth of the aerobic and anaerobic bacteria that catalyze these reactions.

#### CONCLUSIONS

A constructed wetland treatment system must be regarded as an ecosystem, with the various processes that lead to the improvement of water quality inextricably interrelated. Retention of metals and formation of stable inorganic precipitates is mediated by microbes, organic soils, and vegetation. Temperature, pH, and dissolved gases affect all of these components, as does the hydrology of the system, which affects movement of substances from one place to another. The interdependency of components and processes presents a very challenging problem to those who seek to understand and manipulate the functions of such a system.

In spite of the interest and development that has taken place regarding wetland treatment, there is much that needs to be learned before we can optimize system design. For example, we need to know more about rates of metal accumulation in wetlands, and in particular, rates of transformation of accumulated metals into inorganic forms. We also need to know more about the optimum growth conditions for microbes, and which microbial groups would best enhance the performance of constructed treatment systems. Finally, once these systems are proven practical for mountainous regions, we face the problem of developing suitable plant materials in sufficient quantities. None of these problems are insurmountable but solutions will require time. However, we need only to look at the reclamation industry to remind ourselves that rapid technological advancement has taken place in

little more than a decade. We are optimistic that the same will hold true for the development of a wetland-based treatment technology.

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High altitude revegetation research in the Swiss Alps: experimental establishment and performance of native plant populations in machine-graded ski runs above the timberline

by

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Introduction

Research dealing with biological control of erosion above the timberline is of a particular importance to Alpine countries of Europe. The ever-growing popularity of ski sport in these areas brought about an extensive construction of machine-graded and machine-maintained ski runs, numerous ski lifts, etc. All this development resulted in an increasing destruction of alpine soil and vegetation, the danger of erosion becoming quite pronounced in some places. The results of commercial revegetation trials, carried out high above the timberline with a lowland seed material, are not satisfactory in a long run, despite rather intensive maintenance measures (see e. g. Cernusca 1977, Grabherr 1978, Meisterhans 1982, Meisterhans in press, Stolz 1984).

The research programme of the Geobotanical Department, Swiss Federal Institute of Technology, Zürich, represents a minimum-maintenance approach to the problem of revegetation of high-alpine sites (Urbanska 1986, 1986a, Urbanska and Schütz 1986, Urbanska et al. 1987). Each of our current projects deals with a slightly different facet of the biological erosion control, but all field trials follow the same basic concept, which may be outlined as follows:

- native plant material is exclusively used both in seeding and planting;
- plant material and geological substratum are matched i. e. only the plants adapted to dolomite are used in trials upon dolomite, etc.;
- if any at all, only organic fertilizer is applied in a single initial dose;
- no chemical stabilizers are used; the trial surfaces either are covered with biodegradable mats or left unprotected;

- once seeded or planted, the trial surfaces are not managed anymore.

The present paper deals with some results obtained so far, behaviour and performance of selected experimental populations being reviewed. The results reported here are respectively based upon a three-year, two-year, and one-year observation period, which in turn corresponds to four, three, or two vegetation seasons, depending on the exact timing of the field trials.

#### Population types and their establishment

The experimental populations dealt with in the present paper were all established upon dolomite, at about 2400m a. s. l. They represented at the initial phase of trials three different categories:

- A. Populations consisting exclusively of seeds;
- B. Populations comprising only clonal modules of several to numerous ramets each;
- C. Mixed populations including both ramets/clonal modules and seeds.

A. The seed populations discussed here represented 12 taxa and 7 plant families (Table I). All the seeds used were harvested in the year preceding the seeding experiments (see Schütz 1988). The seed mixtures were sown onto plots of 1m<sup>2</sup> each, soon after the early summer snowmelt in the alpine vegetation belt. Each mixed sample weighed approximately 2.5g and roughly corresponded to 1000 seeds. The single initial dose of fertilizer applied in these trials was 120g/plot.

Table I. Seed population established in some plots upon dolomite (after Schütz 1988). \* = seeds partly pretreated prior to seeding.

Taxon	Family
<i>Sesleria coerulea</i>	Gramineae*
<i>Luzula multiflora</i>	Juncaceae
<i>Silene willdenowii</i>	Caryophyllaceae*
<i>Gypsophila repens</i>	Caryophyllaceae
<i>Sagina linnaei</i>	Caryophyllaceae
<i>Biscutella levigata</i>	Cruciferae
<i>Arabis alpina</i>	Cruciferae*
<i>Dryas octopetala</i>	Rosaceae
<i>Lotus alpinus</i>	Leguminosae*
<i>Oxytropis jacquinii</i>	Leguminosae*
<i>Anthyllis alpestris</i>	Leguminosae*
<i>Achillea atrata</i>	Compositae

The seed populations were established in two kinds of sites viz. 1/ natural semi-stabilized scree slopes and 2/ machine-graded ski run. Some seeded plots were covered with the CURLEX mats, others were left unprotected. For further details, the reader is referred to the recent publication by Schütz(1988), from which the data presented here originate.

B. The populations consisting exclusively of clonal modules represented 5 alpine species, all belonging to the family of Gramineae (Table II).

Table II. Clonal module populations established by planting in some plots upon dolomite (partly after Urbanska et al. 1987, some unpublished data if Hefti-Holenstein included).

Taxon	N of clonal modules	
	SP	FP
<i>Festuca pumila</i>	102	0
<i>Poa alpina</i>	40	80
<i>Sesleria coerulea</i>	18	18
<i>Trisetum distichophyllum</i>	40	6
<i>Trisetum spicatum</i>	40	56

SP = summer planting

FP = fall planting

The clonal modules were issued from the single tiller cloning of small tussocks sampled in the wild (Urbanska et al. 1987, Hefti-Holenstein, in preparation). The series, grown in the ROOTRAINER compartments in fertilized garden soil mixture, were first kept in an unheated greenhouse, then in experimental garden in Zürich (400m a. s. l.), and eventually brought for an acclimatization period preceding the actual planting to Davos-Clavadel (Grisons, 1860m a. s. l.).

The clonal modules were planted by hand in machine-graded ski runs, some of them being put into spaces literally hammered out in bare rock. Single-species and mixed-species neighbourhoods were established in a hexagonal design (Urbanska et al. 1987). The planting was carried out in two series, one soon after the summer snowmelt, another in early fall; the corresponding subpopulations were established quite near to each other. The joint surface of revegetated plots was 7.7m<sup>2</sup>, and the clonal modules planted totalled 400 (Table II). No fertilizer was applied in these field trials. The planted plots were covered with the CURLEX mats.

C. The mixed populations of the third group represented 8 alpine taxa of 6 families (Table III). This series included various plant types viz. grasses, graminoids, legumes and forbs. The clonal modules were obtained by single ramet cloning of small samples collected in the wild (Urbanska

et al., in preparation) and grown in the same way as the material of the group B (see also Urbanska et al. 1987).

Table III. Mixed populations established by planting and seeding of some plots upon dolomite (unpublished data of G. Elmer and M. Gasser).

Taxon	Family
<i>Agrostis gigantea</i>	Gramineae
<i>Elyna myosuroides</i>	Cyperaceae
<i>Carex sempervirens</i>	Cyperaceae
<i>Carex firma</i>	Cyperaceae
<i>Anthyllis alpestris</i>	Leguminosae
<i>Plantago atrata</i>	Plantaginaceae
<i>Valeriana montana</i>	Valerianaceae
<i>Chrysanthemum atratum</i>	Compositae

The mixed populations were established in two series, one in early summer, another in early fall. No fertilizer was applied in the trial plots. The ramets and clonal modules were planted by hand in a hexagonal design, with a single module in the centre of each hexagon. Seed samples of 100 seeds each were then sown into selected hexagons representing single-species neighbourhoods of a given taxon. Depending on the availability of the seed material, seeding was carried out either in the early summer or in the fall populations. The whole trial surface was covered with the CURLEX mat.

The revegetated plots had a joint surface of 17.6m<sup>2</sup>; the ramets and clonal modules planted totalled 793.

#### Population performance

##### A. Seed populations

Behaviour of the experimental seed populations was very varied; the onset of seedling emergence, its actual pattern as well as the percentages differed from one taxon to another, from one plot to another, and also from year to year (Schütz 1988). Pronounced differences were observed, too, in the seedling mortality and the genet recruitment.

Of the 12 species used in the seeding experiments discussed here, three did not form so far any lasting cohorts of seedlings or young plants; it seems that they remain rather inert within the seed bank experimentally



established in the trial plots. As far as the performance of the remaining taxa is concerned, Schütz(1988) described several behavioural types. We propose to consider here two of them:

1. Type BS, named after Biscutella levigata and Silene willdenowii, was characterized by a poor germination immediately after seeding in early summer, but by a good germination after the first winter. A remarkable trait of this group was the low seedling mortality(ca. 10%), rather unusual for alpine plants(Fig. 1). According to Schütz, some alpine legumes behave in a similar way when their seeds are sown non-scarified.

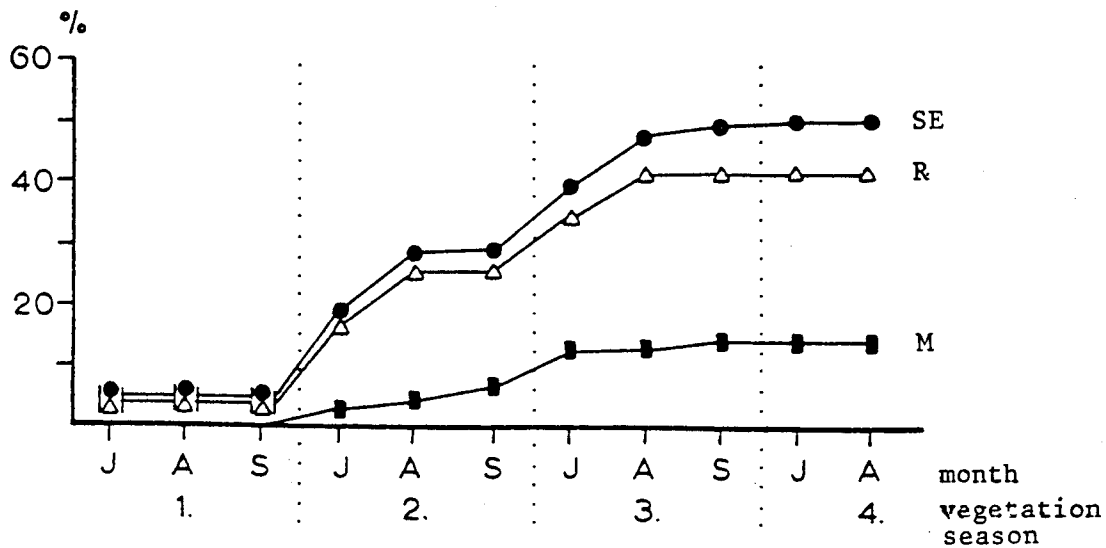


Fig. 1. Seedling emergence, mortality and the genet recruitment in the BS type(after Schütz 1988). SE = seedling emergence; R = recruitment of genets; M = mortality. Early summer trials.

The established genets of the type BS developed well. Some individuals of Biscutella levigata reached the reproductive phase already two years after seeding i. e. in their third vegetation season. They produced flowers and seeds which germinated the next summer in a characteristic cluster, within a short distance from the mother plants. More individuals developed flowers and seeds in the following summer and this tendency is clearly increasing. Flowering in Silene willdenowii occurred for the first time three years after seeding and it is possible that the reproducing genets might be in their fourth vegetation season. However, the seedlings were not marked at the moment of their emergence, and the reproducing individuals might as well represent younger cohorts. At the end of summer in 1987, Silene willdenowii produced several capsules filled with seeds.

2. Type L<sub>s</sub>, representative of scarified seed populations of legumes, was characterized by an exceedingly rapid and very good germination occurring immediately after seeding but followed by a rather high mortality of seedlings and young plantlets during their first winter. No seedling emergence was found during the next vegetation season and it seems that scarified seeds had no chance of winter survival in the alpine soil. The recruited genets developed well, and Anthyllis alpestris undoubtedly was the most vigorous taxon in this category.

As far as the reproductive phase in the group L<sub>s</sub> is concerned, development of flowers and seeds was so far observed only in Anthyllis alpestris; other legumes apparently did not yet reach their reproductive size by the end of the last summer. The first flowers and ripening seeds were produced by several genets of Anthyllis alpestris only three years after seeding (Schütz 1988).

#### B. Clonal module populations

All the clonal module populations representing the series B invariably manifested a 100% survival by the end of the second year after planting. Even some modules of Festuca pumila, considered as lost after a ski run maintenance-machine cut through the CURLEX matting and damaged a part of the plot, were later found healthy and growing in a short distance from the original planting site (Urbanska et al. 1987, Hefti-Holenstein, in preparation). Development of new tillers within the clonal modules and the growth intensity in general varied from one taxon to another and also from one module to another (Hefti-Holenstein, in preparation).

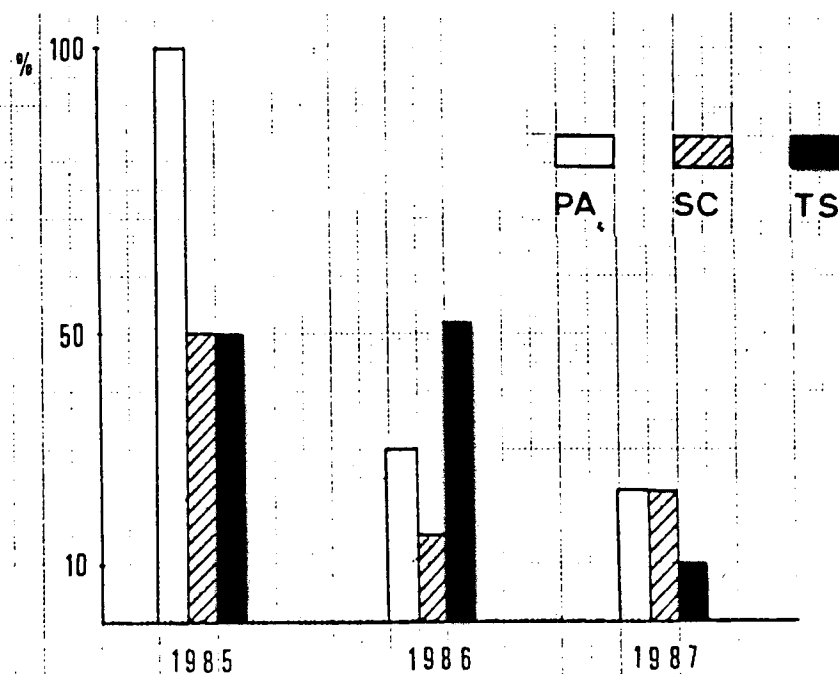


Fig. 2. Flowering in three clonal module populations during three consecutive vegetation seasons. Populations established in early summer of 1985. PA = viviparous Poa alpina; SC = Sesleria coerulea; TS = Trisetum spicatum. Partly after Urbanska et al. 1987, unpublished data of Hefti-Holenstein included.

A very characteristic component of the population performance represented the development of flowers (Urbanska et al. 1987). As far as the populations reviewed here are concerned, three of the five taxa established in early summer trials viz. Poa alpina, Sesleria coerulea and Trisetum spicatum flowered either immediately or soon after planting. They often developed several culms per clonal module, and developing seeds or propagules were observed by the end of the first summer. One year after planting, populations of all the five species used in trials reached the reproductive phase; Trisetum distichophyllum and Festuca pumila flowered for the first time, whereas three other grass species produced already the second generation of flowers and seeds or propagules.

Of a special interest is an apparently changing behavioural pattern noted in the third vegetation season (Fig. 2): flowering in some populations clearly decreased, whereas the clonal growth was becoming positively intensified (Hefti-Holenstein, in preparation).

By the end of the summer of 1987, grass seedlings and young ramets were noted in the plots planted (Table V). It seems that they represented, at least partially, new genets born from seeds produced and dispersed by some clonal modules. Several clusters of small propagule-derived ramets of viviparous Poa alpina were also present; they originated from the clonal modules.

### C. Mixed populations

Given the short observation period (at best, only two vegetation seasons), the data gathered so far on performance of the mixed populations are to be regarded as tendencies rather than actual patterns. For the purpose of a general comparison, some behavioural aspects are presented in Table IV; it should be remembered, however, that the behaviour of particular populations was influenced by seasonal variation and the results of a single census have thus only a limited informative value.

On the whole, the ramets and clonal modules planted in both series survived well except for Elyna myosuroides (Table IV). The general vitality and growth strongly varied amongst taxa. Graminoids frequently manifested a low vitality and their clonal development was often limited or nil; also in this respect, Elyna myosuroides proved to be the worst performer. Plantago atrata was very robust, but produced daughter ramets mostly at the beginning of summer only and the clonal growth decreased afterwards. As far as Valeriana montana is concerned, the ramets in early summer subpopulations were not very vital during the first vegetation season, but after the winter break they developed vigorously; no clonal growth was noted. A much better performance in this respect was observed in the fall subpopulations (Gasser, unpublished).

Chrysanthmum atratum grew very well and produced numerous daughter ramets; in Agrostis gigantea, both subpopulations manifested a good vitality and an exceedingly good clonal growth.

The reproductive behaviour of the taxa studied was varied, too. Elyna myosuroides and both sedges did not produce so far any flowers. Agrostis gi-

gantea developed flowers only in a limited number of ramets, and the flowering was recorded late in season (compare the census of August 28, Table IV). On the other hand, the exceptionally good performance of Valeriana montana, Chrysanthemum atratum, Anthyllis alpestris and Plantago atrata deserved a special comment.

Table IV. Performance of some mixed populations after the first winter break: census of August 28, 1987. Unpublished data of M. Gasser.

Taxon	Ramets planted	Survival (%)	Flowering (%)	Seedling emergence (%)
<i>Agrostis gigantea</i>	ES	94.4	0.0	
	F	96.1	0.0	2
<i>Elyna myosuroides</i>	F	42.5	0.0	1
<i>Carex sempervirens</i>	F	77.6	0.0	6
<i>Carex firma</i>	ES	91.7	0.0	
	F	61.3	0.0	20
<i>Anthyllis alpestris</i>	ES	92.5	75.5	
	F	72.7	31.3	50
<i>Plantago atrata</i>	F	61.1	45.5	5
<i>Valeriana montana</i>	ES	100.0	71.4	45
	F	100.0	58.8	
<i>Chrysanthemum atratum</i>	ES	96.8	56.7	30

ES = early summer 1986  
F = fall 1986

Flowering in the early summer subpopulations of Valeriana montana was observed only nine days after planting, and the ramets which flowered during the first summer corresponded to 14.3%. One year later, flowering in the same subpopulation started soon after the snowmelt and reached 42.9% by the end of July; the maximum percentage of flowering ramets, recorded on August 11, was 85.7%.

Flowering in the early summer subpopulations of Chrysanthemum atratum and Anthyllis alpestris occurred for the first time one year after planting. In these taxa, maximum percentages of reproducing ramets were, respectively, 56.7% (Table IV) and 77.1%.

Plantago atrata, established in the fall trials, flowered for the first time after the winter break. The flowering ramets represented exactly 50% of the population at the beginning of alpine summer; in mid August, their number decreased, but two weeks later a new flush of flowers was observed (Gasser, unpublished).

Seedling emergence in the mixed populations was observed after the first winter. The appearance of seedlings as well as the maximum emergence

percentages widely varied from one taxon to another (Table IV). The worst performance was observed in Elyna myosuroides and Agrostis gigantea (2% each), closely followed by Carex sempervirens (6%); seedlings of Carex firma, emerged, on the other hand, in 20%. The corresponding percentage in Plantago atrata was 15%.

Chrysanthemum atratum, Valeriana montana and Anthyllis alpestris again performed very well, the percentages of emerged seedlings being, respectively, 32%, 45% and 60%. Of a particular interest is the behaviour of Anthyllis alpestris where the rapid emergence of seedlings born from unscarified seeds after the first winter supports the observations of Schütz (1988, see also the first part of the present paper).

#### D. Immigrant populations

While the behaviour of the experimental populations is quite diversified and only some traits seem to appear rather consistently, the performance of taxa not included in our trials but spontaneously established in the seeded and/or planted plots does follow certain patterns.

As far as the actual establishment of the immigrant individuals is concerned, they clearly have a preference for the plots covered with the CURLEX mats; this behaviour indicates improved safe-site conditions in the protected plots.

In the plots seeded, populations of six alpine species were spontaneously established in various combinations (Fig. 3); the only exception was the unprotected ski run plot where no immigrants were found. Schütz (1988) observed a distinct increase of individuals in some populations; it is at least partially due to the rapid production and dispersal of seeds and/or propagules in the immigrant plants.

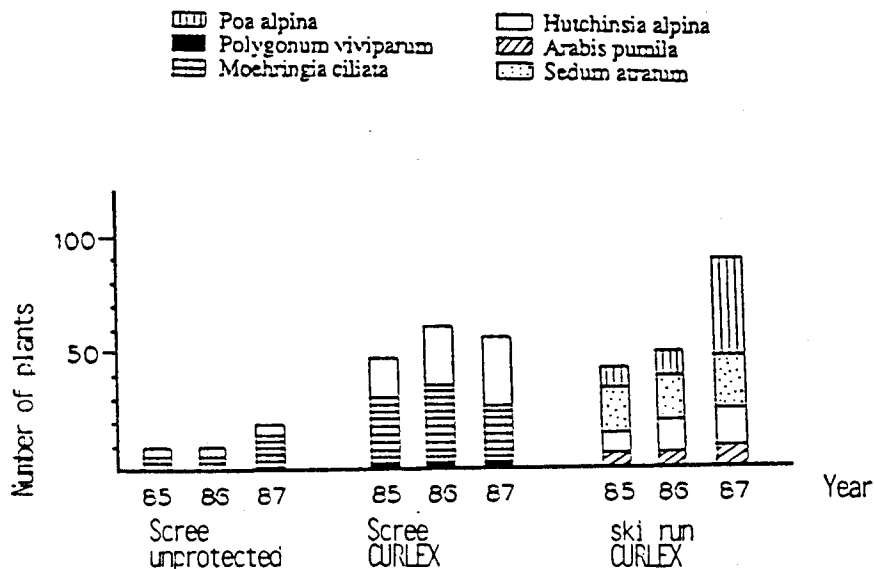


Fig. 3. Populations of species spontaneously established in the plots sown in early summer 1984. No immigrants found in unprotected ski run plot. After Schütz (1988).

Behaviour of species which immigrated into ski run plots protected by the CURLEX matting deserves a brief description. Arabis pumila formed a small population already one year after seeding and the population size did not increase perceptibly over the next two years. On the other hand, populations of Sedum atratum, Hutchinsia alpina and particularly the colony of viviparous Poa alpina were clearly growing in size from year to year (Fig. 3); not only the general vitality of individuals, but also the rapidly reached reproductive phase in these three species were rather striking.

Spontaneously established species were found in other trial series, too. As far as the populations initially consisting of clonal grass modules are concerned, Hefti-Holenstein (unpublished data) found two years after planting numerous seedlings in the trial plots (Table V). Some grass seedlings apparently originated from the seeds produced by the clonal modules planted, and some propagule-derived ramets of viviparous Poa alpina undoubtedly were born in the culms of clonal modules, too, but the majority of seedlings observed represented dicotyledonous plants (Table V).

Table V. Genets found in ski run plots populated experimentally by clonal grass modules (Hefti-Holenstein, in preparation). Data gathered in summer 1987.

Trial series	N of genets		Total
	Grasses	Dicots	
Early summer 1985	37	110	147
Fall 1985	32	64	96

So far, Hutchinsia alpina, Sedum atratum and Plantago atrata were identified amongst the immigrant genets; populations of Hutchinsia alpina and those of Sedum atratum already included some reproducing individuals (Hefti-Holenstein, personal communication). It seems that Leontodon montanus is well established, too, but the genets of the Compositae have yet to be determined precisely.

Immigrant populations were also found in the plots where the mixed colonies including clonal modules and seeds were established. As accurate assessment of the species number and population size was not yet possible (Gasser, personal communication).

#### Population dynamics in the trial plots

We are aware of the fact that the experimental populations established above the timberline are still young and their dynamics may change in the years to come; it seems, however, that some traits recognizable at

this early stage could influence the fate of particular populations. For this reason, they deserve to be considered.

Our seeding experiments resulted both in a rather high number of individuals per plot (Table VI) as well as a high species diversity, as many as 13 different populations being recorded per  $1\text{m}^2$  (Schütz 1988). Another important aspect of the genet behaviour is the rapid flowering observed in some taxa. In this way, the seed bank established initially is soon replenished and enlarged by seeds which not only represent further generations, but also are likely to be formed under the influence of gene flow from the neighbouring wild populations.

As far as the distribution of stage-variants within a given population is concerned, a rather rapid change was observed within the relatively short time. At the initial phase, all the seed populations represented the same chronological age; three years later, genets representing various cohorts appeared and a further stage-influenced differentiation is actually going on, since some genets reached already the reproducing phase.

Table VI. Number of plants in various plots seeded in early summer 1984. Census of August 1987 (Schütz 1988).

Plot	Ski run unprotected	Ski run CURLEX	Scree unprotected	Scree CURLEX
Number of plants*	145	250	205	283

\* immigrant plants included

As expected, the highest genet mortality generally occurred at early life-phases, and the individuals which survived the first two years apparently were well established. In this respect, the experimental populations do resemble the natural alpine colonies.

Particularly interesting are the differences in population dynamics observed between the plots protected by the CURLEX mats and those left uncovered: the latter plots were characterized by a relatively fast seedling turnover, whereas the protected surfaces clearly showed a slowly increasing seedling emergence compensated by a better survival and recruitment of young genets (Schütz 1988, Schütz, personal communication).

The ramet/clonal module populations of alpine grasses issued from planting corresponded initially to a few genotypes, and in some cases even to a single genotype; they might thus be considered as colonies at a later successional stage (Urbanska et al. 1987). The excellent survival, and also the rapid flowering occurring in many ramets indicate that the tussocks, selected initially in the wild for the single ramet

cloning, represented successful genotypes. The abundant flowering and the recent appearance of seedlings suggest that the clonal populations are about to recruit some new genets (Hefti-Holenstein, in preparation). This new development results in an altered population structure, both as to the gene pool as well as the stage-variant distribution.

The mixed populations consisted at the beginning of the trial of both clonal modules and seeds. The altered population structure, recorded only one year later, is particularly striking when the stage-variant distribution is being considered. For instance, the population of Anthyllis alpestris included seeds, seedlings, young plantlets, non-reproducing and reproducing ramets (Gasser, unpublished) and thus did not differ generally from a natural population.

The immigrant populations followed similar patterns in their development. Apart from various stage-variants identified, it seems probable that some part of spontaneously established seeds may still be present beneath the CURLEX matting.

Occurrence and distribution of different stage-variants means that a given population will have a differentiated response towards environmental factors operating at a given time; it may thus experience a lesser risk of death. It is therefore not surprising that both the experimental and the immigrant populations tend to increase this diversity. The surprising aspect is the speed of this differentiation.

#### Concluding remarks

The studies dealt with in the present paper demonstrate that populations of native alpine species can and do function in new ecological situations. It seems that within a rather short time, dynamics of experimental populations may approach that of the wild colonies. Since this development is essential to the success of revegetation, we propose now to consider briefly some tactics helpful in the biological erosion control above the timberline.

More attention should be paid to the development of an adapted plant material, still largely neglected in Europe. The development of such material would indeed correspond to the current market situation (in Switzerland alone, there are about 3.000 ha of machine-graded ski runs to revegetate, areas of ski lifts, etc. not included). Use of such material above the timberline would, above all, help to avoid environmental problems resulting from some current revegetation practices, exemplified here by the massive application of sewage sludge products.

Sewage sludge derivative, recently introduced in large doses into the alpine vegetation belt in Switzerland, is expected to function as fertilizer and to promote soil development in commercially revegetated ski runs. Our preliminary results (Urbanska, in preparation) indicate that this application brings about a heavy-metal contamination of alpine plants and



soils. Since the raw soils in the machine-graded ski runs have a low absorption capacity, some part of the heavy-metal load is likely to pass into the water system of a given area. Also, the impact of heavy-metal increase upon the nutrient cycling in alpine ecosystems is not yet clearly assessed, but it is conceivable that the metabolism of e. g. grazing animals might be affected.

Some studies show that sewage sludge has a delaying effect on seed germination(Wollan et al. 1978, Matt and Muhar 1987), and it may also cause a reduced growth at early developmental stages(Matt and Muhar 1987). Given the short vegetation period in the alpine vegetation belt, the timing of seedling emergence and a good growth at early life phases are crucial, since even a slight delay may carry a heavy penalty in terms of increased mortality. Clearly, not only the ecosystem science but also the population biology contribute data demonstrating that sewage sludge is by no means to be used above the timberline.

Alpine plants do not require an extensive fertilizer application because their life strategy is based on growth efficiency(Canham and Marks 1985) rather than direct growth rates. With use of alpine plant material, heavy doses of fertilizer are superfluous above the timberline. We strongly suggest a more extensive exchange of results and experiences in screening native plants potentially suitable for revegetation of high-alpine sites in Europe.

A successful development of any plant population depends on availability of diverse safe sites(Harper 1977, Urbanska and Schütz 1986). The simulation of safe sites which have to be ecosystem-specific(Urbanska and Schütz 1986) represents thus a very important component to revegetation. Our results show that biodegradable mats are exceedingly helpful in this respect above the timberline: not only are they advantageous in terms of population turnover and recruitment in experimental populations, but also promote a spontaneous colonization by plant species from neighbouring wild vegetation. It should be very useful to compare various geo-textiles, as different sorts might prove suited to different situations and climate types.

#### Acknowledgements

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## DEVELOPING METHODS OF RESTORING VEGETATION COMMUNITIES WHILE PRESERVING GENETIC INTEGRITY

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### INTRODUCTION

Based on the many articles published in High Altitude Revegetation Workshop Proceedings, techniques have evolved to the point that restoration of high elevation sites is now accomplished with a degree of success. In most cases, success is measured by the extent to which the site is stabilized from erosion and aesthetically enhanced by a cover of plant materials.

In a National Park however, two additional concerns should be addressed-- concerns that substantially increase the challenge of high altitude revegetation. The first concern is that of preserving genetic integrity; the second is that of establishing communities that are natural in appearance.

### Two Concerns of Special Interest in a National Park

#### Genetic Integrity

I believe that the genetic integrity of the plant materials we use in restoration projects (both in and out of National Parks) will come under increasing public scrutiny (Weber 1987: 19). The term "genetic integrity" usually refers to the extent that introduced genotypes are similar to local, native genotypes. In practice, the term is subject to a range of interpretations. For example, genetic integrity may be said to be preserved during restoration by restricting the choice of introduced plant materials to native species. But for a widely distributed species such as Deschampsia caespitosa, the genotype provided by a commercial grower may have originated in Europe. A stricter interpretation of the term would restrict the use of plant materials to those originating from a more limited geographical boundary. But in a National Park I believe for reasons that are described below, that we should adopt a standard that is even more conservative.

It is well documented that genotypes within a given species are not homogeneously distributed about the landscape, but are spatially clustered in discrete populations (Linhart et. al. 1981, Schaal and Levin 1978). The genetic clustering is caused in part by the limited dispersal of pollen and/or seeds and in part by heterogeneous differences in habitat (Levin and Kerster 1974). Dynamics of these discrete populations are an important aspect of the evolutionary history of a taxon.

In a world where the reduction of genetic diversity is a matter of great concern, National Parks are areas in which great lengths should be taken to preserve native genotypes and furthermore, to preserve the spatial patterns in which they occur. Intuitively, one would expect the highest degree of clustering to occur in situations with sharp environmental gradients and Rocky Mountain National Park with its isolated high peaks is an area where population differences may be exceptionally distinct.

#### Community Composition

In the severe high elevation environment, we are usually grateful to get anything to grow at all. But in National Parks, our concept of naturalness should extend beyond the the greening of the site (and the genetic composition of the plants) to species composition and the spatial arrangement of plants in the community.

One of the earliest phases of any restoration project should include a formal statement describing the ultimate objective in terms of a "target community". In the case of the National Park Service, I believe the general quality of a target community to be: a self-sustaining, mature plant community with naturally occurring analogues that is ecologically appropriate for the site and consists of genetically appropriate plants.

"Self-sustaining" means that the plant community is relatively stable-- any climatically induced changes would also be observed in an equivalent, undisturbed community. "Mature" means that the species belong to an advanced successional sere. "Naturally occurring analogues ... appropriate for the site" implies that the composition and spatial arrangement would occur elsewhere in a similar, undisturbed situation. The quantitative description of the target community (species density, patchiness, etc.) would best be derived from the description of an appropriate undisturbed community.

The site under restoration may never even closely resemble the qualities described as the target community-- site characteristics and successional processes may direct the development of the community toward a completely unexpected result. But the initial quantitative definition of a target community does provide a framework within which to measure success.

#### How These Concerns are Relevant to Current Paper

A relatively large amount of space has been devoted to describing the above concerns because of the effect they have on how restoration problems must be approached. Limiting the selection of plant materials to genotypes derived from local populations means that plant materials must be produced specifically for a given restoration project-- commercially available materials (seed or plants) would not be appropriate. Establishing a target community as defined above has significant implications for pre-transplant site improvement, for the choice of plant materials and, for the choice of treatments following initial transplant. A considerable research effort will be required if this level of restoration is to be successful.

### TWO RESTORATION PROBLEMS

#### Poor Soil Condition

##### Site Description

Within Rocky Mountain National Park are several miles of barren (and highly visible) road cuts with slope angles averaging approximately 30 degrees. Because of the steep angles, the fine-grained fraction has eroded away, leaving behind a coarse Entisol, low in cation exchange capacity (CEC) and low in organic matter. This soil would have limited ability to retain inorganic nutrients (applied as fertilizer), lacks organic nitrogen available for nitrification, and has poor moisture retention qualities.

##### Conceptual Approach

Traditionally, the site would probably be seeded with perennial grasses in combination with a cover of mulch. But in this case, the target community consists largely of Selaginella, mosses, Arctostaphylos, and isolated patches of grasses and sedges. Establishing a cover of perennial grasses would probably not result in the desired plant community.

Repeated crops of annual ryegrass (*Lolium multiflorum*) are seen as a possible alternative to improving soil quality while still permitting the establishment of desired plant species. Annual ryegrass can be intensively managed for rapid growth. The dead roots would increase soil CEC, soil moisture retention, soil organic nitrogen, and increase slope stability. The dead shoots would form a mulch that would reduce evaporation losses from the surface. Future transplants of container plants would be made on to the improved site. It had been determined from previous experimental seedings that annual ryegrass would not be persistent for than a few years, but plans were made to apply Roundup should persistence be a problem.

### Experimental Design

An experiment was designed to investigate the effect of two experimental variables on soil improvement: the amount of fertilizer applied each year to the ryegrass crop, and the number of years of treatment. Fertilizer was to be applied at an annual rate of 100, 200, and 300 lbs N / acre, the applications divided into three equal treatments. The plots were to be seeded (or reseeded) and fertilized for 1, 2, 3, or 4 years. Including controls, 96 experimental plots were established. The ryegrass was seeded at the time of initial fertilization and lightly covered by a layer of soil. Seeding in 1988 was done in mid-June. It was felt that earlier seeding would result in a longer germination time due to cooler temperatures and the longer the seeds remained on the slope, the more likely they would be washed away by surface runoff.

### Preliminary Results

Unfortunately, mid-summer of 1988 proved to be exceptionally hot and dry. By the end of June it was apparent that germination and seedling establishment would not meet expectations, so the experimental design was modified. The site was reseeded in early July and covered with a shallow layer of pine needles. Within two weeks all plots showed good seedling establishment.

On about 60% of the area, the mulch of needles was bonded to the mineral soil by ryegrass shoots. On 20% of the area, the needles remained on the slope without the presence of the shoots. On about 10% of the area, surface runoff has removed the cover of needles, exposing the bare mineral soil. At the end of the season, much of the treated slopes superficially resembled the soil of the forest above. If repeated treatment can significantly increase soil fertility while bonding a cover of litter to the slope and

if container plants of the appropriate species can be successfully transplanted, the technique offers great promise.

Collecting pine needles causes some disturbance to the soil of the adjacent forest and so pine needles, at least from that source, do not make an ideal mulch. In coming years we will investigate the potential of creating a mulch from chipped and ground tree branches. That mulch would be used to enhance annual ryegrass seed germination. Repeated treatments will be attempted by scarifying the semi-bonded mulch and reseeding.

Soil chemistry sample sites were chosen at random. Unfortunately, sites receiving the pine needle treatment (the site locations of the needle treatment were based on logistic considerations, namely the availability of nearby needles) were not sampled for soil chemistry before treatment. However, soil chemistry samples taken on plots where the ryegrass germinated poorly documents the limited effect of fertilizing an unimproved soil.

Table 1 describes soil chemistry data taken from samples at 10 cm depth. The high organic content of the forest soil reflects the continual input and subsequent decomposition of needles. If erosion were not so active on the slope, it would not be unreasonable to expect a similar soil type in spite of the steep slope angle. Unforested steep slopes occurring on undisturbed areas above do have a high organic content. The sample taken on the slope before and after fertilizer treatment are not unlike. The coarse mineral soil lacks the qualities necessary to bind nutrients. Rapid infiltration of water leaches soluble nutrients, such as nitrate, and the low cation exchange capacity provides little ability to stabilize cations. The conclusion is that soil quality will have to be substantially improved before successful restoration can take place.

#### Unavailability of Appropriate Plant Materials

##### Restoration with Container Plants

Transplanting container plants would be considered an inefficient method of establishing plant materials for most restoration projects. But in this case, container plants

Table 1. A comparison of soil chemistry samples from 1) a nearby, undisturbed soil, 2) the slope before fertilization, and, 3) the slope after fertilization. Ryegrass establishment was unsuccessful at this site. The similarity of the chemistry of the slope samples before and after fertilization indicates that the existing soil will require improvement before fertilization will be effective. Except for % organic matter, data are in ppm; N = 3.

Site	%OM	NO <sub>3</sub> -N	P	K	Zn	Fe	Mn
Forest soil (above slope)	31.1 (1.9)	2.7 (0.6)	10.7 (2.0)	376.7 (6.1)	28.8 (2.3)	536.0 (7.7)	166.1 (9.2)
Slope before fertilization.	2.9 (0.2)	1.3 (0.4)	22.6 (0.5)	91.0 (0.6)	2.4 (0.3)	74.3 (1.7)	12.9 (0.9)
Slope six weeks later.	2.3 (0.4)	7.0* (2.9)	17.1 (1.4)	91.9 (2.9)	1.4 (0.5)	68.0 (2.5)	11.7 (1.1)

\* The rather high mean NO<sub>3</sub>-N of 7 ppm results from a data outlier of 18 ppm-- probably resulting from too heavy an application of fertilizer.

may be the most efficient means of achieving the end objective. Since the plant materials are to be "custom produced" for each project, containerized production is probably the safest way to insure having the plants at a given point in time. Many of the desired species (sedges, for example) do not reproduce readily from seed and must be vegetatively propagated-- the materials are necessarily produced as container plants. And even though a plant species produces seed with a high germination potential, the seed is often difficult to collect in quantity and although viable, may require special pregermination treatments. Given the labor cost of seed collection and the necessity of special germination treatments, these plants too will be most economically increased as container plants under controlled conditions rather than sowing seed on to the restoration site only to experience high mortality. Establishment of container plants also offers the most precise way of producing the desired spatial patterns.



The difficulty in obtaining appropriate plant materials escalates with a more conservative approach to genetic integrity. When the selection of plant materials was only limited by the requirement of using native species, finding commercial sources to provide an acceptable variety was merely difficult. To obtain plant materials that originate from either within the Park-- or more restrictively, from near the restoration site, means that the materials must be specially grown. And because the propagation requirements of most of the required plants are poorly known, a commercial grower will be reluctant to commit to the low cost production of a high volume of material.

The research described below was conducted in cooperation with the Denver Botanic Gardens and was designed to determine the feasibility of propagating some of the species that would be used for restoration.

#### Methods

Intermittent mist irrigation has been demonstrated to be an effective method of producing rooted cuttings. A mist system was established in the research nursery at Rocky Mountain National Park by constructing a 44'-long by 4'-wide by 3'-tall polyethylene covered tube in which a timer operated mist system was installed. The mist was programed to turn on for 5 seconds each 5 minutes during the daylight hours. Cuttings or tiller divisions were placed in flats of perlite under the mist system. After rooting, plants were placed in a soil-less medium in 9 cubic inch containers and finished under the nursery irrigation system.

#### Results and Conclusions

Table 2 describes the results of the vegetative propagation experiments using the polyethylene tube at the Park research nursery. The outdoor mist system was effective in vegetative propagation from about mid-June to mid-August. Before and after this period, outdoor temperatures were too cool and could not be regulated inside the tube. Occasionally, excessively high temperatures were

Table 2. The following species were investigated during the summer of 1987. Except as noted, perlite was the rooting medium.

Species	Propagation Method	Degree of Success
<u>Achillea lanulosa</u>	Division <sup>1</sup>	HIGH
<u>Anaphalis margaritacea</u>	Stem cuttings <sup>2</sup>	HIGH
<u>Antennaria rosea</u>	Division <sup>1</sup>	HIGH
<u>Antennaria parvifolia</u>	Division <sup>1</sup>	HIGH
<u>Arctostaphylos uva-ursi</u>	Stem cuttings <sup>2 3</sup>	HIGH
<u>Artemesia arctica</u>	Crown division <sup>1</sup>	HIGH
<u>Artemesia borealis</u>	Crown division <sup>1</sup>	HIGH
<u>Artemesia ludoviciana</u>	Division <sup>1</sup>	HIGH
<u>Carex nova</u>	Division	HIGH
<u>Carex misandra</u>	Division	HIGH
<u>Carex scopulorum</u>	Division	HIGH
<u>Deschampsia caespitosa</u>	Division	HIGH
<u>Juniperus communis</u>	Cuttings	NONE
<u>Linnaea borealis</u>	Cuttings	HIGH
Moss species	Fragmentation <sup>4 5</sup>	HIGH
<u>Pedicularis racemosa</u>	Cuttings	NONE
<u>Peltigera apthosa</u>	Fragmentation <sup>4</sup>	NONE
<u>Penstemon wippleanus</u>	Division, cuts <sup>2</sup>	HIGH
<u>Polemonium delicatum</u>	Division <sup>2</sup>	LOW
<u>Salix spp.</u>	Cuttings <sup>2</sup>	HIGH
<u>Sambucus racemosa</u>	Cuttings <sup>2</sup> (0.1% IBA)	LOW
<u>Rosa woodsii</u>	Cuttings <sup>2</sup>	HIGH
<u>Sedum lanceolatum</u>	Division <sup>5</sup>	HIGH
<u>Selaginella densa</u>	Division <sup>5</sup>	HIGH
<u>Shepherdia canadensis</u>	Cuttings <sup>2</sup>	LOW
<u>Solidago spathulata</u>	Division <sup>2</sup>	HIGH
<u>Vaccinium myrtillus</u>	Cuttings	LITTLE

<sup>1</sup> Rooted in peat-based potting mix.

<sup>2</sup> Treated in 0.3% IBA (Hormodin #2).

<sup>3</sup> Early season cuttings were substantially more successful.

<sup>4</sup> Mosses and lichens were fragmented using a blender run at low speed.

<sup>5</sup> IBA treatment (at any level) inhibited growth.

experienced in the tube-- precise measurements were not taken, but temperatures certainly exceeded 100 degrees Fahrenheit. While Sambucus and Shepherdia performed poorly at Rocky Mountain National Park, cuttings propagated at the Denver Botanic Gardens greenhouse did well. The lack of success at the Park was probably due to the elevated temperatures in the polyethylene tube.

As Urbanska (1986: 214) describes, many clonal graminoids may be easily propagated by division. Several species of Carex and Deschampsia caespitosa were propagated with a nearly 100% success rate.

The time of year in which plants are propagated is important for two reasons. First, some plants such as Arctostaphylos uva-ursi and Shepherdia canadensis rooted well from early season cuttings but did not root as well from cuttings taken later in the growing season. Secondly, propagation should begin at a point in time so that plants are finished in time for planting out at an optimum period of the growing season. In general, the outdoor mist tube as used at Estes Park, CO is not capable of operation early enough in the growing season.

Some difficulties were caused by frost heaving when the container grown graminoids were transplanted into the alpine. In general, the lesser the amount of soil involved in the transplant the less the disturbance due to heaving. Survivorship approached 100%-- including those plants that were almost totally heaved from the tundra soil. Some experimentation was done with "bare root" transplants on to the tundra. Most of the bare root transplants survived the summer, but their long-term survivorship cannot be guessed at until the summer of 1988.

#### GENERAL CONCLUSION

Based on the limited amount of research completed to date, I conclude that there is a good chance that restoration can meet the standards set earlier in this paper. However, completion of a restoration project may require a significantly longer period of time than that to which we are normally accustomed. The longer time period will be required for two reasons: 1) restoration methods are in a state of development and, 2) the successional processes required will take longer than simply seeding with "restoration grasses" to achieve a stabilizing groundcover.

The most likely means of producing a sufficient quantity of plant materials is to develop a propagation program that combines National Park Service research and specialized labor requirements with contracted greenhouse space and routine maintenance needs.

A continuing research effort will have to be made in several additional areas:

1. What physical characteristics of a site should be most considered when defining a target community?
2. What is the species composition of an initial planting (a "parent community") that can be "steered" toward a desired target community?
3. What are the treatments (ie. fertilization, irrigation) required to control the successional development of a parent community.

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# SOIL MICROBIOLOGICAL PROPERTIES OF RECLAMATION SITES COMPARED TO A NATURAL SUCCESSION

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## ABSTRACT

For any re-establishment of vegetation it is essential that microbial activity is restored to ensure carbon and nutrient turnover. The mediator of this process is the microbial biomass ( $C_{micr}$ ). Thus, if  $C_{micr}$  levels of a reclaimed site approach those of comparable ecosystems, one important part of the reclaimed system has been re-established successfully.

We compared the  $C_{micr}$  levels of two revegetation trials (established in 1982, elevation 2600–2800 m above sea level) with those of an adjacent natural succession. This succession is comprised of a series of recessional moraines of different ages. Before revegetation, the soils were bare and had very low  $C_{micr}$  levels ( $80 \mu\text{g}\cdot\text{g}^{-1}$  soil). In 1986, the plots which had been amended with mineral fertiliser, Bactosol<sup>®</sup> or Biosol<sup>®</sup> (organic fertilisers) had reached biomass levels of 282, 603, and  $584 \mu\text{g}\cdot\text{g}^{-1}$ , respectively. If the equation describing the development of  $C_{micr}$  levels on the natural succession is taken as a calculation base, these figures correspond to 9, 37, and 34 years, respectively, of natural succession.

## INTRODUCTION

Ecosystem functioning comprises two major processes, i.e., primary production and decomposition. For a successful reclamation it is equally important to restore both. The main target of any reclamation effort should be to accelerate this process. For the evaluation of the reclamation success, natural successions may serve as a yardstick. Therefore, it is necessary to select a parameter which is directly related to successional development.

Various soil microbial parameters have been used to study the time course of recovery of reclaimed land. Enzyme activities, ATP levels, and soil respiration have been used by Stroo and Jencks (1982), Schafer et al. (1979), and Visser et al. (1983), respectively, to describe the development of microbial activities in mine

soils. Insam and Domsch (1988) emphasized the feasibility of soil microbial biomass ( $C_{micr}$ ) as a parameter for reclamation studies. They found a close relationship between  $C_{micr}$  levels and the age of reclaimed agricultural and forest soils.

In this study,  $C_{micr}$  of a natural succession is compared to the  $C_{micr}$  levels of secondary successions of revegetation trials.

#### MATERIALS AND METHODS

Two reclamation sites at the Festkogel near Obergurgl (Austria) (2600 m and 2800 m sea level for site I and II, respectively) were established on July 15, 1982. The original vegetation as well as rocks had been removed and the remaining fine material and gravel levelled to make a ski-run. The parent material is silicious, and the organic matter content (attributable to parts of previous top-soil) was 2.9% on site I and 0.3% on site II. The pH of the bare soils before reclamation was 4.4 and 4.2 for site I and II, respectively. On both sites a mixture of grass and herb seeds, mainly Phleum pratense and Festuca rubra, as well as Achillea and Trifolium species, was sown. The sites were divided into plots (4 replicates) which were fertilised annually with inorganic fertiliser (30 g.m<sup>-2</sup>; N:P:K:Mg = 12:12:17:2 + trace elements) or one of two different organic fertilisers, Bactosol® or Biosol®. These fertilisers consisted mainly of dried bacterial or fungal biomass, respectively. They were applied at a rate of 200 g.m<sup>-2</sup>. Three replicate samples were taken from each plot, either shortly after spring thaw before the annual fertiliser application (21/7/83, 20/7/84, 18/7/85, 15/7/86) or at the very end of the vegetation period (18/9/82, 22/9/83, 20/9/84).

The natural succession is comprised of recessional moraines of the Rotmoos Glacier which descends from 3400 m to 2400 m at its toe. Mean annual temperature is about -0.5°C, with a mean of 6.1°C for June-September. Mean annual precipitation is about 1100mm. Petrographic series contributing to the till material are mica schists, phyllites, amphibolites, hornblende, and also some marble layers. From each of five sites, 8 samples were taken on 26 August 1985 and 10 July 1986. These sites, representing soils of different age, are described elsewhere (Jochimsen, 1970; Insam and Haselwandter, 1988).

All samples were sieved (2 mm), stored at 4°C and, prior to analysis, equilibrated to room temperature for at least two days. Microbial biomass ( $\mu\text{g } C_{micr} \cdot \text{g}^{-1}$  soil dry mass) was determined by substrate-induced respiration (Anderson and Domsch, 1973) using an infra-red gas analyser (URAS1, Hartmann and Braun, Frankfurt, FRG). Organic carbon was assessed by dry combustion (Leco induction furnace) after expelling carbonate-C by addition of HCl (10%) and drying of the samples at 70°C.

## RESULTS AND DISCUSSION

The plant succession of the Rotmoos Glacier as described by Jochimsen (1970) was accompanied by a change of microbial biomass levels. The development of  $C_{micr}$  on the Rotmoos Glacier may be described best by the exponential function

$$y = -290.1 + 293.2 \cdot e^{0.003x}$$

where  $x$  is the  $\ln$  of the site age and  $y$  is  $\mu\text{g } C_{micr} \cdot \text{g}^{-1}$  soil.

As can be seen in Fig. 1, in the early stages of succession microbial biomass rose very fast, indicating that increasing amounts of carbon became available for microbial consumption with the initiation of higher plant's primary production. In the subsequent years, the increase of  $C_{micr}$  slowed down. It has to be mentioned that Site V could not be dated exactly; its age may be anywhere between 215 and some 1000 years. We based the calculation of the regression on an age of 999 years. However, any deviation of the actual age from this value would only change the slope of the curve but not its shape.

As outlined in another paper (Insam and Haselwandter, in preparation), organic matter increased and the microbial respiration/biomass ratio declined with time. These parameters, too, indicate the maturation of the system.

On the reclamation site, the  $C_{micr}$  level before reclamation started was about  $80 \mu\text{g } C_{micr} \cdot \text{g}^{-1}$  soil (Insam and Haselwandter, 1985). In contrast to the primary succession described above, where a plant cover only slowly established and thus primary production only slowly increased, the reclamation resulted in a high level of carbon input from the very beginning. This carbon input may be ascribed to the fertiliser and soil stabiliser amendments as well as to plant residue and root exudate inputs which commenced already in the first year after revegetation. As a result, the decomposer biomass ( $C_{micr}$ ) rose sharply from the pre-vegetation level to  $150 \mu\text{g/g}$  and  $250 \mu\text{g/g}$  for the mineral and organic fertilised plots, respectively.

Subsequently, over the next 5 years,  $C_{micr}$  levels rose steadily, more rapidly on the organic than on the mineral fertiliser plots. If the data for both sites are computed together, the linear regressions

(a) $y = 17.86 + 0.031x$	$r^2 = 0.14$
(b) $y = 20.99 + 0.115x$	$r^2 = 0.43$
(c) $y = 33.09 + 0.077x$	$r^2 = 0.18$

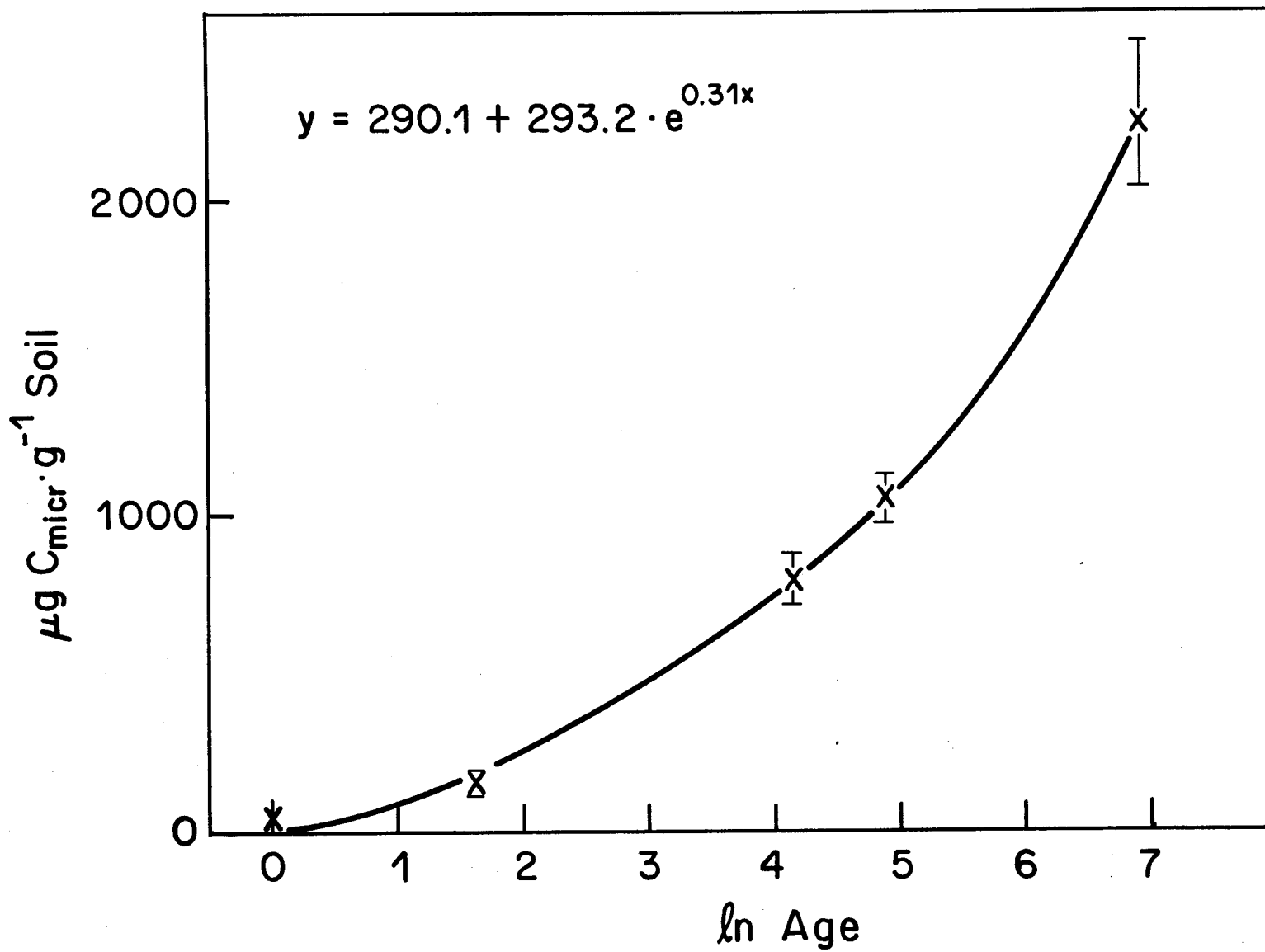


Fig. 1 Development of microbial biomass ( $C_{micr}$ ) levels on the Rotmoos sere with time. Bars indicate the standard error ( $n = 16$ )



describe the development of  $C_{micr}$  levels on the mineral fertiliser, Bactosol® and Biosol® plots, respectively (Fig. 2)<sup>1</sup>.

With time, the difference between organic and mineral fertilisation became more and more pronounced. The same was observed for the state of the plant cover.

If the mean  $C_{micr}$  figures (sites I and II) for 1986 and the regression line for  $C_{micr}$  on the natural succession are used as a calculation base,  $C_{micr}$  levels corresponding to 9, 37, and 34 years of natural succession have been achieved after only 5 years of reclamation, with mineral fertiliser, Bactosol® and Biosol®, respectively.

When the regression lines for the two sites were calculated separately, lower residuals were found. On site II, the initial values were higher, but the slope of the regression was steeper for site I than for site II. The regression lines found for the two sites and the three fertilisers were:

	Site I	Site II
Mineral fertiliser	25.04 + 0.025x $r^2 = 0.22$	10.61 + 0.036x $r^2 = 0.43$
Bactosol®	32.54 + 0.089x $r^2 = 0.30$	9.44 + 0.141x $r^2 = 0.73$
Biosol®	52.49 + 0.043x $r^2 = 0.24$	13.69 + 0.111x $r^2 = 0.49$

$C_{micr}$  on Site II was lower than than on Site I after the first growing season. This may be attributed to the more adverse climatic conditions and the lower organic matter content on Site II compared to Site I. However, the slope of the regression was steeper on Site II than on Site I.

The organic matter content of a soil is considered to be an important factor for its fertility and stability. Increases in organic matter content are often hard to detect directly. However, the amount of microbial biomass per unit soil organic matter may give an indication on whether a soil is losing or accumulating carbon (Insam and Domsch, 1988).

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<sup>1</sup> Note that for the calculation of these regressions a vegetation period of 90 days was assumed, with spring samples taken 10 days after the beginning and fall samples taken 20 days before the end of the vegetation period. The x in the equations refers to the number of days during the vegetation period. y is the predicted  $C_{micr}$ .

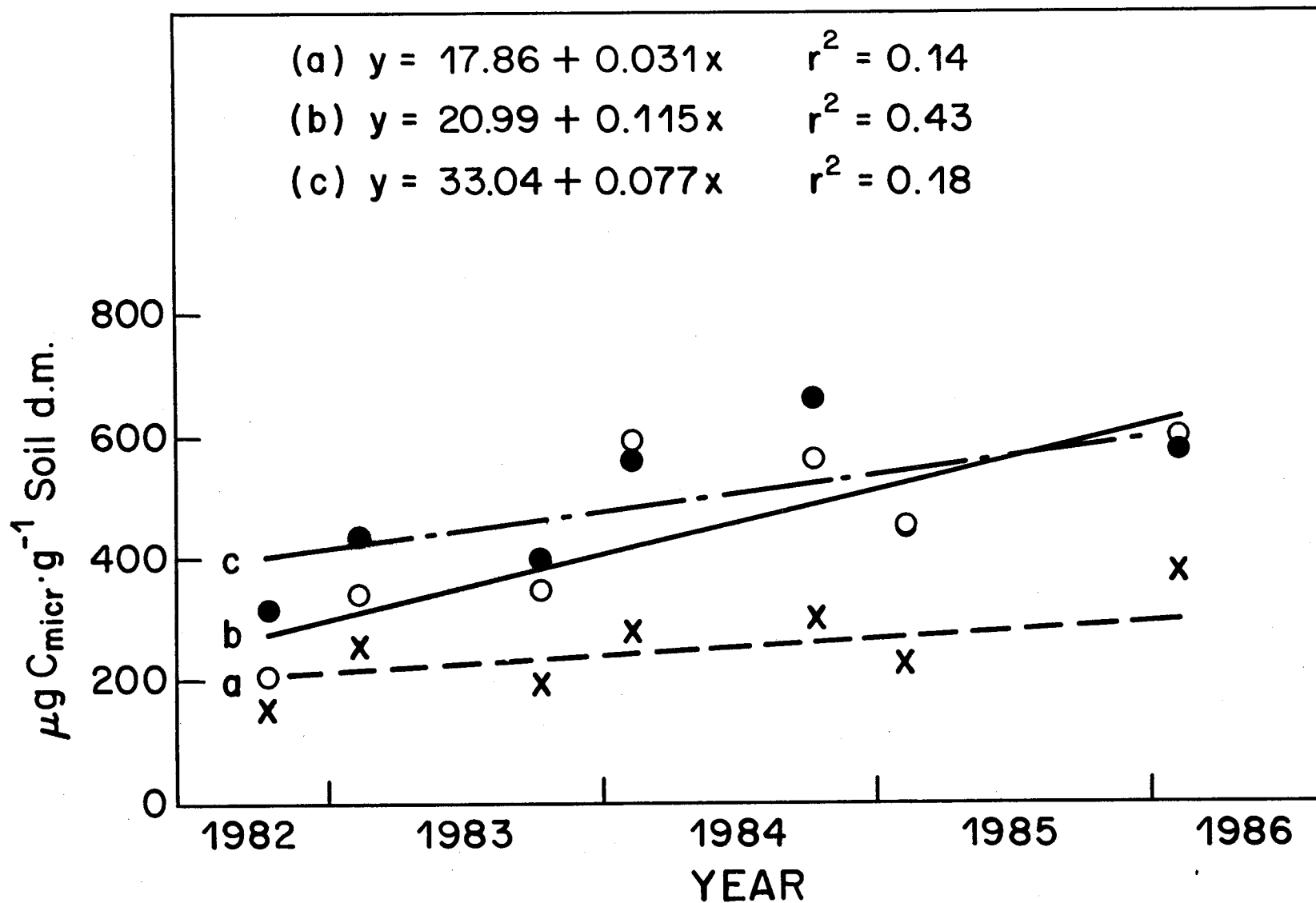


Fig. 2 Microbial biomass levels on the Festkogel reclamation sites receiving mineral fertiliser ( x ), Bactosol® ( O ) or Biosol® ( ● ). The data points represent the mean calculated from 12 single data from each of the two sites.

In 1986, high levels of  $C_{micr}$  within the organic matter ( $C_{org}$ ) have been found on the reclamation sites, particularly on the organic amended plots. For these, 33.5 and 63.1 mg  $C_{micr}/C_{org}$  have been found on Site I and II, respectively. According to Insam and Domsch (1988) this indicates that  $C_{org}$  levels on these plots are rising. For the mineral fertiliser plots the amount of  $C_{micr}/C_{org}$  was found to be lower, 17.9 and 39.0 mg  $C_{micr}/C_{org}$  for Sites I and II, respectively. This indicates a slower accumulation of  $C_{org}$  on the mineral fertilised plots than on those amended with organic fertiliser.

These data seem to indicate a success of revegetation. However, it has to be considered that  $C_{micr}$  is only one of several parameters which are necessary for a functioning ecosystem. Additionally, one major question remains, namely, what will happen to the system once fertilisation is discontinued? Certainly, without invading autochthonous plant species, the system will not become self-sustainable.

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ADAPTATIONS OF DESCHAMPSIA CESPITOSA (TUFTED HAIRGRASS) FOR REVEGETATION  
OF HIGH ELEVATION DISTURBANCES: SOME SELECTION CRITERIA

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INTRODUCTION

Deschampsia cespitosa (L.) Beauv. (tufted hairgrass) is a well-known bunchgrass of circumglobal distribution throughout many cool moist regions of the world. In the Northern Hemisphere this species occurs commonly in moist to wet habitats at all elevations from sea level to over 4,300 m but especially in cool mountainous regions and northern latitudes. It is particularly abundant in stream-side meadows and in open areas surrounding lakes and ponds, and frequently is found in wet road-side ditches. This species is typically found in pure stands and only rarely occurs in the understory of wooded areas. In the Western United States it reaches its greatest development at higher elevations and becomes a nearly ubiquitous floral component of most plant communities above treeline.

Of particular interest to reclamation specialists is the apparent aggressive character of this species to invade and become naturally established on disturbances, especially at higher elevations. D. cespitosa is frequently found as a colonizer on disturbances such as road cuts and fills, mine sites, barrow pits, and other disturbances at higher elevations and in moist habitats in general (Harrington 1946, Putnam 1971, Brown et al. 1976, Brown and Johnston 1978, Surbrugg 1982, Chambers et al. 1984, 1987). Its unique tolerances to acid soil conditions and high soluble metal concentrations are well documented (Cooke et al. 1976, Hutchinson and Kuja 1978, Cox and Hutchinson 1980a, 1980b, Pratt 1982, Surbrugg 1982), and probably explains the occurrence of the species on acidic or pyritic mine spoils at high elevations throughout the Western United States (Brown et al. 1978). D. cespitosa has been successfully used for high elevation revegetation of disturbances for decades (e.g., Harrington 1946, Eaman 1974, Marr et al. 1974, Brown and Johnston 1976, 1978, 1980, Brown et al. 1978, Guillaume 1980, Brown et al. 1984, Chambers 1987).

D. cespitosa (note the spelling change from caespitosa, as suggested by Voss 1966 and formally adopted by most western taxonomists) is a highly complex species exhibiting enormous morphological, physiological, and ecological variation (Kawano 1962, Putnam 1971, Davy 1980). The species possesses broad extremes in polymorphism and ecotypic variation (Lawrence 1945, Kawano 1962, 1966,

Ward 1969). D. cespitosa appears to consist of numerous distinct genetic races differentiated by broad environmental tolerances. Each race is composed of a number of populations representative of local edaphic or other unique conditions (Ward 1969). The unusually large range of ecotypic variation in the species has been extensively studied (Lawrence 1945, Bonham and Ward 1970, Pearcy and Ward 1972, Brown et al. unpublished), and is currently under investigation for identification of populations with potential commercial value (Stranathan 1987, personal communication).

The broad ecotypic variation within the D. cespitosa complex raises questions about the relative adaptability of different populations for revegetation on western high elevation disturbances. In studies of other vascular plant species, performance of populations in terms of survival and other indices of success (including reproductive ability) has been best in environments similar to that of their origin (Clausen et al. 1948, Chapin and Chapin 1981, Quinn and Hodgkinson 1983). D. cespitosa, however, appears to have a greater degree of plasticity in its short-term survival than many species (Pearcy and Ward 1972, Ward 1969). In a study comparing the relative phenological and growth characteristics of 20 different D. cespitosa populations from Montana, Wyoming, and Colorado, Pearcy and Ward (1972) found that all populations had broad ranges of tolerance to different environments, but all were significantly differentiated by phenology and growth development. Plants from higher elevation environments tended to be shorter and to have completed anthesis earlier in common gardens than plants from lower elevations. Thus, patterns of response were closely related to elevational gradients and differences in the length of the growing season of native sites, but there were no differences in survival among the populations in the different gardens.

Common garden conditions alone are not necessarily indicative of environmental limitations on severe disturbances at high elevations. Studies to date have not assessed the relative performance of this species over a long timeframe in terms of characteristics important for revegetation. Important revegetation concerns include not only survival and phenological development, but also variation in plant cover and biomass over extended periods on sites with potentially limiting conditions, and reproductive ability.

The present study evaluates the relative suitability of widely different populations of D. cespitosa for revegetation of severe disturbances at high elevations in the Western United States. We are concerned about the advisability of recommending and using different populations for revegetation and in determining if the broad range of ecotypic variation that is characteristic of this species is useful for revegetating these disturbances. Our hypothesis stated that, due to the broad range of genetic diversity within the species, there

1. (Stranathan, S. E., Upper Colorado Environmental Plant Center, Meeker, Colorado 81641).

are no differences in revegetation potential of D. cespitosa, populations from widely disparate habitats.

#### METHODS

We selected 18 populations of D. cespitosa that maximize variations in geographic origin, habitat conditions, and morphological characteristics (Table 1). Selection was based on data collected from about 325 populations of the species over a period of 10 years in North America and Iceland. Seeds used in this study were collected from each population in 1980 and 1981 and were cleaned and stored using techniques described by Chambers et al. (1987). Germination percentages of each population were determined on saturated filter paper in petri dishes with 3 replications of 50 seeds each following a 60-day cold treatment at 2°C (Table 1).

Research plots of each population were seeded in the fall of 1981 to study their relative responses at two field sites: the Glengary Mine near Cooke City, Montana, and the Climax Mine in central Colorado. A common garden was also established the same year in Logan, Utah with 100 different populations, including these 18. The two high elevation sites represent major alpine disturbances in the interior Western United States, whereas the common garden site offered a more moderate environment with a longer growing season where the availability of water and nutrients could be controlled. These sites provide an excellent opportunity to contrast the relative adaptations of D. cespitosa for revegetation.

The Glengary Mine is an abandoned copper-gold-silver mine located at an elevation of 2,956 m on a northeast facing slope near the southern edge of the Beartooth Mountains. The mine is near treeline and is exposed to extreme winds that severely affect snow distribution patterns. In August 1980 we observed apparent permafrost on a north-facing slope about 2 m below the surface in a mineral exploration site on the mine being excavated by Ranchers Exploration and Development Co, 2). The vegetation in adjacent reference communities is composed of forbs (primarily Lupinus argenteus, Potentilla diversifolia, and Sibbaldia procumbens), sedges (mainly Carex paysonis), and grasses (D. cespitosa, Trisetum spicatum, and Poa alpina) (Chambers et al. 1987). Widely scattered and isolated islands of Abies lasiocarpa are common throughout the area, including some locations on the mine. Natural colonization by D. cespitosa and other species on some mine spoil piles with relatively high pH is evident in localized areas. The growing season at this site averages about 45 to 60 days with cool temperatures, high winds, and frequent periods of frost. The spoil material has remained relatively undisturbed since the mine was abandoned in 1968, is highly pyritic with high concentrations of metal sulfides, has severely low nutrient

2. The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U. S. Department of Agriculture of any product or service.

Table 1. Characteristics of *Deschampsia cespitosa* populations used in revegetation adaptability study.

Population no.	Origin	Date collected	Latitude-Longitude		Elevation meters	Habitat Type	Germination percent
			north	west			
011	Beartooth Pass, Montana	1981	45°00'	109°24'	3139	alpine meadow	51
020	Butte, Montana	1980	46°00'	112°30'	1829	abandoned field	15
045	Lamoille Ck, Nevada	1980	40°38'	115°22'	2530	subalpine meadow	38
058	Peru Creek, Colorado	1980	39°37'	105°48'	3444	alpine meadow	26
102	Logan Airport, Utah	1980	41°47'	111°51'	1372	wet pasture	74
113	Ovid, Idaho	1980	42°18'	111°25'	1798	irrigated pasture	33
169	Navaho Lake, Utah	1980	37°32'	112°50'	2743	subalpine meadow	62
171	V. T. Hill, Arizona	1980	36°25'	112°07'	2666	montane meadow	68
178	Meadow Study Area, Utah	1980	39°18'	111°28'	3018	subalpine meadow	44
195	Tanana River, Alaska	1980	65°00'	147°48'	130	riverbank opening	80
201	Reykjavik, Iceland	1980	64°09'	21°39'	30	coastal grassland	61
231	Gibson Lake, Utah	1981	42°02'	111°37'	2591	montane meadow	21
237	Mud Lake, Utah	1981	38°22'	112°24'	3353	alpine wet meadow	17
243	Cascade, Idaho	1981	44°30'	116°03'	1463	wet meadow	36
255	Enterprise, Oregon	1981	45°28'	117°16'	1188	dry stream channel	19
260	Priest Lake, Idaho	1981	48°31'	116°58'	762	mesic meadow	30
267	Marias Pass, Montana	1981	48°18'	113°22'	1590	montane meadow	19
271	Florence, Montana	1981	46°38'	114°04'	1097	roadside ditch	24



levels, and is locally very acidic. The research plots were established on a 5% north-facing slope on spoil material with a rocky clay loam texture and a pretreatment pH of 4.8.

The McNulty Meadow site, about 700 km SSE of the Glengary area, is adjacent to the Climax Mine at an elevation of 3,627 m, and is representative of large open meadows above treeline in this area. Floristically the meadow is composed of grasses (mainly D. cespitosa, T. spicatum, P. glauca, and Phleum alpinum) and forbs (primarily Geum rossii, S. procumbens, and P. diversifolia). Soils are well developed, nutrient-rich, micaceous sandstones (Guillaume 1980) that are routinely redisturbed by gophers. The growing season probably averages about 90 days, but otherwise is similar to that of the Glengary site. Several years prior to the installation of this study, about 50 cm of topsoil had been removed from a large area of the meadow to develop a revegetation research site on exposed subsoil materials. The research plots were established within this disturbance on loamy textured, moderately rocky, subsoil with a pH of 4.8.

A completely randomized block design was used at both high elevation field sites to establish seeded research plots of each population. Three replicate plots of the 18 populations were randomly located at each site, one plot in each of three blocks (3 x 18 = 54 plots). Each plot was 1.0 m<sup>2</sup> in size, and all were laid out adjacent to each other with no unseeded space between plots. The entire plot area at both sites was raked clear of rocks, then uniformly fertilized with a 16-40-5 granular fertilizer at 11.2 g N m<sup>-2</sup>, which was raked into the surface to a depth of about 5 cm. Seeds of each population were broadcast evenly in appropriate plots at the equivalent rate of 2.8 g m<sup>-2</sup> of germinable seed, then lightly raked to cover the seed with soil. Surface mulch was applied as a "sandwich" of dry straw between two layers of Con-Wed nylon netting, all staked down with steel "U" pins to minimize redistribution by wind. The straw was applied at the rate of 448 g m<sup>-2</sup>. Refertilization at the same rates was performed at Glengary for the next 2 years (1982 and 1983), only in 1982 at the McNulty Meadow plots and in 1982-1984 for the common garden plots in Logan.

Germination percentages (Table 1) were used to compute the actual amount of seeds required to broadcast at the rate used. The seeding rate of each population was based on total weight of germinable seeds rather than the number of germinable seeds per unit area. Subsequent studies (Brown 1984, unpublished) showed that the number of seeds per gram for these populations varied from 2,105 to 5,542. Therefore, although the germinable seeding rate of each population was equal by weight, the total number of germinable seeds per unit area varied considerably among populations.

One of the 18 populations at each study site was a "native" that represents local genetic stock that is probably climatically adapted to the area, but which is not necessarily suited to disturbed edaphic conditions. For Glengary, the local population was 011

(Beartooth), for McNulty it was 058 (Peru Creek), and for the Logan common garden it was 102 (Logan Airport). In general, these populations were compared with each other and all other populations for each location.

The common garden in Logan, Utah, is located at the Forestry Sciences Laboratory, about 375 km SSW of the Glengary Mine (and about 550 km NW of McNulty Meadow) at an elevation of 1,463 m. The growing season in Logan is about 135 days in length and is characterized by warm temperatures and mostly clear skies. Wind is rarely a stress factor, although early morning easterly canyon gales are common. The garden soil is composed of a 30 cm surface layer of silty-clay loam that originated in an Acer grandidentatum stand in the Wasatch Mountains near Logan. This soil was evenly spread over a well-drained natural loamy clay subsoil with a high composition of cobblestones. Plants of each population were grown from seeds in a greenhouse until they were well-rooted in small pots, then were transplanted into the garden on 40 cm spacings in the fall of 1981. A randomized block design was used to establish 10 plants of each of the 100 populations throughout the garden. The garden was fertilized with a granular 16-40-5 fertilizer (percent of N-P-K) at the equivalent rate of 11.2 g N m<sup>-2</sup> several weeks after planting and each spring until the end of the study. Soil water potential was maintained at or near field capacity during the growing season with a sprinkler irrigation system.

Seedling establishment and growth response data for each replicate plot of all populations at all locations were gathered in the fall of succeeding years. In the fall of 1982, one full year after seeding at both high elevation sites, plant density (number of individuals per unit area) was determined within a single 0.1 m<sup>2</sup> quadrat frame (20 x 50 cm) in each plot. At the Glengary site, 20 first-year seedlings of each population were harvested to estimate above-ground dry weight production based on number of seedlings, but these data were not collected at McNulty. Additional growth data were not collected at McNulty until 1987 because of budget restrictions for travel.

At the Glengary Mine routine annual assessments of plant growth characteristics were continued from 1983 through 1987 (except 1986 when apparent heavy grazing by small mammals during the growing season severely removed the vegetation from most plots). A 0.1 m<sup>2</sup> quadrat in each plot was used to collect vegetation data including percent cover, density, plant height, and biomass. Beginning in the fall of 1983, plant cover was determined from vertical photographs taken of the quadrat within each plot with a 35 mm camera attached to a tripod. Slides were later projected onto a grid from which litter, bare ground, and rock cover were quantitatively estimated. Plant density and total plant height were determined within the same quadrat frame; these data were collected from 1982 through 1985, after which it became impossible to distinguish individual plants. Above ground dry weight biomass of each population within each quadrat frame was determined by harvesting to ground level and later oven drying at 80°C until reaching a constant weight. Other species that invaded the plots were harvested

separately. These same methods were used for the McNulty plots in 1987.

Growth responses of individual plants in the common garden at Logan were assessed each year from 1982 through 1984. Total plant height (both inflorescence and vegetative crown), basal crown diameter, inflorescence height, vegetative crown diameter, and plant dry weight biomass were measured in the fall for each individual plant.

Trends in population performance in terms of density, height, cover, and biomass over time were determined only for the Glengary Mine because of the larger data set for this site. The 1987 population response data from McNulty Meadow were compared with those from Glengary to determine the relative similarities and differences among populations at the two locations. Analyses of variance (ANOVA) were used to determine differences among populations, years, and locations for each factor, and rank correlation analysis was used to determine the similarity of population performance at the two high elevation sites.

The only significant difference among blocks at the two high elevation sites was for plant density for the 1982 and 1987 data ( $p \leq 0.05$ ), but differences were not significant ( $p \geq 0.05$ ) for other factors. Therefore, we treated blocks as replicate plots for each population at both sites.

## RESULTS

Performances of each population varied greatly at the different study sites, therefore data were first summarized for each location separately. Population comparisons among study locations were then analyzed using rank correlation analysis and cluster analysis.

### Glengary Mine, 1982 to 1987

The ANOVAs for density, plant height, cover, and dry weight biomass over time at the Glengary Mine clearly illustrate variations in population performance. Density (number of plants  $m^{-2}$ ) differences were highly significant for years and populations, and there was a significant year x population interaction ( $p \leq 0.01$ ). To simplify, only mean densities for the three native populations (011 from Glengary, 058 from McNulty, and 102 from Logan), together with the mean of all other populations from 1982 through 1985 are illustrated in Figure 1. The total range in density in 1982, when plants were first-year seedlings, varied from fewer than 400 individuals to over 1,500 individuals  $m^{-2}$  (population 260). However, by 1985 densities ranged from only 33 (population 260) to 120 plants  $m^{-2}$  (population 171). Of particular interest is the precipitous decline in plant density in all populations following the first year after seeding, and the convergence in total density for all populations by 1985. The significant population x year interaction indicates that differences among populations were not consistent over time.

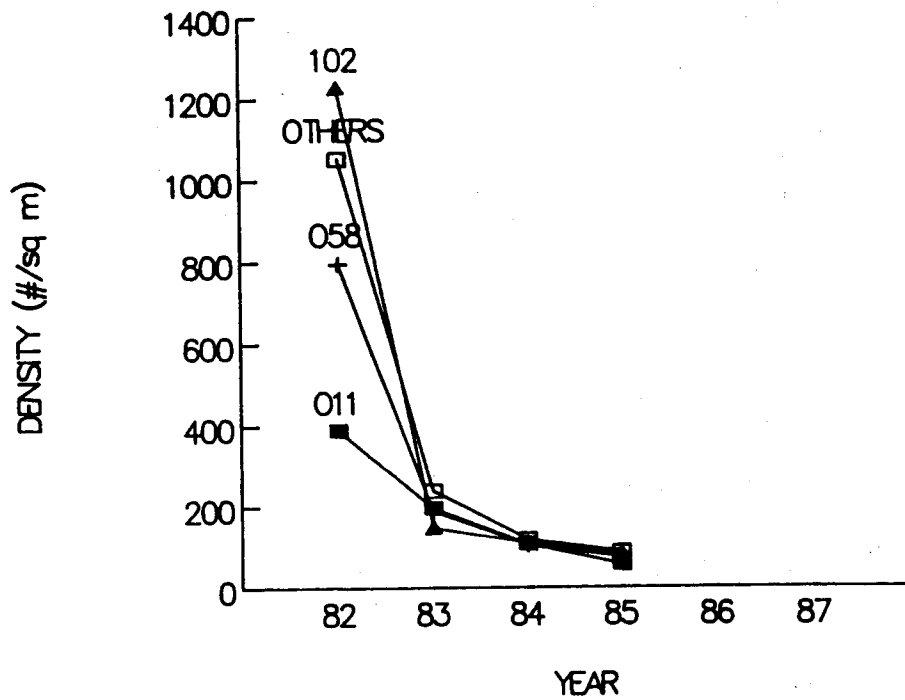


Figure 1. Average plant density (no. plants  $m^{-2}$ ) for the three native populations of each study site and the mean of all other populations at Glengary Mine for the period 1982-1985.

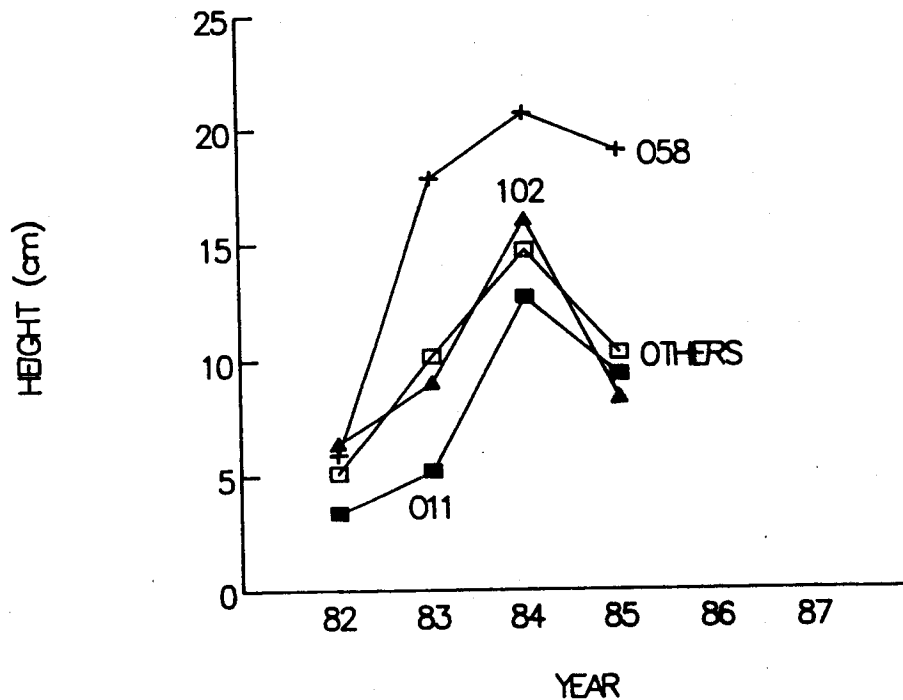


Figure 2. Average plant height (cm) for the three native populations of each study site and the mean of all other populations at Glengary Mine for the period 1982-1985.

Height growth from 1982 to 1985 showed highly significant differences among years and populations ( $p \leq 0.01$ ). Most populations showed a tendency to peak in height growth in the third year after seeding (Figure 2), except populations 260 and 271 (Priest Lake and Florence), which reached maximum height in 2 years, and populations 195 and 201 (Tanana River and Reykjavik), which increased in height each year through 1985. It is interesting to note that plants of population 058, the native from McNulty, were among the tallest on the Glengary Mine, whereas Glengary native (011) plants were generally among the shortest.

Percent vegetation cover for the three native populations of each study site, together with the mean of all other populations, for 1983-1987 is illustrated in Figure 3. Litter cover for the same period is illustrated in Figure 4; data for bare ground and rock are not shown. In general, percent vegetation cover for all populations increased sharply from 1982 (when it was zero) to 1984, then decreased precipitously through 1987. Litter cover progressively increased in complimentary fashion during the same period (Figure 4). The ANOVA for both vegetation and litter cover show no significant differences among populations ( $p \geq 0.05$ ), but differences among years were highly significant ( $p \leq 0.01$ ).

Figure 5 illustrates dry weight biomass for the Glengary site for the period 1982 to 1987 (1986 data are missing due to grazing damage). Biomass tended to increase sharply after 1982, peak in 1984, and then decrease abruptly through 1987 for most populations. However, the native population at Glengary peaked in 1983 and then declined more gradually. Differences among populations were not significant ( $p \geq 0.05$ ), but differences among years were highly significant ( $p \leq 0.01$ ). Despite these results, it is interesting to note that population 058, the McNulty native, had much greater biomass in 1983 and 1984 than the Glengary native (011), and generally higher biomass than any of the other populations.

#### Comparisons Between Glengary and McNulty, 1982 and 1987

Because data were collected at McNulty Meadow only in 1982 and 1987, separate analyses for this site alone are of little value. However, comparisons of population data between the two high elevation sites for those years are useful.

Comparisons of populations at both high elevation sites for each factor for 1982 and 1987 yielded variable results. Differences among populations were highly significant ( $p \leq 0.01$ ) for height at both Glengary and McNulty. Density differences among populations were significant ( $p \leq 0.05$ ) at Glengary but not at McNulty, whereas dry weight biomass was significant ( $p \leq 0.01$ ) at McNulty but not at Glengary. Total vegetation and litter cover were not significantly different among populations ( $p \geq 0.05$ ) at either location.

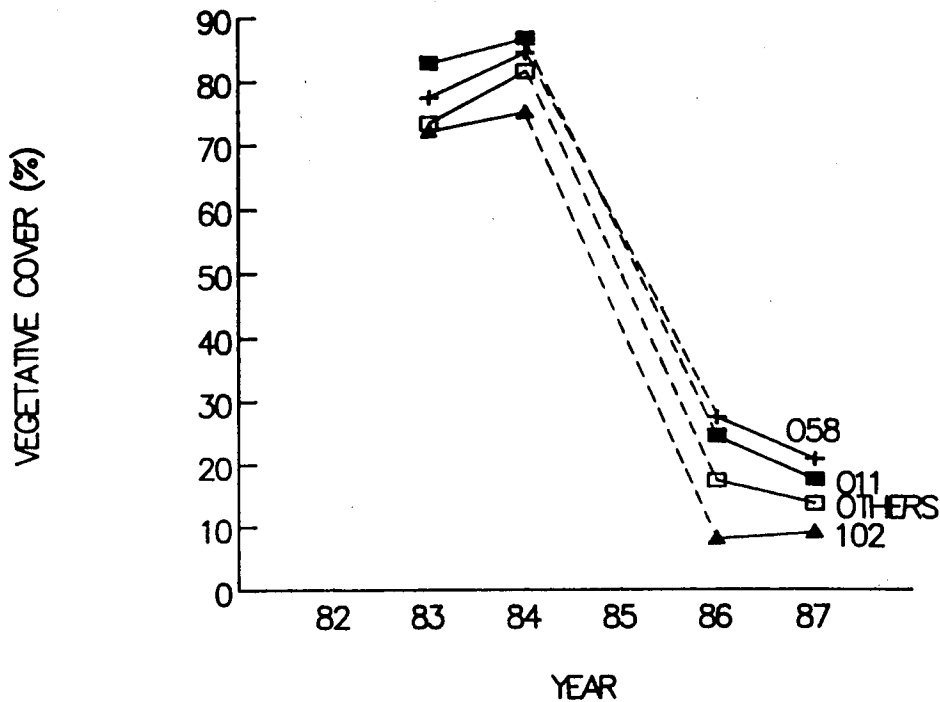


Figure 3. Average vegetative cover (%) for the three native populations and the mean of all other populations at the Glengary Mine for the period 1983-1987. The 1985 data are missing, and the dashed line connects the 1984 and 1986 data points.

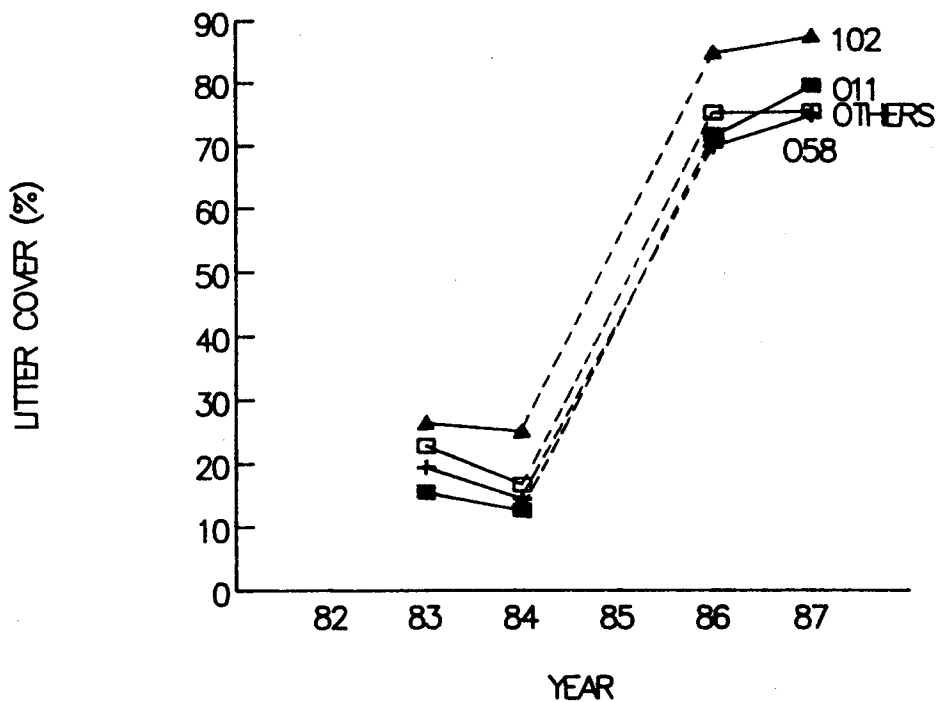


Figure 4. Average litter cover (%) for the three native populations and the mean of all other populations at the Glengary Mine for the period 1983-1987. The 1985 data are missing, and the dashed line connects 1984 and 1986 data points.

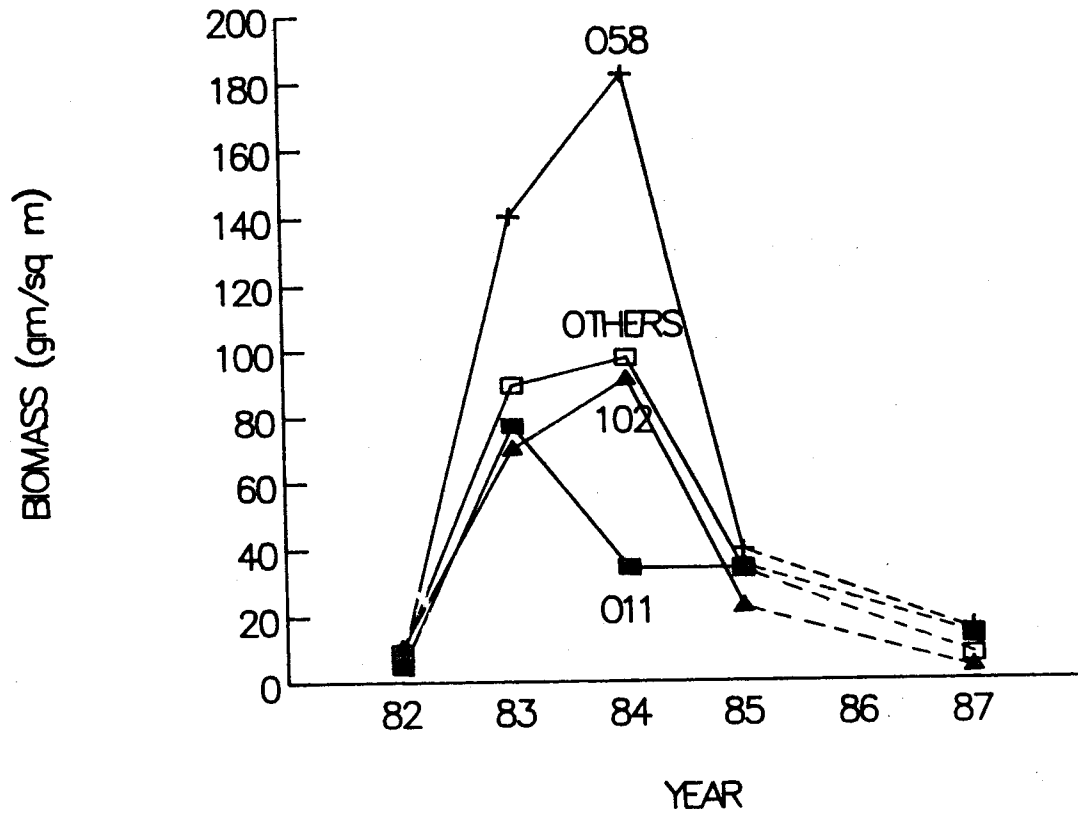


Figure 5. Average biomass ( $\text{g m}^{-2}$ ) for the three native populations and the mean of all other populations for 1982-1987 at the Glengary Mine. The 1986 data are missing, and the dashed line connects the 1985 and 1987 data points.

Comparisons of site differences showed that McNulty and Glengary differed significantly ( $p \leq 0.01$ ) for all factors. Also, the interaction of location x population showed that populations responded differently ( $p \leq 0.05$ ) at the two sites only for height and dry weight biomass. Population 260 (Enterprise) was consistently among the tallest at both sites, while population 201 (Reykjavik) was consistently the shortest. No consistent relationship was noted for biomass among populations. Some populations appeared to respond well (e.g., 011 and 058) on both sites, while others (e.g., 267 and 271) grew well at one location but responded poorly at the other.

In general, population growth responses show McNulty Meadow to be a more favorable site than the Glengary Mine (figures 6 through 10). Plant density, height, percent vegetation cover, and biomass were all greater at McNulty than at Glengary for both the native and most other populations. Litter was consistently lower (Figure 9) at McNulty than at Glengary. Interestingly the native population at Glengary never exceeded the performance of the McNulty native population at either location, except in litter production. However, the McNulty native population at the McNulty site exceeded the performance of all other populations for density in 1982 (Figure 6) and for biomass in 1987 (Figure 10).

In 1987 we separated the total biomass of each plot into that contributed by D. cespitosa and that contributed by other invading species. In general, all populations at McNulty experienced more invasion by other species than they did at Glengary. Also, the proportion of total biomass contributed by invading species was higher at McNulty (about 59.1%) than at Glengary (about 5.5%). When population biomass is ranked in decreasing order for McNulty (Figure 11) and compared with that at Glengary, it is clear that variability in population growth between the two sites is high. Neither the ranking nor the relative proportion of total biomass contributed by D. cespitosa and by other species were the same at the two sites. The same is true for the native populations (011 for Glengary, 058 for McNulty, and 102 for Logan). Also, variability in biomass produced by the 18 populations at McNulty was much greater than at Glengary. As illustrated in Figure 11, the total relative contribution to biomass by invading species increased dramatically at McNulty as D. cespitosa biomass decreased, but this pattern was not as evident at Glengary.

Percent cover at both of the high elevation sites remained relatively high in 1987 (Figure 12). At McNulty, percent vegetation cover ranged from about 68 to 83 percent, while litter ranged from about 12 to 25 percent. At Glengary, vegetation cover ranged from about 5 to 25 percent and litter from about 60 to 92 percent. Although the vegetation cover at McNulty is similar to the litter cover at Glengary, the total cover for all populations (vegetation + litter) at both sites generally exceeds 80%.



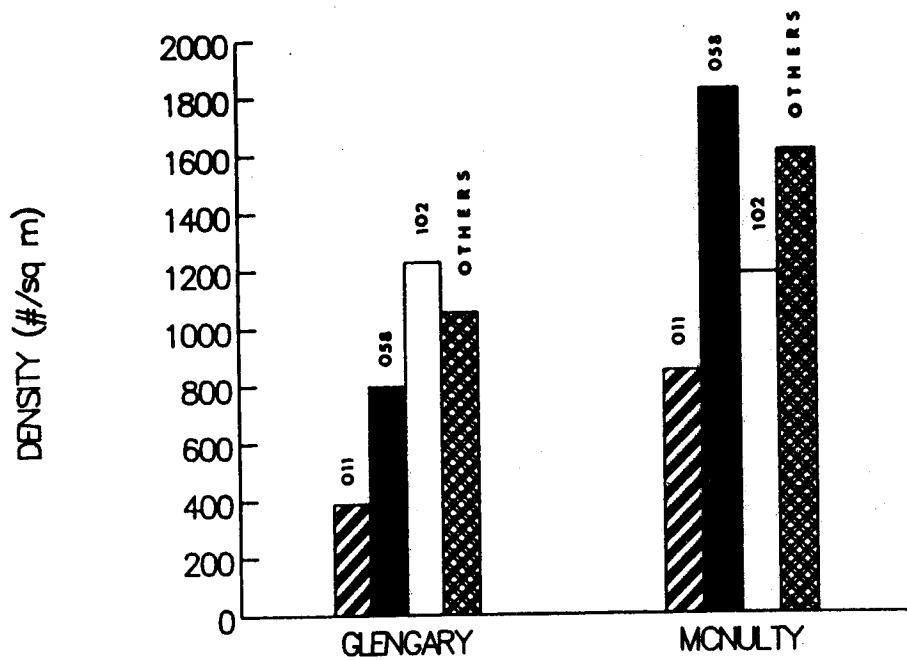


Figure 6. Comparison of mean plant density data at Glengary and McNulty for the three native populations and the mean of the other 15 populations for 1982.

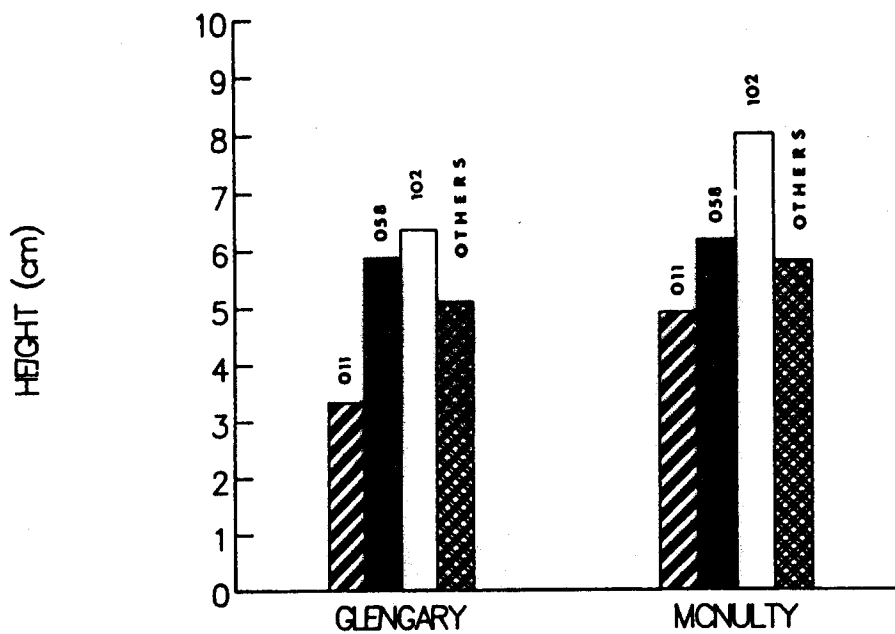


Figure 7. Comparison of mean height (cm) for the three native populations and the mean of the other 15 populations at Glengary and McNulty for 1982.

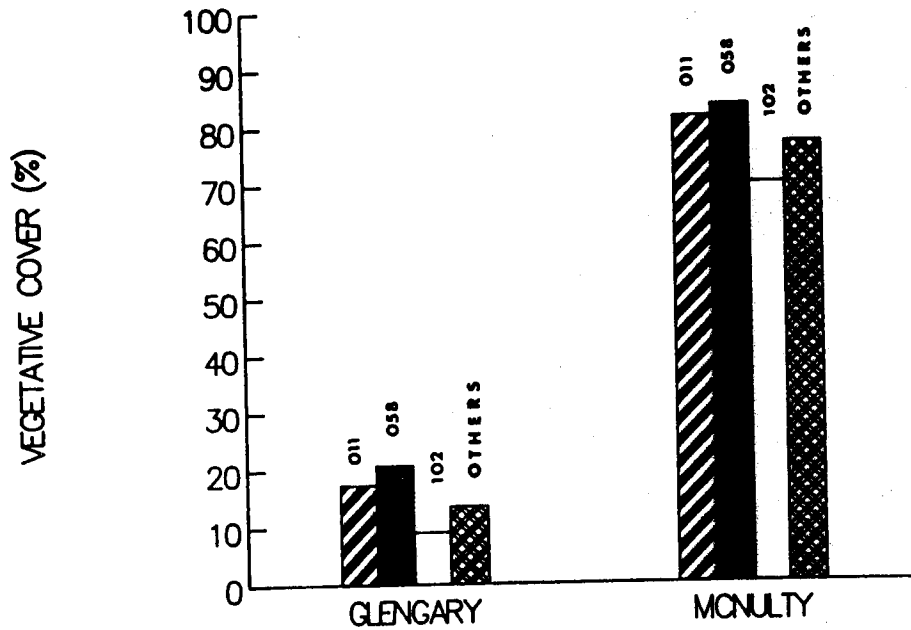


Figure 8. Comparison of mean vegetative cover (%) for Glengary and McNulty for the three native populations and the mean of the other 15 populations for 1987.

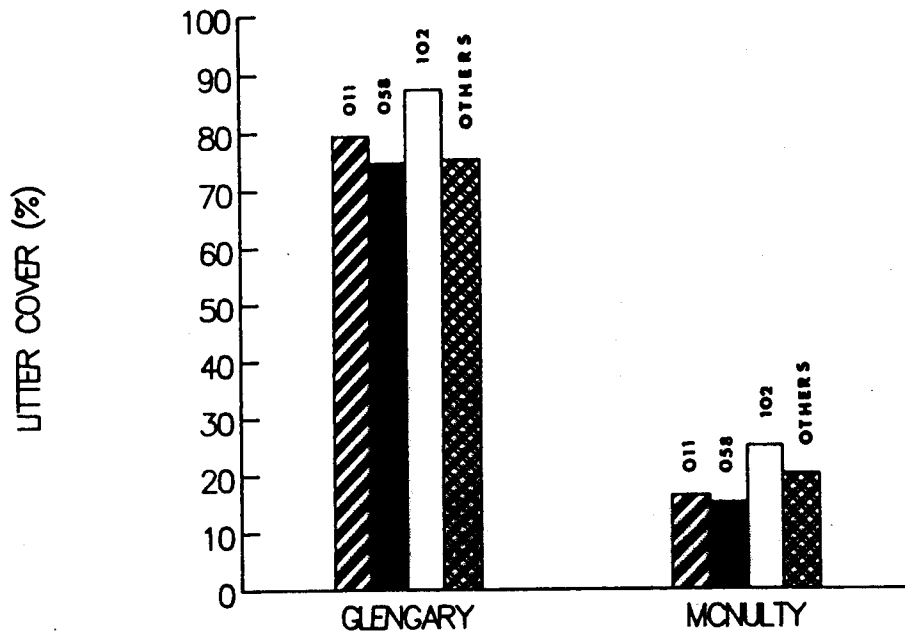


Figure 9. Comparison of mean litter cover (%) for Glengary and McNulty for the three native populations and the mean of the other 15 populations for 1987.

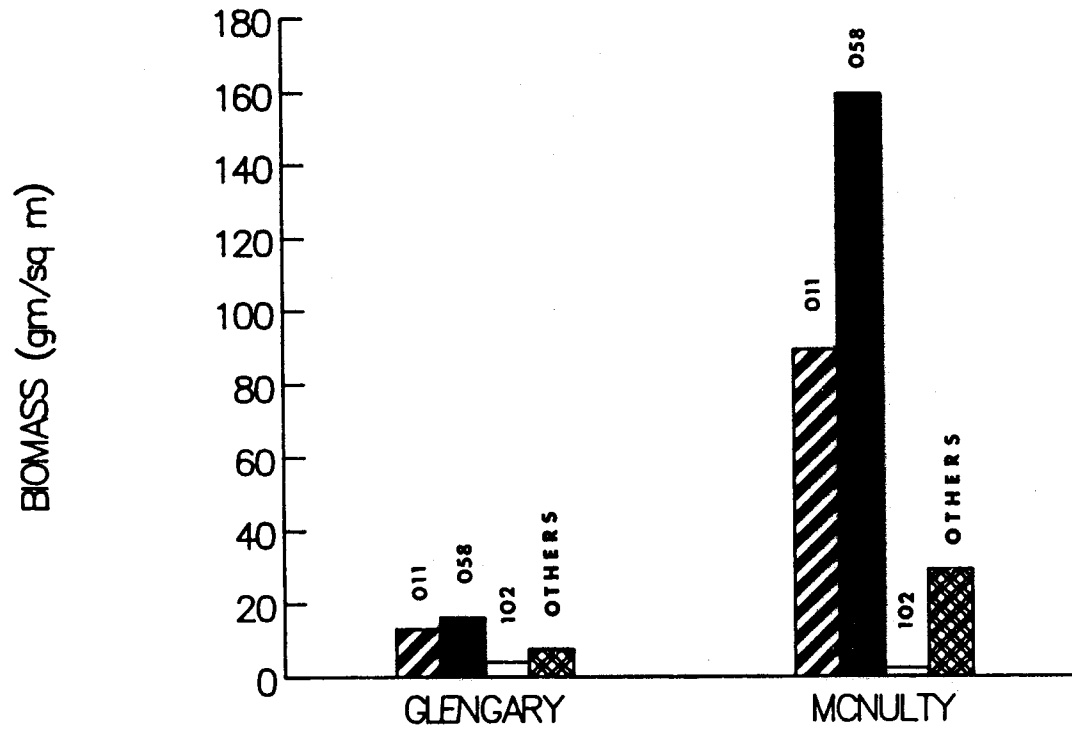


Figure 10. Comparison of mean biomass ( $\text{g m}^{-2}$ ) at Glengary and McNulty for the three native populations and the mean of the other 15 populations in 1987.

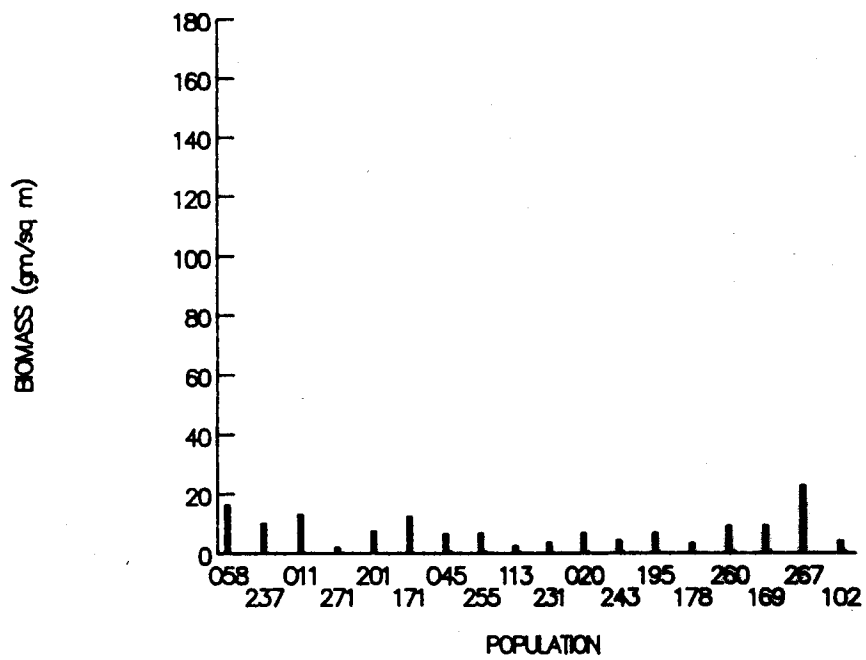
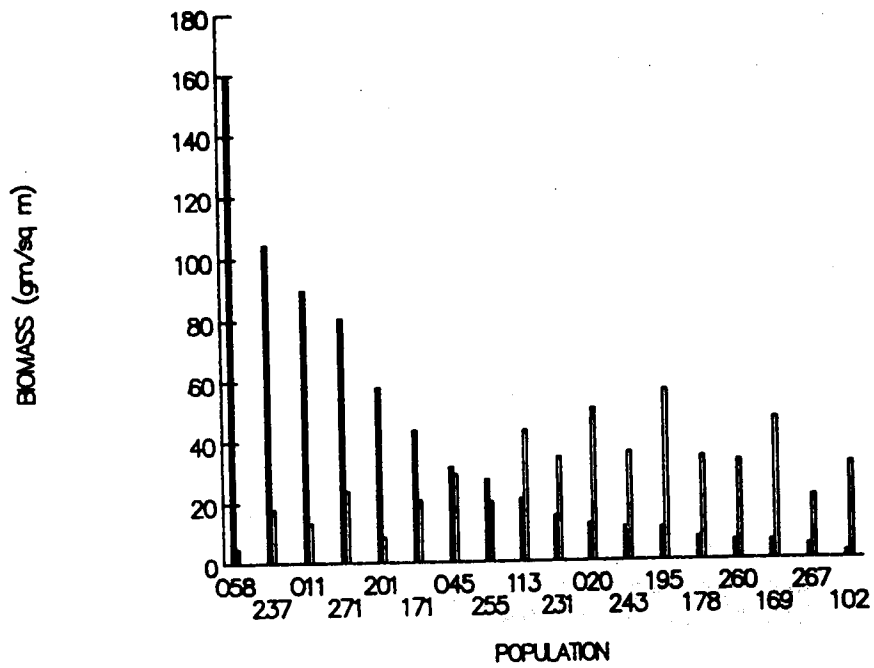


Figure 11. Comparison of biomass ( $\text{g m}^{-2}$ ) at McNulty (above) and Glengary (below) in 1987 for the 18 populations. The solid bars are biomass of *D. cespitosa* and the open bars are biomass of other species.

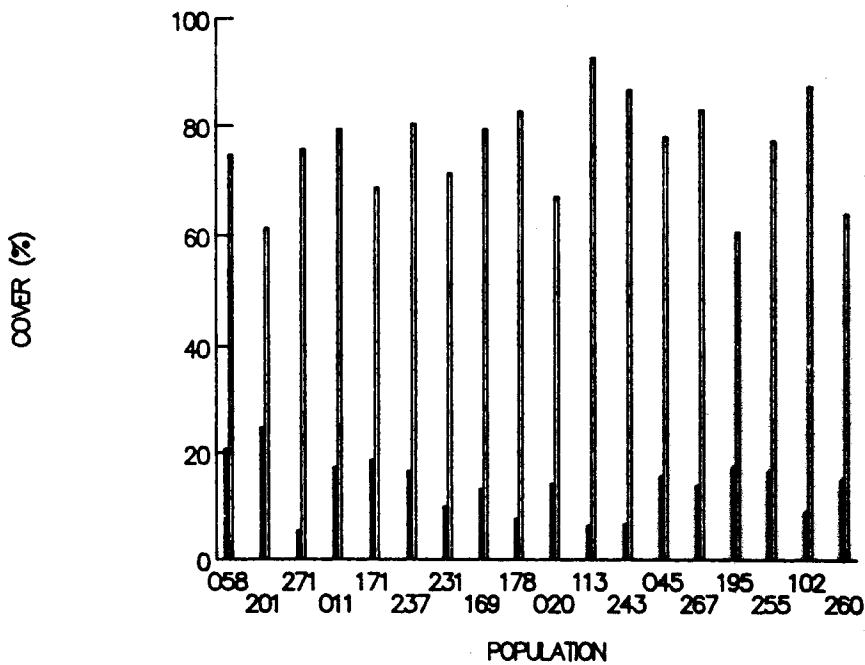
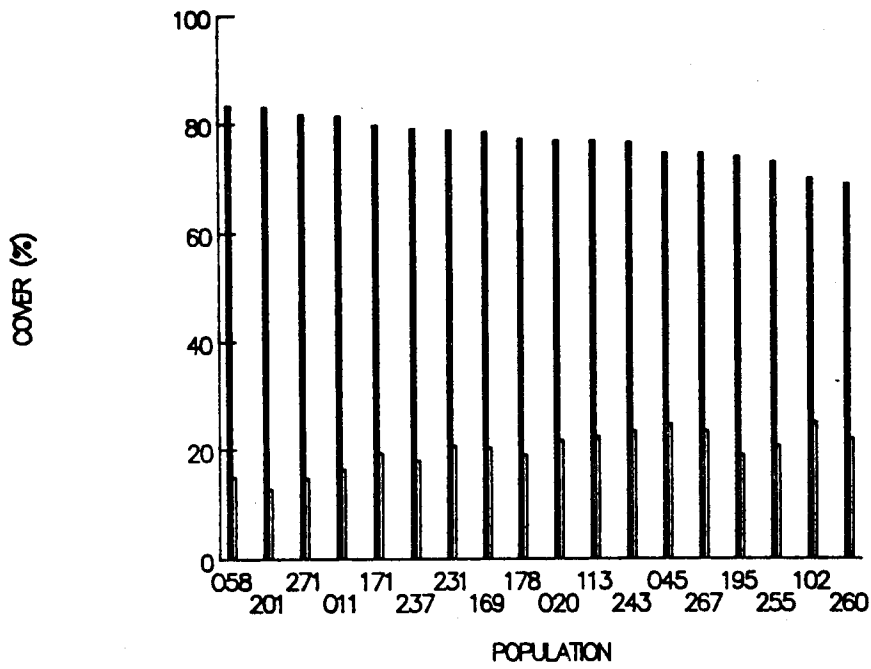


Figure 12. Comparison of vegetation and litter cover (%) at McNulty (above) and Glengary (below) in 1987 for the 18 populations. The solid bars indicate cover by D. cespitosa, and the open bars indicate litter cover.

## Rank Correlations and Cluster Analyses of Populations

Rank correlation analysis was used to compare overall population performance among the two field sites and the common garden in Logan, Utah. Data from the two high elevation sites that were compared in the rankings included plant density, plant height, percent vegetation cover, and biomass. Population data from the garden used in the ranking included plant crown diameter (compared with percent cover from the high elevation sites), plant height, and plant biomass. Each growth response factor was ranked separately for different pairs of location comparisons. Theoretical correlation coefficients potentially range from -1.0 (perfect inverse correlation), to +1.0 (perfect positive correlation). A correlation of 0 indicates no association. The correlation coefficients and their statistical significance (ns = not significant) are summarized in Table 2.

Table 2: Spearman's rank-correlation coefficients comparing performance of *D. cespitosa* populations at McNulty Meadow, Glengary Mine, and Logan Common Garden. Comparisons were made in the latest year when data were available (shown in parentheses).

<u>Factor:</u>	<u>McNulty-Glengary</u>	<u>McNulty-Garden</u>	<u>Glengary-Garden</u>
density	0.2033 (ns) (1982)	not applicable	not applicable
height	0.8400 (p .01) (1982)	0.5335 (p .05) (1982)	0.5955 (p .01) (1984)
veg. cover	0.2807 (ns) (1987)	0.0423 (ns) (1987 - 1984)	-0.1966 (ns) (1987 - 1984)
litter cover	0.4706 (p 0.1) (1987)	not applicable	not applicable
biomass	0.1847 (ns) (1987)	-0.0444 (ns) (1987 - 1984)	0.0568 (ns) (1987 - 1984)

The common garden study was terminated following the 1984 growing season, hence the data collected that year were used in the correlations with the last year data were collected at the two high elevation sites. However, height correlations between McNulty and the garden were restricted to 1982 data because that was the only year height was measured at McNulty. Similarly, correlations for height at Glengary and the common garden were restricted to 1984.

The 18 populations were more closely correlated for height and litter cover at McNulty and Glengary than for other factors (Table 2). Litter cover data were only marginally significant ( $p \leq 0.1$ ). The

correlation coefficient for comparisons of height between McNulty and the garden was significant ( $p \leq 0.05$ ) in 1982, and was highly significant ( $p \leq 0.01$ ) between Glengary and the garden in 1984.

Hierarchical cluster analysis (CLUSTAR) were used to determine population relationships for the two high elevation sites (Chambers et al. 1984). Of interest are the apparent relationships of the native populations (011 from Glengary and 058 from McNulty) at each study location with each other and with the more distant populations introduced (Figure 13). By 1987 the McNulty data were not clearly grouped into population associations. Populations 011 and 058 were closely associated, but no clear trends with other populations could be related to habitat origin other than high biomass and cover production. The 1987 data for Glengary, however, show quite different population associations. Two distinct groups of populations were evident: 1) those from high elevations and northern latitudes that produced high cover and biomass, including populations 011 and 058, and 2) those from lower elevations, more southern latitudes, and wet habitats such as population 102 from Logan that produced lower biomass and cover. Population associations based on data collected in other years at both high elevation sites were inconsistent, and afforded little insight.

#### DISCUSSION

It is apparent that D. cespitosa has a substantial genetic diversity corresponding to its broad ecological range (Lawrence 1945, Ward 1969, Percy and Ward 1972). The ecotypic variability of the species offers many possibilities for revegetation of high elevation disturbances. Although local populations are likely to be better suited to local conditions, severe disturbances such as surface mines that result in the total destruction of the edaphic integrity of the soil almost negate the concept of "native" adaptability, and may sharply diminish any expected advantages that native geneotypes would exhibit with respect to other populations. The populations originating from the three study sites described here can only be considered "native" in the sense that they are probably climatically adapted to the area. The pyritic nature of the spoil material at Glengary is quite dissimilar to the native soil characterizing the surrounding ecosystem (Chambers et al. 1987). Also, the soils at McNulty and those used in the common garden study are totally unlike that supporting native stands of D. cespitosa in either location. Thus, in some cases distant populations may be better suited for revegetation of some disturbances than are local populations.

Throughout the study it was difficult to visually detect strong differences in overall population performances among the 18 populations studied. Reproductive capability, expressed as mature seed production, was not measured because dates of flowering and anthesis varied widely among the populations. Phenological development among the 18 populations studied appeared to differ by several weeks during the growing season. All populations appeared to flower and produce seed,

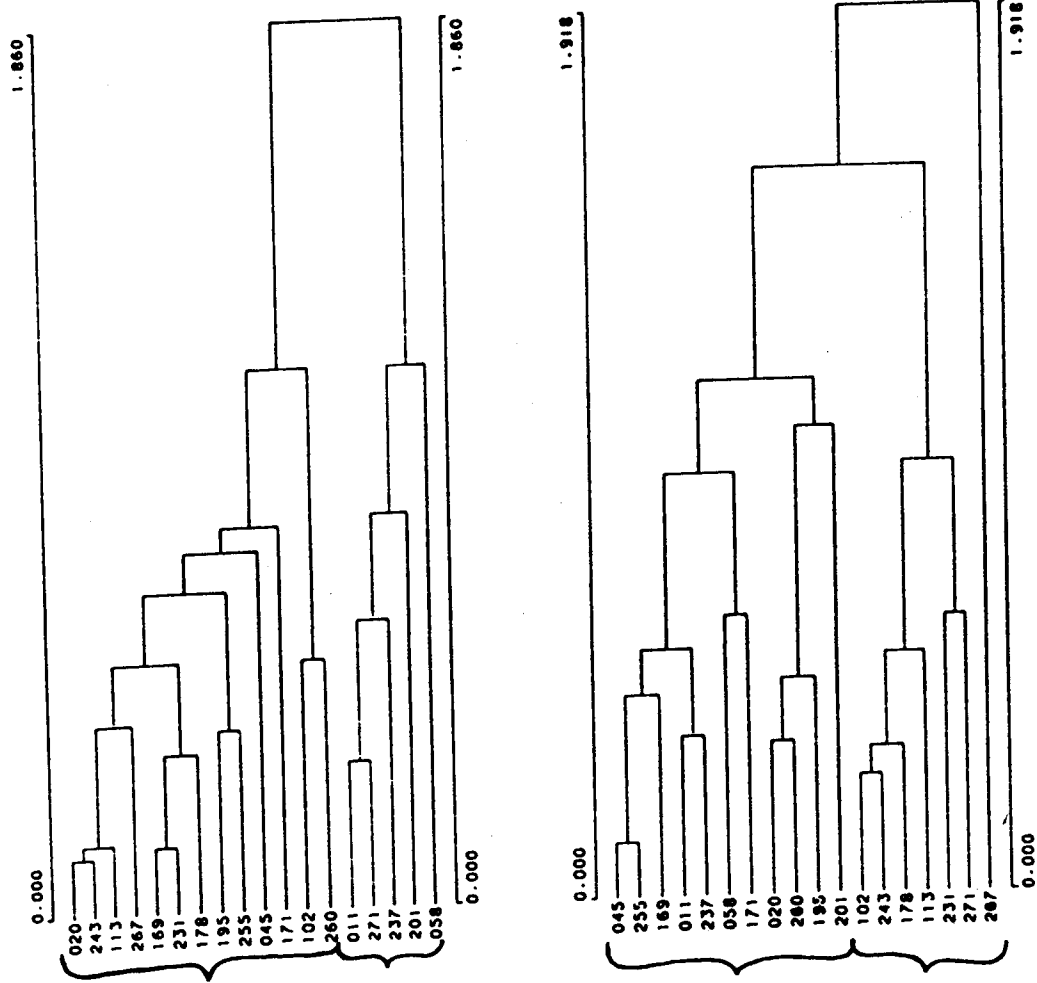


Figure 13. Comparison of cluster analysis dendrograms for McNulty (left) and Glengary (right) populations in 1987 using cover and biomass data.



but seed viability of the 18 populations was difficult to quantify because sampling at appropriate times was impossible. We noted that anthesis appeared to occur earlier for populations originating from northern and higher elevations, and later from lower elevations in southern latitudes. Given the short growing season at both high elevation sites, it is reasonable to expect that some populations introduced in this study would be unable to complete normal seed maturity, hence long-term selection against them would probably be complete. Unfortunately, we were unable to quantify this variable.

For purposes of this study, attributes used to describe the suitability of *D. cespitosa* for revegetation included density, height, vegetation cover, litter cover, and biomass. Survival is implied in plant density data over time. Although there was wide variability in plant density among populations during the first growing season at both high elevation sites, these differences were soon narrowed at Glengary in succeeding years as mortality reduced the number of plants of all populations. By 1985 we could no longer distinguish individual plants with certainty at Glengary, hence density counts were discontinued.

Height growth appears to be genetically controlled (Pearcy and Ward 1972), being influenced by local edaphic and climatic variables somewhat uniformly among all populations. We noted that relative height among the populations tended to remain nearly constant throughout the study, and was the one variable that visually distinguished populations. Populations 058 (Peru Creek) and 255 (Enterprise) were consistently the tallest, and 195 (Tanana River) and 201 (Reykjavik) were consistently the shortest.

Cover is one of the more important factors in successful revegetation because it provides surface protection of the soil or spoil. At Glengary all populations had a vegetative cover greater than 50% during the second growing season and averaged over 80% by the end of the third season. When refertilization was discontinued, vegetative cover declined rapidly in all populations and by 1987 averaged only about 15% at Glengary and about 75% at McNulty. However, litter cover that had accumulated since 1983 averaged about 75% at Glengary and only about 20% at McNulty. The total cover at both high elevation sites generally was above 75% for all populations. Refertilization after seeding appeared to be important, especially at Glengary where spoil characteristics are poor, because high biomass production in the first few years provided a large quantity of plant litter material. After refertilization was discontinued and vegetative cover began to decline, litter provided the bulk of the surface cover.

For favorable sites such as McNulty where soils are deep and rich, frequent refertilization may not be critical. Plant cover remained high throughout the study, and litter contributed much less of the total cover than at Glengary.

Biomass production is also of major importance in successful revegetation and represents an excellent measure of site productivity.

Effects of the richer, deeper soils at McNulty Meadow were apparent by the end of the study as indicated by the much higher biomass produced by all 18 populations than that produced at Glengary. Glengary had been refertilized several times following seeding, but McNulty had been refertilized only in 1982. Yet, at McNulty biomass production in 1987 was still about 5 to 10 times greater than that at Glengary for some populations (e.g., populations 011 and 058).

The proportion of total vegetative cover and biomass at the two sites provided by colonizing species is much higher at McNulty than at Glengary. Although the two sites were seeded at the same level, and even though Glengary was refertilized more often, McNulty provided higher levels of cover, biomass, and species diversity by the end of the study. On the average, 59.1% of the total biomass at McNulty was contributed by invading species, whereas at Glengary the average was 5.5%. In most cases, the biomass contributed by invading species at McNulty was greater than that contributed by D. cespitosa at Glengary.

At locations such as McNulty Meadow where soils are deeply developed and do not contain deleterious levels of toxic substances, selection of the most adapted population may not be as critical for successful revegetation as it may be at Glengary. The high seeding rates used in this study, especially with the most adapted populations, may inhibit succession and the establishment of higher species diversity on sites similar to McNulty. If the objective of revegetation is to provide immediate surface protection together with long-term successional development of a highly diverse community, then at sites such as McNulty Meadow lower seeding rates with one of many different relatively well-adapted populations will probably be successful.

However, at sites similar to the Glengary Mine with severely limiting edaphic factors, selection of the best adapted population is more critical. Invading colonizer species will rarely contribute significantly to successful revegetation until limiting spoil conditions are ameliorated. Thus, it is likely that the seeded species will remain as the primary contributors to successful revegetation. On such sites, relatively higher seeding rates than those used on favorable sites, ameliorative spoil treatments, and refertilization may be necessary to achieve revegetation goals. On such sites it appears that populations such as 011 and 058 are the best suited for revegetation, although for other areas population and species trials on-site are recommended before final selection can be made.

To select populations for revegetation of high elevation disturbances, adaptability characteristics should be carefully examined. In this study various populations displayed consistent attributes that would be advantageous for revegetation. For example, populations 011 and 058 (from Glengary and McNulty, respectively) appear to be well suited for revegetation in their respective native habitats. However, population 058 displayed more favorable characteristics at Glengary and McNulty Meadow than did 011 for most

factors measured, suggesting that this population would be the best adapted. Yet, in the common garden study at Logan, population 011 consistently displayed greater biomass and crown size than population 058.

Comparisons of growth characteristics at the two high elevation sites with those from the common garden help illustrate some potential dangers in using common garden data alone as an indicator of suitability. In this study, many of the population growth characteristics were ranked in reverse order between the garden and the high elevation sites. For example, population 102 (Logan) was ranked among the highest in biomass and cover in the common garden, but ranked among the poorest at both McNulty and Glengary. Also, populations 011 and 058, both consistently high in cover and biomass among the 18 populations at the high elevation sites, were among the lowest in the common garden. Thus, common garden studies located at revegetation sites will likely be more useful for evaluating potentially adapted species or populations than those conducted in a neutral location.

#### CONCLUSIONS

D. cespitosa has a broad range of genetic diversity that can be useful for revegetation of high elevation disturbances. However, it is probably not advisable to generalize about the suitability of a particular population for most high elevation disturbances because of the extreme range of factors that characterize both sites and populations. Selection of the best adapted species or populations for revegetation should be based upon on-site evaluations of critical revegetation factors such as plant cover, litter production, biomass, ability to reproduce, and ability to permit invasion by other species. Criteria of adaptedness determined only in common gardens in neutral locations can be misleading. For disturbances with well-developed soils that contain minimum amounts of toxic substances, revegetation goals can potentially be achieved by selecting from a broad range of relatively well-adapted populations. In such cases, seeding and fertilization rates can be manipulated to encourage successional development of more diverse plant communities. However, on sites with limiting soil characteristics, selection criteria for adapted populations are more critical. At these locations it is recommended that species and population trials be conducted that include tests of seeding and nutrient enhancement alternatives to determine the most favorable practices required to achieve revegetation goals.

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SEEDLING ESTABLISHMENT IN DISTURBED ALPINE ECOSYSTEMS:  
IMPLICATIONS FOR REVEGETATION

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INTRODUCTION

Results of previous reclamation studies on severely disturbed alpine areas indicate that an understanding of the basic processes that determine succession is necessary to restore an acceptable level of ecosystem functioning on these areas. Most of the species commonly used in western montane revegetation cannot survive and reproduce under true alpine conditions. Revegetation efforts in alpine areas have focused mainly on native alpine grasses that are frequent colonizers on disturbed areas and that have high reproductive rates and exhibit rapid growth characteristics (Brown et al. 1978, Brown and Johnston 1979). Alpine areas reclaimed with these grasses show only slight colonization by species from adjacent vegetation and thus little change in species composition even after 8 years (Brown et al. 1984). In addition, without continuous fertilization, standing crop biomass of reclaimed severely disturbed areas appears to peak within 2 to 3 years after seeding and then to decline to very low levels.

Understanding the processes that affect seedling establishment in alpine ecosystems is essential for determining successional pathways and outcomes and developing successful reclamation methods. Natural seedling establishment in alpine ecosystems depends upon the proper set of growing conditions and is frequently episodic (Bliss 1985). The extreme and variable nature of the alpine environment, the characteristics of the disturbance, the reclamation methods used, and the physical and life history traits of individual species all are important determinants of seedling establishment following disturbance. Successional processes are determined by the relationships among each of these factors and the species that initially establish on disturbed areas. This paper summarizes the results of several studies that have examined some of the effects of these factors on alpine seedling establishment.

Few mechanistic studies of the processes that affect seedling establishment in alpine ecosystems have been performed. We conducted a field study on the Beartooth Plateau in southwestern Montana that examined the effects of disturbance type on seedling environment and establishment of alpine species with different physiological and life history traits. Soil temperatures, water potentials, and nutrients within *Geum* turf vegetation on an undeveloped alpine soil typical of a severe disturbance type were compared with those on a highly organic, well-developed soil representative of a less severe disturbance type. Seedling emergence, growth, and survival of six seeded species and emergence and survival of five naturally colonizing species were evaluated on both disturbance types. The effects of fertilizer and mulch

on soil characteristics and seedling establishment were examined on the severe disturbance type. In addition, laboratory experiments with these same species were performed that investigated seed germination characteristics and the variations in seed viability among and within years. Also, a fertilization study was conducted that examined nutrient responses of two broadly distributed alpine species.

#### DISTURBANCE TYPE

In alpine ecosystems, two types of disturbance can be distinguished. Severe disturbances are those that remove surface soil horizons. They are caused primarily by geomorphological processes such as landslides and avalanches and by the activities of people, such as mining and road building. Less severe disturbances are those that leave surface soil horizons in place or mix surface and subsurface soil. They can result from soil movement by freeze-thaw action (Johnson and Billings 1962), small mammal burrowing and tunneling (Thorn 1982), and human recreational activities. The two types of disturbances result in significantly different seedling environments.

In the field study on the Beartooth Plateau, the less severely disturbed area was located within the Geum turf vegetation type. All vegetation on the study area had been killed with herbicides and then removed by hand. The soil was a highly organic dark-colored peat. The severely disturbed area was a 30-year-old gravel barrow pit that had mineral loamy sand soils. The less severely disturbed area had higher soil temperatures, especially at the surface and 5-cm depth, than the severely disturbed area (Fig. 1). Peat soils are characterized by lower thermal conductivities, heat capacities, thermal diffusivities, and thermal contact coefficients than loamy sand soils (Cochran 1969). Effects on the seedling environment of peat soils include large diurnal fluctuations in soil surface temperatures and generally higher soil temperatures at shallow depths during periods of moderate to high solar radiation. In contrast, mineral soils have smaller daily temperature fluctuations but cooler temperatures during periods of high insolation. During cool periods, the thermal characteristics of the highly organic soils on less severely disturbed areas and resultant higher soil temperatures may improve seedling survival. However, during warm periods, and especially when soil water potentials are low, temperatures may be so high that seedling mortality results.

The peat soils on the less severely disturbed area had higher levels of organic matter and available nitrogen (N) and phosphorus (P) and higher cation exchange capacities than the loamy sand soils of the severely disturbed area (Table 1). The differences between the two disturbance types in soil temperatures and nutrient levels were similar to those that have been observed on disturbances of different magnitude in more temperate ecosystems (Bazzaz 1983, Chapin 1983, Vitousek 1985). In this study, the higher levels of soil nutrients in combination with higher soil temperatures resulted in greater seedling growth and survival on the less severe disturbance type than on the severe disturbance type.



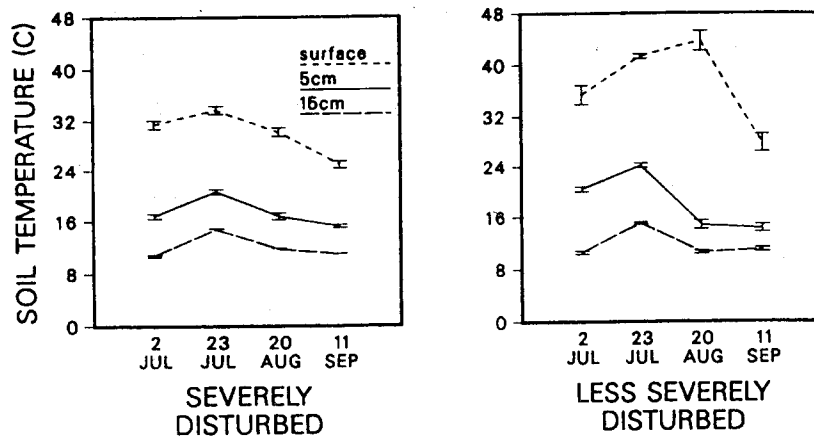


Fig. 1. Soil temperatures averaged over treatments for surface, 5 cm, and 15 cm depths during the 1985 growing season on the severely and less severely disturbed areas, Beartooth Plateau, Montana. Values are means and error bars represent  $\pm 1$  S.E.;  $n = 18$ .

Table 1. Soil chemical properties of severely and less severely disturbed areas on the Beartooth Plateau, Montana 2 years after fertilization treatment was applied. Values are mean  $\pm$  S.E.

Property	Severely disturbed area		Less severely disturbed area
	Fertilized	Not fertilized	
Organic matter (%)	0.61 $\pm$ 0.08	0.65 $\pm$ 0.13	10.2 $\pm$ 0.25
Total nitrogen (%)	0.02 $\pm$ 0.004	0.02 $\pm$ 0.003	0.56 $\pm$ 0.04
NO <sub>3</sub> (mg/kg)	4.30 $\pm$ 0.42	2.50 $\pm$ 0.34	30.33 $\pm$ 4.67
NH <sub>4</sub> (mg/kg)	2.67 $\pm$ 0.48	1.50 $\pm$ 0.32	5.07 $\pm$ 0.32
P (mg/kg)	37.50 $\pm$ 3.99	7.00 $\pm$ 0.45	17.30 $\pm$ 1.67
K (mg/kg)	62.17 $\pm$ 0.70	66.67 $\pm$ 4.87	133.83 $\pm$ 6.94
pH	6.18 $\pm$ 0.09	6.35 $\pm$ 0.08	5.38 $\pm$ 0.04
Cation exchange capacity (umol/kg)	7.48 $\pm$ 0.20	7.21 $\pm$ 0.14	14.83 $\pm$ 0.40

High seedling mortality in other tundra areas has been attributed to soil drought (Bliss 1971, Bell and Bliss 1980) or needle ice activity (Osburn 1961, Brink et al. 1967, Bliss 1971, Roach and Marchand 1984). The soil water stress ( $< -1.5$  MPa) observed in other alpine ecosystems during the growing season (Ehleringer and Miller 1975, Johnson and Caldwell 1975) did not occur during the 2 years of this study on either disturbance type (Fig. 2). This may in part result from different weather patterns in the Beartooth Mountains than in other Rocky Mountain ranges.

Needle ice occurs primarily on saturated mineral soils that are not protected by vegetation or surface organic layers (Brink 1964). In this study, limited evidence of needle ice existed on not mulched plots on the severely disturbed area, but no evidence of needle ice was found on the less severely disturbed area.

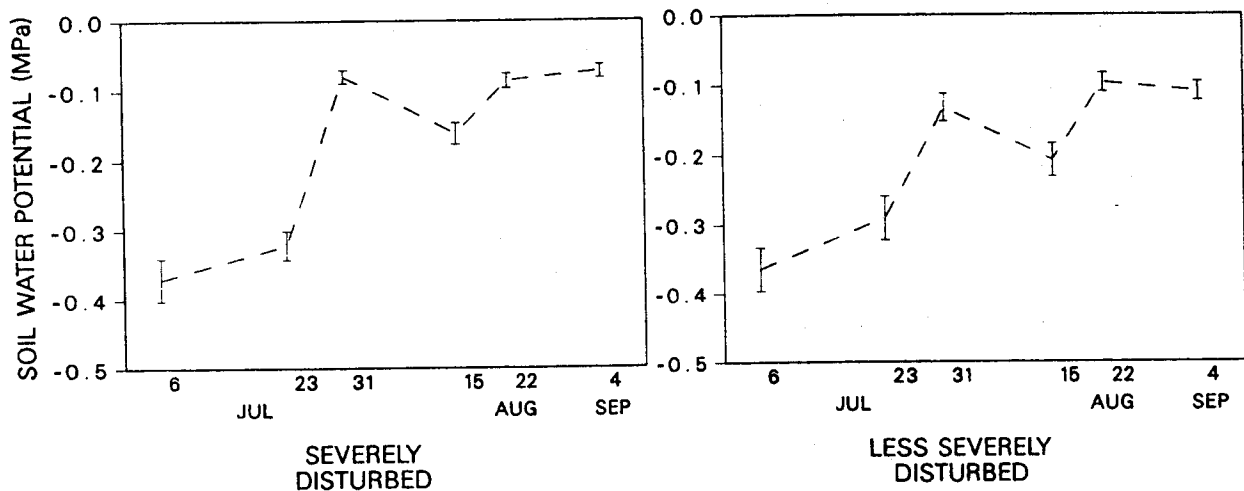


Fig. 2. Soil water potential values averaged over treatments and depths for the 1985 growing season on the severely and less severely disturbed areas, Beartooth Plateau, Montana. Values are means and error bars represent  $\pm 1$  S.E.;  $n = 45$ .

## REVEGETATION NEEDS

### Fertilizer

Levels of soil nutrients may affect seedling growth and survival in tundra ecosystems because primary production is frequently limited due to cold soils and slow rates of decomposition (Chapin 1981). Indeed, slow seedling development may be a major cause of seedling mortality (Wager 1938, Bell and Bliss 1980). On severely disturbed alpine mine soils, nutrient amendments have increased seedling establishment (Brown et al. 1976, 1978). In contrast, on disturbed tundra sites with surface soil horizons in place, fertilization has had no effect on seedling survival (Roach and Marchand 1984).

On the severely disturbed area on the Beartooth Plateau, we compared plots that were fertilized with 8.2 and 15.6 g/m<sup>2</sup> (80 and 150 lb/ac) of N and P, respectively, applied as (NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub> and CaH<sub>4</sub>(PO<sub>4</sub>)<sub>2</sub> with plots that were not fertilized. Two years after fertilization levels of available N (NO<sub>3</sub> and NH<sub>4</sub>) and P were higher in fertilized than in not fertilized plots, but only about half the amount of P and less than a tenth the amount of N originally applied remained in the soil (Table 1). Loamy sand soils, such as those on the disturbed area, are characterized by high porosities, low cation exchange capacities and, consequently, low nutrient retention (Tisdale and Nelson 1975). Nitrogen is highly mobile in these soils and it is likely that the effect of nitrogen fertilization on the seedling environment was a pulse of nitrogen at the beginning of the first growing season followed by a gradual decline during the remainder of the growing season in response to subsequent precipitation. Further losses probably occurred at the start of the second growing season during spring runoff. Higher levels of phosphorus in fertilized plots reflect the immobility of the phosphate anion in the soil.

Fertilization had no effect on seedling mortality or resulted in greater seedling mortality despite higher seedling weights (Table 2). These results were unexpected as higher seedling weights normally result in lower mortality in more temperate ecosystems (Cooke 1979), and slow growth has been suggested as one of the primary causes of mortality in tundra seedlings (Wager 1938, Bell and Bliss 1980). The higher mortality on fertilized plots, especially for colonizer species, probably resulted from an initial pulse of N and P, followed by a rapid decline in N. Declines in fertility following a nutrient pulse can result in decreased nutrient absorption, photosynthesis, and growth, and in turn, cause greater susceptibility to other stresses (Chapin 1980).

On severely disturbed alpine areas inorganic fertilizers are not reliable sources of nutrients for plant growth unless applied repeatedly over long time periods (Brown et al. 1984, Chambers 1988). Maintenance of adequate levels of nutrients to support the desired vegetation on reclaimed disturbed areas is dependent on the retention of these elements within the system via nutrient cycling. Less severely disturbed areas

Table 2. Percent of seedlings that emerged in 1985 or 1986 and survived through the 1986 growing season in 0.1-m<sup>2</sup> plots on the Beartooth Plateau on different disturbance types and under different treatments. Treatment codes are: FM = fertilized, mulched; FNM = fertilized, not mulched, NFM = not fertilized mulched; and NFNM = not fertilized, not mulched.

Species	Severely disturbed area				Less severely disturbed area
	FM	FNM	NFM	NFNM	
<u>Seeded species</u>					
<u>Geum rossii</u>					
1985	82	100	94	60	-
1986	-	-	-	-	82
<u>Artemisia scopulorum</u>					
1985	87	100	82	98	-
1986	92	100	93	88	94
<u>Festuca idahoensis</u>					
1985	30	0	45	33	-
1986	-	66	78	-	92
<u>Potentilla diversifolia</u>					
1985	95	86	88	93	-
1986	53	100	69	97	97
<u>Sibbaldia procumbens</u>					
1985	100	-	90	100	-
1986	81	92	91	91	82
<u>Deschampsia cespitosa</u>					
1985	85	44	66	68	-
1986	75	100	75	86	90
<u>Colonizer species</u>					
<u>Cerastium arvense</u>					
1985	84	6	94	76	-
1986	100	100	100	100	100
<u>Draba crassifolia</u>					
1985	92	25	89	77	-
1986	100	100	97	94	-
<u>Arenaria obtusiloba</u>					
1985	79	19	81	80	-
1986	93	96	100	96	80
<u>Androsace septentrionalis</u>					
1985	100	38	100	50	-
1986	100	100	100	92	-
<u>Draba incerta</u>					
1985	84	53	85	62	-
1986	100	100	100	100	94

or areas that are topsoiled often have inherently higher nutrient retention capacities than severely disturbed areas. Severely disturbed areas frequently require amendments to increase nutrient retention capacities and to accelerate the development of a desirable nutrient cycle. The ability of mineral soils or spoils to provide a "good" growing medium for plants can be greatly increased by incorporating organic matter. Organic matter improves soil structure by decreasing bulk densities and increasing aeration. It also increases nutrient retention by increasing cation exchange capacities, increases moisture retention, and provides a continuous, though limited, supply of plant nutrients (Tisdale and Nelson 1975). When organic matter with a high C:N ratio is incorporated into soil, it is necessary to increase the initial amounts of nitrogen applied to facilitate microbial breakdown. Nitrogen relations on severely disturbed reclaimed areas can be further improved by planting species with nitrogen-fixing symbionts. If it is not feasible to topsoil or incorporate organic matter into a low nutrient soil, then species that are adapted to low nutrient conditions should be included in or dominate the seed mix.

### Mulch

Organic mulches can benefit alpine seedling establishment by decreasing soil water loss and moderating soil surface temperatures (Cochran 1969). Mulches can prevent surface wind erosion of both soil and seeds and, in some instances, may trap wind-blown seeds and soil. In addition, needle ice is less likely to form in areas protected by an organic mulch (Brink 1964).

In the field study on the Beartooth Plateau, plots that were mulched with  $224 \text{ g/m}^2$  (2 ton/ac) of straw were compared with plots that were not mulched. The mulch helped prevent surface soil erosion and seed removal by wind. These observations were substantiated by significantly greater seedling emergence on plots that were mulched than on plots that were not mulched (Table 3). In addition, extremely poor seedling emergence on the less severely disturbed area during the first growing season necessitated reseedling of the area and then pinning the soils firmly in place with two layers of plastic netting (1-cm mesh). On the severely disturbed area, mulch had almost no measured effects on soil nutrients, water potential, or temperature. Despite this, mulch did increase seedling survival of some species. On mulched plots wind removed or redistributed a significant amount of the straw. Microenvironmental variation created by the patchy distribution of the mulch may have resulted in microsites that favored seedling survival. Mulch, even if patchy, may significantly ameliorate the harmful effects of wind by acting as a partial buffer or roughness element. This can improve the physiological status of plants by decreasing transpiration and allowing higher leaf temperatures. Also, the physical effects of wind may be ameliorated by decreased soil movement and, consequently, decreased plant abrasion and root exposure (Cochran 1969).

Table 3. Average numbers of seedlings that emerged in 1985 or 1986 in 0.1 m<sup>2</sup> plots on the Beartooth Plateau on different disturbance types and under different treatments. Treatment codes are: FM = fertilized, mulched; FNM = fertilized, not mulched, NFM = not fertilized, not mulched; and NFNM = not fertilized, not mulched.

Species	Severely disturbed area				Less severely disturbed area
	FM	FNM	NFM	NFNM	
<b>Seeded species</b>					
<u>Geum rossii</u>					
1985	55	4	85	5	-
1986	0	0	0	0	39
<u>Artemisia scopulorum</u>					
1985	104	4	171	53	-
1986	13	8	29	8	199
<u>Festuca idahoensis</u>					
1985	27	3	34	3	-
1986	0	3	9	0	13
<u>Potentilla diversifolia</u>					
1985	93	7	120	27	-
1986	19	1	39	32	204
<u>Sibbaldia procumbens</u>					
1985	7	0	20	4	-
1986	88	26	184	57	146
<u>Deschampsia cespitosa</u>					
1985	55	11	44	19	-
1986	40	10	40	7	263
<b>Colonizer species</b>					
<u>Cerastium arvense</u>					
1985	31	35	31	51	-
1986	6	9	9	1	35
<u>Draba crassifolia</u>					
1985	37	141	75	98	-
1986	1	32	33	17	0
<u>Arenaria obtusiloba</u>					
1985	197	235	99	103	-
1986	14	25	38	55	66
<u>Androsace septentrionalis</u>					
1985	7	43	19	30	-
1986	8	7	10	12	0
<u>Draba incerta</u>					
1985	37	34	20	16	-
1986	5	5	9	3	141

Clearly, in windy alpine environments mulching is an essential component of the reclamation process, regardless of the severity of the disturbance. Pre-woven mulches or straw mulches sandwiched between two layers of a plastic netting minimize redistribution of straw fibers. The mulch selected must be staked firmly in place and be able to maintain its integrity under extremely windy conditions.

### SPECIES CHARACTERISTICS

Among the most important criteria for species selection is adaptability to site conditions. Alpine ecosystems have only a small pool of species, all of which are adapted to the low temperatures and generally low nutrient levels of the harsh environment (Muller 1952). All seeded species, except F. idahoensis, and many of the colonizer species studied, occur in varying relative importances in three of the four major vegetation types on the Beartooth Plateau; the only exception is bog vegetation on very wet soils (Johnson and Billings 1962). In the field study on the Beartooth Plateau, both seeded and colonizer species had generally low mortality on both the severe and less severe disturbance types indicating broad physiological tolerance ranges even as seedlings (Table 2). Despite this, distinct differences in species composition frequently exist between early and late seral stages (Willard and Marr 1971). Results of this and other studies show that alpine species differ significantly in their physiological and life history traits, including seed morphology, viability, and germination characteristics, growth responses, and survivorship. The traits exhibited by different alpine species can frequently be categorized as typical of early or late seral species (see Grime 1979, Chapin 1980).

A profile of some of the life history and physiological traits of the alpine species found on the Beartooth Plateau, Montana is presented in Table 4. In more temperate ecosystems, species typical of early succession have small, long-lived seeds that are easily dispersed, while species from late successional areas have large, short-lived seeds that are not readily dispersed (Harper et al. 1970, Grime 1979). In addition, early successional species tend to have high growth rates and low root:plant ratios. In contrast late successional species have low growth rates and high root:plant ratios (Chapin 1980). The characteristics of the alpine species studied help to explain their natural distributions (Chambers 1988). Geum rossii is the dominant in late seral Geum turf vegetation, but is also a colonizer on weathered porphyry intrusions or wind-eroded areas characterized by gravel mulch. Entrapment of its large seeds in soils with large particle sizes and its slow growth in a nutrient-deficient environment may enable it to colonize sites with gravel surfaces. Festuca idahoensis and Artemisia scopulorum are abundant in late seral Geum turf vegetation and are infrequent colonizers. The large seeds of F. idahoensis have no apparent dormancy mechanisms (Chambers et al. 1987a), a characteristic typical of late seral dominants (Harper et al. 1970). A. scopulorum has small but short-lived seeds (Chambers 1988). Seedlings of this species have a long tap root with few adventitious roots and are highly susceptible to removal by wind. Its establishment is benefited by physical barriers to

Table 4. Profile of life history and physiological traits of alpine species from the Beartooth Plateau, Montana.

Species	Seed characteristics			Growth responses		
	Length (mm)	Weight (g)	Longevity	Dispersal capability	Growth rate	Root:plant ratio
Seeded species						
<u>Geum rossii</u>	8.9	0.164	short	poor	low	high
<u>Artemisia scopulorum</u>	1.8	0.032	short	fair	low	high
<u>Festuca idahoensis</u>	9.7	0.091	int.	poor	high	low
<u>Potentilla diversifolia</u>	1.5	0.065	int.	good	int.	int.
<u>Sibbaldia procumbens</u>	1.5	0.053	long	good	high	low
<u>Deschampsia cespitosa</u>	4.7	0.034	long	good	high	low
Colonizer species						
<u>Cerastium arvense</u>	0.8	0.018	-	excellent	-	-
<u>Draba crassifolia</u>	1.2	0.023	-	excellent	-	-
<u>Arenaria obtusiloba</u>	0.8	0.003	-	excellent	-	-
<u>Androsace septentrionalis</u>	1.4	0.035	-	excellent	-	-



wind. Deschampsia cespitosa, Potentilla diversifolia, and Sibbaldia procumbens colonize a wide range of disturbance types and are also present in late seral areas. Despite this, their widespread occurrence on disturbed areas on the Beartooth Plateau indicates high rates of dispersal (Chambers et al. 1984). High growth rates or low root:plant ratios observed for these species typify the responses of early seral species. The colonizer species exhibit many traits typical of early successional species, such as small plant size, early reproduction, and small, readily dispersed seeds. Differences in the physiological and life history traits of alpine plant species have implications not only for species selection, but also for seed collection and storage and seeding methods and rates.

### Seed Viability and Longevity

Due to the severe and unpredictable nature of the environment, the quantity and quality of seeds produced by tundra species varies both temporally and spatially (Bliss 1956, Billings 1974). To examine the nature of the variability among and within years for seeds of the same alpine species used in the field experiment, seed fill of the grasses and seed viability and longevity (survival of a seed population over time) of grasses and forbs were examined for seeds collected in 1983, 1984, 1985, and 1986 on the Beartooth Plateau (Chambers 1988). As expected, seed fill for grass species and the seed viability of both grass and forb species differed significantly among years (Fig. 3). These differences can be attributed to variability in weather conditions. Detailed weather measurements taken on the Beartooth Plateau in 1984 and 1985 at the seed collection areas showed large differences in the date of snow melt (3 wk), timing and amount of precipitation, and ambient and soil temperatures (Chambers 1987). Large differences in seed viability existed among species within most years (Fig. 3). In general, grass species had lower and more variable seed viability than forb species. Years with low seed viability coincided with low seed-fill years for the grass species, indicating poor seed development. Longevity of seeds collected in 1983 varied among species and was related to seed characteristics and the life history and physiological traits of individual species (Table 5). Seed longevity of species with life history and physiological traits typical of late seral species was shorter than that of species with traits typical of early species.

The variability in seed viability and longevity of alpine species among and within years has several implications for reclamation of disturbed alpine ecosystems. It is always desirable to determine the viability of the seed lot. This permits calculation of seeding rates based upon the seed viability of individual species, which ensures that success or failure of individual species will not be attributed to the wrong cause when low seed viability is the problem. Because production of mature and viable seed varies not only among years but also among species within any given year, seed collection must be opportunistic to take advantage of good seed production years for different species. It may be necessary to harvest seeds one to several years before reclamation of a disturbed area to obtain an adequate supply of the desired species. If seeds are harvested in advance, careful monitoring

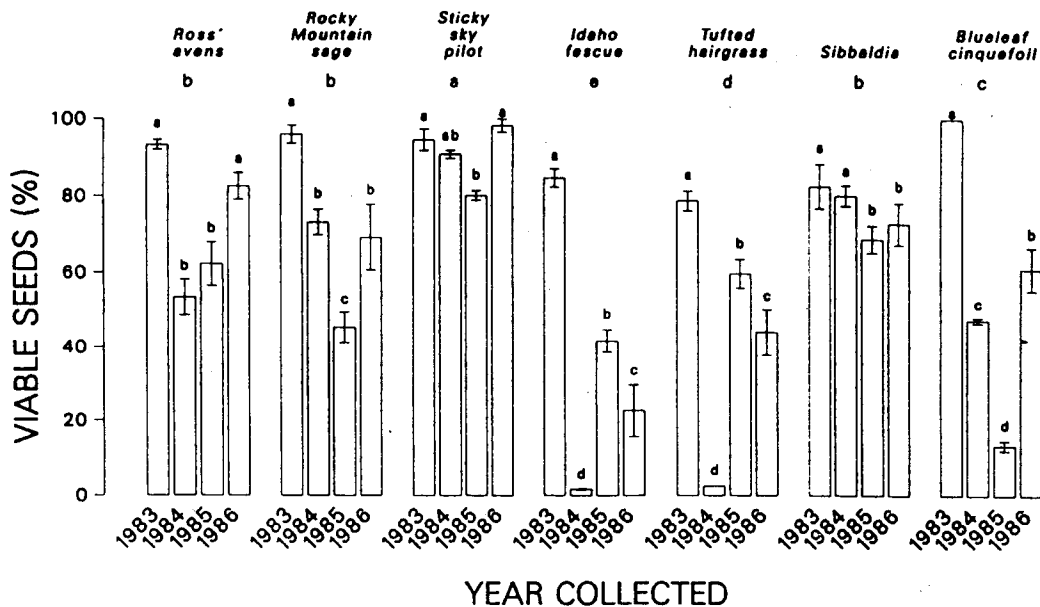


Fig. 3. Viability of seeds of alpine species collected during 4 consecutive years on the Beartooth Plateau, Montana, and tested for viability the year of collection. Values are means and error bars represent  $\pm 1$  S.E. Unlike letters indicate significant differences in average seed viability among species and among species within years for the first and second rows of letters, respectively ( $P < .05$ ).

Table 5. Change in percent viability for seeds of alpine species collected on the Beartooth Plateau, Montana and stored for four years at  $1-2^{\circ}$  C and 70-85% relative humidity. Unlike letters indicate significant differences (Fisher's Protected LSD,  $P < .05$ ).

Species	Change in viability (mean $\pm$ S.E.)
<u>Geum rossii</u>	81.3 $\pm$ 6.1 e
<u>Artemisia scopulorum</u>	66.7 $\pm$ 5.2 de
<u>Polemonium viscosum</u>	9.7 $\pm$ 2.5 a
<u>Festuca idahoensis</u>	52.9 $\pm$ 2.3 bcd
<u>Calamagrostis purperascens</u>	41.3 $\pm$ 1.8 b
<u>Deschampsia cespitosa</u>	44.6 $\pm$ 5.7 bc
<u>Sibbaldia procumbens</u>	49.4 $\pm$ 8.7 bc
<u>Potentilla diversifolia</u>	58.7 $\pm$ 9.3 cd

of storage conditions is required, as well as longevity of seeds in storage. Moisture content of the seeds and storage temperature are important determinants of longevity of seeds in storage (Copeland and McDonald 1985, Young and Young 1986). Storage conditions that maximize longevity of crop seeds (1-5°C and seed moisture contents of 5-14%) may not be ideal for alpine species. Storing seeds of alpine species at -18°C and low seed moisture contents may increase their longevity (Billings and Mooney 1968).

### Seed Germination

Knowledge of the seed germination characteristics of individual species is necessary to determine successful seeding methods. The germination responses of the same species used in the field study to light or dark conditions and dry or wet cold storage (stratification) were examined in a controlled laboratory study (Chambers et al. 1987a). Seed germination of the forb species was generally greater under light than dark conditions and following wet cold storage (Fig. 4). The grass species had less specific germination requirements than the forbs (they showed less response to the treatments). Wet cold storage increased the rate of germination of both grasses and forbs.

The fact that light enhances seed germination of the majority of the forb species indicates that these species should be sown close to the soil surface. The less specific germination requirements of the grasses indicate that adequate field germination could be obtained either by sowing close to the soil surface or shallow drilling. The increase in the rate of seed germination of all of the species following wet cold storage indicates that natural stratification can decrease the number of days required for germination and, consequently, can increase the likelihood of plant establishment. Autumn seeding maximizes the opportunity for natural stratification to occur.

### Nutrient Responses

Fertilization is a common practice in the revegetation of disturbed alpine ecosystems (Brown and Johnston 1979), yet little is known about growth responses or nutrient uptake characteristics of individual alpine species under varying levels of N and P availability. Species responses to N and P can vary greatly and often depend on the levels of these nutrients in their native environment. Availability of nutrients, especially N, and nutrient retention capacities on disturbed areas are often determined by the severity of the disturbance (Tilman 1982).

We examined the growth responses and nutrient uptake characteristics of two species that differ widely in their physiological and life history traits, *G. rossii*, a forb, and *D. cespitosa*, a grass. A complete factorial greenhouse experiment was used with four levels of N (4.2, 38.8, 73.3, and 107.6 mg/kg, NO<sub>3</sub>-N plus NH<sub>4</sub>-N) and four levels of P (6.7, 39.5, 72.4, and 105.0 mg/kg, PO<sub>4</sub>-P). *G. rossii* responded like a species from a low nutrient environment, exhibiting a much lower growth rate and generally higher root:shoot ratio than *D. cespitosa* (Fig. 5).

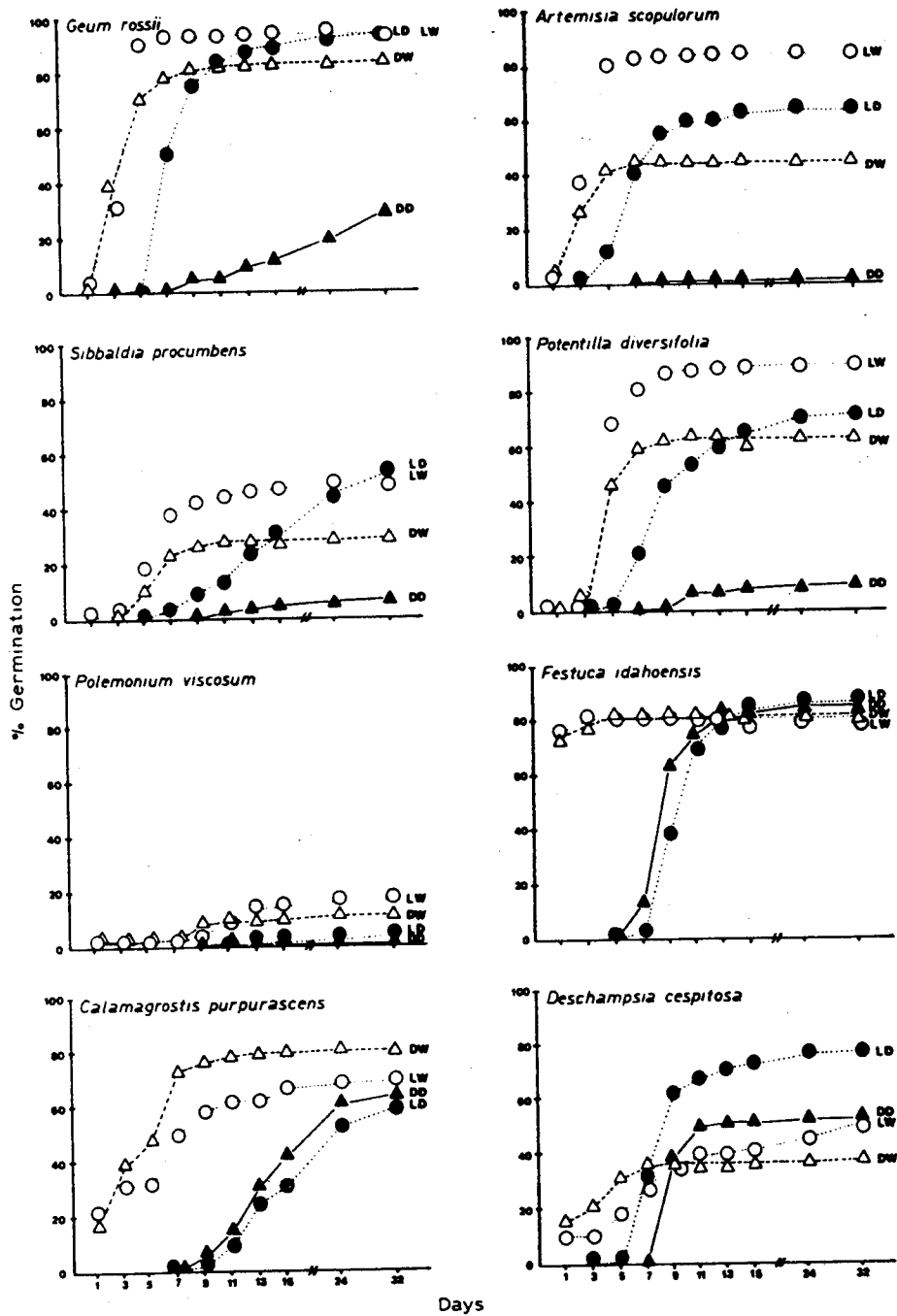


Fig. 4. Germination response (total germination percentage) of early and late seral dominant alpine forbs and grasses over a 32-day period under light (L) or dark (D) conditions following wet (W) or dry (D) cold storage: LW, light/wet; LD, light/dry; DW, dark/wet; DD, dark/dry (from Chambers et al. 1987a).

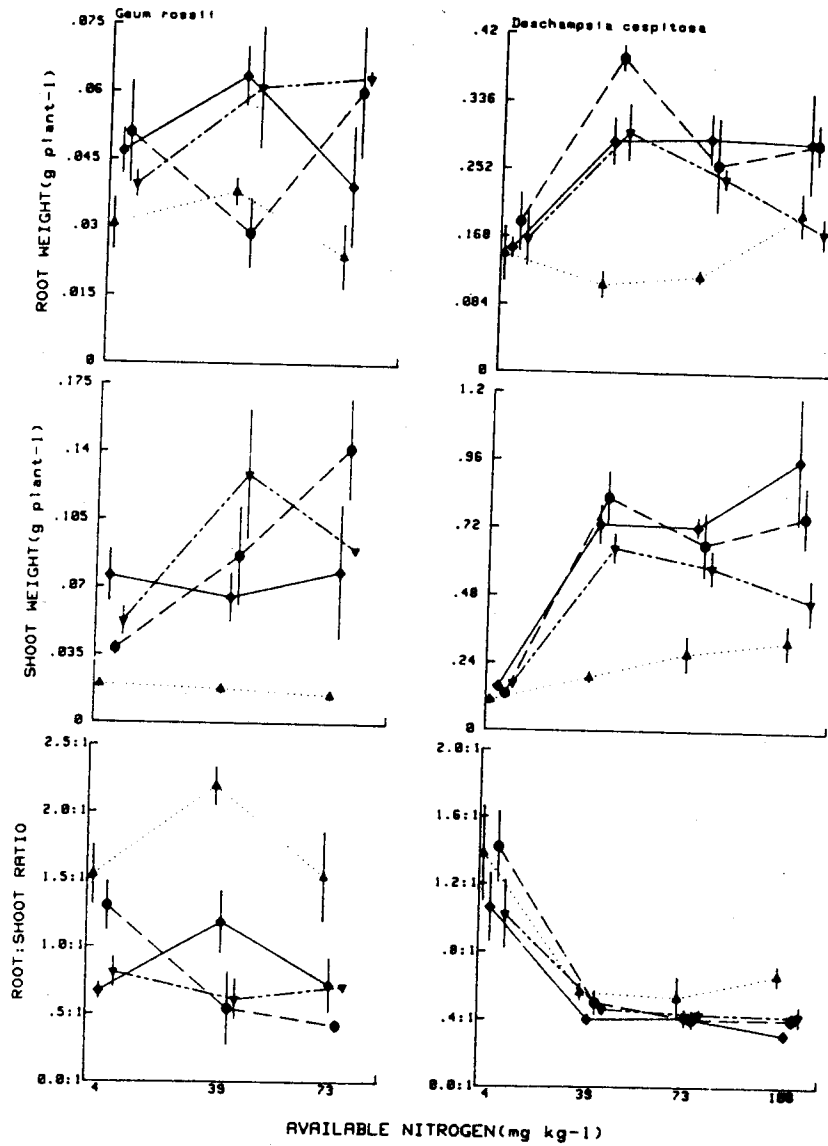


Fig. 5. Mean shoot and root weights and R:S ratios of *G. rossii* and *D. cespitosa* seedlings grown for 8 weeks in a factorial experiment at four levels of available N ( $\text{NH}_4^+$  plus  $\text{NO}_3^-$ ) and P ( $\text{PO}_4^{2-}$ ). Levels of P = 6.7 (▲), 39.5 (◆), 72.4 (●) and 105.0 (▼) mg/kg (from Chambers et al. 1987b)

Similar results were later observed in the field experiment on the Beartooth Plateau. In the greenhouse study, D. cespitosa showed a greater response to N, while G. rossii was more sensitive to P. Soils from late-successional alpine areas in the Beartooth Mountains have five to ten times more P than paired early seres, but only 1.5 times the available N ( $\text{NO}_3\text{-N} + \text{NO}_4\text{-N}$ ) (Chambers et al. 1987c). D. cespitosa had greater rates of growth than G. rossii at all levels of N and P, suggesting competitive superiority over a wide range of N and P concentrations. However, a higher sensitivity of G. rossii to levels of P and the dominance of G. rossii in late seral Geum turf vegetation indicates that factors other than fertility and growth rate are affecting the outcome of interactions between these two species.

Low growth rates and high root:shoot ratios are important attributes of species adapted to low nutrient conditions (Chapin 1980). However, the effect of low growth rates in increasing survival may only be detectable under low nutrient conditions (Clarkson 1967). Including species that are adapted to low nutrient conditions and that have low growth rates can help to ensure the long-term stability of nonintensively managed reclaimed areas.

Species with high growth rates may be competitively superior to species with low growth rates over a range of soil nutrient conditions (e.g., Tilman 1986). High rates of fertilization or repeated fertilization can increase the competitive ability of species with high growth rates. To allow species with both high and low growth rates to establish on the same area, it is necessary to use moderate seeding rates and to seed species with low growth rates at densities equal to or greater than those with high growth rates. In addition, moderate amounts of fertilizer should be used.

#### RESEARCH NEEDS

Results of these studies suggest fruitful avenues for further reclamation research in disturbed alpine ecosystems. Additional information is required on the effects of reclamation methods, including soil amendments and species selection, on nutrient retention and cycling in disturbed alpine ecosystems. This information should be correlated with data on soil weathering processes. Also, a more detailed understanding of the life history and physiological traits of promising reclamation species is needed. This research should include species that are frequent colonizers on disturbed lands and species that are most abundant in late seral areas. Particular attention should be given to species nutrient response characteristics and long-term interactions. In addition, more information about characteristics of species with nitrogen-fixing symbionts is needed.

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**ADVANCES IN PLANT MATERIAL AND  
REVEGETATION TECHNOLOGY IN ALASKA**

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**ABSTRACT**

The construction of the Trans Alaska Pipeline triggered the current research activity in reclamation for Alaska. However, since the pipeline, ideas associated with revegetation have changed. Continued oil development, renewed interest in surface and placer mining, as well as new federal, state and local regulations have caused applied research activities to address 'reclamation' as defined by regulations, which in some cases has precluded the use of "traditional" plant material and planting technology.

The Alaska Plant Materials Center continues to lead in applied research for cost-effective technology for use in reclamation and erosion control. Extending planting seasons through the use of dormant seedings, cost-effective and successful methods in willow planting, wetland and coastal restoration, are all priorities for the Plant Materials Center.

This paper outlines the present state of applied reclamation research being conducted by the Plant Materials Center. The paper will also present an overview based on 149 plot years of data on reclamation and erosion control species adapted to various regions of Alaska.

**PREFACE**

This paper will present a great deal of information in a small amount of space. It is a composite of individual reports available from the Alaska Plant Materials Center on request. The intent of the paper is to present the state of the Alaska Plant Materials Center's reclamation and revegetation research. This paper provides a general introduction to the Alaska Plant Materials Center and the methods employed to conduct the research. The paper will present general revegetation recommendations and techniques in willow planting, wetland restoration, and coastal revegetation.

## INTRODUCTION

The Alaska Plant Materials Center (PMC) is a section of the Division of Agriculture within the Department of Natural Resources. In contrast to other PMCs, the Alaska center is fully state funded. The remainder of the centers in the United States are basically federally funded. Early attempts in establishing a federal Plant Materials Center in Alaska failed. The U.S. Department of Agriculture maintained that the centers at Pullman, Washington and Corvallis, Oregon could service the needs of Alaska.

Not to be discouraged by the lack of federal interest, the Alaska Legislature, at the urging of the University of Alaska, conservation groups, and farmers, prepared legislation for the establishment of the Alaska Plant Material Center. In 1972, Governor William Egan signed into law a bill creating the Alaska Plant Material Center. This legislation directed the Plant Materials Center to fulfill several more traditional agricultural responsibilities, and to develop plant varieties and techniques for revegetation and erosion control, and provide technical assistance to industry in the field of reclamation.

Following enactment, 285 acres were selected near Palmer for the Plant Materials Center. An additional 120 acres were acquired through a land exchange with the Matanuska-Susitna Borough in 1982. This gave the PMC 405 acres to accomplish its mandated duties, which not only includes revegetation oriented work, but also horticultural development, foundation seed production, and disease-free potato seed stock production.

In the spring of 1979, the Conservation Plant Project was established with one full time agronomist, and in 1982 a second agronomist was added. In 1987, the Conservation Plant Project was combined with the Foundation Seed Project to form the North Latitude Revegetation and Seed Project.

## Methods

Since the establishment of the Alaska Plant Materials Center (PMC) in 1972, native and introduced plants have been screened and evaluated for conservation uses.

The PMC follows seven basic steps to establish a resource of conservation plants for use in land reclamation, wildlife habitat improvement and erosion control. They are: 1) Define and anticipate conservation problems and establish priorities; 2) research and assemble candidate plant materials; 3) conduct initial evaluations; 4) establish small scale seed or vegetative increases; 5) advanced and final testing and field evaluation plantings; 6) establish large scale seed or vegetative increases; and, 7) release of a variety or cultivar.

The following describes each step in the evaluation process:

1. DEFINE AND ANTICIPATE CONSERVATION PROBLEMS AND ESTABLISH PRIORITIES.

The PMC anticipates plant materials needs in Alaska by becoming familiar with the regulations and laws regarding development and reclamation. The PMC also contacts regulatory agencies, land and resource management agencies, developers, and private groups for their input. For example, the Alaska Department of Fish and Game suggested that the PMC evaluate sedges, arrow grass (Triglochin maritimum), and Plantain (Plantago sp.) for waterfowl habitat improvement.

2. RESEARCH AND ASSEMBLE CANDIDATE PLANT MATERIALS.

Once a species has been identified for evaluation, the search for seed or vegetative materials begins. The plant material may be collected by PMC staff, interested parties, or the PMC may request plant material from the National Plant Materials Center, Regional Plant Introduction Centers, universities, agricultural experiment stations, and foreign countries.

3. INITIAL EVALUATION.

When the Center receives an adequate number of accessions of a species, preferably 20 to 40, initial evaluation plots are established. For herbaceous material, these plots are single row plantings, 20 feet in length for each accession, with usually 3 feet between accessions.

For woody material, the spacing is 8 to 10 feet between plants, 20 feet between rows and each row usually contains 10 plants.

The plots of herbaceous perennials are established and maintained for the seedling year plus three full years. Woody evaluations are set up for a minimum of 10 years. Annual and biennial species, as their name implies, are maintained for one and two years, respectively.

The evaluation process involves rating each accession against a "standard" if one is available. A standard is the best available variety of the species for Alaska. For instance, if Red fescue (*Festuca rubra*) were being evaluated, variety 'Arctared' would be used as the standard of comparison. See Figure 1 for list of standards. If no standard exists, comparisons are made against the best accession of the species tested in the past, or all the accessions of the species are rated against each other. A listing of accessions selected for advanced testing based on performances can be seen on Figure 2.

The rating systems can be tailored to the plant's intended use, or toward a specific characteristic. All evaluations rate: hardiness, vigor, seed production, and adaptation. Additional ratings can include attractiveness, leaf or flower color, and wildlife preference or palatability.

The total number of accessions under evaluation each year varies. From 1974 to date, in excess of 2,600 accessions have been evaluated.

#### 4. SMALL-SCALE INCREASE.

When an accession under initial evaluation has exhibited superior qualities, seed or vegetative cuttings are collected and planted to produce the additional stock needed for further testing. Figure 3 shows the number of accessions selected for increase and advanced evaluation.

#### 5. ADVANCED TESTING AND FIELD EVALUATION PLANTINGS.

This aspect of the program allows plant material to be evaluated in a wide range of edaphic and climatic conditions. See Figures 4 and 5 for location of test sites and typical plot layout. Some important species that may have failed at Palmer can thrive at other locations, and these plots provide the opportunity to evaluate the accessions' performance elsewhere. Basically, this phase revolves around two classes of plantings: 1) advanced evaluation and demonstration plots, and 2) mining and industrial evaluation plots.

## Standards Of Comparison

<b>Kentucky Bluegrass</b>	<b>Brome</b>
<p style="margin: 0;">‘Nugget’ ‘Merion’ ‘Banff’ ‘Park’  ‘Sydsport’ ‘Fylking’ ‘Troy’</p>	<p style="margin: 0;">‘Polar’ ‘Manchar’ ‘Carlton’</p>
<b>Miscellaneous Grasses</b>	
<p style="text-align: center; margin: 0;"><b>Other Bluegrasses</b></p>	<p style="margin: 0;">‘Engmo’      Timothy ‘Climax’ ‘Norcoast’      Bering Hairgrass ‘Sourdough’      Bluejoint — Meadow Foxtail — ‘Garrison’      Creeping Foxtail ‘Alyeska’      Polar Grass</p>
<p style="margin: 0;">‘Sherman’      Big Bluegrass ‘Canbar’      Canby Bluegrass ‘Rubans’      Canada Bluegrass ‘Tundra’      Glaucous Bluegrass</p>	<p style="text-align: center; margin: 0;"><b>Fescues</b></p>
<p style="text-align: center; margin: 0;"><b>Wheatgrasses</b></p>	<p style="margin: 0;">‘Arctared’      Red Fescue ‘Boreal’      Red Fescue ‘Pennlawn’      Red Fescue ‘Highlight’      Sheep Fescue ‘Covar’      Sheep Fescue ‘Durar’      Hard Fescue</p>
<p style="margin: 0;">‘Sodar’      Streambank Wheatgrass ‘Nordan’      Crested Wheatgrass ‘Fairway’      Crested Wheatgrass ‘Summit’      Crested Wheatgrass ‘Critana’      Thickspike Wheatgrass</p>	

FIGURE 1

**Advance Test Species  
Selected In 1981**

<u>Species</u>	<u>Common Name</u>	<u>Native Introduced</u>	<u>Source</u>	<u>Potential Use*</u>
<i>Agropyron subsecundum</i>	Bearded Wheatgrass	N	Canada	FOR RVG (D)
<i>A. subsecundum</i>	Bearded Wheatgrass	N	Alaska	FOR RVG (D)
<i>A. violaceum</i>	Violet Wheatgrass	N	Alaska	RVG REC (D)
<i>A. pectiniforme</i>	Crested Wheatgrass	I	USSR	FOR
<i>A. boreal</i>	Boreal Wheatgrass	N	Alaska	RVG
<i>A. yukonense</i>	Yukon Wheatgrass	N	Alaska	EC REC
<i>Alopecurus geniculatus</i>	Water Foxtail	I	USSR	RVG (W)
<i>Artemisia tilesii</i>	Tilesy Sage	N	Alaska	EC HAB
<i>Beckmannia syzigachne</i>	Sloughgrass	N	Alaska	REC HAB (W) FOR
<i>Calamagrostis canadensis</i>	Bluejoint	N	Alaska	REC HAB FOR
<i>Calamagrostis inexpansa</i>	Northern Reedgrass	N	Canada	RVG
<i>Deschampsia caespitosa</i>	Tufted Hairgrass	N	Alaska	EC REC (D) FOR
<i>Elymus arenarius</i>	Beach Wildrye	N	Norway	EC SP FOR REC
<i>E. sibiricus</i>	Siberian Wildrye	N?	USSR	FOR EC RVG REC? (D)
<i>Festuca ovina</i>	Sheep Fescue	I	USSR	RVG LDS
<i>F. rubra</i>	Red Fescue	N	USSR	RVG EC LDS
<i>F. scabrella</i>	Rough Fescue	I	Canada	RVG (D)
<i>Poa angustifolia</i>	Bluegrass	I	France	RVG (W)
<i>P. ampla</i>	Big Bluegrass	I	Canada	RVG LDS FOR
<i>P. alpina</i>	Alpine Bluegrass	N	Alaska	REC
<i>P. glauca</i>	Glaucous Bluegrass	N	Denmark	REC

\* Key To Potential Uses

(D) - Dryland Use  
(W) - Wetland Use  
EC - Erosion Control  
FOR - Forage  
HAB - Habitat Enhancement

LDS - Landscape  
RED - Reclamation  
RVG - Revegetation  
SP - Shore Protection

FIGURE 2

Number of Accessions Selected for Increase and Advanced Evaluation

Plot	Number of Accessions Planted	Number Selected for Increase	Number Planted in Advance Test Plots
1979 grass plot	481	15	8
1979 forb plot	173	1	0
1980 grass plot	220	7	3
1980 forb plot	420	0	0
1982 grass plot	28	0	0
1982 forb plot	94	2	0
1983 grass plot	13	1	0
1983 forb plot	149	0	0
1983 wetland plot	111	1	0
1984 wetland plot	230	7	7
Woody plot <sup>1</sup>	402	7	7

<sup>1</sup> The numbers for this plot include all woody species evaluated since 1975.

Figure 3.



Advanced Evaluation and Demonstration Plots (AEDP) are established throughout Alaska for three purposes. The first is the advanced or final evaluation of plant materials that have performed well at the Palmer PMC for a period of at least three years. This offsite evaluation is important so that a plant's adaptability and range of suitability can be determined.

The second purpose is for demonstration plantings of plant material already recommended for the area. These recommendations are taken from The Revegetative Guide for Alaska. These plantings allow local people to view the varieties and allows for changes to be made in the Guide, if necessary.

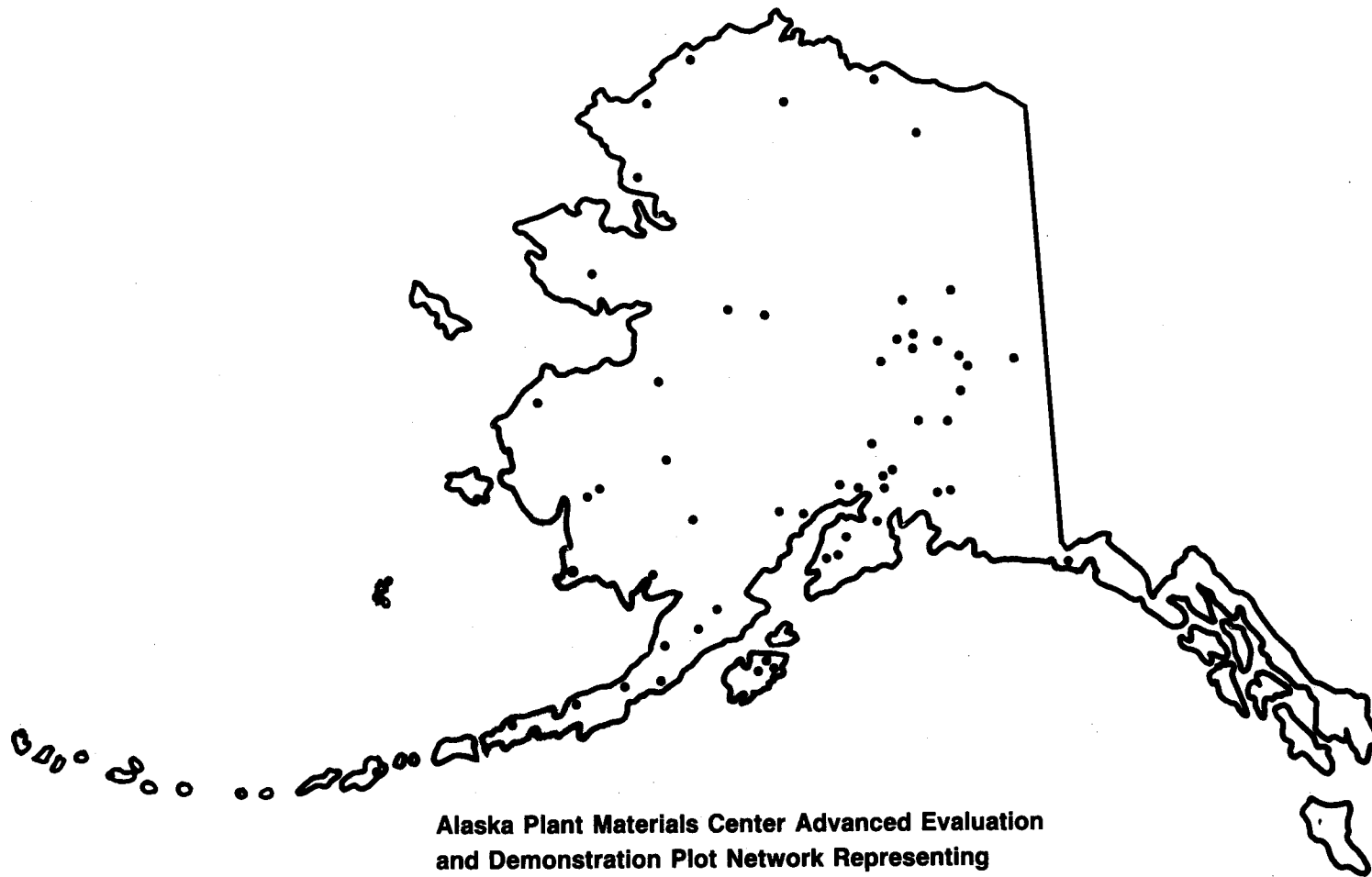
The third reason for AEDP is to provide a centralized area for local plantings by the cooperative Extension agents and other cooperators. This allows the agent to tailor the plot to local interests. The plots also give the agent a "classroom" where specific plant materials may be viewed and worked with by local farmers, students, and other groups interested in farming or gardening.

Mining and Industrial Evaluation Plots (MIEP) are usually designed for reclamation and/or erosion control and are located in diverse geographical and ecological locations. The plots are developed in a manner consistent with the clients intended final management practice, i.e., "fertilize it once and forget about it." The practice of minimal maintenance is generally necessary for industry to eliminate costly yearly maintenance programs. Therefore, the plots are established with minimal surface preparation and are only fertilized at the time of planting. The plantings are then evaluated for their ability to survive on these harsh sites with no maintenance, Topsoil is not used, and the plantings are made on the substrate that is expected to be available when reclamation occurs.

The MIEP also serves as an advanced evaluation of plant materials that have been selected at the PMC for their outstanding performance. In addition, the program also evaluates new techniques of planting and maintenance which could make the entire reclamation or erosion control process more cost effective.

The cooperator is allowed to set some of the parameters in the testing procedures, so that the test will provide useful data for the client's particular conditions. These plots also allow the PMC to make meaningful recommendations when similar conditions are encountered by someone other than the original client.

This class of evaluation plots probably provides the most important and useful information to the North Latitude Revegetation and Seed Project.



**Alaska Plant Materials Center Advanced Evaluation  
and Demonstration Plot Network Representing  
149 Plot Years as of 1987**

FIGURE 4

### Typical Plot Layout

<b>Nugget Kentucky Bluegrass</b>	<b>Merion Kentucky Bluegrass</b>
<b>Park Kentucky Bluegrass</b>	<b>Banff Kentucky Bluegrass</b>
<b>Sydsport Kentucky Bluegrass</b>	<b>Fylking Kentucky Bluegrass</b>
<b>Poa Ampla</b>	<b>Troy Kentucky Bluegrass</b>
<b>Sherman Big Bluegrass</b>	<b>Canbar Canby Bluegrass</b>
<b>Tundra Bluegrass</b>	<b>Reubans Canada Bluegrass</b>
<b>Poa Glauca T08867</b>	<b>Poa Alpina</b>
<b>Agropyron Subsecundum 371698</b>	<b>Sodar Streambank Wheatgrass</b>
<b>Nordan Crested Wheatgrass</b>	<b>Agropyron Subsecundum</b>
<b>Fairway Crested Wheatgrass</b>	<b>Agropyron Violaceum</b>
<b>Summit Crested Wheatgrass</b>	<b>Agropyron Boreal</b>
<b>Critana Thickspike Wheatgrass</b>	<b>Agropyron Yukonese</b>
<b>Fults Alkaligrass</b>	<b>Vantage Reed Canarygrass</b>
<b>Climax Timothy</b>	<b>Engmo Timothy</b>
<b>Elymus Arenarius</b>	<b>Elymus Sibiricus 34560</b>
<b>Elymus Sibiricus 1966</b>	<b>Elymus Sibiricus 2144</b>
<b>Norcoast Bering Hairgrass</b>	<b>Tufted Hairgrass</b>
<b>Sourdough Bluejoint</b>	<b>Calamagrostis Canadensis</b>
<b>Meadow Foxtail</b>	<b>Alopecurus Genuiculatus</b>
<b>Garrison Creeping Foxtail</b>	<b>Arctared Red Fescue</b>
<b>Boreal Red Fescue</b>	<b>Festuca Scabrella</b>
<b>Beckmannia</b>	<b>Pennlawn Red Fescue</b>
<b>Durar Hard Fescue</b>	<b>Highlight Red Fescue</b>
<b>Covar Sheep Fescue</b>	<b>Manchar Smooth Brome</b>
<b>Alyeska</b>	<b>Carlton Smooth Brome</b>
<b>Tilesy Sage</b>	<b>Polar Brome</b>

FIGURE 5

6. LARGE-SCALE INCREASE.

Plant material will be grown from breeder blocks established and maintained at the PMC for foundation level production. The progeny from foundation production will be made available to private growers for further increase and distribution.

7. CULTIVAR RELEASE.

When an accession has proven to be superior through the evaluation process, and specific cultural and management techniques have been developed, the accession is released.

If it is agreed that the accession is superior and a need exists for the material, the accession is named, released, and promoted. All releases by the Alaska Plant Materials Center have been a cooperative effort with the Soil Conservation Service, USDA. Other agencies are invited to join in releases if they have interests in the species or intended uses.

**RESULTS: RELEASES, RECOMMENDATIONS AND TECHNOLOGY ADVANCES**

**New Releases**

The evaluation network established by the Alaska Plant Materials Center and the data collected from these plots has resulted in the release of two new grass cultivars and five willow cultivars. Within three years, an additional four grasses and one willow may be released.

From 1985 to date, the following cultivars have been released by the Alaska Plant Materials Center:

- |                                  |                              |
|----------------------------------|------------------------------|
| 1. 'Egan' American Sloughgrass   | <u>Beckmannia syzigachne</u> |
| 2. 'Gruening' Alpine Bluegrass   | <u>Poa alpina</u>            |
| 3. 'Roland' Pacific willow       | <u>Salix lasiandra</u>       |
| 4. 'Wilson' Bebb willow          | <u>Salix bebbiana</u>        |
| 5. 'Long' Barclay willow         | <u>Salix barclayi</u>        |
| 6. 'Oliver' Barren Ground willow | <u>Salix brachycarpa</u>     |
| 7. 'Rhode' Feltleaf willow       | <u>Salix alaxensis</u>       |

The following narratives describe each cultivar.

**'Egan' American Sloughgrass:** Beckmannia syzigachne is generally described as a light green grass with tufted culms native to cooler regions of North America. This species, which is usually associated with wet ground, can grow to 90 cm in height.

Many North American descriptions of American Sloughgrass, classify it as an annual. This has not, however, been the experience of the Alaska Plant Materials Center staff or other investigators working with the species in Alaska. The staff has found that 'Egan' American Sloughgrass, as well as the other accessions of Beckmannia syzigachne that have been tested, are short-lived perennials. Stands tend to decline after four to five years, and stand decline can be hastened by competition when more aggressive grass species become established in a Beckmannia stand.

'Egan' American Sloughgrass was tested in three initial screening trials at the Plant Materials Center at Palmer from 1974 to 1983. Additional offsite testing started in 1980, and to date, 'Egan' has been or is being tested at 26 sites in Alaska and the Yukon Territories of Canada.

Original seed increase occurred in 1979 and again in 1981. A one-acre increase plot was established in 1983.

Much has been written about the species' value as forage both in North America and Eurasia, but this application is, by law, not a priority for the Plant Materials Center. Seed of this accession has been supplied to interested farmers in Alaska, as well as the University of Alaska Agricultural and Forestry Experiment Station and South Dakota State University for forage research.

'Egan' American Sloughgrass is recommended for reclamation or erosion control plantings in seasonally wet areas such as ditches, streambanks, or fresh water shorelines. Because of the species' documented use by waterfowl, it is also recommended for plantings intended to benefit ducks and geese.

Based on offsite evaluations, species characteristics, and the natural range of the species, 'Egan' American Sloughgrass can be expected to perform satisfactorily between 60° north latitude, and the Arctic Circle. Evaluation is not complete beyond this region. Its value in Southeast Alaska has not yet been determined, and it has been found not to survive on Kodiak Island or the Aleutian Chain.

Although 'Egan' American Sloughgrass is less susceptible to seed shatter than any other accession of Beckmannia that were tested, seed shatter remains a moderate problem. In general, seed production, harvesting and cleaning of 'Egan' is easier than some native grasses in production at this time. Harvesting and cleaning can be accomplished with standard equipment.

Yields of clean seed off a one-acre plot are as follows: 1984 - 453 pounds, 1985 - 305 pounds. The lower yields from the 1985 crop resulted from shatter caused by a severe wind prior to harvest. Seed has generally been ready for harvest during the second or third week in August.

Because this species is most highly adapted to wet sites, seed production will be restricted to certified seed growers having the ability to irrigate production fields (Hulten 1968, Walsh 1974, Wright 1986a).

**'Gruening' Alpine Bluegrass:** *Poa alpina* is generally described as a perennial bunch grass that is native to arctic and boreal regions throughout most of Alaska with the exception of the Aleutian Islands and the southern portion of Southeast Alaska. Within North America, the species can be found from Alaska eastward throughout arctic and boreal Canada, and south to Quebec and northern Michigan. Further southern extension occurs in North America into Colorado and Utah at high elevations of the Continental Divide. Similar latitudinal and elevation extensions occur in Europe and Asia for this circumpolar species.

This non-rhizomatous species usually grows to a height of 10-40 centimeters with stout leaves 2-5 millimeters wide. This species forms a noticeable thatch of leaves from previous years' growth.

'Gruening' Alpine Bluegrass has been tested at the Alaska Plant Materials Center at Palmer since 1979. This accession has outperformed 24 other accessions of *Poa alpina* in all aspects, while under initial evaluation from 1979 through 1983.

Off-site evaluation began in 1983 at 18 sites throughout Alaska. Original seed increase occurred in 1981, and again in 1983 and 1984. In 1985, a quarter acre planting was established. The first harvest from this plot occurred on July 7, 1986.

It is doubtful that this cultivar will have any value as an agricultural forage crop, although literature states that alpine bluegrass has been and is being used as a high elevation meadow forage by domestic livestock in North America and Europe.

Both the initial evaluation at Palmer and the off-site evaluations at other areas in Alaska, indicate that 'Gruening' Alpine Bluegrass will be used mainly for erosion control and reclamation ranging from streambanks to gravelly alpine sites. It is expected that this cultivar will replace a portion of the Kentucky Bluegrasses presently used for reclamation in some areas of Alaska. The low-growing nature and adaptation to gravelly sites indicate that this cultivar will also have use in highway revegetation where mowing becomes a concern.

Based on off-site evaluations, species characteristics, and the natural range of the species, 'Gruening' Alpine Bluegrass can be expected to perform satisfactorily from 60° north latitude to beyond the Arctic Circle and to high elevation areas above the timberline, south to 57° north latitude.

Within its range of adaptation, 'Gruening' Alpine Bluegrass can be expected to perform well under a wide range of conditions. This species is often found in dry, gravelly, or rocky sites, but testing has shown that this cultivar will also perform well on wetter sites with silty soils.

In general, seed production and characteristics of 'Gruening' Alpine Bluegrass will be similar to 'Nugget' Kentucky Bluegrass. Yields can be expected to be approximately 200 pounds per acre. Shatter can be severe if fields are not harvested at the first indication of maturity.

A major advantage of 'Gruening' Alpine Bluegrass, is also a potentially serious management problem. Because the seed of this cultivar is mature in the last week of June or the first week in July, and inflorescences appear simultaneously with spring recovery in early May, weed control with herbicides will be difficult, if not impossible. This trait may require the use of mechanical weed control until seed is harvested (Hulten 1968, Walsh 1974, Wright 1986b).

**'Roland' Pacific willow:** Salix lasiandra (Benth.), is a riparian species that inhabits river banks, alluvial deposits and wet meadows in boreal regions of Central Alaska, and Southeastern Alaska from Glacier Bay to the northern end of Lynn Canal. It also occurs in the Yukon Territory and eastward to the forests of Saskatchewan, and southward in the cordillera to California and New Mexico (Argus 1973).

Pacific willow is a tall shrub or small tree with grayish bark, growing to a height of six meters. The twigs of this attractive tree are shiny and somewhat stout. Leaves are thick, lance-shaped, 5-12.5 cm long and 12-25 mm wide with a very long point and a round base. They are dark, shiny green above and paler beneath (Viereck 1972).

The variety 'Roland' originated from a collection of softwood cuttings taken from a single shrub located at mile 2.4 Clark Wolverine Road near Palmer, Alaska in May, 1974. It has been under continual evaluation at the Alaska Plant Materials Center at Palmer, as Accession No. L161 or T7554, since collection. Off-site testing is being conducted at Fairbanks, Delta, Kenny Lake, and various mine sites throughout Alaska.

During the ten years of evaluation at the Palmer Plant Materials Center, this collection has not shown any sign of winter damage, or insect infestation. Similar results are being observed elsewhere.

This willow is expected to be used primarily for streambank restoration and erosion control, and secondarily for mine restoration. 'Roland' Pacific willow also has a great deal of potential as a home or commercial landscape variety. The landscape industry may become an important outlet for this variety.

Predation by moose can be a serious concern when growing willow in Alaska, however, no browsing has been noticed on 'Roland' at the Palmer Plant Materials Center. This is not a guarantee that browsing will not occur elsewhere.

'Roland' Pacific willow production will only be permitted by vegetative methods. The variety roots readily in any moist to wet rooting medium. When propagation methods include bottom heat at 18° - 20° C (65° - 68° F) and intermittent mist, root success approaches 100% (Wright 1985).

**'Wilson' Bebb willow:** Salix bebbiana Sarg. ranges widely in boreal and temperate regions. It can be found in Central Alaska, Eastern Alaska Peninsula, and Kodiak Island, but is absent in Pacific Coastal Alaska from Prince William Sound to Southeastern Alaska. It is also found throughout the southern half of the Yukon Territory, and the Northwest Territories of Canada. The range continues south to Arizona and New Mexico, and eastward across the northern tier of the United States. In the eastern hemisphere, it ranges in Eurasia, from the Kola Peninsula to Chukotsk Peninsula. Within this range, Bebb willow is usually encountered in riparian or mixed upland forests. It may form pure stands in wet lowland areas, but it can also be found on dry south-facing slopes and disturbed areas (Argus 1973).

This accession has been selected after being tested at Palmer and elsewhere in Alaska. It has carried the accession number L143 and T7536.

The original cuttings required to start this accession, were collected from a single plant in May 1974, near the Bodenbug Butte, south of Palmer.

Bebb willow can be described as a large shrub or a small, bushy tree .5 to 10 meters high. The leaves may be elliptic and pointed at both ends, or broadly oblanceolate or obovate-oval. The leaves range from 2.5 to 9 cm long and 10 to 25 mm wide. The leaf margins lack serrations but can be wavy. The coloration of the leaves are dull green on top and gray underneath and are somewhat hairy on both sides. Slender yellowish to brown twigs branching at wide angles are characteristic of the species (Viereck 1972).



'Wilson' Bebb willow is a very dense, tall shrub making it ideal for windbreak and screening uses. If it is used in windbreak applications, 'Wilson' Bebb willow should be planted in multi-row, or multi-species arrangements. It is expected that 'Wilson' will be used for reclamation and restoration projects within the variety's range of adaptability. Bebb willow is listed as an important moose browse species in Interior Alaska. For this reason, 'Wilson' could be used for moose habitat enhancement.

'Wilson' Bebb willow propagation is restricted to vegetative methods. Bebb willow is more difficult to root than most other willows. In order to assure successful rooting, the best results have been obtained by using subsurface heat (70° to 75° F) in mist beds. A five second soak of Woods Rooting Compound (1.03IBA + .51 NAA) diluted with water 30:1 has provided the best results (Wright 1985).

**'Long' Barclay willow:** Salix barclayi Anderss., is found throughout southern coastal Alaska with the exception of the western Aleutian Islands. It's northern range extends to the Alaska Range and Tanana River. The eastern range runs through southern portions of the Yukon and Northwest Territories and continues south in the Rocky Mountains to British Columbia, Washington and Alberta (Argus 1973).

Within this range, Barclay willow can form large thickets along lake and river margins and on glacial moraines. It also inhabits sub-alpine and alpine slopes. It may occasionally be found in muskegs.

The accession was collected on May 28, 1974 at mile 1.9 Clark Wolverine Road near Palmer, Alaska. Hardwood cuttings were taken from a single plant growing on a disturbed roadside. The parent plant was heavily browsed by moose. The accession was assigned a local number of L171 and a national number of T07557.

'Long' has performed well at the Plant Materials Center, and has had no problems with disease or pests since planting in 1975.

Barclay willow is a large shrub that may take on tree-like appearances. This species is characterized by heavy, dense branching. Typically, it grows to two meters in height, but shrubs have been found up to six meters tall. The leaves are broad, elliptical or ovate, ranging from 2-7.5 cm long and 1-3 cm wide. Leaf margins will vary from serrate to entire. The upper surfaces of the leaves are yellowish green, occasionally with short, red hairs on the mid rib. The lower surfaces are whitish. The mature twigs are reddish-brown and hairless (Viereck 1972).

'Long' Barclay willow should become an important reclamation and erosion control variety throughout Southcentral Alaska. The dense growth form of 'Long' Barclay willow is sufficient to merit its use as a windbreak or shelterbelt variety.

Propagation of 'Long' Barclay willow will be restricted to vegetative methods. The actual propagation of Barclay willow is easily accomplished by placing hardwood cuttings in any suitable rooting medium with intermittent mist. No additional propagation techniques are required (Wright 1985).

**'Oliver' Barren ground willow:** Salix brachycarpa Nutt. ssp. niphoclada (Rydb.) Argus, is found throughout central Alaska, the Alaska Range, arctic Alaska, and parts of the Alaska Peninsula, and in the Yukon Territory south to northern British Columbia, and eastward throughout the Northwest Territories to Hudson Bay. Within this range, Barren ground willow occupies different niches. In the arctic, it can be found in shrub tundra and along streambanks. In mountainous regions, it is found on dry alpine and limestone talus slopes. In boreal areas, it occurs as a pioneer species on alluvial and glacial deposits (Argus 1973).

This accession has been tested as L104 and T07542. 'Oliver' parent stock was collected by the Matanuska River bridge, south of Palmer, in April 1974. It has been evaluated at the Plant Materials Center since it was collected. Additional testing has occurred at Delta, Fairbanks and mine sites in Southcentral and Interior Alaska.

Barren ground willow is a gray-appearing, low-growing shrub which can grow to two meters in protected areas. The leaves of this species are variable, usually obovate to lanceolate, and are short and pointed with the upper surfaces being green, and thinly hairy, while the lower sides are whitish and more densely hairy. Leaves measure 25-40 mm in length and 5-10 mm wide. Twigs are thin and reddish-brown and covered with dense hairs when young. The catkins develop with the leaves and persist throughout the summer and sometimes through the following winter (Viereck 1972).

'Oliver' Barren ground willow has performed well in windbreaks and can be used in a multi-row windbreak or shelter belt providing low to mid-height protection.

'Oliver' has also performed well on drastically disturbed soils characteristic of mining disturbances. This performance indicates the variety's potential for use in reclamation projects.

'Oliver Barren ground willow propagation will be restricted to vegetative methods. Hardwood cuttings placed in moist rooting medium, usually sand, provide very good results. To enhance rooting, it is suggested that the cuttings be subjected to intermittent mist and bottom heat at 18° to 20° C (65° to 68° F) while in sand. A weak application of IBA (.1% in Talc) is optional, but does not appear to be necessary.

**'Rhode' Feltleaf willow:** Salix alaxensis (Andress.) Cov., is a species that can be found in arctic, alpine and boreal habitats throughout Alaska, with the exception of most of the Aleutian Islands, some Bering Sea islands, and southeastern Alaska south of Glacier Bay. It also occurs throughout the Yukon Territory, British Columbia and eastward across the Canadian arctic, and south in the Rocky Mountains to Jasper National Park. Feltleaf willow is also found in Asia from the Yanisei River, eastward to the Chukotsk Peninsula and southward to Lake Baikal (Argus 1973).

Within this range, Feltleaf willow can be found growing on gravel bars, along river and streambanks, lake terraces and alpine meadows.

This accession was collected from a single parent plant near Palmer in April 1974, and has been under evaluation as accession L-113 (or T07512) since that date.

Feltleaf willow is a shrub or small tree six to nine meters high. The species, when growing in exposed areas, may become dwarfed or prostrate (Hulten, 1968). Young twigs are woolly becoming smooth and shiny with age. Leaves are oblanceolate to elliptic with dense, white felt underneath. The upper surface of the leaves is dull green and hairless (Viereck 1972).

'Rhode' has exhibited vigorous annual growth and exceptional resistance to cold and drought.

'Rhode' has performed well at various mines in southcentral and interior Alaska. In addition, moose often select this variety over other accessions of the same species, which makes 'Rhode' an excellent candidate for habitat enhancement as well as mine reclamation.

### Variety Selection Chart

Variety/Species	Region				
	South Central	Kenai Pen. & Kodiak	Interior (S. of Yukon R.)	Western	South-Eastern
'Roland' Pacific willow	X	?	X	No	?
'Wilson' Bebb willow	X	X	X	X	?
'Long' Barclay willow	X	X	X	?	X
'Rhode' Feltleaf willow	X	X	X	?	X
'Oliver' Barren ground willow	X	No	X	No	No

FIGURE 6

The fast growth rate also makes this variety suitable for incorporation into windbreaks in Alaska.

All propagation of 'Rhode' is restricted to vegetative methods. Feltleaf willow's preformed root initials make it exceptionally easy to propagate from hardwood cuttings. 'Rhode' requires no special treatment other than moist rooting medium to achieve nearly 100% rooting (Wright 1985).

### Regional Recommendations

In addition to the new plant materials released for production, the plot network has allowed a base of knowledge to be developed for revegetative recommendations. This systematic evaluation network has allowed for ground truthing and refining past standard recommendations and developing new recommendations.

The basic recommendations developed in this report do not include 'Kenai' Polar grass, *Arctagrostis latifolia*, or 'Nortran' Tufted Hairgrass, *Deschampsia caespitosa*. These two cultivars have been recently developed by Dr. Mitchell of the University of Alaska. 'Nortran' will probably replace or supplement 'Norcoast' Bering Hairgrass as a recommended variety for interior Alaska recommendations. 'Kenai' Polar grass will in some cases, replace or supplement 'Alyeska' Polar grass in some revegetation regions of Alaska. Revegetation regions are outlined in Figure 7.

Figures 8, 9, 10, 11 and 12 represent the findings (or lack of findings for Figure 13) from the evaluation network (Moore 1986a, 1986b, Wright 1986c, 1987a, 1987b, 1987c, 1987d, 1987e, 1988a, 1988b, 1988c, 1988d, Wright - Moore 1986).

As with all general regional revegetation recommendations, the Alaska Plant Materials Center does not suggest that these be followed without site specific refinement.

Specific site recommendations can be developed with specific information on soil conditions (texture, pH, and moisture), exposure and other microclimatic factors, i.e., elevation.

These factors would allow specific seed mixtures to be recommended using adapted varieties and secondary cultivars in specific proportions. The same applies to the willow variety selection chart presented in Figure 6.

Commercial availability of native cultivars will always be a factor in developing recommendations. The seed industry in Alaska is still in its infancy, and a degree of reluctance to grow new cultivars still exists in the commercial sector. This causes somewhat of a chicken and egg situation. The growers are reluctant to grow potentially valuable cultivars until it is in demand and users are reluctant to recommend or demand cultivars until they are commercially available.

The listing on Figure 14 identifies commercially available native seed for Alaska and estimates availability dates.

# Revegetation Regions of Alaska

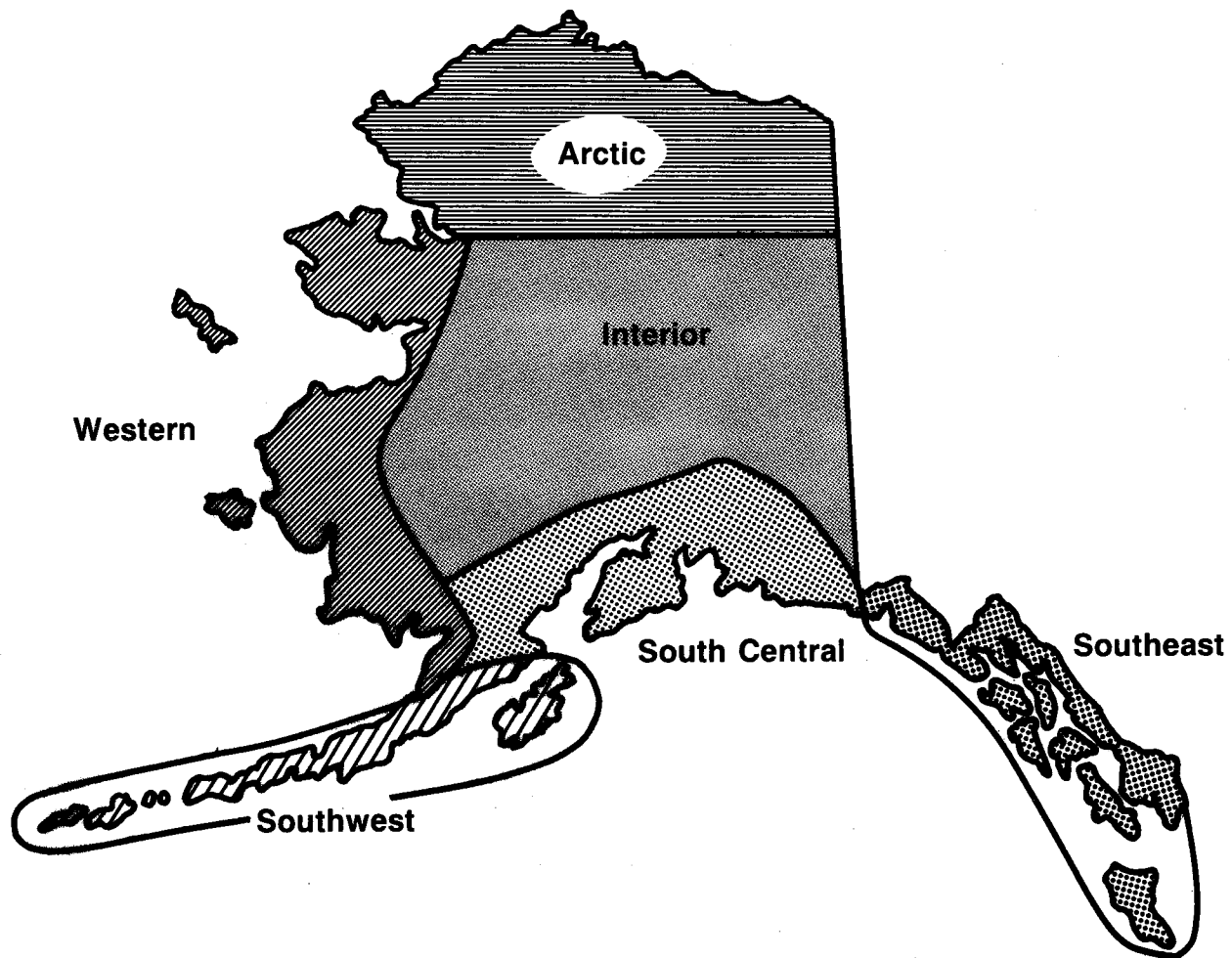


FIGURE 7

# Arctic Region Revegetation Recommendations

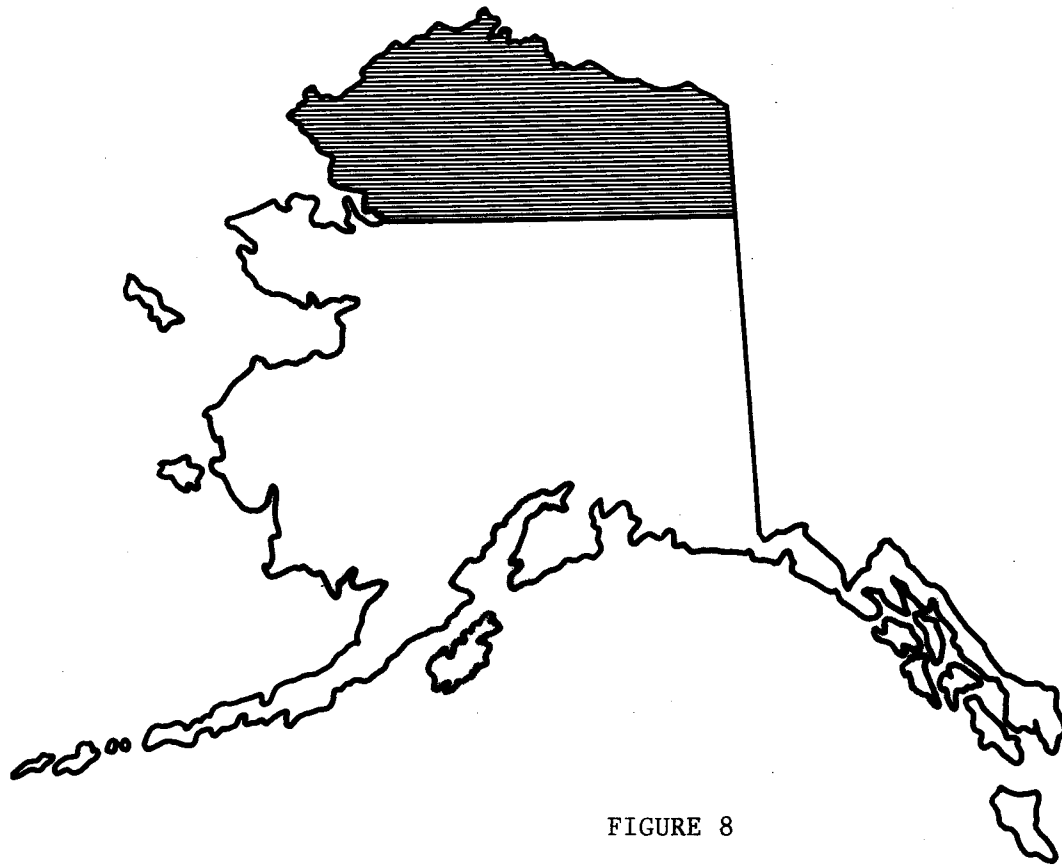


FIGURE 8

## Cultivars Adapted For Use In Arctic Alaska

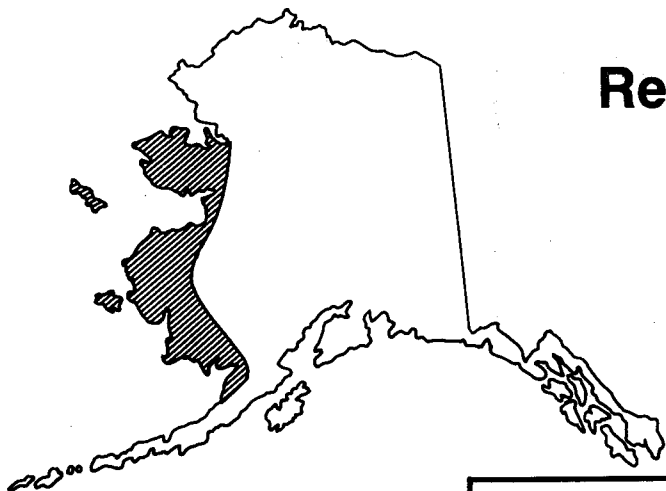
- 'Tundra' Glaucous Bluegrass
- 'Alyeska' Polar grass
- 'Arctared' Red fescue
- 'Egan' American Sloughgrass
- 'Gruening' Alpine Bluegrass

## Secondary Cultivars And Collections Yet To Be Released

- 'Nugget' Kentucky Bluegrass
- 'Norcoast' Bering hairgrass
- 'Sourdough' Blue joint
- '?' Violet wheatgrass



# Western Region Revegetation Recommendations

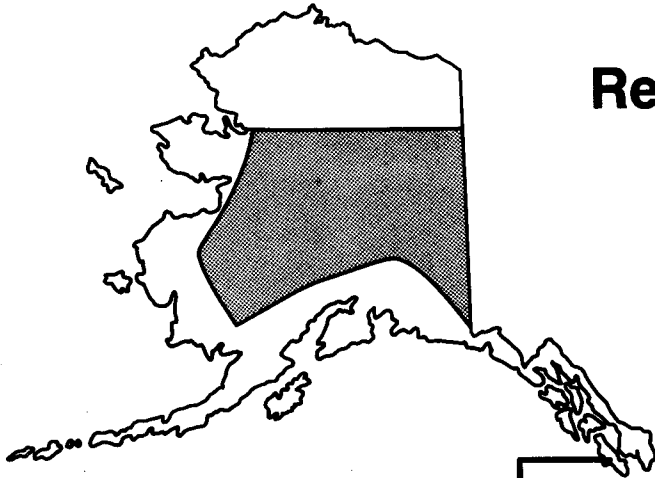


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Cultivars Adapted For Use In Western Alaska	Secondary Cultivars And Collections Yet To Be Released
<p>'Norcoast' Bering Hairgrass</p> <p>'Nugget' Kentucky Bluegrass</p> <p>'Tundra' Glaucous Bluegrass</p> <p>'Sourdough' Bluejoint</p> <p>'Arctared' } — Red Fescue</p> <p>'Boreal' }</p> <p>'Egan' American Sloughgrass</p> <p>'Alyeska' Polargrass</p> <p>'Polar' Brome</p>	<p>'Merion' } — Kentucky Bluegrass</p> <p>'Sydsport' }</p> <p>'Highligh' Sheep Fescue</p> <p>'Manchar' Smooth brome</p> <p>'Vantage' Reed Canary Grass</p> <p>'?' Rough Fescue</p> <p>'?' Tilesy Sage</p> <p>'?' Big Bluegrass</p> <p>'?' Beach Wildrye</p>

FIGURE 9

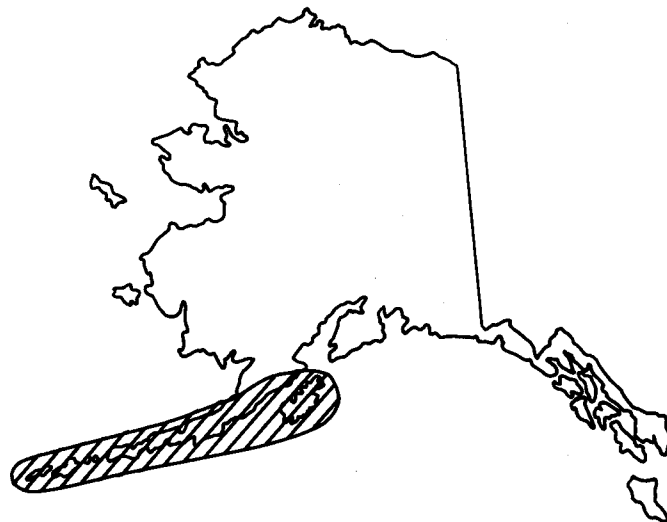
# Interior Region Revegetation Recommendations



Cultivars Adapted For Use In Interior Alaska	Secondary Cultivars And Collections Yet To Be Released
'Nugget' } 'Park' } — Kentucky Bluegrass	'Kamalinski 7' Siberian Wildrye
'Tundra' Glaucous Bluegrass	'Merion' } 'Sydsport' } — Kentucky Bluegrass
'Gruening' Alpine Bluegrass	'Fyking'
'Engmo' Timothy	— Meadow Foxtail —
'Norcoast' Bering Hairgrass	'?' Big Bluegrass
'Sourdough' Bluejoint	'?' Violet Wheatgrass
'Arctared' } 'Boreal' } — Red Fescue	'?' Boreal Wheatgrass
'Egan' American Sloughgrass	'?' Rough Fescue
'Manchar' Smooth Brome	'?' Tilesy Sage
'Polar' Brome	

FIGURE 10

# Southwestern Region Revegetation Recommendations

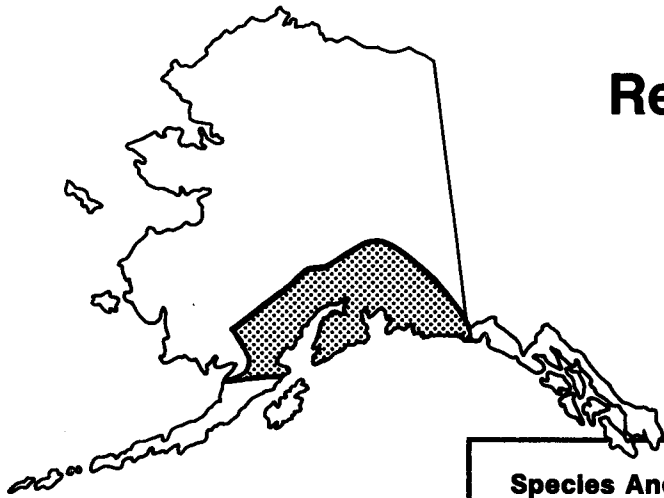


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Cultivars Adapted For Use In Southwest Alaska	Secondary Cultivars And Collections Yet To Be Released	Preferred Cultivars For Alpine Areas In Southwest Alaska
<p>'Norcoast' Bering Hairgrass</p> <p>'Vantage' Reed Canary Grass</p> <p>'Boreal' } — Red Fescue</p> <p>'Pennlawn' }</p> <p>'Nugget' } — Kentucky Bluegrass</p> <p>'Merion' }</p> <p>'Sourdough' Bluejoint</p>	<p>'Arctared' Red Fescue</p> <p>'Fylking' Kentucky Bluegrass</p> <p>— Meadow Foxtail —</p> <p>'?' Tilesy Sage</p> <p>'?' Beach Wildrye</p> <p>'?' Rough Fescue</p>	<p>'Arctared' } Red fescue</p> <p>'Boreal' }</p> <p>'Gruening' Alpine Bluegrass</p> <p>'Norcoast' Bering Hairgrass</p> <p>'Sourdough' Bluejoint</p>

FIGURE 11

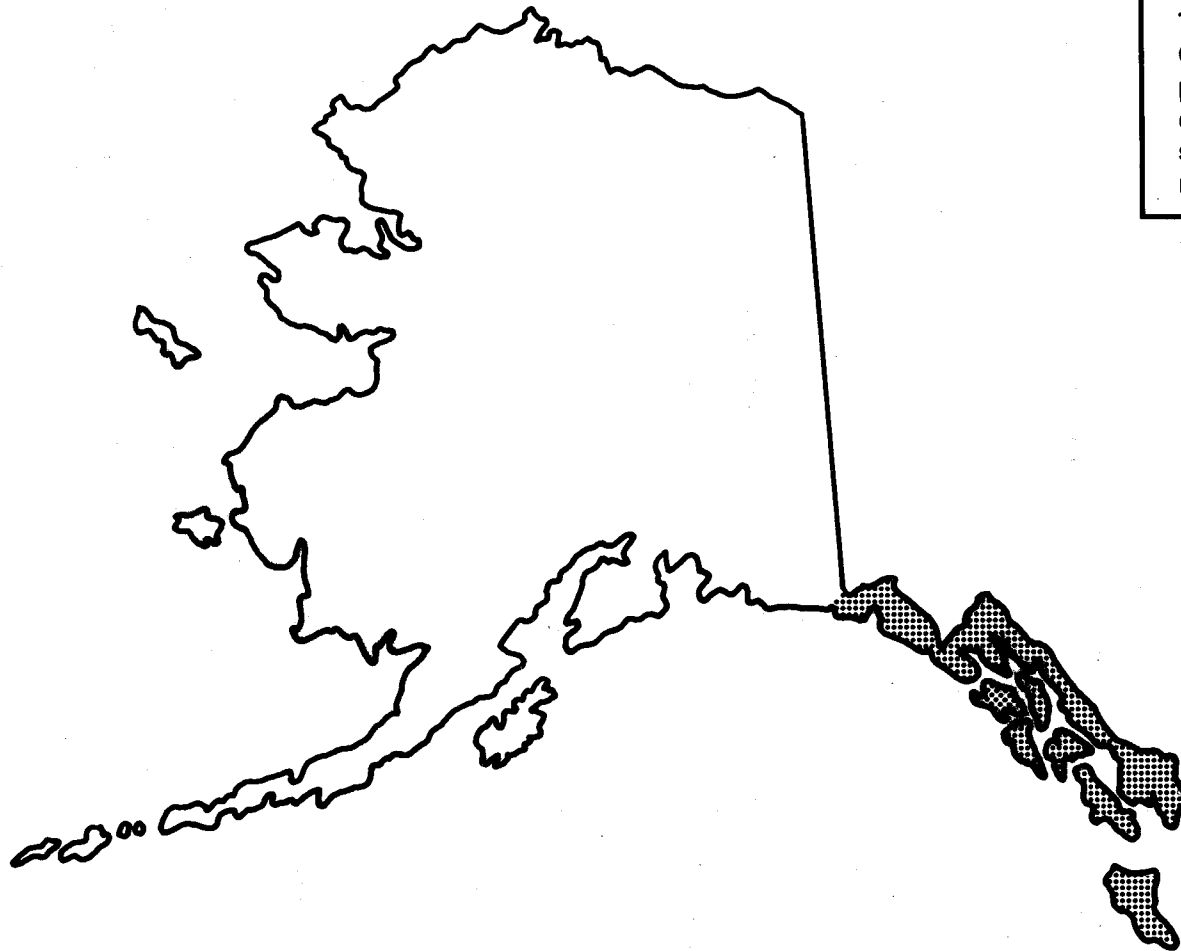
# Southcentral Region Revegetation Recommendations



Species And Cultivars Adapted For Use In Soutcentral Alaska	Secondary Choices And Collections Yet To Be Released
<p>'Nugget' Kentucky Bluegrass</p> <p>'Gruening' Alpine Bluegrass</p> <p>'Engmo' Timothy</p> <p>'Norcoast' Bering hairgrass</p> <p>'Sourdough' Bluejoint</p> <p>'Arctared' } — Red Fescue</p> <p>'Boreal' }</p> <p>'Pennlawn' }</p> <p>'Manchar' Smooth Brome</p> <p>'Alyeska' Polar grass</p> <p>'Polar' Brome</p> <p>'Egan' American Sloughrass</p>	<p>'Park' } — Kentucky Bluegrass</p> <p>'Merion' }</p> <p>'Sydsport' }</p> <p>'Fylking' }</p> <p>'?' Glaucous Bluegrass</p> <p>'Kamalinski 7' Siberian wildrye</p> <p style="text-align: center;">— Meadow foxtail—</p> <p>'?' Rough Fescue</p> <p>'Highlight' Sheep Fescue</p> <p>'?' Tilesy Sage</p>

FIGURE 12

# Southeastern Region Revegetation Recommendations



The Alaska Plant Materials Center has not evaluated plant material in Southeast Alaska. Local knowledge should be utilized, for revegetation specifications.

FIGURE 13

COMMERCIALLY AVAILABLE NATIVE SEED

1988

'ARCTARED'	Red Fescue	<u>Festuca rubra</u>
'NORCOAST'	Bering Hairgrass	<u>Deschampsia beringensis</u>
'ALYESKA'	Polar Grass	<u>Arctagrostis latifolia</u>
'TUNDRA'	Glaucous Bluegrass	<u>Poa glauca</u>
'NUGGET'	Kentucky Bluegrass	<u>Poa pratensis</u>

1989

'EGAN'	American Sloughgrass	<u>Beckmannia syzigache</u>
'GRUENING'	Alpine Bluegrass	<u>Poa alpina</u>

1990 and later

'SOURDOUGH'	Bluejoint	<u>Calamagrostis canadensis</u>
'NORTRAN'	Tufted Hairgrass	<u>Deschampsia caespitosa</u>
---	Tiley Sage	<u>Artemesia tilesii</u>
---	Beach Wildrye	<u>Elymus arenarius</u>
'KENAI'	Polar grass	<u>Arctagrostis latifolia</u>

Figure 14.

## WILLOW PLANTING TECHNIQUES

The Plant Materials Center has released for commercial use, five cultivars of willow from five species. Commercial production may not substantially reduce the cost of planting willow on a large scale, but it will make regional proven material available. Prior to the present commercial production, the only source of willow was the native stands or a very limited supply of seedlings.

Out of all the methods used in Alaskan reclamation, willow planting is, by far, the most maligned. The only large scale use of willow by industry has been the plantings conducted on the Trans Alaska Pipeline. A decade has past since Alyeska's attempts and methods have improved.

The procedures used by Alyeska during the first year of willow plantings relied on cuttings rooted in "Jiffy Pots." This method was dropped during the second year and direct planting of dormant sprigs was attempted. Also, Alyeska selected sites more suitable for willow establishment than those selected by the regulatory agencies. The dormant cuttings proved to be much more successful, especially when they were not planted in upland rip-rap pits.

In 1979, the Plant Materials Center started investigating improved methods to conduct willow plantings. These methods not only needed to produce a high degree of success, but also needed to be cost-effective. Willow planting had to become an effective revegetation technique.

The Plant Materials Center started with 8-10 inch dormant, unrooted cuttings. This method has proven successful, provided grass competition is not significant and adequate moisture is available. Dormant, unrooted cutting provides an advantage as being easy to prepare and plant as well as being low in cost.

The disadvantages of this method are: 1) the cuttings must be kept in cold storage until planted, 2) they must not be permitted to dry out or become excessively wet during storage, 3) they have a lower survival rate than other methods, and 4) requires planting sites with adequate soil moisture.

The next method that was adopted by the Plant Materials Center, was bundling of dormant material. This method has also been referred to as wattling. This technique involved tying four-foot long, dormant willow branches in bundles 4-6 inches in diameter. The bundles are then planted horizontally to a depth three fourths of the bundle's diameter. This method has proven to be more able to compete with grass. The prime advantage to this technique is the physical block that the bundle mass provides in erosion control. Bundles also provide quick linear cover.

The disadvantages are the same as for dormant cuttings except soil moisture is not as critical. This method does require more plant material than any other method.

The use of container grown cuttings is probably the most effective method to establish willow. The method is more costly than using dormant material. It also requires more care in planting.

The advantages are obvious. The plants are established and growing when planted. The container material is also more suited to dry sites. The age of the planting stock can range from material rooted in the year of planting to 1 - 0 and older stock (Moore et al 1986, Wright - Moore 1986).

More efficient methods of planting need to be developed before large-scale plantings are likely in Alaska. This is being explored by the Plant Materials Center at this time.

#### **DORMANT SEEDING VS. TRADITIONAL SPRING SEEDINGS OF GRASSES**

The Alaska Plant Materials Center is actively attempting to determine if dormant seeding is a viable procedure in Alaska. Because of Alaska's long winters, heavy snowfall, and rapid melt, it has been the feeling of many in Alaska that dormant seedings are not practical.

This has forced all revegetation activities to occur in a relatively short "seeding window." The "seeding window" is the period allowed for seedling establishment prior to winter. In the Arctic, this could have forced all seedings into a period as short as 20 - 30 days. By permitting dormant seedings, the period to seed would be greatly increased. This would, of course, allow greater flexibility in scheduling revegetation.



By permitting dormant seedings, the period to seed would be greatly increased. This would, of course, allow greater flexibility in scheduling revegetation.

Recent findings by the Plant Materials Center at the Kuparuk Oil field and the Beluga Coal fields, has suggested that dormant seedings are possible. The critical factor in dormant seedings still remains to be slope and spring run-off. On level ground, as was used in the Kuparuk plots and the Beluga plots, no difference in overall success was noted. However, in the Kuparuk plots, prolonged dormancy in some of the spring seeded grasses occurred. In fact, some accessions did not break dormancy for one year. The dormant seedings produced measureable stands the spring following planting. A slight increase in vigor was noted for the dormant seedings (Wright 1986c, Wright 1987e).

#### WETLAND REVEGETATION AND RESTORATION

The importance of wetlands in Alaska cannot be understated. In addition to the ecological importance of these areas the regulations developed to protect them can be overwhelming.

The North Latitude Revegetation and Seed Project is the only agency in State government attempting to solve revegetation problems associated with revegetation of wetlands.

The Plant Materials Center has worked with the Alaska Department of Fish and Game and Ducks Unlimited in the revegetation of two waterfowl habitat enhancement projects. These projects at Palmer and Fairbanks have demonstrated the effectiveness of new wetland cultivars developed in Alaska; primarily 'Egan' American Sloughgrass and 'Norcoast' Bering Hairgrass.

Another demonstration project that was designed to revegetate a wetland area was the Bethel Small Boat Harbor. This project, initiated in 1984 in cooperation with the Corps of Engineers, proved the adaptability of 'Egan' American Sloughgrass and 'Norcoast' Bering Hairgrass to the Bethel region of western Alaska (Moore 1986a).

Presently, the North Latitude Revegetation and Seed Project, in cooperation with ARCO Alaska, is attempting to determine the potential of successfully establishing Arctic pendant grass, Arctophila fulva, in the Arctic. Arctic pendant grass is an emergent grass species usually associated with lakes and ponds in the Arctic.

Initial findings after the third year of the investigations, have been inconclusive as to success and economic feasibility of transplanting arctic pendant grass (Moore - Wright, in press).

This project will continue for at least one more year before it is determined whether or not to proceed with further studies.

#### **COASTAL RESTORATION AND EROSION CONTROL**

The State of Alaska has more coastal shoreline than the remainder of the United States combined. Therefore, coastal revegetation merits study.

The first major project involving coastal revegetation and erosion control in Alaska occurred on Shemya Air Force Base.

Shemya Air Force Base is located approximately 1,500 air miles south of Anchorage, on Shemya Island in the last group of islands at the western extreme of the Aleutian Island chain. Shemya Island is roughly four miles east to west and two miles north to south.

Climatically, the island is classified as maritime. Seasonal variations in temperature are small. Mean daily temperatures in January are approximately 31° F, and in July they are approximately 45° F. Average annual precipitation is slightly less than 28 inches. The most obvious and overriding climatic factor is wind and fog. Severe winds, at times in excess of 70 knots, can lash the island. The most significant winds occur during late fall, winter and early spring.

In 1987, construction adjacent to the runway at Shemya Air Force Base, removed existing dunes and vegetation and exposed 27 acres of erodable sand to the winds. Transported sand would cause aircraft maintenance and safety problems.

Previous attempts to revegetate the Lateral Clear Zone failed. In 1987, the U. S. Army Corps of Engineers Alaska District and the Alaska Plant Materials Center, Department of Natural Resources, designed a revegetation and erosion control project to prevent erosion on the area planned for construction in 1987.

Based on initial studies in 1986, it was determined that Beach wildrye *Elymus arenarius* L. (also referred to as *E. mollis* Trin.) could be established using transplanted sprigs (Wright 1986d).

The revegetation plan also called for seeding with the following grasses:

<u>Cultivar</u>	<u>Common Name</u>	<u>% By Weight</u>
'Norcoast'	Bering Hairgrass	40%
'Pennlawn'	Red Fescue	25%
'Boreal'	Red Fescue	30%
	Annual Ryegrass	3%

The seed mix was applied at a rate of 60 pounds per acre.

Prior to sprigging, the area was fertilized at a rate of 500 pounds per acre of 14-30-14. A supplemental application of 75 pounds per acre of 34-0-0 occurred 60 days after seeding.

The contractor was given a choice of two chemical soil stabilizers, Coherex and Soil Seal to apply for temporary erosion control. Both stabilizers were proven to have no adverse effect on Beach wildrye sprigs.

In May 1987, the contractor, aided by the Alaska Plant Materials Center, started the revegetation project. Minor modifications to the available construction equipment, allowed the methods for harvest and planting to be simplified.

Production rate for planting one acre (20,000 sprigs) was 60 man hours. The ideal crew consisted of three diggers and three planters.

In September 1987, the area was evaluated. Twelve 50-meter transects indicated that 90% of the Beach wildrye sprigs had become established.

Overall ground cover was 80-85%, 41% of which was Beach wildrye, 43% seeded perennial grasses, 15% annual rye grass, and <1% invading native broadleaf species. The vigor of the vegetation was good to excellent.

Stand diversity was higher than expected. Propagules from broadleaf native species had been introduced when a thin (2-4 inches) veneer of peat had been applied to the area as a temporary solution to reduce wind erosion.

Data indicated that established vegetation consisted of 75% perennial grasses (seeded and sprigged), 18% annual grasses, and 2% invading broadleaf species (Wright et.al. 1987d).

The project was the first major attempt to establish Beach wildrye in Alaska. The success of the project indicates that it is a viable reclamation and erosion control method.

Future projects would be able to reduce costs by reducing the number of sprigs per acre, reducing the amount of seed used, and possibly eliminating the use of soil stabilizers. Both the elimination or the reduction of any component must be weighed against 1) consequences of a partial failure, 2) intent of the project, or 3) value of what is to be restored or protected.

#### **ACKNOWLEDGEMENT**

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# HAS RESEARCH CONTRIBUTED SIGNIFICANTLY TO MINED LAND RECLAMATION?<sup>1</sup>

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## INTRODUCTION

Reclamation science is new, just a baby so to speak. Standards, techniques, and experience are all relatively new and untested. Inflexible success standards may become flexible with the tests of time. It is stated in reclamation regulations that reference areas must be selected and must be representative of geology, soil, slope, and vegetation type for the respective sites that are to be restored after disturbance by mining.

It is questionable as to whether or not site characteristics in premining situations can truly be reconstructed for similar postmining appearance and use. Reclamation in the west possesses a significant interrelationship among aridity zones, technology, and restoration success. More favorable climates make technology less essential to reclamation success. Most problems are not in reclamation planning, but rather in selecting the procedure and technology for accomplishing restoration on each individual site.

It is disturbing to witness the neglect of known technology in actual everyday restoration procedures. Reclamation research information is not easily found, and many persons supervising mined land restoration are inexperienced as well as untrained. Mine reclamation may have to endure the tests of time as did revegetation of road right-of-way projects during the federal government's super highway construction period in the late 1950s and the 1960s.

## RESEARCH

Reclamation science is, indeed, a new discipline, and research in this area has developed in almost overwhelming proportions in only a brief period of time. Intensive research of perhaps not more than a decade and one half has produced hundreds or, perhaps, even thousands of scientific articles. Early research in range management, before mined land reclamation research, contributed substantially to rehabilitation in areas of control of unwanted plant species and in range seeding. These early studies dealt with chemical and mechanical control of plants prior to seeding, as well as control of undesirable species in established

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<sup>1</sup>This paper was solicited by the Program Committee and was agreed upon to present largely the views of the author as gleaned from his research and experience as a consultant the past 20 years.



plant communities. Early research in seeding consisted of procedures such as broadcasting or drilling along with methods of seed bed preparation. Much knowledge in reclamation still comes from the early rangeland seeding trials which started seriously in the 1930s.

Significant technological advancements have been made in plant materials development, planting methods, soil amendments, handling of toxic materials, and functions of the soil ecosystem. In spite of the intensive activity in reclamation research there are many technical questions that remain unanswered, especially for site specific renovation procedures. However, the likelihood of obtaining satisfactory results are many times reinforced by research, compared to our knowledge before 1977 when the Surface Mining Control and Reclamation Act (SMCRA) was passed.

It is important to state that even though research in reclamation of mined land is relatively abundant, it is not generally found in the annals of science in recognized accredited libraries. Articles in land restoration, even though there are many hundreds of them, are found in various symposia proceedings and annual research reports. Peer review journals that specialize in reclamation or have special sections for reporting reclamation research are rare or, at the present, almost non-existent.

If there is a fault in reclamation research to this point in time, it is the neglect of applied technology and the lack of economic cost evaluations, with respect to various increments or phases of mined land restoration (marginal costs). The testing of realism in regulations to reduce the misunderstanding of regulatory processes by governmental legislation may well be included in research.

It can indeed be said, without reservation, that reclamation research has contributed significantly to appropriate restoration of mined land. The challenge is, can the researchers of the future recognize the voids in information and fill in these gaps in the order of technological needs.

#### KNOWLEDGE AVAILABLE BUT OFTEN UNUSED

Perhaps the failure to review the literature for seeding mined land is the most common mistake in practice today. The derelictions of using available technology are many and should be brought to our attention.

#### Selecting the Seed Mixture

Since people are obsessed with the idea of obtaining diversity, it is generally the rule to add a host of species to the mixture, many of which are not adapted and will only compete as a weed in the stand for a few years. It is commonly believed that if the mixture is broad enough, the same mixture can be seeded on all disturbed sites over the mine. Too

little is known about site specific adaptability of even the native species in most general locations of the mine in question. It seems appropriate to make an honest effort to acquire species known, or strongly believed, to grow on each of the sites to be reclaimed, and then plant them accordingly. The point is, we are not using what is known about species habitat requirements.

#### Method of Planting

This technology is perhaps the most commonly neglected in mined land restoration. Most environmental engineers feel that drilling is the most dependable method, so a new grain drill is purchased. Just why a grain drill is purchased rather than a grass drill is not known to the author, but this is the case. A suitable drill, in most cases, is not an ordinary grain drill. The seeding implement should possess a separate box for small seed, a seed agitator, and a force-feed mechanism that allows awned seed and fuzzy seed to be drilled along with smooth seed. Depth bands are not necessary, but for inexperienced people, it is definitely an advantage. In most soils, a disk-type drill is much preferred to a shovel-type planter mechanism. The latter plants the seed much too deeply in most seedbeds.

#### Control of Weeds

Many reclamation personnel make the mistake of allowing annual weeds to suffocate a prescribed perennial seed mixture. In the arid west, it is necessary to control annual forbs and grasses during, at least, the first growing season. There are several ways this can be accomplished: 1) a thorough summer fallow practice, 2) use of pre-emergence herbicide prior to planting, and 3) if only a grass stand is planned, a post-emergence herbicide can be used. If sorghum or oat crop are planted for stubble mulch, a post-emergence herbicide (2,4-D) can be used to control annual forbs in the stubble mulch seeding prior to planting the seed mix.

#### Fertilizers

It is generally conceded that fertilizers are needed for revegetation of mined land. This is a result of chemical test of soils for N, P, and K that indicate that rangeland soils are deficient in these elements because of the relatively high standard for domestic farm crops. However, many scientists, including this author, feel that the top soils of most rangelands are not deficient in N, P, and K for establishing native range plants. Actually, the laboratory tests for these elements show large variability within range sites, and accurate standards for seedling establishment of range plants are unknown. Under more favorable site conditions, fertilizer favors grasses at the expense of forbs and shrubs. Fertilizers, likewise, produce vigorous growth in annuals which cause them to crowd the small seedlings of the seeded mixture from the stand. Most regulatory agencies look favorably upon a restoration plan that

provides for the use of 60 to 70 pounds per acre of N, P, and K in some mixture. Do we really need more research on fertilizer benefits, or should we continue to fertilize for support of the approval of the mining permit?

### Irrigation

In arid and semiarid localities where annual precipitation is about 8 and 12 inches, respectively, it is generally believed that supplementary water will enhance the establishment of plants on restored mined land, especially on harsh sites such as south and west slopes. This belief is, indeed, correct since irrigation of young plants does reduce mortality during seedling emergence and establishment. However, when water is withdrawn and the natural vagaries of the weather are allowed to stress the young plants, the previous benefit of supplemental water on these harsh sites seemingly disappears. In desert areas, natural plant regeneration occurs only every 7 to 10 years when two favorable years appear in succession. Therefore, it would appear that complementary water would materially aid new seedlings. The inference is that we know little about how to wean young plants from irrigation water during the first few years of their establishment. In arid sites, the results consist of poor establishment for both watered and unwatered areas, usually. On semiarid sites where the annual precipitation may be 12 to 14 inches, the plants receiving water for a year or two are more dense and higher producers for perhaps as many as 4 to 5 years. However, after 8 to 10 years have passed, there often is no discernable difference between the watered and unwatered plants.

Available information on the benefits of supplemental water lacks site specific application for western land reclamation. Yet, plans for restoration of harsh sites invariably include irrigation to add assurance to establishment of a plant community. These irrigation projects are merely mitigations of a worst-case scenario for a mining permit.

### Mulches

Mined land regulations require a mulch for arid land reclamation. This is a general requirement without regard for harshness of site. Often, a straw or hay mulch is applied after seeding, especially on difficult slopes, but it is not held in place appropriately because it is either covered too deeply by soil by disking or roto-tilling or it is crimped only lightly by running an ordinary disk over the area without disturbing the soil. Thus, the mulch is either covered too deeply with soil or is blown away. The heavy duty crimpers are the only satisfactory machine for keeping the mulch in place and allowing it to serve as a true mulch. Even the heavy crimper is not effective on hard compacted soil.

When wood fiber is used as a mulch on steep slopes, it is frequently applied with a hydroseeder and with both the seed mix and fertilizer included in order to reduce the cost of application. This practice

reduces the viability of the seed in the mixture and leaves most of the seed above the soil surface in the wood fiber mulch. Therefore, many seed germinate, but the mulch dries and the seeds never have a chance to project their roots into the soil and, consequently, die.

Except on critical slopes, a stubble mulch is considered effective and costs considerably less than hay, straw, or wood fiber. Two commonly used stubble mulches are milo-maize and domestic oats. These are planted the spring before seeding in the fall or seeding the following spring. Sometimes these crops are mowed before maturity at about 10 to 12 inches in height with the mowed portion falling to the surface to remain as litter. Mistakes that commonly occur in stubble mulching is that the stubble crop is also used as a cover crop where the seed mixture is seeded at the same time as the milo or oats. These crops present rather severe competition when used as a cover crop. In addition, cover crops are not generally recommended for establishing native range plants under arid climatic conditions common in the west. An equally bad mistake in stubble mulching is using domestic winter wheat or domestic rye. These plants are severe competitors with seeded native range species and lead to failure in most arid climates of the west because they produce volunteer stands year after year.

#### Shrub Planting

In preparing the reclamation plan for a mining permit, it is often assumed that shrubs will establish as easily as grasses or forbs. As a result, mining companies over-commit to reestablishing large areas of rather dense stands of shrubs.

Some shrubs are not easily established through seeding by means of drilling or broadcasting, while others appear to establish rather well when seeded by conventional means along with grasses and forbs. It is rather well known that most arid or semiarid shrub species appear to establish better in rocky soils of somewhat lower fertility when seeded with grasses. This is believed to be the result of deeper moisture penetration, thus favoring the deeper rooted shrubs over grasses. Many shrubs appear to have high mortality unless planted as tubelings supplemented by at least an adequate moisture supply when planted. This procedure is expensive and needs to consider the cost when regulations demand substantially large quantities of a particular shrub species in the reclamation plan.

#### Drought and/or Insects

Regardless of how meticulous the planting procedure is carried out, a failure may occur because of natural hazards, especially drought, during the seedling establishment period. Insects, such as grubs, army worms, Mormon crickets, wheatgrass bugs, etc., can destroy new seedlings. These failures are unrelated to good or bad reclamation techniques but

should be considered in the risk of seeding success and accompanying costs.

## RECONSTRUCTION

It is the estimation of the author that reshaping and erosion are the two most neglected considerations in reclamation. This is largely the result of the generalities addressed in the regulations with respect to guidelines for reconstruction prior to revegetation. It is costly to move soil both in the process of mining and in restoration. Therefore, it behooves one to plan so minimum movement of soil is the first order for reconstruction of sites for revegetation. Many times a distance of moving overburden and topsoil is excessive in order to have the assurance that it will not be covering another area that will be mined. Reduced mining operations to smaller areas, so that mine spoil and subsoils can be moved relatively short distances into the excavated pit along with topsoil from smaller and closer salvage piles, would reduce costs substantially. Faulty planning is rather apparent in most open-pit mines. In most cases of this nature, mining companies eventually want a variance to seed the overburden material in place, even though it is just a large mound of material quite unlike any other topographic features. In fact, moving the overburden back in place into the pit would cost considerably more than the loss of the mining bond.

### Land Shaping

In shaping mined overburden material, it is of prime importance to reconstruct the material to reduce runoff, and to provide slopes that have a gradient that will support a vegetation cover. It is generally preferable to shape the topographic features so that the terrain is undulating rather than shaping it with a grader or bulldozer so that it is free of humps and basins as if it were to be paved or used as a road bed. Things of this nature invariably happen when the regrading is left largely to the machine operators.

It is rather common in surface mining, where rather deep overburden is to be removed, for large mounds and long slopes to result. The reconstructed slopes are often times one quarter to one half mile in length with no contours or terraces to reduce water runoff. Thus, a small trickle in a small rill becomes a large riffle of water in a very noticeable gully in a rather short time.

Slope aspect and gradient are important factors in evaluating a site for reclamation potential. North-facing slopes present the most favorable growing conditions; next, the east-facing; third, the west-facing; and least favorable are the south-facing slopes. In areas of limited precipitation (10-12 inches annually), south-facing slopes may be very difficult to revegetate, even on rather gentle slopes (3:1), while on north-facing slopes of similar gradients, revegetation is much easier. Degree of slope is often mentioned in reclamation guidelines but not

always are they restrictive with respect to site-aspect reconstruction. It is generally recognized that most machinery can operate on a 3-to-1 slope and, as a result, they are practical in reclamation of arid lands. A 3-to-1 slope on a south aspect in arid climates should be the minimum, but many examples show that slopes much steeper on south and west slopes are being attempted with little or no success over the long-time period. North and east slopes also have their limitations, but the slope can be somewhat steeper. However, when in doubt, try to approximate a 3-to-1 or lower gradient on the slope. It really does not cost much more for the added reduction in risk of failure.

Demonstration seedings in Colorado at two locations had about 60 to 70 species that were believed suitable to areas for range rehabilitation. One seeding was made in about 1950, and the other about 1971, and both areas showed that most species produced satisfactory stands, initially. However, after 10 years and the stress of a 2-year draught in each of the locations, only 8 to 10 species maintained satisfactory stands in each of the demonstration areas. Mortality of species and plants within species were higher on south-facing slopes than on north-facing slopes or on level terrain. Such trails indicate that seeding success under arid site conditions must display the tolerance to withstand intermittent drought situations which are natural and certain to occur.

#### Erosion

Erosion on restored mined land slopes goes unnoticed unless there are obvious gullies on the landscape. Even these are frequently corrected by merely plugging the gully every few years. Contour furrows or benches on long slopes are not generally required by regulations. If so, there are no guidelines showing their location or construction. If the mining company prevents sediment from leaving the mining lease, the regulatory responsibilities, for the most part, are met.

Erosion is quite evident on many surface mines of the west and should be taken more seriously by both the mining companies and the regulatory agencies. A simple sediment pond here and there at the bottom of the slope is not the complete answer to land stabilization. Do we really know what constitutes a natural gully system? Can we reconstruct an effective gully system, or do we have to depend upon erosion and runoff to dictate the ultimate configuration?

#### REGULATIONS AND RESTORATION

Regulations are many times formulated without basic knowledge or adequate experience in mined land reclamation. Therefore, research must test the soundness of guidelines if the scientist is to calm the waters. For instance, lack of technology, with respect to discrimination against introduced species in seed mixtures, has caused and is causing great concern among reclamation scientists. It appears the forces of mother nature have ruled against introduced species because they are strangers

and their capabilities and adaptabilities are still unknown with respect to site specific requirements. Questions still unanswered about introduced species are drought tolerance, site adaptation, and susceptibility to disease infection and insect infestation. It is only natural to require historical information or on-site demonstrations to show that introduced species deserve to be included in the seed mixture.

### Seeding Success

Successful restoration by regulation standards generally required that postmining rehabilitation compare favorably with premining conditions. Is seeding success essentially identified as meeting bond release standards? Most regulations addressing revegetation success use a general statement such as establishment of a diverse, effective, and permanent cover comparable to premining conditions. Most technicians responsible for collecting baseline data feel that guidelines are really nothing more than a detailed subregulation that outlines exacting responsibilities for mining companies. These may or may not be practical or even possible.

### Reference Areas

Recognizing there are other alternatives for proving revegetation success for bond release, the reference area comparison appears to be favored by most regulatory agencies. In many respects, it is the most difficult to rationalize as an appropriate method of proving success.

Baseline premining measurements may be precisely planned and carefully documented, but reconstruction of the same site characteristics, such as subsoil and topsoil structure, texture and depth, and slope aspect and gradient, are difficult and may be next to impossible to obtain. Exacting duplication of site characteristics is costly and, of course, resisted in favor of something similar. Federal regulations, by their inherent nature, do not allow for flexibility. Most reclamation specialist feel that regulatory specifics for bond release are largely statistical comparisons of reference areas to presupposed duplicates or a facsimile for postmining sites. Guidelines state that postmining restoration on any site must be comparable, to its reference area in plant cover, biomass, diversity, and shrub and tree density, with certain confidence intervals that include statistical probabilities and deviations from the mean or mean differences being tested.

Are site duplications for reference areas really possible after mining as presented in the mining plan? An honest answer to this is "no" for most reference areas and their counterparts for postmining revegetated sites. Reclaimed sites are different from their premining reference area because physical properties of the soil are changed, and topography is generally different because of soil movement in the mining process. Premining condition of the range may have been poor or, at best, only fair. Diversity of plant species, for the most part, is greater on

poor condition range than on good or excellent range. If restoration is reclaimed to poor condition range, the assumption is that succession will go forward to higher expressions of range condition. It is also assumed that the same plant cover, diversity, and biomass suggests soil stability, ecological stability, or reclamation success, which may be a very weak assumption.

Reference areas in shrub and/or tree types make scientists wonder if the effort in collecting information has any real meaning in postmined land revegetation. Two common types of this nature are sagebrush and oakbrush. No one is expected to put as many sagebrush or oakbrush plants back; thus, these will be decidedly absent, except in small patches of perhaps as much as 10 percent of the total area. The question now arises as to how much cover, biomass, and diversity is required for the grasses and forbs to satisfy bond release, and how the detailed and statistically validated baseline data is really used for a standard of success or for bond release?

It is recognized that regulations must address some sort of standard that can reasonably be obtained and practically measured. This is not easily formulated so that all or even most situations can be included. There needs to be flexibility that allows negotiation for something reasonable rather than following a perfunctory procedure that is irrational.

#### SUMMARY

Reclamation science is new, and most research has been recent. As a result, standards, techniques, and experiences are untested. Significant technology has increased in plant materials, planting methods, soil amendments, soil replacement, toxic spoil material, and functions of soil ecosystems. Reclamation research, although only rather recent, has contributed significantly to mined land restoration. A rather serious neglect in research has been the lack of applied technology for site specific situations and marginal cost evaluations for phases of restoration.

Even though much technology is available, it is often unused in reclamation procedures. These procedures include: 1) appropriate seedbed preparation, 2) selecting appropriate seed mixtures for various site situations, 3) controlling annual weeds in the soil prior to seeding, 4) improper use of mulches, and 5) improper planting procedures for shrubs. This, in part, may be a result of reclamation research information being in proceedings of symposia and in annual project reports rather than in peer review journals and accredited scientific libraries.

Reconstruction procedures are often more costly than previously anticipated during premining planning because of required soil movement. Precise planning in placement of topsoil and overburden during mining is often a neglected item. Reshaping overburden is often an afterthought



and is more or less left up to the equipment operators, which results in large mounds with long and steep slopes without construction measures for controlling runoff and erosion. Justification should always accompany the use of slopes steeper than 3-to-1 in reclamation. South-facing slopes are more difficult to revegetate than north-facing slopes and, as a result, need greater attention.

Regulations infer that seeding success is measured by results that merit bond release. This generally requires statistical comparisons of a restored area to premining baseline data on a reference area. The use of reference areas to compare statistically to a restored site of similar topography for bond release is indeed controversial. This results from the belief that it is virtually impossible or infeasible to duplicate a reference area with respect to physical properties of the soil, topographic features, and plant diversity. Range condition of the reference areas is generally not identified and, therefore, confounds the entire issues confronting the use of reference areas as legitimate comparisons for restoration purposes. Reference areas are of doubtful value when comparing shrub and tree types with herbaceous understory to restored herbaceous vegetation with only local restoration of premining densities of wood overstory. Regulatory flexibility that allows negotiation for a reasonable solution, rather than following an irrational procedure, is recommended for proof of satisfactory restoration.

## **COST-EFFECTIVE TECHNIQUES FOR SUCCESSFUL EROSION CONTROL**

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Ten years ago erosion control was easy. We had seed drills, straw blowers, hydroseeders, excelsior and jute. We just tried to make the grass grow. We did not have to be concerned with terms like flow velocity, sheer strength, Manning's Equation, roughness coefficients and the like. In the past five years, the erosion control industry has progressed at a mind-boggling rate. Erosion control is rapidly becoming a high tech industry. It seems like every month a new product is introduced to control erosion in increasingly specific applications. We are finding ways to establish vegetation on sites or areas that ten years ago were simply out of bounds to plant life. In the old days, control of erosion on super steep slopes, medium to high velocity channels, mine tailing sites and other harsh places was accomplished with rocks, timbers, concrete, asphalt or not at all.

Just what is erosion control? To control erosion is to curb or restrain (not completely stop) the gradual or sudden wearing away of soils. We have all seen extreme examples of excessive erosion such as gullied hill slopes or stream channels choked with debris, but often erosion goes unchecked on flat to moderately sloping terrain. Soil loss is a continually occurring process in natural ecosystems as well as successfully reclaimed sites--without it our scenery would be very boring. The goal of any revegetation or erosion control project should be to stabilize soils and manage erosion in a cost-effective manner.

In our times of shrinking budgets, a decision maker is hard pressed to reclaim a disturbed site at the minimum cost. Given the site conditions such as slope angles, precipitation, runoff, soil profile, etc., the specifier must select with confidence a technique he (she) feels will perform up to expectations at the lowest cost. One can be overwhelmed by the volume of reports and claims for various erosion control practices and techniques. It is safe to say that all of these practices are functional, but where do they work best, how much do they cost and, most importantly, which technique will be the most cost-effective treatment for a particular site or situation?

Clearly, the single-most important means of insuring long-term erosion control is the selection of seeds and plant materials that will adapt to site conditions. Through proper species selection, the process of natural plant succession can be greatly accelerated. Eliminated or greatly reduced are the weedy successional sequences leading up to the climax plant community--those species that nature would select to form a stable and constant ecosystem. The less time it takes for deeper

rooted vegetation to become established, the quicker erosion control will be accomplished.

Mulching nearly always shortens the time needed to establish suitable plant cover while protecting the site from erosive forces. Seed coverage---mulching with soil--is the single most important practice! Yes, soil may be considered to be a mulch. In our often arid climate, it is of paramount importance to have seedlings rooted in the soil, not on top of the soil trying to root down into the surface. Soil mulch may also prevent premature germination caused by other mulches in the absence of adequate moisture for continued growth. Even folks from wetter parts of the country are seeing the benefits of this concept. And, of course, whenever possible, topsoil is the obvious choice for a soil mulch.

The easiest, quickest and most economical method of obtaining seed burial (soil mulching) is to use drill seeding techniques. The process involves tilling the soil material to loosen it, then planting the seed into the ground. The prime reason for drill seeding is the positive placement and uniform dispersion of seed at a regulated depth into the soil where levels of moisture are most consistent and the actions of wind and water will not easily remove the seed from the treated area (Brammer and Theisen, 1981).

There are several types of drills and some handle different types of seeds better than others. It is important to select a drill that can handle very small seeds in addition to rough or "trashy" seeds. Smooth, consistent seeds generally are not a problem. Often it takes some imagination to insure that seeds of varying sizes and shapes are seeded at the specified rates.

In park lands or wherever drill rows are unacceptable, seeding may be accomplished with a Brillion seeder or other types of broadcast seeders. Regardless of technique, it is advisable to drag a chain or a scotch harrow behind the seeder for proper seed burial.

Drill seeding should be employed whenever possible unless site constraints such as rocky ground, tight areas or safety (steep slopes) dictate alternative methods. Basically, if a slope can be traversed with a tractor, either wheel or crawler type, it can be drill seeded. Wheel tractors with dual wheel arrangements can work a 3 to 1 slope in most instances. Four-wheel drive and crawler-type equipment may handle up to 2 to 1 slopes depending upon soil texture. Only very experienced operators should attempt these maneuvers! On more severe sites broadcast methods must be used; and, whenever possible, soil mulching should be performed.

Once seed burial has been accomplished, it is important to consider the benefits of applying a supplemental mulch such as straw, hay or hydromulch. It has been proven time and time again that mulching will substantially increase the chances of obtaining successful stands of

grasses. Side by side plot studies have demonstrated that properly mulched plots, as compared to unmulched plots, can achieve up to 80% greater grass cover in just one growing season! Therefore, it makes a lot more sense to apply the mulch during the initial seeding program rather than risk the chances of more expensive remedial seedings later.

Some of the most beneficial aspects of mulches are:

1. Anchored mulches greatly assist in soil stabilization, immediately reducing wind and water erosion.
2. Mulches reduce soil temperatures, decreasing soil moisture evaporation and heat stress upon the plants.
3. Mulches tend to capture and retain moisture, reducing soil moisture loss.
4. Mulches capture blowing snow, increasing the effective capture of winter precipitation.
5. As mulches decompose, valuable organic matter becomes incorporated into the soil.
6. The greater the fiber length of the mulch the more effective the mulch is at providing its benefits.
7. Seeds present in native grass hay and even straw will germinate and provide additional plant materials for reclaiming bare sites (Brammer and Theisen, 1982).

The choice of mulch treatment or product is determined by site characteristics, availability of products, costs and effectiveness. The effectiveness of a mulch is roughly related to the size and shape of the mulch particles. Long, narrow particles are superior to finely ground products. Costwise, straw and hay offer the best results in both protection and encouragement of plant growth if resulting weeds or fire hazards are not a concern. In most situations where site conditions do not prohibit such techniques, drill seeding and dry (straw or hay) mulching are the most cost-effective means of revegetating a site.

The time of planting may also determine the success of a dryland seeding. Theoretically, dryland plantings should be accomplished prior to when the highest probability of rainfall is expected for the climatic zone. Ideally, this means that all planting would have to take place at the same time of the year. However, work schedules or timing of construction does not always allow for that. A landscape or reclamation contractor cannot be everywhere at once.

Most dryland seeding specifications call for early spring or late fall dormant plantings. These may be the safest times to seed, but successful plantings can take place at any time of the year. Probably the

most dangerous months for seeding in the lower elevations of Colorado are June through September, although conditions may be ideal during wet summers, especially if warm season species are in the seed mix. Conversely, in the high country seeding can be accomplished whenever the soil is free of snow, not frozen or muddy. This normally occurs during the period of late spring through fall, until the first big snows. Of course, during very dry summers, it may be wise to hold off until the fall for dormant seedings.

In the lower elevations during the winter months, frozen ground may bring all seeding operations to a halt. However, during mild winters conditions may be ideal for dormant seedings. In fact, when conditions are acceptable, the author favors winter and early spring plantings over fall plantings because the site will be subjected to fewer erosive events such as high winds, rain and snowstorms prior to seed germination. In other years, conditions may prohibit seeding until well into May or even June. It is important to use good judgment and not be tied to inflexible seeding dates. Soil and weather conditions and not just the time of year should dictate the proper course of action.

Dry mulches such as hay and straw can be applied with specially designed spreaders (blowers) or spread by hand. Commercial mulch spreaders or straw blowers using conventional bales under field conditions with a crew of four may be expected to apply up to 10 tons per hour at a distance of up to 70 feet. Large bale spreaders may put down six to eight tons per hour at a distance of up to 40 feet, but this is accomplished with only one operator. The basic limitations with big bale machines are their inherent lack of uniform coverage, they cannot be used on appreciable slopes and are not effective in small areas.

Of great importance is the quality of the mulch material to be applied. Material which is baled long is preferable to short baled material. Extremely dry material is undesirable because it will shatter too easily while going through the blower, resulting in very short fibers with lots of powder. Wet or moldy materials will exit the blower as "bird nests" which are of little mulch value. They also have the potential of plugging up the machine. The greater the length of the applied material the more effective it will be as a mulch. This can be controlled in most blowers by adjusting or removing the flail chains to increase fiber length.

Finally, when using hay mulches, alfalfa should be strictly avoided because of its tendency to powder when going through the machine. Remember, material to be crimped should be relatively long so as to be incorporated into the soil effectively and still leave tufts or whisker dams.

Crimping is accomplished with commercial implements (crimpers) which utilize blunt, notched, coulter disks which are forced into the soil by a weighted tractor-drawn carriage. Crimpers will not penetrate hard soil so it is imperative to have good soil preparation to insure adequate anchoring of the mulch into the ground. Agricultural disks

are sometimes utilized to anchor straw or hay but are of questionable value. Disks are implements designed for plowing. The sharp disks on these implements tend to chop up the mulch fibers as well as plowing them into the ground. This effectively minimizes the mulch effect that is trying to be accomplished.

On relatively steep slopes, crimping becomes difficult and a variety of nets have been designed to hold dry mulches in place: twisted-woven kraft paper, plastic netting, poultry netting, concrete reinforcing wire, and jute. Price and the length of service required determine the product that should be used. All of these netting products must be anchored at enough points (stapled) to prevent lifting by wind or washouts from overland water flow.

The most common method of holding dry mulches on slopes is the use of a tackifier. This method may be used on relatively steep slopes which have limited access and soil too hard for crimping. The original tackifier was asphalt emulsion applied at 200-500 gallons per acre either on top of the mulch or applied simultaneously during the mulch spreading operation. In recent years, asphalt has fallen into disfavor because of its unsightliness and carcinogenic properties.

Wood fiber, or newer products used in combination with wood fiber, have been demonstrated to be equally effective, less in cost, and environmentally more acceptable (Kay 1978). Although wood fiber alone is effective as a short-term tackifier, a glue must be added to give protection for more than a few weeks. Currently, the most popular glues being used are organic tackifiers derived from extracts of guar, seaweed and psyllium (*Plantago*) plant materials.

These wettable powders have been shown to be viable alternatives to anchoring mulches with netting techniques. A savings of \$2500 to \$4300 per acre may be realized by tacking mulches with an organic tackifier in lieu of nettings (Brammer and Theisen, 1982).

Using standard hydromulching equipment, an organic tackifier-hydromulch solution may be mixed on site and applied as an overspray on top of the mulch. Wood fiber is an essential addition to most hydraulically applied chemicals, including straw tackifiers. Many soil-binding chemicals will not hold seed, fertilizer or straw to a slope unless wood fiber is included (Kay 1978). In order to insure a homogeneous slurry, it is important to utilize hydromulch composed of virgin wood cellulose fibers of a consistent texture that disperses evenly and remains suspended in agitated water. Manufacturers' recommendations must also be strictly followed to insure the proper proportion of components including water. Using the proper amount of water per load or acre insures optimal stickiness and that the mulch will not only be glued to itself but also glued to the soil.

Another class of hydraulically applied erosion control agents is inorganic soil stabilizers. Soil stabilizers come in several forms,

but the majority of products are plastic emulsions such as polyvinyl acetates (PVA), vinyl acrylic copolymers, copolymer acrylates, and styrene butadiene (SBR). They are basic ingredients in paints and glues and are composed of high-molecular weight polymeric particles dispersed in a continued aqueous phase.

Especially popular in California, plastic emulsions have effectively bound surface soil particles for protection from wind and water erosion for over 20 years. Their inherent resistance to ultraviolet radiation seems to greatly assist their longevity under field conditions. For this reason plastic emulsions have been used as longer-term tackifiers, and they are unsurpassed for dust control on static sites. Their use in revegetation has been somewhat limited by relatively high costs and the difficulty of working with liquids in the field. Also, these products will not perform in cold weather and will not withstand traffic.

A liquid, organic, humate soil stabilizer that can be applied in cold weather, one which will withstand vehicular traffic and shows promise as a tackifier, has recently entered the marketplace. In addition, it has been shown to be beneficial to plant life. It remains to be seen if this product, as well as the other soil stabilizers, will be effectively utilized for revegetation in our area.

Labor-intensive installation of nettings and the logistics of transporting bulky materials to the reclamation site can in many instances be superseded by using hydromulch equipment. Of course, there are situations where netting techniques should be employed. Sites with access restrictions are an example. Hydromulching machines may not be capable of reaching the tops of long slopes. Other sites may be too rough, too steep or otherwise limit the travel of hydromulchers. In such instances, netting treatments may be the only feasible method for critical erosion abatement.

The terrain of some sites may also be conducive to netting techniques. On very steep 1:1 or very rocky slopes or extremely windy sites, nettings may be necessary to hold the mulch in place. Still other sites may lack the necessary access to the large quantities of water required for mulch tacking. More will be said about nettings later in this article.

Hydromulching is the practice of applying a ground wood fiber or paper product in a water slurry with a specially designed machine (hydromulcher). This same slurry may also contain seed, fertilizer, organic tackifiers, soil stabilizers, growth regulators, soil amendments, etc., and is popular because of low labor requirements. Hydromulches must have a particle size small enough for easy pumping through 0.5-inch nozzles and must not be too buoyant to remain in suspension with moderate agitation. Due to the particle size restraints, hydromulches cannot provide nearly the "mulch effect" exhibited by the longer-fibered mulches such as hay and straw. However, short-fibered hydromulches will adhere more readily to steep slopes than dry mulches. Their tenacity is greatly enhanced

by the addition of organic tackifiers, soil stabilizers, and synthetic fibers.

Used most commonly for hydromulches are specially manufactured fibers of alder and aspen. Other wood species are utilized but often are more difficult to pump. Of even shorter fiber length are products composed of recycled materials such as newsprint and corrugated boxes. Recycled hydromulches have become increasingly popular because of their relatively low cost, but their performance in the field has been questionable. The most important quality of a hydromulch is that it must adhere to the soil even on steep slopes and hold the seed in place during heavy rainfalls and strong winds. If it fails in those functions, other characteristics (water-holding capacity, appearance, cost, etc.) simply do not matter. To quote Burgess Kay (1978), "Commercial materials made of office waste, newsprint, and seed screenings are vastly inferior... the performance of recycled products could probably be improved if more attention were paid to fiber length." In fact, the new synthetic fibers on the market have been shown to dramatically improve recycled wood cellulose mulches.

Another major problem with newsprint and cardboard hydromulches is their tendency to "mache" or harden, inhibiting seedling development. This is especially a problem in drier climates.

In recent years, several short-fibered wood hydromulches have come and gone from the marketplace. These sawdust-type mulches lack the fiber length to provide much in the way of erosion resistance and insulation value and often wash away with the first wind and rainstorms. Only the addition of large amounts of tackifiers can increase the holding power of these wood fiber mulches. Unfortunately, they meet many of the virgin wood fiber specifications being generated and only the inclusion of minimum fiber length requirements into the specifications will eliminate these unacceptable mulch products.

Although seed, fertilizer and hydromulch may be applied in one operation, this practice has been generally discounted because of the likelihood of the seed being suspended in the mulch and thus not in contact with the soil (Fraser and Wolfe, 1982). On dryland sites, such an approach can elicit "plant suicide" when the seeds germinate in the moist hydromulch, and their roots never even make it into the ground before they burn up in the hot sun. A more logical approach is to put the seed and fertilizer down first, bury them, and then follow with the hydromulch and any other additives.

Commercial fibers are usually dyed with a fugitive green dye which should last for a few days. This visual aid assists in obtaining a more even distribution of products. In fact, it is not a bad idea to mix small amounts of wood fiber with the seed during the seeding sequence for better visual metering of the seeding. In addition, wood fiber acts as a carrier for seed, allowing the operator to shoot farther and more evenly than with pure water.



Application rates generally range from 1500-2000 pounds per acre, although it takes nearly 3000 pounds per acre to begin to attain a true "mulch effect." Unfortunately, 3000 pounds per acre is usually cost-prohibitive.

One area where hydroseeding/mulching is rapidly gaining popularity is for turf and wildflower installations. Now that we are finally becoming more water conscious, there has been a renewed emphasis on using native or drought tolerant grasses for turf establishment. Hydroseeding/mulching allows for the effective blending of various grass species for turf or native grass establishment at a fraction of the cost of sodding. Another benefit is that hydromulches contain no weed seeds. Using hoses, operators can reach those hard-to-reach areas so common on commercial or residential projects.

Currently, there are several types of nettings and erosion control blankets on the market. Most common are jute, excelsior blankets, woven paper or plastic fibers, blankets composed of straw and/or coconut fiber, and polypropylene netting. All of these products are provided in rolls and must be fastened to the soil with wire staples at rates of one to two staples per square yard. Fiberglass roving (which is blown on with compressed air and tacked with asphalt emulsion) is also available as a nonbiodegradable substitute.

The use of these products is limited by their cost and effectiveness. They have the advantage of being weed free but may be unsightly, a fire hazard, or (in some cases) nonbiodegradable or too rapidly biodegradable to be effective. Installation of these rolled up products is extremely labor intensive and may cost up to four times that of tacked straw. Other limitations are that some of these products may not conform to rough surfaces or rocky areas, and erosion beneath these products is common if soil contact is not maintained. Another problem is "tenting" or "parachuting" when weedy species literally lift the nettings off of the ground. These problems can be countered with extensive stapling or anchoring and by the installation of trenches as check slots or edge anchors.

The most successful nettings should have enough weight and flexibility to maintain good soil contact. Through the years, jute and excelsior have been the most effective netting products. Because of its flexibility, jute has been shown to be the most effective product on rocky sites, particularly when hay or straw are placed beneath it.

Excelsior has always been an attractive product because a weed-free mulch covered with a polypropylene netting can be laid down in one step. Excelsior is generally preferable on more manicured sites. The new double-netted and/or high velocity excelsior products have shown to be effective on steeper slopes and ditches with moderate water flow rates.

Probably the fastest growing netting concept for less critical sites is to simply use the polypropylene netting on top of hay or straw. This

method is particularly well suited to large areas to be netted, such as long slopes which are inaccessible to hydromulchers. It is also favorable in high wind areas where organic tackifiers may be ineffective. Of course, this method is very desirable in areas accessible to mulch spreaders but too steep or rocky for crimping, such as highway or ski slopes and mine benches. This lightweight netting comes in rolls which are 10-15 feet in width, weigh only 120 pounds and will cover an acre or more. Installation of this product is less labor intensive than traditional netting products.

Showing considerable promise in the future are the straw and/or coconut blankets. Both field and laboratory testing have demonstrated that these products have the potential to provide superior erosion control protection over any organic blankets currently available on the market. Utilizing two of nature's finest mulches, straw and coconut, these blankets are single or double netted and stitched, inhibiting movement of the mulch. Both straw and coconut allow water to pass through them and then trap the moisture in the soil. These fibers do not absorb appreciable amounts of water as do wood mulches, and they tie up less nitrogen during decomposition than wood fibers. The coconut fibers break down very slowly (five to seven years) providing for longer-term erosion protection. Depending upon the composition of these blankets, they can afford erosion protection on sites of considerable flow rates (velocities up to 12 feet per second). Of course, you get what you pay for and, not surprisingly, the pure coconut blankets can cost up to three times that of lower-end excelsior products. However, they have opened up new cost-effective niches in the revegetation industry.

Well, at this point, it would be safe to say that if none of the previously mentioned products or techniques will establish vegetation, then it is time to begin using riprap, gabions, slope paving or concrete channels for erosion control, right? Not necessarily so! There are two new and exciting concepts for controlling erosion in areas of even higher water flow velocities. Erosion control and revegetation mats (ECRM's) are three-dimensionally nonbiodegradable mats composed of polyethylene, nylon or vinyl monofilaments fused into a continuous matrix. Soil confinement systems or geocells are expandable honey-comb structures used to confine cohesionless or unstable soils, sands or gravel.

ECRM's are designed to work in a markedly different manner than traditional erosion control products. ECRM's are rolled out, staked or stapled into the ground, edge-anchored and check-slotted just as traditional nettings are installed. Seed, fertilizer and soil amendments may be added before or after the mat is installed, although it is probably best to seed both before and after installation.

The mat begins to act as a mulch, trapping moisture and reducing raindrop impact. Then the mat protects the young seedlings until their roots begin to wrap around the mat material. All the while, the mat captures sediments from runoff and begins to accumulate organic matter

until it disappears from view. As the vegetation becomes more dense, the soil, root and mat matrix continues to strengthen. The standing vegetation acts to slow down flow velocities, further reducing erosion potential at the point of installation as well as downstream. Because these products are nonbiodegradable, these are permanent installations.

Soil confinement systems work in a dramatically unique fashion in that strength or stabilization by confinement is achieved by a series of three-dimensional cells up to eight inches deep. When expanded into position, the polyethylene or polyester cells have the appearance of a large honeycomb, one of nature's most efficient structures. The cells are then backfilled with soil, sand or gravel, depending upon application. For revegetation, the soil-backfilled cells are then seeded, fertilized and covered by either hydromulch, a dry mulch with a tackifier or an organic erosion control blanket. The mulches provide surface protection while the cells greatly reduce the chances of subsurface failure.

Research on both ECRM's and soil confinement systems suggest that these products may withstand flow velocities from 10 to 20 feet per second depending upon substrate. Above 15 feet per second is whitewater! Surely these types of products have a bright future in the rehabilitation of channels, ditches and wetlands. This is one aspect of revegetation that sorely needs improvement, and considerable research is being devoted to this aspect of erosion control.

One should not be alarmed at the high cost of these products. They are not designed to be used in place of or to compete with our more traditional revegetation techniques. They are designed to be a cost-effective, aesthetically pleasing alternative to featureless rock, asphalt and concrete structures. Remember these products the next time you are looking at a cobble-lined or riprapped channel and then compare prices. It will be interesting to note the upcoming development of ECRM's and soil confinement systems in both the erosion control and landscape industries.

I have briefly touched upon all of the major erosion control techniques currently being utilized in the Rocky Mountain region. You may say to yourself, I still do not know when each technique should be properly used in any given situation. Several of these treatments have considerable overlap as to where they may be used. The bottom line is how much does each treatment cost on a relative basis and what are its limitations. The idea is to minimize both "overkill and underkill." Field experience and on-site experimentation will enable you to fine tune your cost-effective determinations. But remember, always keep an open eye to new products and techniques because "you ain't seen nothin' yet!"

With the assistance of David Chenoweth of Western States Reclamation, Inc., of Broomfield, Colorado, and Stuart Cameron of Randall and Blake, Inc., of Littleton, Colorado, I have prepared a table which summarizes a variety of erosion control techniques. This chart, adapted from earlier tables developed by Burgess Kay (1976) and Theisen (1986), describes

**TABLE 1: SUMMARY OF METHODS AND COSTS OF COMMON EROSION CONTROL PRACTICES**

TREATMENT	COMMENT	POTENTIAL FOR EROSION CONTROL & REVEGETATION SUCCESS *	APPROXIMATE \$ COST PER ACRE
1. Seeds and fertilizer broadcasted on the surface, no soil coverage or mulch.**	Not very effective except on rough seed beds with minimum slope and erodibility. Should be used only in areas inaccessible to machinery.	1	280 - 400
2. Same as #1, seed buried**	More effective than #1 and worth the extra cost for seed burial.	2	320 - 450
3. Drill seed (assumes seed buried & fertilized), no soil preparation or mulch.	Fast and far more cost-effective than broadcast methods. Should be utilized wherever drill seeding equipment is accessible.	3	185 - 250
4. Same as #3 with soil preparation.	Soil preparation is well worth the investment.	4 - 5	225 - 275
5. Hydroseed, fertilize and wood fiber hydro-mulch at 1600#/acre using one-step method. **	Not worth the cost and should be avoided due to the danger of "plant suicide." Hydromulch provides only a minimal mulch effect.	2	800 - 1000
6. Same as #5 using two-step method, no seed burial.**	Acceptable method on slopes, tight areas, or for turf and wildflower establishment.	3 - 4	825 - 1100
7. Same as #6, seed buried.**	Well worth the cost for seed burial. Slope seedings need all the help they can get. Not feasible on very steep slopes.	4 - 5	900 - 1200

TABLE 1 (Cont.)

TREATMENT	COMMENT	POTENTIAL FOR EROSION CONTROL & REVEGETATION SUCCESS *	APPROXIMATE \$ COST PER ACRE
8. Same as #6, add organic tackifier at 100#/acre to hydro-mulch.**	Tackifiers worth the investment on steep slopes, windy or highly erodible sites. No increase in labor or machinery costs.	5 - 6	1050 - 1350
9. Same as #6, add plastic soil stabilizer at 30 gal/acre.**	Good for longer term tackifier requirements. Liquids may be difficult to use in remote areas and in cool weather.	5 - 7	1200 - 1600
10. Drill seed, fertilize, soil preparation and dry mulched with hay at 1½ T/acre or straw at 2 T/acre, mulch crimped in.	Use whenever site conditions allow. May be effectively utilized on slopes 3:1 or greater. Windy sites may be a problem.	5 - 7	500 - 800
11. Hydroseed, fertilize, dry mulch at same rate as in #10. Tacked with organic tackifier at 100#/acre and hydromulch at 150#/acre with water at 700 gal/acre.**	Cost-effective method for anchoring dry mulches on relatively steep slopes. High wind sites still a problem. Far less expensive than nettings.	5 - 7	900 - 1200

TABLE 1 (Cont.)

TREATMENT	COMMENT	POTENTIAL FOR EROSION CONTROL & REVEGETATION SUCCESS *	APPROXIMATE \$ COST PER ACRE
12. Broadcast seed and fertilizer, dry mulch as in #11. Anchor mulch with plastic erosion control netting.**	Cost-effective netting technique for noncritical slopes. Green netting may break down too quickly on south facing slopes. Long lasting netting has a greater visual impact.	5 - 7	2200 - 3200
13. Broadcast seed and fertilizer, anchor with excelsior erosion control blanketing.**	Good, weed-free mulch adapted to small areas. Green netting still a problem. May not maintain good soil contact on rocky sites. Possible fire hazard. Moderate visual impact. Double netted products provide more protection.	6 - 8	4000 - 6000
14. Broadcast seed and fertilizer, anchor with straw erosion control blanket.**	Lower visual impact. Possible fire hazard. Better soil contact. Mulch and netting are seamed together. Slightly better erosion protection.	6 - 8	4000 - 6000
15. Broadcast seed and fertilizer, anchor with jute netting.**	Good treatment on rocky sites. Possible fire hazard. Higher visual impact. Smolder-resistant jute available.	6 - 8	6400 - 7400
16. Broadcast seed and fertilizer, dry mulch as in #11. Anchor with jute netting.**	Same as #14. Dry mulch below jute improves soil contact and often is a good investment.	6 - 8+	6700 - 7800

TABLE 1 (Cont.)

TREATMENT	COMMENT	POTENTIAL FOR EROSION CONTROL & REVEGETATION SUCCESS *	APPROXIMATE \$ COST PER ACRE
17. Broadcast seed and fertilizer, anchor with double netted straw and/or coconut erosion control blanketing.**	Lower visual impact. Good soil contact. Mulch and both layers of netting sewn together keep the mulch from moving.	7 - 9	6000 - 9000
18. Broadcast seed and fertilizer, anchor with double netted coconut erosion control blanketing.**	Very cost-effective alternative to protection such as rip-rap, cobble and trickle channels, concrete lined channels and slope paving. Non-permanent treatment. Coconut fiber will degrade in 5-8 years.	8 - 9+	8500 -11,000
19. Broadcast seed and fertilizer, anchor with an erosion control and revegetation mat.**	Permanent, nonbiogradable treatment. Cost-effective alternative to armored protection. Due to high costs, ECRM's must be used judiciously.	9 -10	30,000 -43,000
20. Backfill soil into 4" web structure Broadcast seed and fertilizer, cover with hydromulch, dry mulch with tackifier or organic erosion control blankets.**	Most complete and effective vegetative erosion control approach on the market. May also be used with rock and/or gravel. Expensive but still a cost-effective alternative to armored protection.	9 -10	45,000 -60,000

\* 1 = minimal

10 = Excellent

\*\*Assume double seeding rate whenever broadcasting or hydroseeding.

each technique with applicable comments, assigns relative values for erosion control and revegetation potential, and gives current per acre prices for each treatment. Mr. Cameron and Mr. Chenoweth helped in providing the cost estimates only. I am solely responsible for any comments and the relative values for erosion control effectiveness.

The cost estimates were based upon fixed per acre seed, fertilizer and dry mulch costs, as well as comparable project sizes. Hydromulch, tackifier, soil stabilizer, netting and matting costs were based upon current market prices. Caution! These numbers are for comparison only and should not be used for estimating purposes in any particular project! For erosion control cost estimates in specific situations, always seek the assistance of an experienced and qualified reclamation consultant and/or contractor. Questions regarding this article or the erosion control chart should be directed to the author.



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ALPINE SKI SLOPES, THE CAUSES OF THE PROBLEMS,  
AND POSSIBLE WAYS OF REHABILITATION  
WITH THE HELP OF SPECIALTY FERTILIZERS

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GENERAL ASPECTS

Since ever larger areas are being used for skiing, the resulting environmental problems are becoming more and more severe. Today, nobody can deny that on many ski slopes vegetation has been largely reduced, which means not only a considerable loss of scenic beauty, but also increased danger of water erosion.

In Europe, the methods of landscape modeling have changed completely within the past few years. Today, alterations to the terrain are limited to small areas, and the bulldozer has largely been replaced by the back-hoe. Thus, no humus is lost and any unnecessary destruction of the natural soil structure is avoided. As to the seed material used, special attention is paid to the selection of lawn-forming grasses, and the species to be employed are chosen only after investigating the local flora.

Many of today's recultivation techniques are successful in the beginning. Later, however, symptoms of degeneration can often be observed: The vegetation carpet is stunted, leaving the soil exposed to water and wind erosion. Therefore, products will have to be found which guarantee a continuous development of the soil.

THE CAUSES OF THE PROBLEMS

Originally, ski slopes were constructed almost exclusively with the help of bulldozers. The results were not very encouraging. Often, the valuable humus cover was buried under a layer of one or several feet of humusless raw soil poor in nutrients. Without human intervention it would take centuries for a closed plant cover to develop at such sites. Apart from using bulldozers, which had a completely devastating effect, another mistake was made by employing only cheap seed material which was not adapted to the local requirements. In addition, the application of mineral fertilizers prevented the immigration of autochthonous species, which do not like saline soils. Autochthonous plants require less nutritive substances, however, these have to be supplied at the constant rates throughout the entire vegetation period. As can be seen from Table 1, undisturbed alpine soils have extremely high humus contents, and therefore, great nutrient resources (Naschberger, S. and Köck, L., 1983). Thus, a continuous nutrient supply is guaranteed under normal

Table 1: TYPICAL ANALYTICAL VALUES OBTAINED FROM GRADED (SKI SLOPES) & NATURAL, UNDISTURBED SOILS

SKI AREA	Humus (org.s.) (%)	pH (0.1 KCl)	Phosphoric mg./100 g. of soil	Potassium mg./100 g. of soil	Magnesium mg./100 g. of soil	Soil Type
St. Anton Valluga 6,930 ft.*	13.2	5.7	2	15	30	Brown Earth Natural Undisturbed
St. Anton Valluga 6,930 ft.*	0.9	7.6	2	3	5	Graded Ski Slope
Canada Panorama-Invermere 5,280 ft.*	1.0	5.4	2	6	15	Graded Ski Slope
Colorado, USA Vail 10,560 ft.*	1.6	5.9	6	11	19	Graded Ski Slope

\* Above Sea Level

climatic conditions. This explains why mostly the natural, local flora is rich in species and grows without fertilization. Through the grading, however, the high humus content is lost almost completely; in most cases less than ten per cent (10%) of the original content is left. There are also considerable losses of potassium and magnesium. Only the pH is slightly improved as soil layers with a higher calcium content are brought to the surface. To improve growth conditions permanently, it is primarily necessary to achieve a lasting increase in humus and, in close connection with this, a biological activation of the soil.

### CONSTRUCTION AND SEEDING

The first important step has to be made when shaping the terrain. Alterations to the terrain should not involve deeper soil layers and ski slopes should not be larger than is absolutely necessary.

The best method of conserving the humus is the following: Removal of the humus and deposition along the edges of the construction site with the help of a back-hoe, shaping of the raw soil underneath, distribution of the humus, and construction of sufficient ditches to drain off surface waters.

An expert in pedology and plant breeding should be consulted, at the latest, after the main grading work has been done. Soil improvement agents, fertilizers, and seeds should be chosen only after the soil has been analyzed. For acid soil, a lime fertilizer or magnesium lime would be recommendable. As a rule, the products employed should act slowly but permanently. Lime and magnesium fertilizers are most effective when applied in the form of carbonates. Abrupt changes of the degree of acidity in the soil should by all means be avoided; a value of 5.0 to 5.5 will suffice. Otherwise, the local plants would find it extremely difficult to immigrate, as they prefer acid soils.

The selection of the most appropriate seed materials also require expert knowledge. Not only should unpretentious, resistant species be chosen, but also, those that enable the rapid formation of a closed vegetation carpet during the initial stage. Species forming deep, and/or far-reaching, root systems have the special function of permeating and thereby activating the subsoil and of binding the topsoil to the underlying layers. The exact composition of the seed mix can only be determined with the help of an expert familiar with the local conditions of the corresponding region.

Up to now, ski slope fertilization has often been limited to the more or less regular application of mineral fertilizers. This method is unobjectionable in low areas and on soil with high humus content. However, on raw soils and ski slopes at exposed and more elevated locations, the application of special fertilizers is required.

Based on experiments started as early as 1974, an organic fertilizer consisting of microbial biomass was developed. This product, which has been commercialized under the trade name of Biosol, has a number of specific properties which make it superior to other fertilizers. The most important of these properties are indicated below:

Biosol has a content of organic matter of more than seventy per cent (70%). Organic substances are the "raw material" for the development of humus. As shown in experiments carried out in Obergurgl, Austria, at 8,580 to 9,240 feet above sea level, the regular application of Biosol leads to an annual increase in humus of two-tenths to three-tenths per cent (0.2 to 0.3%).

Biosol contains only organically fixed nitrogen, which is released through microbial activity depending on the temperature and the moisture content in the soil. Therefore, the nitrogen acts slowly and in accordance with the demand of the plants. Even in the second year, the effect is still clearly noticeable. The fertilizer may be applied at any time of year except when the ground is covered with snow.

From Table 2, it can be seen that the product is completely safe in terms of hygiene. It is also shown that it does not contain inadmissible amounts of heavy metals, and that it does not cause any damage even if applied in high doses. As Biosol is a by-product of penicillin fermentation, it is also important to make sure that residual antibiotic is contained.

Figure 1 shows the effect of the fertilizer on the respiration activity of the soil microorganisms. As was proved in field trials, the effect is still clearly measurable one year after fertilization (Insam, H. and Haselwandter, H., 1985).

Biosol not only activates the soil microorganisms permanently but also increases the number of other small organisms living in the soil. Thus, the soil becomes biologically more active and consequently more dynamic and healthy.

Figure 2, also shows the superiority of microbial biomass fertilizer. After nine (9) applications carried out at regular intervals, a plant density of almost one hundred per cent (100%) has been obtained. On the contrary, with the mineral fertilizer, a success was achieved during only the first season after fertilization.

#### VEGETATION TECHNIQUES, FERTILIZATION, AND MAINTENANCE

On flat ski slopes, only seed material (132-176 lbs./acre) and Biosol (1584-1760 lbs./acre) have to be applied. These two materials should be lightly worked into the topsoil. If necessary, magnesium and lime (880-1320 lbs./acre) will have to be added.

Table 2: BIOSOL-CERTIFICATE OF ANALYSIS

1) Microbiological Examinations

According to the results obtained, Biosol is completely safe with regard to hygiene.

2) Contents of Heavy Metals

These are far below the tolerance limits for fertilizer.

3) Residual Penicillin

No penicillinase-sensitive penicillin detectable (detection limit 0.02 µg/g).

4) Value Determining Components

Water content (%) in the DS	5.5
Organic substances (%) in the DS	80.0
Nitrogen (%) DS, organically fixed	6.5
P <sub>2</sub> O <sub>5</sub> (%) DS	1.7
K <sub>2</sub> O (%) DS	3.8
Mg (%) DS	1.3
Ca (%) DS	3.1
Fe (ppm)	212.0
Mn (ppm)	14.0
Cu (ppm)	12.0
Zn (ppm)	55.0
Co (ppm)	5.0

Trace elements

Vitamins

Siderophores

5) Compatibility for Plants

1% of Biosol mixed into a standard substrate mixture is completely harmless to garden cress.

Figure 1: CHANGES IN THE QUANTITY OF MICROBIAL BIOMASS IN RENDZINA  
Institute of Microbiology of the University of Innsbruck

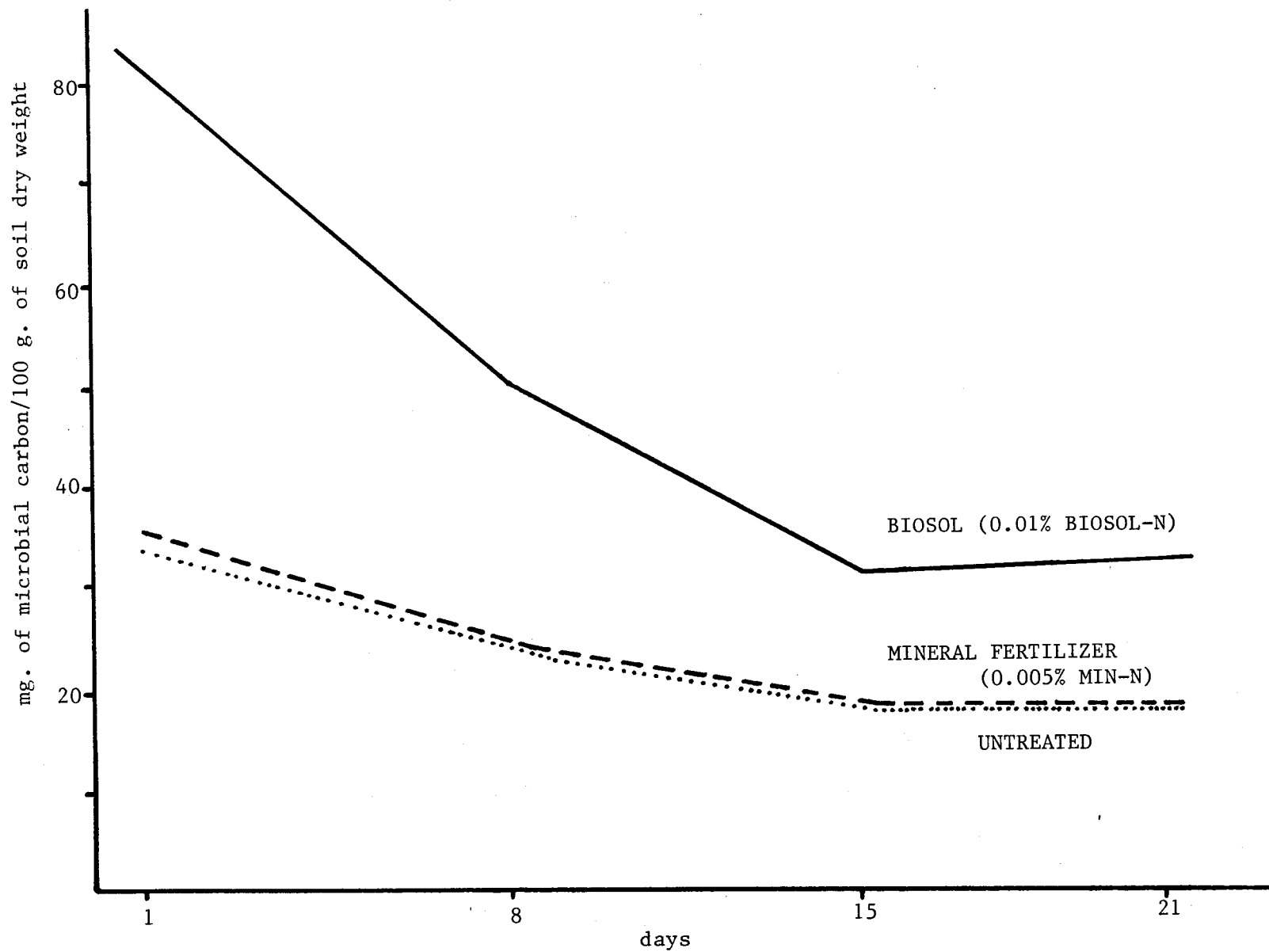
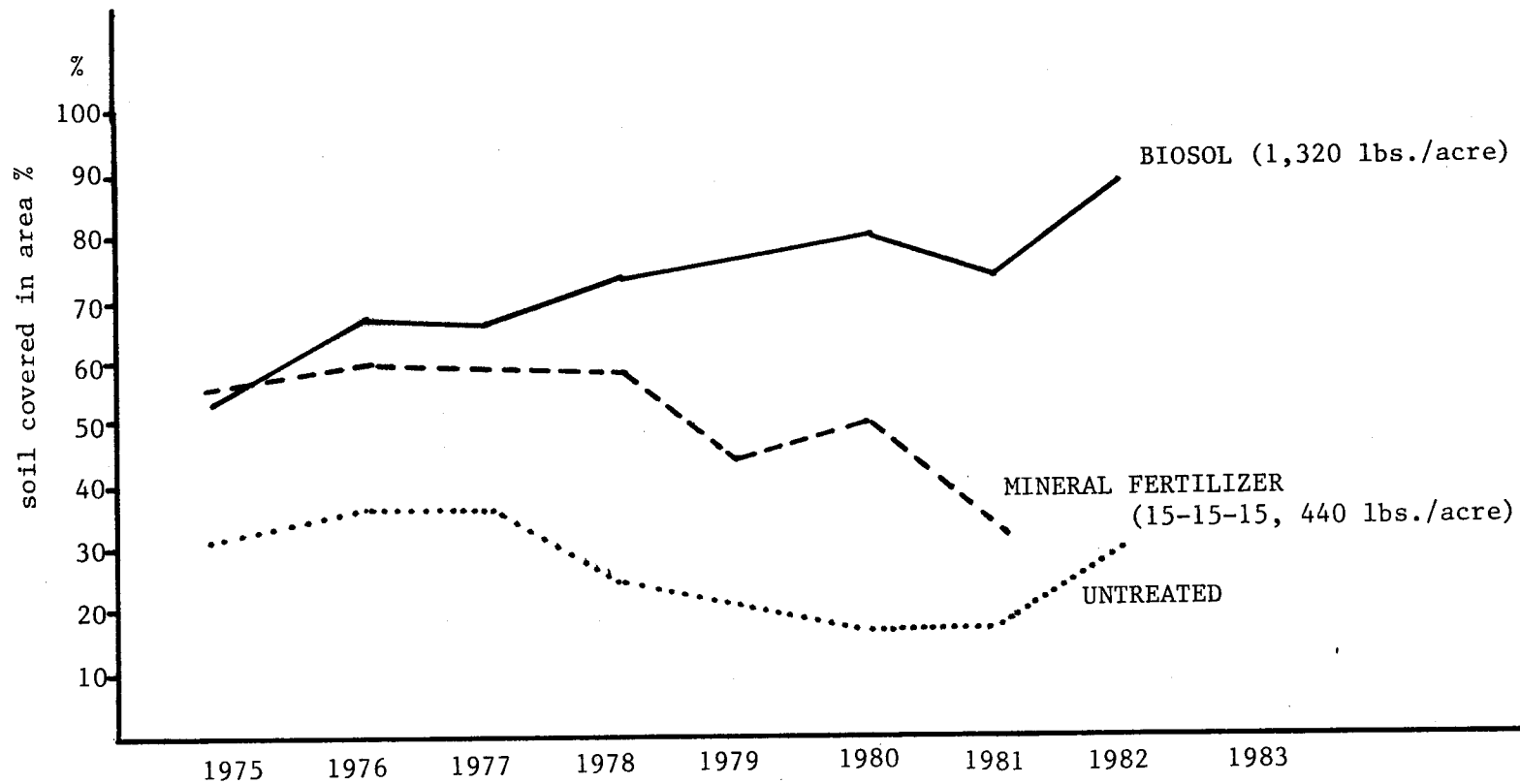


Figure 2: FERTILIZATION EXPERIMENTS ON SKI SLOPES  
Landesanstalt für Pflanzenzucht und Samenprüfung, Rinn  
(Institute of plant breeding and seed control of the Tyrol in Rinn)





In the past, straw and bitumen were often employed for steep ski slopes. This method is still successfully used at extreme sites such as steep, south-facing, and stony slopes, and sites with an extremely low humus content. It has been shown that here, too, vegetation would be more effective if organic fertilizers were applied.

Today, hydroseeding with Biosol and Terravest (a soil stabilizer) is becoming more and more popular. For hydroseeding, the following components are required:

Seeds	132-	176	lbs./acre
Terravest Soil Stabilizer	88-	132	lbs./acre
Biosol	1,320-	1,760	lbs./acre
Water	728-	1,040	gals./acre

According to requirements, magnesium or lime fertilizers (880-1320 lbs./acre) have to be added. This method is inexpensive in terms of labor, and in most cases, the results obtained are better than those of conventional methods.

It is a widely held opinion that ski slopes need not be fertilized for the simple reason that natural vegetation does not need any foreign nutrients to grow. The seed mixes available for vegetation purposes contain the seeds of selected agricultural species which require specific minimum amounts of certain determined plant nutrients. Without fertilization the plants at the vegetation site would "die of hunger" in the course of several years. Only since ski slopes have been fertilized regularly, has a lasting effect been achieved. The breakthrough, however, was not made until slow-acting organic fertilizers were employed. Such fertilizers increase the biological activity of the soil, which leads to higher fertility. Consequently, higher yields and healthier plants are produced.

The application rate of Biosol is very high initially, 1320-1760 lbs./acre. However, after only a few years, an amount of 440-880 lbs./acre will suffice. The first fertilization trials carried out in Vail, Colorado, have shown that in areas with little precipitation, the initial application rate need not be higher than 880-1320 lbs./acre. The reason for this is to be seen in high potassium and magnesium values. The fact that with the regular application of a suitable organic fertilizer, smaller and smaller application rates are required, implies that the soil must have improved. Soon the intervals in between fertilizations can be prolonged to two (2) or three (3) years.

Other suitable maintenance measures are grazing and mulch mowing. In Europe, ski slopes are frequently used for grazing cattle and sheep. Some ski area companies maintain their slopes by means of mulch mowing: In late summer, the grass is evenly cut and finely chopped with the help of special apparatus. Both grazing and mulch mowing are aimed at increasing the plant density. The desired vegetation goal is a lawn similar to that of sport grounds.

The vegetation carpet of a ski slope can also be improved indirectly by applying an artificial snow cover. The first examinations have shown that the snow prevents deeper soil layers from freezing and plants, especially their epigeous parts and root collars, from being damaged through the impact of mechanical forces eg: ski edges.

Afforestations along the edges of the ski slopes are yet another measure by which ecological damage resulting from construction work can be minimized. Here, it is often necessary to plant coniferous, woody plants in raw soil. Without fertilization only stunted plant growth can be expected during the initial stage; in most cases the plantlets would even die. Experiments in the greenhouse and in the field showed that in such soils Biosol leads to an excellent development during the initial stage (Glatzel, G. and Fuchs, J., 1986). According to the experiments made so far, no danger of the root corrosion has been experienced.

Another field of application of the microbial biomass fertilizer is the revitalization of old forest stands affected by environmental pollution. According to the results obtained in the latest experiments, Biosol not only improves the health of the plants dramatically but also increases wood production considerably. For forests which have a protective function either for whole skiing areas or for certain ski slopes, a revitalization might well become necessary under certain circumstances.

#### SUMMARY

For many years now, the advantages and disadvantages of creating ski slopes have been fiercely debated. Unfortunately, a trend set in Austria has often been completely ignored. From intensive research, we now have the means and methods available which enable a lasting and environmentally compatible recultivation of such extreme sites. Here, the application of selected seed mixes and microbial biomass fertilizer such as Biosol, as well as, appropriate maintenance such as mulch mowing or grazing are of decisive importance. The fertilizer, specifically developed for use at high altitudes, is also successfully employed in afforesting the edges of ski slopes, which is a popular measure. With the help of Biosol, coniferous woody plants can also be planted directly into humusless raw soil.

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THE IMPORTANCE OF THE IONS AND THEIR CAPABILITY OF EXCHANGE FOR  
THE REDEVELOPMENT OF EXTREME LOCATIONS, WITH A SPECIAL  
ATTENTION TO THE RECULTIVATION OF THE VOLCANO ASH OF  
MOUNT ST. HELEN IN THE STATE OF OREGON,\*USA

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## 1. GENERAL

Problematic areas, problematic soils or problematic locations originate from natural causes or were created and are still being created by man.

Methods have been developed in the field of erosion safety which have been improved over the years, have proved to be efficient in cultivating normal locations with no top soil.

Very often these standard methods are not sufficient for extreme locations. Pure ashes with pH values exceeding 10, tertiary dumps with pH values below 2, pure, sterile sands, or sands with high salt contents or locations contaminated with heavy metals, show distinctly that on these various substratum location specific methods are absolutely necessary. These methods must be respective to the separate situations and requirements of the location specific factors proved by site investigations.

## 2. THE SUBSTRATE

For all living creatures, whether high or low, the minimum requirements of the medium or substrate they live in must apply indispensably. Light, air, water and nutrients are an essential part of these requirements. If the substrate contains harmful factors, the life prospects of, e.g. Poaceae, Gramineae (sweet grasses) are only a question of the height and amounts of these factors which, with increasing amounts lead inevitably to DL - dosis letalis. Negative synergetic effects are usually apparent when there is a combination of two or more negative factors. It is therefore unavoidable for, on the one hand the living conditions and, on the other hand the composition and effects to be known in detail. Proceeding from this knowledge, the choice of methods to be used for, e.g. the initial cultivation of problematic grounds can be made according to the situation.

(\* MT Saint Helens is in the State of Washington - eds.)

Pollutents-salts, heavy metals etc. - must be either eliminated, reduced or, due to the lack of probate means, be transformed into chemical or physical conditions which makes them no longer available to the plants.

### 3. EARTH CHEMISTRY

Ions - from ancient Greek - electrically charged particles, develop when combinations in watery solutions separate. The positive charged particles are called "cations" because they tend to wander towards the negative anions during electrolysis. The negative charged particles are called "anions" because they are drawn towards the positive anodes. Among the electrolytic segregating chemicals, known as electrolytes, we distinguish between three large groups "acids" - "bases" - "salts".

An important colloid-chemical characteristic of earth is the capability of cation exchange. Hereby, the cations penetrating the soil (e.g. by fertilizing) kept in a form in which they are secured against washing out, but at the same time are available to the plants. The cathiodes exchange engages thus immediately into the substance household of a landscape as well as in the mineral supply of the plants. Furthermore, the exchangeable cathiodes influence the earth characteristics as well as the soil structure, the water and air household of the soil, the biological activity and the soil reactions.

Most nutrient elements in the soil are of soluble or bound form. Solubles form only an insignificant part. Approximately 98 % are contained in minerals, combinations of low solubility such as sulphates, phosphates, carbonates and other organic materials and are only released very slowly by weather and decomposition influences which makes them available as nutrients. The remaining approximately 2 % is absorbatively exchangeably bound to colloidal soil particles. These ions are - contrary to the free ones - not easily washed out. They can be absorbed by plants for ions which are exchanged for ions which the plants discharge.

Plants are capable of accepting and selecting from their medium just those ions which are preferable to them and discriminate against those which are not required (selective absorption).

All smaller soil particles which are capable of catalyst exchange are combined under the collective name of exchanger or soil colloids. They are of anorganic or organic nature and the exchange capacity varies. These mineral and organic soil particles have a large specific surface which is capable of ion absorption due to electrical charges. These mostly negative surplus charges develop, for example in clay, by the multi-valued grid atoms (Si, Al) being replaced by two and one valued catalysts. The positive charge reduced in this way (instead of Si<sup>++++</sup> resp. Al<sup>+++</sup> now e.g. Ca<sup>++</sup> resp. K<sup>+</sup>) causes a negative surplus charge.

As these negative charges are caused by the crystalline grid itself, they are always present and are known as permanent charges.

Beside this, there are also the pH dependant charges. Among these are all organic exchangers whose COOH groups and phenolic OH groups, after their release from  $H^+$  can store catalysts freely. The degree of release is strongly dependant on pH to provide negative charges. The exchange capacity of such exchange is therefore variable.

#### 4. COLLOID TECHNOLOGY IN CONNECTION WITH SILICIC ACIDS AND PHOSPHORIC ACIDS

The soil consists more or less of rough mineral particles. Very light soils, for examples rough land etc. take only a minor part in colloid dispersion. The level of particles in colloid substance and the quality are largely determined by the good and bad characteristics of the soil. The colloid characteristics of a soil are largely increased by amorphous silicic acid. The soluble silicate, as soluble humus, too, with their dispersion parts almost reach the point of molecular dispersion sphere.

Colloids at highest possible dispersion and with the greatest possible surfaces are most suitable for inserting lacking colloid substances or for preparing present colloid substances in the soil for new functions.

To imagine that the natural soil is an unchangeable system, is outmoded. With the colloid-technology we are no longer concerned whether the genetic side of a soil substrate is, for example, hydrophil or hydrophobe, but whether and how we can change these characteristics for development and plant production. Even in case of sterile sands or natural shifting sands where, according to soil scientific views, we have no structure, it is possible to achieve an agglomeration in almost colloid free substrat with specific agents.

The use of plant nutrients for decades in the form of one-sided salt additions is inadmissible as these lead to a preferential concentration of one catalyst. The best efficiency can only be achieved with highly dispersed colloid substances.

Only colloids are capable of changing their size and aggregate distances after water has been added (swelling). Colloid lacking soils are not subject to swelling due to their rough capillary structure.

A technical supplement to extreme locations demands not only supplementary materials or substances, but also additional energies. Foam plastics, for example, can generally only be used for the heterogenous structure of soils or for the minor structure of special horizons.

A profound influence on soil systems can only be attained by using activating substances which are equipped with a polarity of their own.

If, for instance, sour colloid brew is given to saliferous sands, an enlargement of the solution layers takes place and an enlargement of the viscosity of the system. With a "swollen" system, a high salt concentration in the outer solution draws water from the ion-solution in the osmotic way; thus the water sheath is reduced and the soil particle has the possibility of approaching the distance influenced by van der Waal energies. A coagulation takes place even in Na-soils and leads to structure formations.

In most extreme locations, problems occur in the pore area. The water containing pore area of sands must be enlarged. On the other hand, the air pores of power station ashes have to be expanded. The first case deals with the supplement of colloids, the second case deals with the changing of colloids.

The pore areas and the pore area contents of the soil can be influenced by colloidal silicate materials. The added colloid agents must have polarity besides greater specific surfaces.

Of further great importance to the plant during the initial stage is the avoidance of all damaging influences. It is additionally necessary during this initial stage to encourage a short initiating by applying an energetic phosphor-nitrogen combination. Organic, flow-retarding multi-fertilizers or soil auxiliary materials take over the further supply of nutrients. Here, long term tests have proved that, BIOSOL, developed by Dr. Stefan Naschberger in 1976/77, a biological-organic soil improver with well-balanced nutrients and an Austrian product, ensures long-term success and contributes immensely to lowering costs. The effects of high ion-concentration, embedded in the colloid system and being available to the plant roots, is much milder in comparison to the same concentration found in salt solutions. The ion-movement in the colloid system is slower than the ion-movement in salt solutions.

Long-term research and large area cultivation in inland, but especially abroad show that it is problematical to initiate cultivation of extreme location without soil stabilizers. These stabilizers are particularly essential on, for example, embankment slopes where e.g., grass seeds must be point fixed. From the many stabilizing products all over the world, one product has proved, by a large margin, to be the best. It is the product of Terravest, developed by the firm of Hüls AG.

## 5. MOUNT ST. HELEN, STATE OF OREGON

Finally I would like to present to you a most interesting re-development project, namely that concerning the re-development of the volcano ash of the Mount St. Helen in the State of Oregon, USA.

This volcano mountain, which, for the last time erupted in 1980 spreading ash over an area of more than 40.000 ha and covering this surface with a layer of 2 to 3 m thickness, causes increasingly more and more problems, since this ash is - by precipitation water - contaminating the water of the rivers. Standard methods of re-development have failed.

In September, 1986, I took soil samples of this volcano ash myself, and had them sent to Germany, where, initially full-scale soil analyses had been effected by the Materials Testing Institute for rocks and earth at the University of Clausthal-Zellerfeld, West Germany.

The examination of the samples revealed the following results:

pH value	7,5
	ppm
Na	31.281
K	10.557
Ca	36.417
Mg	16.947

The heavy metal content in the soil shows values which are within the tolerable norm.

The high Na-content of the soil, however, amounting to approx. 3,1 % of the total substrate, turned out to be problematic, since it prevents normal growth of the plants.

Small-scale trial runs for recultivation were started on open ground on 09.10.1986 and were carried on in the greenhouse in winter.

The first trial run included the following kinds of treatment:

variation A	-	untreated
variation B	-	organic fertilizer
variation C	-	a system based on colloids
variation D	-	a special mixture of components, named FRISOL

Based on the results of this initial trial run, further extended tests had been effected in order to reveal the most efficient and economic combination of the mixture D - FRISOL. A further trial run had been carried out with different variations A to H.



The density of vegetation variation D was showing on 05.02.87 - variation D was the first to reach 100 % density - as well as the vitality of the plants, their growth and their biomass, revealed that with variation D we already found the most economic and efficient solution. The combination of components for this trial run consisted of

Biosol - phosphoric acid - sugary -  
nitrogen base - polybutadienoil = Terravest  
and 30 g of grass seeds.

Moreover this mixture - 360 g/m<sup>2</sup> of which had been required - turned out to be very economic and, in this way, suitable for practical use.

Without special treatment such substrates as e.g. the above mentioned ash cannot be recultivated. It is of special importance that, through scientifically based investigations combined with many years of practical experience and know-how in the area of recultivation of extreme locations, solutions will be revealed. This had been proved when people of the IEC succeeded - due to their many years of practical experience - in stabilizing the volcano ash of the Mount St. Helen, which up to now seemed to be impossible to recultivate.

EROSION CONTROL AT THE  
SUMMITVILLE GOLD MINE

Jack Clark

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ABSTRACT

Gold mining activity at the Summitville District began in the 1870's and has continued sporadically through present time. Early efforts of erosion control were employed only to protect roads, buildings and other mine investments. Reclamation laws and general awareness of land conservation have led to large expenditures to save soil from erosion and provide for adequate revegetation. Operation and reclamation of an open pit mine and heap leach at 11,500 feet in one of the nation's heaviest snow belts requires certain special techniques and attention to detail. This paper describes the techniques used to date at Summitville to reduce soil erosion and to establish vegetative cover.

## **Alpine Revegetation on Rollins Pass After 18 Years**

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**and**

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### **Introduction**

In the late 1960's, West Slope Gas Company had identified the need for a second supply of natural gas to Middle Park customers. The chosen route passed from the Denver area across Rollins Pass to Middle Park, west of the Front Range. Rollins Pass, elevation 11,680 feet, is located above upper tree limit, and the extensive alpine tundra of the area posed an obstacle to the use of normal pipeline construction procedures, given the well-known fragility of alpine ecosystems and the high level of recreational use of the area by hikers and automobile tourists. A carefully planned construction program included placement of the pipe in the Rollins Pass roadbed for most of the distance through alpine landscapes. However, the plan included an element of compromise that saved considerable pipeline length (and cost) allowing the pipeline to drop from the Rollins Pass road across approximately 1,500 feet of tundra to a point where the route entered subalpine forest.

To minimize the impact of pipeline placement on the alpine vegetation, the following steps were taken. Heavy equipment impact on the area was minimized by limiting its use to two passes along the route. In the first pass, a rubber-tired backhoe moved down the route, simultaneously 1) removing the alpine turf with the backhoe bucket, 2) digging the trench, and 3) dragging a cable attached to a bulldozer winch. Turf sections peeled up by the backhoe bucket were carefully moved by hand and placed on a plastic sheet underlain by burlap and immediately covered with burlap. Spoil from the pipeline trench was also placed on burlap to reduce burial of underlying intact vegetation and probable damage as spoil was removed to backfill the trench. The winch cable was used to pull pre-welded pipe through the trench, thus placing the pipe without additional passes of heavy equipment. The backhoe made its second and final pass backfilling the trench. Turf sections were then carefully placed over the backfilled trench by hand.

Observations on the recovery of the disturbed alpine vegetation were initiated in 1970. Early results were reported to the first convening of this workshop (Marr, Buckner and Johnson 1974). The area was revisited in August 1987 to gather qualitative and quantitative information on recovery after 18 years. Quantitative sampling was conducted along transects spaced at 5 meter intervals along the length of the alpine portion of the pipeline. These

transects were 6 meters long, centered on and oriented perpendicular to the pipeline. Data were collected from twelve 20 x 50 cm microplots placed end to end along the transect. Within each microplot, each plant species, as well as bare soil, litter, and rock, were assigned a cover class using the six step scale of Daubenmire (1959).

Placement of the transects allowed assessment of vegetational response in four distinct zones (Figure 1):

- o The roughly 2m wide zone north of the pipeline where the only disturbance was two passes by the rubber-tired backhoe and which has shown no visible effect after the first year. This area has been deemed to approximate undisturbed conditions within each community.

- o The top of the low ridge of soil and rock located directly over the pipeline trench itself. Although mostly only about 3 to 4 inches high, conditions on top of this ridge are sufficiently more exposed to cause adjustments in species response.

- o The concave microsite immediately adjacent to the pipeline ridge on either side. Extra protection offered by the pipeline ridge has produced a distinct environment that has elicited observable species responses.

- o The zone on the south side of the pipeline where the spoil from the trench was piled and where the turf was stored during the construction. This area is referred to below as the backfill piling area.

## Results and Discussion

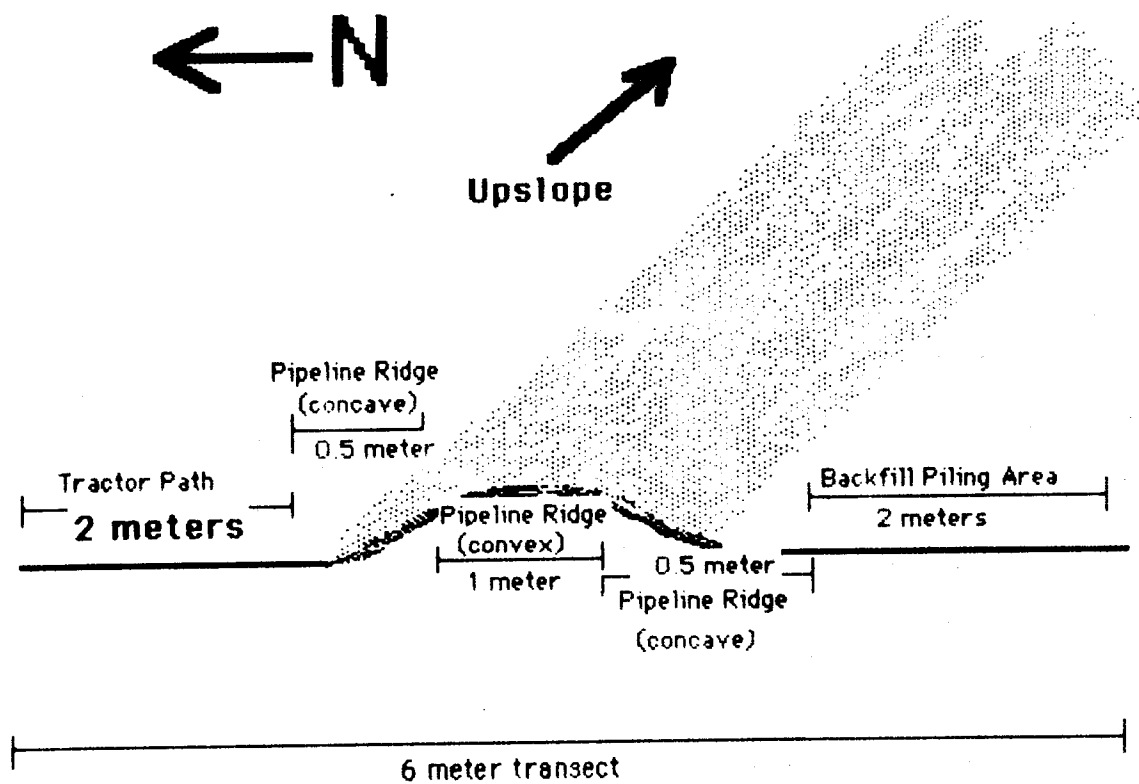
### Plant Communities

During the earliest observations, five plant communities were identified (Marr, Buckner and Johnson 1974). The five were Deschampsia, Sibbaldia, Sibbaldia/Artemisia, Vaccinium, and Danthonia/Trisetum.

The Deschampsia community is heavily dominated by tufted hairgrass (Deschampsia cespitosa). Major subdominants present include subalpine daisy (Erigeron peregrinus), sibbaldia (Sibbaldia procumbens), thistle groundsel (Senecio crassulus), and mountain wild dandelion (Agoseris glauca). Pocket gopher activity is minimal and exposed rock is scarce.

Sibbaldia forms a near monoculture within the community of that name. The most frequently encountered additional species are subalpine daisy, tufted hairgrass, Drummond's rush (Juncus drummondii), and mountain wild dandelion. As in the Deschampsia community, pocket gopher disturbance and exposed rock are infrequent.

By comparison, however, pocket gopher activities are extensive in the Sibbaldia/Artemisia



**Figure 1. Location of disturbance area types along sample transect.**

community. The most abundant species present are tufted hairgrass, arctic sage (Artemisia arctica ssp. saxicola), sibbaldia, and mountain avens (Acomastylis rossii). In the absence of pocket gophers, it is apparent that this community would segregate into Deschampsia and Sibbaldia community areas. Arctic sage and mountain avens along with Parry clover (Trifolium parryi), varileaf cinquefoil (Potentilla diversifolia), and little gentian (Gentianella amarella) are more abundant than in either of the "parent" communities, occupying pocket gopher spoils where competition is low. In the first few years following the construction of the pipeline, pocket gophers invaded the loose material over the trench in the Sibbaldia/Artemisia community and caused extensive damage to the replaced turf sections. As a result, the area directly over the pipeline trench in this community experienced some erosion for lack of protective vegetation cover.

The Vaccinium community is similar to the Sibbaldia/Artemisia community in species composition, except for the abundance of broom huckleberry (Vaccinium scoparium), a species most often encountered in the understory of subalpine forests. The slightly concave nature of the microsites on which this community occurs offers more protection and may cause slightly longer snow cover. The shrubby lifeform of broom huckleberry is an uncommon occurrence in Rocky Mountain alpine vegetation that allows the plant to maintain a presence on the site without having to reconstruct its above-ground parts each season, a distinct advantage in an environment where short growing season and low temperatures limit carbon fixation. The species is, however, clearly at the limit of its ecological range here, and reacts negatively to any additional stress as will be discussed below.

The Danthonia/Trisetum community exists as a turf that occupies the most exposed portions of the site. Exposure is greater because of slightly steeper west facing aspect and convex shape. As such it becomes permanently snow-covered slightly later in the fall and emerges from snow cover slightly earlier in the spring. Although most of the major species are those of the Sibbaldia/Artemisia community, the abundant presence of timber danthonia (Danthonia intermedia), which does not occur in any of the other communities, along with spike trisetum (Trisetum spicatum), which occurs only very sparsely if at all in the other communities, indicates clearly the presence of an important difference in environmental factors.

#### Recovery As of 1987

Qualitatively, the pipeline disturbance has recovered quite well. In particular, the Deschampsia community has reestablished a very continuous and natural-appearing cover of tufted hairgrass (Figure 2). Likewise, the vegetation cover over the pipeline in the other communities has recovered sufficiently that the eye is not drawn to the disturbed area. The major feature attracting visual attention is the slightly greater concentration of rocks along the pipeline in some locations. This resulted from the erosion and settling of fine material from around large rocks brought to the surface during the process of excavation and



Figure 2. Rollins Pass alpine vegetation; Deschampsia community disturbed by pipeline construction (pipeline extends from center foreground to center background). Recovery shown as of October 1987, eighteen years after construction.

backfilling of the pipeline trench.

Quantitative data from the 1987 sampling are presented in Tables 1 through 5. These data are organized into four columns representing the four zones described above. The first column includes the data from the 2m band to the north side of the pipeline trench where passage of the large rubber tires of the backhoe comprised the disturbance. The impact of this disturbance has been so minimal that data from this area can reasonably be taken to represent undisturbed conditions. In the second column, data from the convex top of the pipeline ridge are shown. These data, in addition to reflecting recovery in the most heavily disturbed of all areas, can be taken to represent the response of the vegetation to an increased degree of exposure to environmental stresses including wind and drought. In the third column are located data from the concave strip where the pipeline ridge joins the original surface (Figure 1). This area experienced disturbance nearly as extensive as the ridge directly over the trench (that is now a ridge) but, by virtue of the concave microtopography, represents an environment with slightly lessened wind and drought stress, compared to the original surface. Finally, in the fourth column are located data that describe conditions in the 2m wide zone south of the pipeline trench where the impact of piled spoil and turf was variable and after the first few years, virtually undiscernible to the eye.

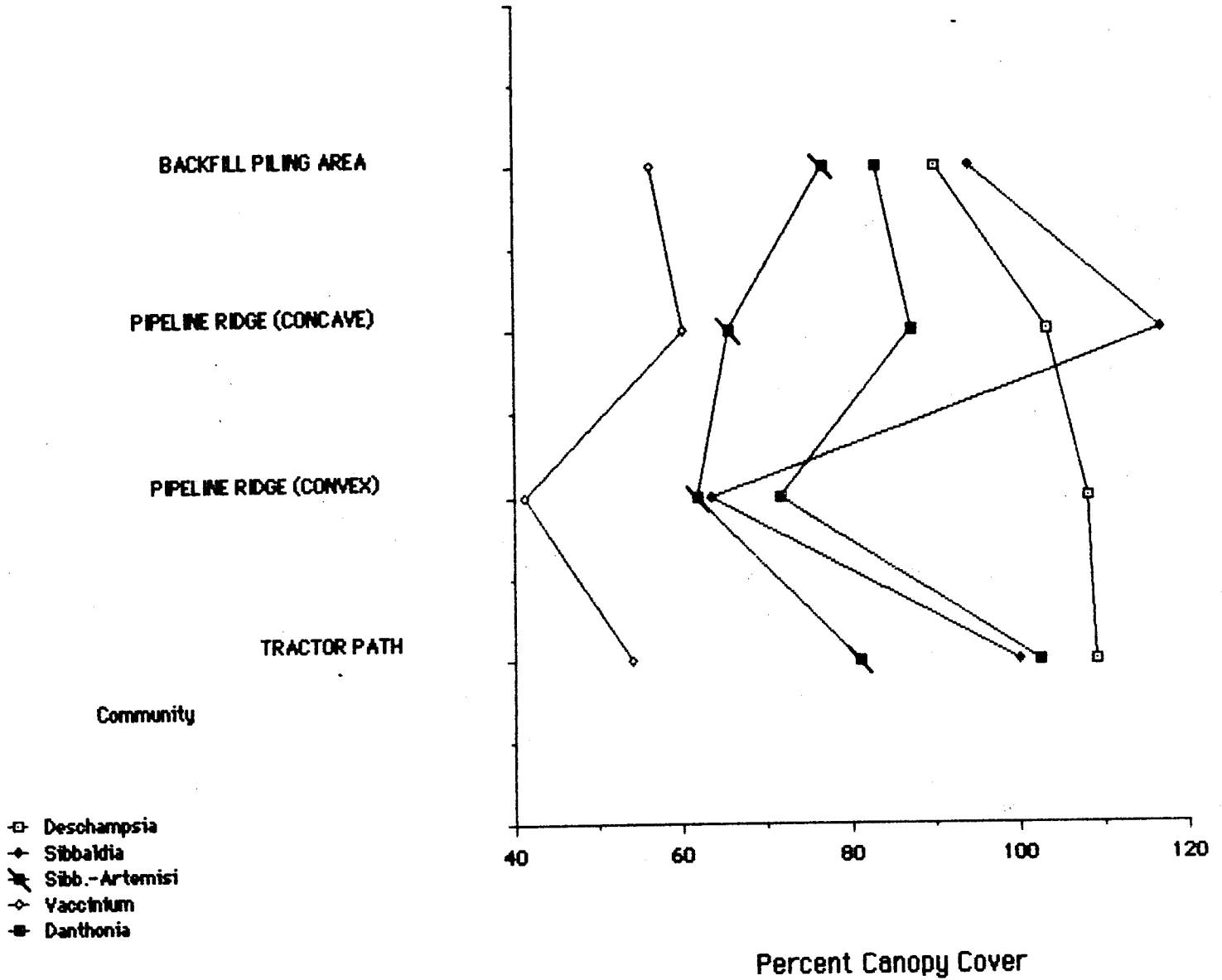
Figure 3 shows data on total vegetation cover by community for each of the four bands of disturbance and altered topography. Since data collected were the canopy cover of each species, and species' canopies often overlap, the sum of species' canopy cover may exceed 100 percent. Note that the Vaccinium community consistently has the lowest total vegetation cover, followed by the Sibbaldia/Artemisia and Danthonia/Trisetum communities, respectively. The Deschampsia and Sibbaldia communities generally have the highest vegetation cover, at, or slightly exceeding, 100 percent. All communities except Deschampsia show a depression in total vegetation cover directly over the pipeline trench. The most severe depression directly over the pipeline trench was found in the Sibbaldia community.

Although rather heavily disturbed during construction, the concave sites adjacent to the pipeline ridge have mostly recovered total vegetation cover to levels equaling or exceeding less severely disturbed sites. The exception to this statement is the Sibbaldia/Artemisia community where effects of the initial pocket gopher depredations still linger. The total vegetation cover data suggest that the backfill piling area still shows effects of the initial disturbance in the highly grass-dominated Deschampsia and Danthonia/Trisetum types.

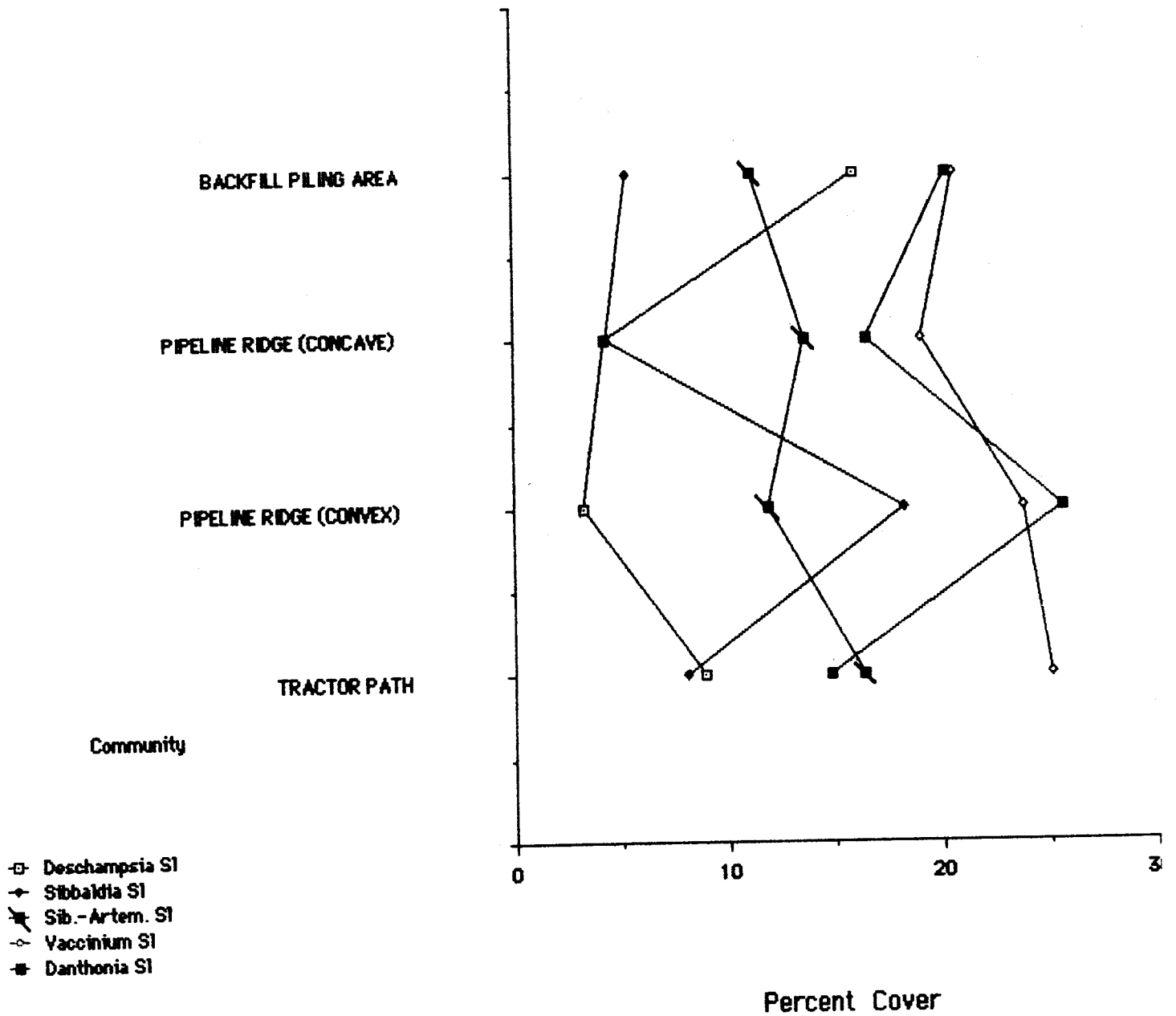
Figure 4, Bare Soil Cover by Community, and Figure 5, Rock Cover by Community, show that in these aspects, the communities have reacted differently. In the Deschampsia community, both bare soil and rock cover are least on the pipeline ridge, whereas in the Sibbaldia community both are greatest on the pipeline ridge. In the Sibbaldia/Artemisia community,



**Figure 3. Total Vegetation Cover by Community**



**Figure 4. Bare Soil Cover by Community**



**Figure 5. Rock Cover by Community**

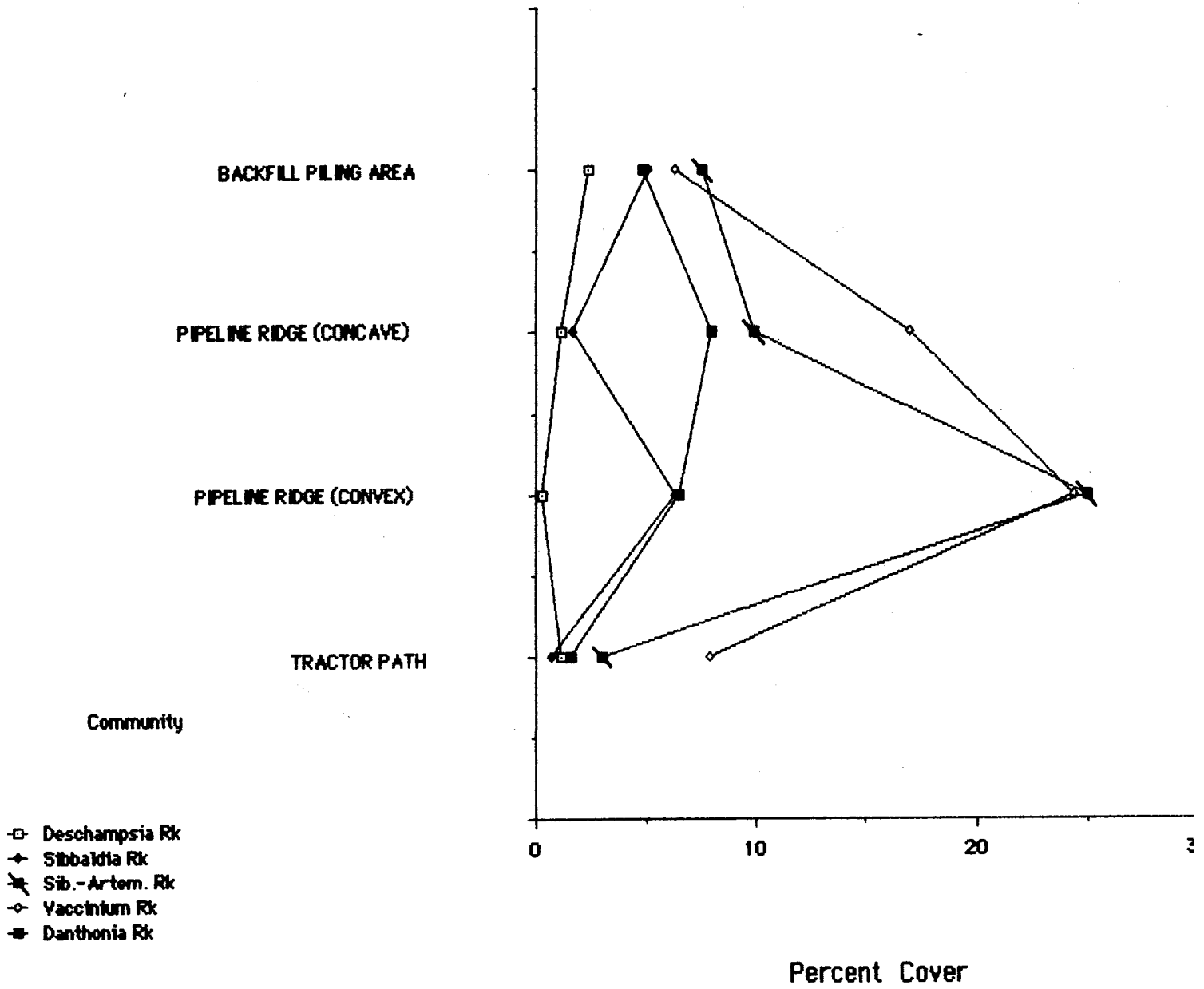


TABLE 1. COVER AND FREQUENCY DATA - DESCHAMPSIA COMMUNITY

Species	Tractor Path		Pipeline Ridge (convex)		Pipeline Ridge (concave)		Backfill Piling Area	
	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%
HIGHER PLANTS								
<i>Deschampsia cespitosa</i>	41.3	100	53.6	100	53.4	100	33.3	93
<i>Erigeron peregrinus</i>	14.3	63	3.4	35	2.6	30	5.7	37
<i>Sibbaldia procumbens</i>	12.8	43	3.8	30	1.0	15	9.4	50
<i>Senecio crassulus</i>	11.1	47	10.6	45	12.6	55	9.5	47
<i>Agoseris glauca</i>	8.3	70	8.5	65	12.6	70	9.1	80
<i>Artemisia arctica</i>	3.9	30	8.8	60	2.0	30	4.0	43
<i>Aster foliaceus apricus</i>	3.0	23	7.5	55	4.3	45	1.8	23
<i>Poa fendleriana</i>	2.3	43	2.9	40	0.8	5	0.0	0
<i>Carex ebenea</i>	2.0	17	0.4	15	1.6	15	3.1	40
<i>Potentilla diversifolia</i>	1.2	30	0.9	35	1.5	35	0.9	37
<i>Thlaspi montanum</i>	1.2	47	0.9	35	0.5	20	0.7	27
<i>Bistorta bistortoides</i>	1.1	27	1.5	35	1.3	25	1.3	37
<i>Veronica wormskjoldii</i>	1.1	10	0.2	10	0.4	15	0.2	7
<i>Phleum alpinum</i>	0.9	37	0.3	10	0.0	0	0.0	0
<i>Trifolium parryi</i>	0.9	20	2.4	20	3.6	45	2.0	30
<i>Poa reflexa</i>	0.8	30	0.2	10	0.2	10	0.3	13
<i>Juncus drummondii</i>	0.5	3	0.0	0	0.0	0	0.5	3
<i>Acomastylis rossii</i>	0.4	17	0.1	5	1.9	5	4.3	17
<i>Polygonum douglasii</i>	0.4	17	0.0	0	1.0	15	0.6	23
<i>Luzula spicata</i>	0.3	10	0.2	10	0.2	10	0.4	17
<i>Stellaria laeta</i>	0.3	13	0.4	15	0.5	20	0.2	7
<i>Draba crassifolia</i>	0.2	7	0.0	0	0.0	0	0.2	7
<i>Hieracium gracile</i>	0.2	7	0.2	10	0.2	10	0.4	17
<i>Senecio dimorphophyllus</i>	0.2	7	0.2	10	0.0	0	0.1	3
<i>Lewisia pygmaea</i>	0.1	3	0.0	0	0.0	0	0.3	10
<i>Ranunculus adoneus</i>	0.1	3	0.0	0	0.0	0	0.1	3
<i>Viola adunca</i>	0.1	3	0.2	10	0.2	10	0.2	7
<i>Achillea millefolium</i>	0.0	0	0.0	0	0.0	0	0.1	3
<i>Agropyron trachycaulum</i>	0.0	0	0.0	0	0.0	0	0.5	3
<i>Festuca brachyphylla</i>	0.0	0	0.1	5	0.0	0	0.2	7
<i>Gentianella amarella</i>	0.0	0	0.4	15	0.0	0	0.3	13
<i>Minuartia biflora</i>	0.0	0	0.0	0	0.0	0	0.1	3
<i>Taraxacum officinale</i>	0.0	0	0.0	0	0.1	5	0.0	0
<i>Trisetum spicatum</i>	0.0	0	0.1	5	0.1	5	0.2	7
LOWER PLANTS								
Lichen	0.0	0	0.1	5	0.8	5	0.0	0
Moss	0.0	0	0.2	10	0.0	0	0.1	3
BARE SOIL								
	8.9	67	3.3	55	4.3	70	16.0	73
LITTER								
	7.1	87	11.4	90	13.0	100	7.8	100
ROCK								
	1.1	27	0.3	10	1.1	20	2.4	47
TOTAL VEGETATION COVER	109.0		108.1		103.4		90.1	

TABLE 2. COVER AND FREQUENCY DATA - SIBBALDIA COMMUNITY

Species	Tractor Path		Pipeline Ridge (convex)		Pipeline Ridge (concave)		Backfill Piling Area	
	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%
<b>HIGHER PLANTS</b>								
<i>Sibbaldia procumbens</i>	60.0	100	24.4	67	55.0	100	42.5	100
<i>Erigeron peregrinus</i>	11.8	72	9.0	67	34.8	92	18.9	89
<i>Deschampsia cespitosa</i>	6.8	78	10.4	92	7.9	92	3.3	50
<i>Juncus drummondii</i>	4.3	33	0.8	33	1.9	33	5.6	56
<i>Agoseris glauca</i>	2.6	50	10.8	67	1.7	33	2.5	44
<i>Artemisia arctica saxicola</i>	2.6	22	0.4	17	2.7	25	2.1	28
<i>Trifolium parryi</i>	1.8	17	0.4	17	0.0	0	2.8	28
<i>Bistorta bistortoides</i>	1.4	56	1.7	67	1.3	50	2.2	61
<i>Carex ebenea</i>	1.0	11	1.5	17	1.5	8	0.3	11
<i>Phleum alpinum</i>	1.0	39	0.4	17	1.7	25	0.4	17
<i>Vaccinium scoparium</i>	1.0	11	0.2	8	2.5	17	6.0	50
<i>Ranunculus adoneus</i>	0.8	33	0.0	0	0.8	33	2.1	56
<i>Solidago spathulata</i>	0.8	6	0.0	0	0.0	0	0.0	0
<i>Gentianella amarella</i>	0.7	28	0.4	17	0.6	25	0.4	17
<i>Poa glauca</i>	0.7	28	0.2	8	0.4	17	1.7	39
<i>Potentilla diversifolia</i>	0.6	22	0.6	25	0.2	8	0.8	6
<i>Veronica wormskjoldii</i>	0.4	17	0.0	0	0.0	0	0.0	0
<i>Festuca brachyphylla</i>	0.3	11	0.0	0	0.0	0	0.0	0
<i>Heiracium gracile</i>	0.3	11	0.0	0	0.2	8	0.6	22
<i>Viola adunca</i>	0.3	11	1.3	8	0.8	33	0.7	28
<i>Achillea millefolium</i>	0.1	6	0.2	8	0.2	8	0.0	0
<i>Aster foliaceus apricus</i>	0.1	6	0.2	8	0.2	8	0.0	0
<i>Draba crassifolia</i>	0.1	6	0.2	8	1.3	8	0.3	11
<i>Lewisia pygmaea</i>	0.1	6	0.0	0	0.0	0	0.3	11
<i>Poa reflexa</i>	0.1	6	0.0	0	0.2	8	0.0	0
<i>Senecio crassulus</i>	0.1	6	0.0	0	0.0	0	0.0	0
<i>Thlaspi montanum</i>	0.1	6	0.0	0	0.4	17	0.1	6
<i>Androsace septentrionalis</i>	0.0	0	0.0	0	0.2	8	0.0	0
<i>Luzula spicata</i>	0.0	0	0.4	17	0.6	25	0.3	11
<i>Minuartia biflora</i>	0.0	0	0.0	0	0.2	8	0.0	0
<b>LOWER PLANTS</b>								
Moss	0.1	6	0.4	17	0.0	0	0.3	11
<b>BARE SOIL</b>								
	8.1	56	18.3	92	4.4	50	5.4	78
<b>LITTER</b>								
	3.9	72	5.0	75	5.8	67	2.9	89
<b>ROCK</b>								
	0.7	28	6.3	50	1.7	25	5.1	44
<b>TOTAL VEGETATION COVER</b>	<b>100.0</b>		<b>63.9</b>		<b>117.3</b>		<b>94.2</b>	

TABLE 3. COVER AND FREQUENCY DATA - SIBBALDIA/ARTEMISIA COMMUNITY

Species	Tractor Path		Pipeline Ridge (convex)		Pipeline Ridge (concave)		Backfill Piling Area	
	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%
<b>HIGHER PLANTS</b>								
<i>Deschampsia cespitosa</i>	17.0	82	11.4	95	13.8	86	17.3	85
<i>Artemisia arctica saxicola</i>	11.1	76	11.3	77	9.0	86	9.4	82
<i>Sibbaldia procumbens</i>	8.9	61	11.5	55	13.4	73	10.9	79
<i>Acomastylis rossii</i>	8.6	33	2.2	18	4.8	37	2.4	24
<i>Erigeron peregrinus</i>	4.8	58	2.6	36	6.4	55	3.0	42
<i>Agoseris glauca</i>	4.7	67	5.6	45	2.8	45	8.3	73
<i>Trifolium parryi</i>	3.6	70	3.1	55	2.7	64	9.2	73
<i>Carex ebenea</i>	2.8	52	1.3	27	0.5	18	2.4	52
<i>Potentilla diversifolia</i>	2.1	55	1.8	50	1.6	41	0.6	24
<i>Gentianella amarella</i>	1.9	61	0.8	32	1.0	41	1.4	55
<i>Bistorta bistortoides</i>	1.7	55	1.1	45	2.5	55	1.4	55
<i>Luzula spicata</i>	1.7	36	0.6	23	0.3	14	1.1	45
<i>Poa fendleriana</i>	1.7	39	1.5	36	0.7	27	1.8	42
<i>Juncus drummondii</i>	1.4	12	0.0	0	0.1	5	0.0	0
<i>Aster foliaceus apricus</i>	1.3	21	1.0	18	0.1	5	1.8	27
<i>Thlaspi montanum</i>	1.3	52	0.7	27	0.6	23	0.9	36
<i>Ranunculus adoneus</i>	1.0	39	0.2	9	0.2	9	0.8	30
<i>Poa reflexa</i>	0.7	27	0.2	9	0.3	14	0.7	27
<i>Veronica wormskjoldii</i>	0.6	9	0.2	9	0.2	9	0.1	3
<i>Trisetum spicatum</i>	0.5	18	0.6	23	0.3	14	0.2	9
<i>Castilleja occidentalis</i>	0.3	12	0.0	0	0.1	5	0.0	0
<i>Draba crassifolia</i>	0.3	12	0.0	0	0.2	9	0.0	0
<i>Festuca brachyphylla</i>	0.3	12	0.3	14	0.3	174	0.2	6
<i>Achillea millefolium</i>	0.2	9	1.6	18	1.6	18	0.1	3
<i>Artemisia scopulorum</i>	0.2	6	0.0	0	0.0	0	0.2	9
<i>Hieracium gracile</i>	0.2	9	0.1	5	0.0	0	0.2	6
<i>Lewisia pygmaea</i>	0.2	6	0.0	0	0.0	0	0.0	0
<i>Phleum alpinum</i>	0.2	9	0.1	5	0.2	9	0.2	9
<i>Polygonum douglasii</i>	0.2	6	0.1	5	0.1	5	0.2	9
<i>Saxifraga rhomboidea</i>	0.2	9	0.2	9	0.0	0	0.1	3
<i>Stellaria laeta</i>	0.2	6	0.2	9	0.1	5	0.0	0
<i>Vaccinium scoparium</i>	0.2	6	0.0	0	0.7	5	0.1	3
<i>Viola adunca</i>	0.2	9	0.1	5	0.5	18	0.5	21
<i>Agropyron trachycaulum</i>	0.1	3	0.0	0	0.0	0	0.0	0
<i>Angelica grayi</i>	0.1	3	0.0	0	0.1	5	0.1	3
<i>Cerastium arvense</i>	0.1	3	0.3	14	0.1	5	0.2	9
<i>Minuartia biflora</i>	0.0	0	0.0	0	0.0	0	0.1	3
<i>Sedum lanceolatum</i>	0.0	0	0.1	5	0.1	5	0.0	0
<i>Solidago spathulata</i>	0.0	0	0.7	5	0.1	5	0.2	9
<b>LOWER PLANTS</b>								
Moss	0.1	3	0.3	14	0.2	9	0.2	9
<b>BARE SOIL</b>								
	16.4	88	11.9	77	13.6	68	11.2	79
<b>LITTER</b>								
	7.0	100	10.2	100	9.1	95	5.9	85
<b>ROCK</b>								
	3.0	45	25.0	91	9.9	73	7.6	76
<b>TOTAL VEGETATION COVER</b>								
	43.7		27.6		29.5		38.7	

TABLE 4. COVER AND FREQUENCY DATA - VACCINIUM COMMUNITY

Species	Tractor Path		Pipeline Ridge (convex)		Pipeline Ridge (concave)		Backfill Piling Area	
	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%
HIGHER PLANTS								
<i>Sibbaldia procumbens</i>	9.1	63	6.9	63	8.8	75	10.8	75
<i>Deschampsia cespitosa</i>	8.2	67	5.9	56	9.2	69	9.2	58
<i>Artemisia arctica saxicola</i>	6.4	67	4.5	56	9.1	44	10.6	92
<i>Vaccinium scoparium</i>	4.6	58	0.3	13	2.3	31	1.7	25
<i>Trifolium parryi</i>	4.4	75	5.8	81	8	81	5.8	88
<i>Erigeron peregrinus</i>	3.2	67	2.8	50	5.6	44	3.5	38
<i>Agoseris glauca</i>	2.1	21	1.4	25	2.7	19	0.3	13
<i>Bistorta bistortoides</i>	1.6	42	1.1	44	0.9	38	1.1	46
<i>Potentilla diversifolia</i>	1.6	42	0.8	31	1.6	31	0.8	33
<i>Carex ebenea</i>	1.5	21	2.4	31	1.6	32	1.2	29
<i>Acomastylis rossii</i>	1.4	13	0	0	1.1	13	1	21
<i>Castilleja occidentalis</i>	1.4	13	0	0	0	0	0	0
<i>Viola adunca</i>	1.1	46	0.2	6	0.3	13	0.8	33
<i>Hieracium gracile</i>	0.9	17	0.5	19	0.2	6	0	0
<i>Poa reflexa</i>	0.7	29	0.2	6	0.5	19	0.4	17
<i>Lewisia pygmaea</i>	0.6	25	0.2	6	0.2	6	0.2	8
<i>Polygonum douglasii</i>	0.6	25	0	0	0.5	19	0.3	13
<i>Gentianella amarella</i>	0.5	21	1.1	44	1.3	50	1.1	46
<i>Luzula spicata</i>	0.5	21	0.5	19	0.5	19	0.9	38
<i>Ranunculus adoneus</i>	0.5	21	0	0	0.8	31	1.3	29
<i>Saxifraga rhomboidea</i>	0.5	21	0.3	13	0	0	0.5	21
<i>Thlaspi montanum</i>	0.5	21	0.6	25	0.8	31	0.6	25
<i>Veronica wormsjkoldii</i>	0.4	17	0.2	6	0	0	0	0
<i>Achillea millefolium</i>	0.3	13	0	0	0.2	6	0	0
<i>Agropyron trachycaulum</i>	0.2	8	0	0	0	0	0.2	8
<i>Phleum alpinum</i>	0.2	8	0.2	6	1.1	13	0.3	13
<i>Poa fendleriana</i>	0.2	8	0.5	19	0.5	19	0.3	13
<i>Solidago spathulata</i>	0.2	8	0.3	13	0	0	1.7	25
<i>Androsace septentrionalis</i>	0.1	4	0	0	0	0	0	0
<i>Angelica grayii</i>	0.1	4	0	0	0	0	0	0
<i>Aster foliaceus apricus</i>	0.1	4	0.2	6	0.9	6	0.6	25
<i>Trisetum spicatum</i>	0.1	4	1.9	44	0	0	0.1	4
<i>Cerastium arvense</i>	0	0	0.2	6	0.9	6	0.4	17
<i>Draba crassifolia</i>	0	0	0.8	31	0.2	6	0.1	4
<i>Festuca brachyphylla</i>	0	0	0.5	19	0.2	6	0.2	8
<i>Minuartia biflora</i>	0	0	0.2	6	0	0	0	0
<i>Senecio dimorphophyllus</i>	0	0	0.2	6	0	0	0	0
<i>Stellaria laeta</i>	0	0	0	0	0	0	0.4	17
LOWER PLANTS								
Moss	0.1	4	0.6	25	0.3	13	0.1	4
BARE SOIL								
	25.1	92	23.8	100	19.1	94	20.6	96
LITTER								
	6.9	88	9.2	88	8.3	88	10.1	92
ROCK								
	7.9	75	24.4	100	17	100	6.3	92
TOTAL VEGETATION COVER	53.9		41.3		60.3		56.5	

TABLE 5. COVER AND FREQUENCY DATA - DANTHONIA/TRISETUM COMMUNITY

Species	Tractor Path		Pipeline Ridge (convex)		Pipeline Ridge (concave)		Backfill Piling Area	
	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%	Cover%	Freq.%
HIGHER PLANTS								
<i>Artemisia arctica saxicola</i>	21.7	100	13.9	75	12.5	75	12.5	93
<i>Sibbaldia procumbens</i>	21.2	97	15.0	85	15.1	65	14.3	60
<i>Danthonia intermedia</i>	13.7	83	4.9	50	7.4	70	7.8	70
<i>Deschampsia cespitosa</i>	12.4	77	8.9	65	11.6	65	7.1	57
<i>Trifolium parryi</i>	7.8	93	3.8	75	5.9	65	6.2	63
<i>Acomastylis rossii</i>	3.0	37	0.3	10	5.0	30	0.4	17
<i>Trisetum spicatum</i>	2.3	43	2.1	35	1.0	40	2.2	53
<i>Potentilla diversifolia</i>	1.9	43	1.8	45	1.0	40	1.1	43
<i>Artemisia scopulorum</i>	1.7	33	1.4	30	2.9	40	0.6	23
<i>Bistorta bistortoides</i>	1.6	63	1.3	50	3.1	55	1.8	57
<i>Gentianella amarella</i>	1.6	63	0.9	35	1.9	50	1.1	53
<i>Viola adunca</i>	1.6	30	0.3	10	1.0	15	0.4	17
<i>Poa fendleriana</i>	1.4	23	2.4	20	1.0	40	2.7	40
<i>Festuca brachyphylla</i>	1.2	30	0.6	25	1.3	25	1.1	27
<i>Luzula spicata</i>	1.2	47	2.3	40	0.6	25	1.1	43
<i>Thlaspi montanum</i>	1.2	47	1.3	50	1.5	60	1.2	47
<i>Vaccinium scoparium</i>	1.2	13	1.6	15	2.3	15	1.4	23
<i>Aster foliaceus apricus</i>	0.7	27	1.5	35	0.4	15	2.6	37
<i>Antennaria rosea</i>	0.6	7	0.0	0	0.0	0	0.4	17
<i>Erigeron simplex</i>	0.5	20	0.4	15	1.0	15	1.4	10
<i>Poa reflexa</i>	0.5	17	0.5	20	0.4	25	0.3	10
<i>Carex ebenea</i>	0.3	10	1.0	15	1.6	15	1.3	33
<i>Minuartia biflora</i>	0.3	10	0.4	15	0.3	10	0.3	10
<i>Pedicularis parryi</i>	0.3	13	0.0	0	0.1	5	0.3	13
<i>Ranunculus adoneus</i>	0.3	10	0.4	15	0.6	25	0.8	13
<i>Solidago spathulata</i>	0.2	7	0.4	15	1.5	10	1.8	20
<i>Veronica wormskjoldii</i>	0.2	7	0.0	0	0.0	0	0.0	0
<i>Agoseris glauca</i>	0.1	3	0.9	10	2.9	20	5.3	47
<i>Lewisia pygmaea</i>	0.1	3	0.1	5	0.0	0	0.0	0
<i>Lloydia serotina</i>	0.1	3	0.0	0	0.0	0	0.0	0
<i>Phleum alpinum</i>	0.1	3	0.8	5	0.1	5	0.7	10
<i>Saxifraga rhomboidea</i>	0.1	3	0.0	0	0.1	5	0.1	3
<i>Sedum lanceolatum</i>	0.1	3	0.0	0	0.0	0	0.0	0
<i>Androsace septentrionalis</i>	0.0	0	0.0	0	0.0	0	0.1	3
<i>Draba crassifolia</i>	0.0	0	0.0	0	0.3	10	0.1	3
<i>Erigeron peregrinus</i>	0.0	0	0.4	15	2.6	30	2.5	20
<i>Hieracium gracile</i>	0.0	0	0.0	0	0.0	0	0.1	5
LOWER PLANTS								
Lichen - <i>Cetraria islandica</i>	0.0	0	0.0	0	0.1	5	0.2	7
Lichen - <i>Cladonia</i> spp.	0.3	10	0.1	5	0.0	0	0.0	0
Moss	0.8	13	2.0	30	0.3	10	1.8	27
<i>Selaginella densa</i>	0.0	0	0.0	0	0.0	0	0.2	7
BARE SOIL								
	14.8	90	25.6	85	16.5	100	20.3	80
LITTER								
	6.6	97	8.4	95	1.6	65	2.1	67
ROCK								
	1.6	40	6.5	85	8.0	75	4.8	73
TOTAL VEGETATION COVER	102.3		71.7		87.4		83.3	



bare soil is lowest on the pipeline ridge top, but rock cover is far greater than in the other locations. This is a result of the substantial erosion that occurred in this type in the early years.

Another measure of community structure, total number of species encountered in each location (Figure 6) shows an ordered relationship between communities that is consistent on all situations except on the pipeline ridge top where the Danthonia/Trisetum and Vaccinium communities barely reverse their order. In general, the Sibbaldia and Deschampsia communities have the fewest species, while the Sibbaldia/Artemisia community has the most. The latter is a community characterized by recurring disturbance as pocket gophers continually churn the soil. In this community, the micro-mosaic of seral stages offers a variety of degrees of exposure and competition that allow a large number of species to exist. In the Sibbaldia and Deschampsia communities, the heavy, uniform dominance by a single species excludes the occurrence of many species.

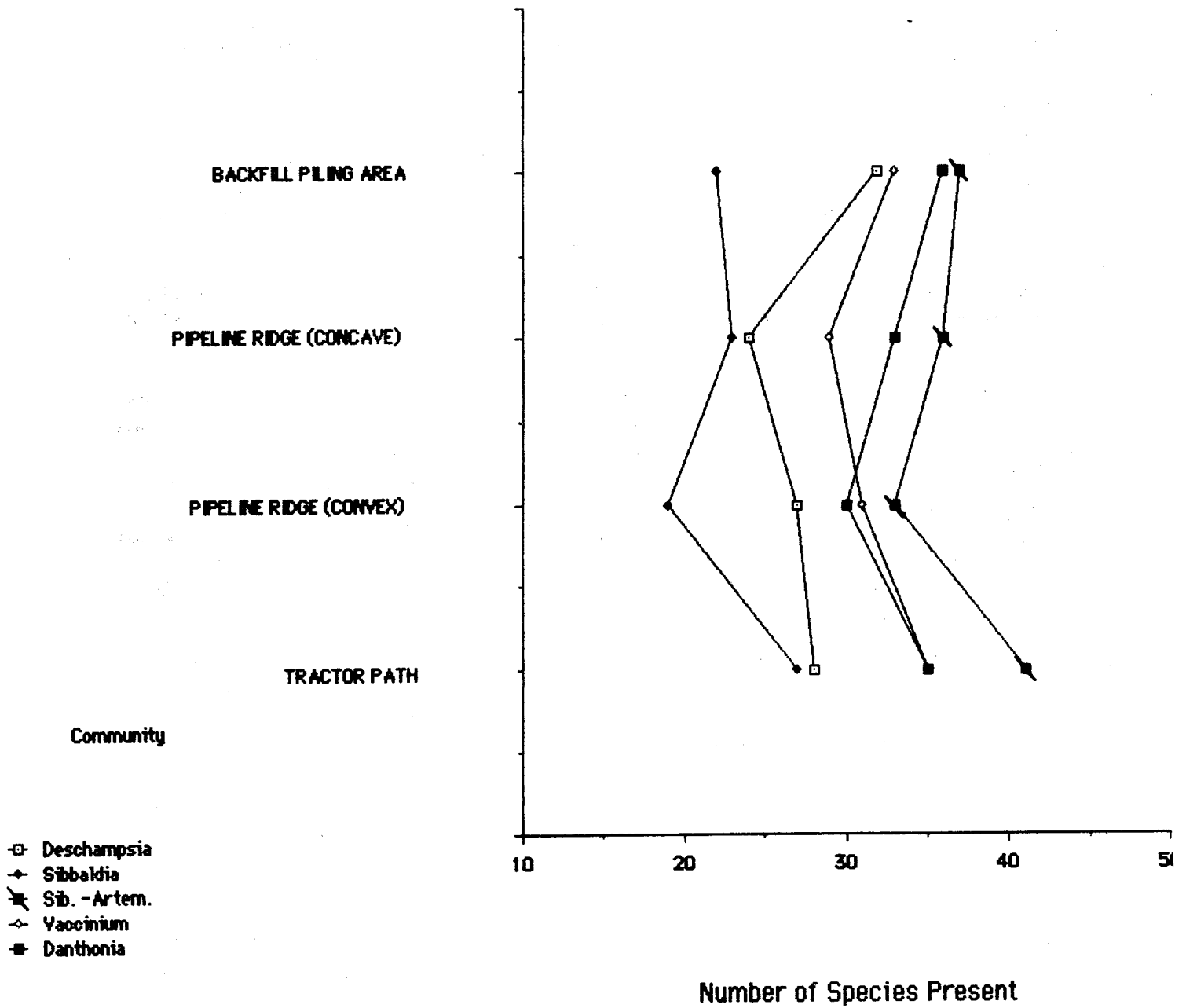
Examination of the data in Tables 1 through 5 for individual species provides an opportunity to view details of the ecology of many important alpine species. Among the observations that can be made are:

- o Deschampsia cespitosa - Within the Deschampsia community, the species was distinctly more abundant on the pipeline ridge environments (both convex and concave). In the Sibbaldia community, the slightly raised topography of the pipeline ridge or reduced competition from sibbaldia allowed tufted hairgrass to increase in abundance compared to other locations within the community. In the Sibbaldia/Artemisia, Vaccinium, and Danthonia/Trisetum communities, the abundance of tufted hairgrass was slightly depressed on the pipeline ridge. This indicates that these three communities experience greater exposure than the Sibbaldia or Deschampsia communities and that the added exposure on the pipeline ridge exceeds the limits of tufted hairgrass to proliferate as it has in the Deschampsia and Sibbaldia communities.

- o Sibbaldia procumbens - This species shows a dramatic decrease in abundance over the pipeline ridge in the Sibbaldia community indicating sensitivity to exposure or competitive response to invaders such as tufted hairgrass. Reduced abundance in the Deschampsia community over the pipeline ridge correlates with the greater abundance of tufted hairgrass. In the other three communities where there has been no large scale invasion by species of much larger stature, sibbaldia has a presence on the pipeline ridge comparable to the less disturbed positions.

- o Erigeron peregrinus - Subalpine daisy has responded to disturbance most distinctively in the Sibbaldia community (already little exposed) where the additional shelter afforded within the concave sites adjacent to the pipeline ridge elicited 15 to 25 percent more

**Figure 6. Species Number by Community**



canopy cover than in the less disturbed areas.

o Trisetum spicatum - This species occurs only in the more exposed communities; its reaction in the Vaccinium and Danthonia/Trisetum communities is particularly illustrative of the microecology of this species. The Danthonia/Trisetum community is the only one in which spike trisetum is very abundant at all. On the pipeline ridge within the community, spike trisetum is undiminished. However, in the shelter of the concave sites adjacent to the pipeline ridge, the lack of exposure correlates with a distinct reduction in the abundance of spike trisetum. In the Vaccinium community, the species is barely present except on the pipeline ridge where additional exposure has apparently brought conditions within the ecological range of spike trisetum, and its abundance there is close to that in the Danthonia/Trisetum community.

o Trifolium parryi - In the Sibbaldia and Vaccinium communities, Parry's clover showed negative reaction to the additional exposure of the pipeline ridge environment; in the Sibbaldia and Sibbaldia/Artemisia communities, the species showed negative reaction to the sheltered concave environment adjacent to the pipeline ridge. In no situation has there been a dramatic invasion by this species into a disturbed environment. However, in four of the five communities, Parry's clover has greater abundance in the backfill piling area than in the tractor path (the environment with the least disturbance).

o Vaccinium scoparium - In no community was there a marked positive response to disturbance by broom huckleberry except perhaps in the Sibbaldia community in the backfill piling area. The species showed negative response to the most severe disturbance (the pipeline ridge) in all communities (it does not occur in the Deschampsia community).

o Aster foliaceus var. apricus - Alpine bracted aster appears to have a distinct affinity for graminoid-dominated communities; it is abundant only in the Deschampsia and Danthonia/Trisetum communities. The only occasion of dramatic decrease of the species was in the Danthonia/Trisetum community on the pipeline ridge, where, concurrently, the major grasses present (tufted hairgrass and timber oatgrass) are also substantially reduced. The species has responded positively to the pipeline ridge and adjacent concave sites where again the grass cover (mostly tufted hairgrass) is greater.

o Agoseris glauca - Mountain wild dandelion seems to be quite sensitive to exposure; in the Sibbaldia community (the least exposed community), its abundance is much greater on the pipeline ridge. In the Deschampsia community, where it occurs in greatest abundance in general, the additional shelter of the concave sites adjacent to the pipeline ridge accompanies yet greater presence of the dandelion.

## Conclusions

Examination of the recovery of the alpine communities disturbed by the Rollins Pass pipeline after eighteen years of recovery shows that at least for these alpine communities, located along the more protected end of the exposure gradient among Front Range alpine communities, visual characteristics have substantially recovered (Figure 2). Future efforts of the this sort could be improved by removal of coarse rock from the surface of the backfill materials; the extra abundance of rock is the primary visual indicator of the presence of the Rollins Pass pipeline.

Detailed examination of the plant community composition on the variously disturbed areas shows that the recovery is not perfect anywhere; the alpine plant species present are finely sensitive to exposure and competition and, after 18 years, still show response to changes in microenvironments and interspecies competition caused by pipeline construction. Detailed plant cover and frequency data of this sort offer the opportunity to examine details of species' microecology as they respond to subtle changes in microenvironmental factors.

## Acknowledgements

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REVEGETATION PRINCIPLES, PRACTICES, AND PROBLEMS  
ASSOCIATED WITH THE DEVELOPMENT OF A  
MOUNTAIN RESORT

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INTRODUCTION

The creation of a high quality, year-round, world class resort often begins as a dream. Once a site has been acquired that provides potential for all aspects of the resort development, the feasibility studies begin. They generally result in an extensive plan and report which is compiled in the form of a Planned Unit Development. Based on it's approval along with financial backing, that which was once a dream slowly develops into a reality. The Telluride Mountain Village has taken steps toward becoming a reality.

SITE DESCRIPTION

Telluride is located in the San Juan Mountain Range of Southern Rocky Mountains. The Telluride Mountain Village site is located on Highway 145 approximately 2 miles west of the Town of Telluride, Colorado. It is nestled in an 1,800 acre site of which 92 acres will be devoted to development leaving 1,700 acres devoted to park land, natural forest, open space, and recreation. The emphasis will not be on high numbers, but on quality, uncrowded experience, year round. The Mountain Village will comprise recreational and cultural facilities to include a conference center, an elaborate athletic and health spa, a golf course, alpine skiing, jogging trails, ice skating, cross-country skiing, and numerous shops and restaurants.

Other support systems will include constructing water storage ponds and tanks, water, sewer, gas and electric lines, and roads. The proposed gondola transit will provide a vital link between the Town, the Ski Mountain, and the Mountain Village.

Physical features

Physically the site is dominated in the south by general northeast, southwest trending ridges and west descending slopes, while the northern portion of the site is dominated by north descending slopes and areas of disrupted drainage.

Slope angles of the site are highly variable. They range from nearly level (about 2%) on some ridge crests to about 60% on slopes descending into creeks. In general, slopes on the property range from between 10% and 25%. Elevations vary from a maximum of about 10,200 feet in the extreme southern portion of the site to about 8,950 feet along Prospect Creek where it crosses the northern most property line. The ski area adjacent to the village has an elevation of over 11,000 feet at it's present peak.

#### Climate

Historical records show that the average annual precipitation for the Town of Telluride is 23.26 inches with the wettest months of the year being July and August. The average snowfall for a year is 181.9 inches. The climatic conditions are typical of high elevation areas with wide seasonal and temperature variations. Minimum average temperature in June, for example, is 35.4 degrees Fahrenheit with maximum average temperature for the same month being 72 degrees Fahrenheit. The average annual temperature is 39.5 degrees Fahrenheit.

#### Vegetation

Vegetation within the Mountain Village property is typical of the San Juan Mountains. It comprises three vegetation zones, the upper montane, the sub-alpine and the alpine. The site is divided between grassland and woodland, with woodland predominating. The woodland covers the majority of the hillsides and ridges and is dominated by aspen. Interspersed with aspen and predominating in areas are sub-alpine fir, engleman spruce, and douglas fir. Blue spruce grows in drainages throughout the site in moist areas below 9,800 feet. Ponderosa pine is found on one location at the northern part of the site at about 9,000 feet. Within the drainage bottoms more lush vegetation can be found consisting of thick bunch grasses, willows, alders and reeds. The meadows and parks at one time in climax conditions contained a mixed plant community of Arizona Fescue, Slender Wheatgrass, Native Bluegrass, Brome Grass and Needle Grass. Due to years of overgrazing by livestock and/or game animals the most palatable forage grasses have disappeared leaving Native Bluegrass which comprises 90% of the total vegetative composition. Although it is less desirable as a forage plant it is considered an excellent erosion control plant and is more desirable for stabilizing soil.

#### Geology

The site is located on what is commonly called the Silver Mountain Landslide (slope failure complex). Within the slope failure complex of the site, some relatively intact blocks of formational materials are recognized. These include Dakota Sandstone, Mancos Shale, and blocks of andesite porphyry and rhyolite porphyry intrusions. Since the soils derived from these formations are

considered to have significant erosion potential, the construction of roads, ski runs, etc. can drastically increase erosion if either peak runoff or flow velocities are increased. This type of erosion can rapidly damage the capacity of land to support vegetation, and could result in land damage.

## PRINCIPLES RELATED TO REVEGETATION

A simple principle which is considered in both design and construction is that no land should be cleared or disturbed unnecessarily. Land that is disturbed should be limited to that which is necessary for actual construction. Local traffic and construction equipment are required to travel on designated roadways, and site grading is limited to the areas in the immediate vicinity of buildings and roadways. When building ski runs timber is cleared, but underlying vegetation should remain intact whenever possible. Although tree stumps may remain and pose potential hazards for skiing in lean snow years, the erosion that is deterred as a result by not grading runs with heavy equipment, can be significant. This method is prudent when grading is not required to make better skiing terrain.

The maximum slope approved for roads within the Mountain Village is 8%. Since the site is variable in topography, generally 10% or steeper, cut and fill banks usually result due to road construction. Design parameters on cuts and fills recommend banks to be no steeper than 3:1, but in some case will allow 1 1/2:1 cut banks and 2:1 fill slopes. Slopes that are 3:1 or less are easier to topsoil and revegetate.

When cutting through aspen forests for ski runs and roads, consideration should be given to avoid clearing wide open spaces in areas where previously shaded trees will be exposed to extreme radiation from the sun. Equipment operators are instructed to avoid contact with aspen when driving heavy equipment. Aspen are extremely vulnerable to fungal cankers due to its thin bark structure. Mechanical abrasion and sun scalding are common sources for providing entry of the fungal organisms. This is another example where the vegetative composition of the site will be improved over what would result if the act of disturbing the site is not properly managed.

Because July and August are historically the wettest months in the summer, with adequate moisture in the spring, seasonal scheduling for re-seeding is not generally required. It is more important to re-seed immediately after construction when the ground is still broken and friable. If mulch cannot be applied at the time due to cost constraints or other factors, it is still better to get the seed in the ground to avoid re-tilling the soil. Overseeding and mulching bare spots can be implemented as part of an ongoing maintenance program in areas where seed does not germinate.

The principle used when designing a seed mix is based on providing quick cover, erosion control potential, and the potential of creating a climax plant community that will blend in with the existing vegetation. For this reason, many seed mixes are developed for the Mountain Village and Ski Area that are site specific. They generally are comprised of a mix of bunch grasses, native bluegrass, and wildflowers. Occasional monitoring of the plant succession in these revegetated areas can improve the ability to design a seed mix to fit a specific site.

When viewing revegetation from the economic sense, the general rule within the development and ski area is to provide adequate revegetation, in the worst case. In most cases where disturbances are highly visible to the public, the revegetation plan may exceed that which would generally be required. This principle helps to create a positive image for the developer in the minds of the general public. The visual impact of an unsightly disturbance that is left without any effort to revegetate can create a negative impression of the development. If it is allowed to become a public issue, it can become costly to the developer from a marketing standpoint.

## REVEGETATION PRACTICES

Common revegetation practices are used at the ski area and development that are generally created by the design and construction principles, the equipment available, and the budget constraints related to the disturbance.

### Site Preparation

An important factor to consider when constructing roads, ski runs, etc. is to strip and stockpile topsoil so that it can be spread over the disturbed area after construction is completed. When redistributing the topsoil, it is most commonly spread with a bulldozer. The tracks on the bulldozer leave depressions which catch and hold the seed. It is important that operators know that when spreading soil it should not be back-bladed to create a smooth surface. Some operators feel that a smooth surface is more desirable visibly, however, the surface will not hold seed as well as a surface with "cleat marks."

On long slopes or banks (particularly on ski runs), water bars are installed across the slope every 20 feet of vertical fall to reduce quantity and velocity of water flow. This practice will reduce erosion and consequently provide better revegetation results.



## Mulching

Straw or hay is most commonly used as a mulch on ski runs and within the development. A shredder/blower pulled by a snow cat is used to distribute hay over ski runs. Once the hay is distributed evenly over the disturbance, the snow cat is driven over the straw or hay in order to crimp it to the surface. On road cuts, the same method is used, substituting a bulldozer for a snow cat.

Many areas are either too steep to mechanically crimp or high winds prevail, so plastic erosion control netting or blankets are necessary to hold mulch in place. The plastic netting is most commonly used on long, wide slopes that cover a lot of area. Straw blankets (straw sown into plastic netting) are now being used more often on short steep road cuts. Ease of installation, as well as bypassing the step of spreading straw, has proven to be a cost savings over the two-step process.

## Fertilization

Fertilization has become a part of the revegetation process at the ski area as well as the Mountain Village. Although the cost of fertilization can be prohibitive, especially on the ski runs, it is becoming apparent that it is a necessary step when establishing vegetation on poor soils. Areas that are sparse or bare one year after initial seeding are overseeded and fertilized. Lush green grasses are more desirable along the roads in the development, so fertilization has become a part of the yearly maintenance budget.

### PROBLEMS RELATED TO REVEGETATION AT A MOUNTAIN RESORT DEVELOPMENT

Even though revegetation plans are made, and schedules are created, when working within a large scale development in mountainous terrain many unplanned situations will occur. One of the most common problems is timing. It is important to reseed and mulch immediately after construction. Often, road banks will be finish graded and topsoiled prior to installing utilities to future phases of the project. Ultimately, grasses that are becoming well established from the first seeding are destroyed when the utilities are installed. The cost of returning to the disturbance and beginning the same process over again is costly as well as frustrating.

Another problem related to timing is when new projects are created unexpectedly late in the fall, and may not be completed until after snow begins to fall. Seeding and mulching generally has to wait until spring, after spring runoff, at which time considerable erosion has already occurred.

Wildlife can also play a role in creating revegetation problems. Although forage grasses exist over much of the site, elk seem to prefer hay that has been spread as mulch cover. The elk also seem to enjoy tearing up straw blankets used along road cuts. The tracks observed seem to indicate that they mill around and pull at the netting trying to get at the straw until they become frustrated, they trample the area often tearing out large areas of blankets.

#### Summary

In summary, the problems that exist just add to the challenge of trying to keep up with new disturbances. An important factor to keep in mind is awareness. Often times the developer may consider the old cliché "out of sight, out of mind." The job of the person who deals with revegetating disturbances in a large development is to make sure that that line of thinking is not allowed to occur.

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**An Evaluation of Revegetation Projects at Three High-Altitude Lakes, Summer, 1987**

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The Indian Peaks Wilderness Area (IPWA), west of Boulder, Colorado, is a high mountain environment of extraordinary beauty and easy access. These qualities have combined rather unfortunately and predictably to cause the area to suffer from high human use: tent sites, fire places, and shortcuts have damaged trees and ground cover, in some cases so severely that the areas were denuded with resulting soil erosion.

In 1981, under the auspices of the United States Forest Service (USFS), five sites at Lake Isabell were selected for revegetation.; in 1982 sites at Mitchell Lake and Blue Lake were added. The plan was to establish a ground cover to stabilize the soil, halt erosion, and provide time for the native plants to re-establish their delicate and highly specialized systems. Each area was mulched, and, except for Site One at Lake Isabell, was seeded with a mixture of exotic and non-alpine plants: Sheep fescue (*Festuca ovina*, introduced from Europe), Common timothy (*Phleum pratense*, introduced from Europe), Slender wheatgrass (*Agropyron trachycaulum*, native non-alpine), and Strawberry clover (*Trifolium fragiferum*, introduced). Theoretically, the exotic and non-alpine species would not reproduce in the high-alpine environment and would gradually die out, enabling the native alpine species to reinvade the habitat and prevent further loss of soil.

During the summer of 1987 I visited nine of these sites, to evaluate the present state of stabilization and species populations. I tested three hypotheses:

1. Native plants will re-establish themselves if they are competing with introduced plants which are not adapted to the rigors of an alpine environment and cannot reproduce.
2. Introduced species may adapt to the alpine environment and reproduce successfully, thereby replacing native species.
3. A high-use area cannot be removed from human access and successfully revegetated.

At each site I took photographs from designated photo sites, for comparison with Forest Service photos. I did plant inventories to determine whether or not any of the introduced species were still present. I have assigned a Frissell classification to each site, in accordance with Frissell's System, 1978, which rates sites from one to five in order of deterioration.

Frissell's Classification:

- 1 Ground vegetation flattened but not permanently injured. Minimal physical change except for possibly a simple rock fireplace.
- 2 Ground vegetation worn away around fireplace or center of activity.
- 3 Ground vegetation lost on most of site, but humus and litter still present in all but a few areas.
- 4 Bare mineral soil widespread. Tree roots exposed on surface.
- 5 Soil erosion obvious. Trees reduced in vigor or dead.

Although the Forest Service originally had ropes and signs at all the sites, only two sites, Lake Isabell Sites Two and Three, still had ropes this summer. Some of the signs were gone. One of the roped sites, Lake Isabelle Three, was the healthiest site I studied, the only one rated 1 on the Frissell scale. The two worst, Mitchell Lake Two and Lake Isabelle Four, both Frissell 4, still had signs.

At several sites I found common timothy (*Phleum pratense*), but no other plant used in re-seeding. Wildflowers and grasses have moved into the sites, but only one woody species, *Vaccinium*, even where it probably would occur naturally. Plant cover at each site was more sparse than in surrounding or nearby areas of similar aspect. Soil was visually more compact, less hummocky, than soil beyond the damaged areas.

People were generally curious about what I was doing, and pleased and supportive when I explained about revegetation. It was apparent, however, that they had no idea that any steps had been taken, or that any were needed. It appeared to me that education is paramount in acquiring public support and co-operation.

At the end of the summer, the USFS removed all remaining signs and ropes. I have not yet had time to confer with John Oppenlander about the reasoning behind this move.

For future site protection, I would like very much to see a permit system implemented for day hiking as well as camping in the IPWA. The funding system needs to be revamped: fees charged in IPWA need to be kept there.

A quick overview of the sites follows:

**Blue Lake, Site Two** (never found Site One)

Visited June 14, July 2, July 4, Aug. 2, 31, Sept. 5

No revegetation species present.

Bare mineral earth visually noticeable; Frissell classification 3.

Rope and sign missing; no public awareness.

High use, as eating area and bathroom.

Recommend replace rope and sign.

**Mitchell Lake**

Visited Mar. 15, April 12, 25, June 14, July 2, 4, Aug. 5, 8, 12, Sept. 5, 13

**Site One**

Open meadow with large rock next to lake.

Soil compacted.

No revegetation species.

Late snow cover: snow present end of May.

Bare earth around prominent rock at center; Frissell classification 3.

Rope and sign gone; no public awareness.

High use as rest stop, lake access, eating spot; good views.

Recommend replacing rope and sign .

The revegetated site is in a direct line of access to Mitchell Lake, with its central boulder inviting people to stop and sit. A control site, adjacent to and west of Site One, in the same meadow, is undamaged, with visually lush vegetation occurring in microhabitats on and around the many hummocks that comprise its soil cover. Two transections were done here, one through the revegetated site itself, one through the control site. On the lines of transect, I placed lines of intersection every two feet and perpendicular to transect. I counted a point every two feet along the intersect, and at each point, counted root clumps in an area one inch by one inch . Thus, POINT means point of intersection of transect and intersect; COUNT means one root clump or one bare spot. The damaged area had 55 bare points, for 27% of 204 points, 24% of 215 counts, while the control transect had 13 bare points, for 8% of 165 points, 6% of 215 counts. The control also had a higher percentage of multiple occurrences, points occupied by more than one root clump: 29.6% for the control transect, 22.7% for the revegetated site.

In identifying plants at the intersect points, I made the following generalizations:

grass: generic designation, including *Heirochloe hirta*, *Poa alpina*, *Poa compressa*, *Poa arctica*, *Poa fendleriana*, *Deschampsia caespitosa*, *Deschampsia alpicola*, *Festuca rubra*, *Phleum commutatum (alpinum)*. I did not find *Phleum Pratense*, *Festuca ovina*, *Agropyron trachycaulum*, or *Trifolium fragiferum* at any point on any transect.

SHP: small herbaceous plant

G/R: tiny or immature grass/rush plant I couldn't identify

I have not identified any plant more specifically than needed to determine whether or not it was a revegetation species.

**Mitchell Lake cont.**

**Site One Transect: 204 points, 234 counts (one plant or one bare spot)**

Species occurrence:	count	% of .204	% of .234
Grass	94	46.0%	40.0%
Sedge	19	09.0%	08.0%
Marsh Marigold	28	13.7%	11.9%
Matt Plant	11	5.3%	4.7%
Umbellifer	5	2.4%	2.1%
Bistort	1	0.49%	0.42%
Moss	6	2.9%	2.6%
Speedwell	2	1.0%	0.85%
Composite	6	2.9%	2.6%
Bedstraw	1	0.49%	0.42%
SHP	2	1.0%	0.85%
Sibbaldia	4	2.0%	1.7%
Bare	55	27.0%	24.0%
<b>Multiple Occurances at one point:</b>			
Total multiples	25	12.0%	10.6%
Multiple 2	20	10.0%	
Multiple 3	05	2.4%	

**Control Transect: 165 pts, 215 counts (either one plant or one bare spot).**

Species occurrence:	count	25% of .165	19% of .215
Grass	41	25.0%	18.0%
Rush	38	23.0%	18.0%
G/R	50	30.0%	23.0%
Sibbaldia	17	10.0%	08.0%
Marsh Marigold	40	24.0%	19.0%
Umbellifer	8	05.0%	04.0%
Bistort	3	02.0%	1.3%
Moss/lichen	1	0.6%	0.5%
Club moss	2	1.2%	0.9%
Speedwell	1	0.6%	0.5%
Vaccinium	1	0.6%	0.5%
Bare	13	8.0%	6.0%
<b>Multiple occurrences at one point:</b>			
Total	49	29.6%	22.7%
Multiple 2	40	24.0%	
Multiple 3	7	04.0%	
Multiple 4	1	0.6%	
Multiple 5	1	0.6%	

**Mitchell Lake cont.**

**Site Two**

Open to south, trees on three sides, shaded, large flat rock.

One clump of common timothy.

Bare earth present, root distribution sparse. Frissell 3.

Wildflowers predominant re-invading species; adjacent site with similar aspect thickly covered with *Vaccinium*, a woody species.

Sign present, rope gone.

I never saw anyone using this site, but from the type of deterioration and disturbance I saw over the summer, I suspect it may be a wayside play spot for children and dogs. Rotting logs were disturbed and small pieces tossed about.

Recommend replacing rope and sign.

**Site Three**

The trail goes through this site. It was one of the worst of all sites visited.

Extremely sparse plant growth, almost entirely bare mineral earth with tree roots showing. Frissell 4.

Sign present, rope gone. Public apathy.

Recommend replacing rope and sign.

Suspect site will never recover.

**Lake Isabelle**

Visited June 28, July 5, Aug 15, Sept. 12

**Site One**

This is the only site I studied which was not reseeded. It was scarified, roped, and signed.

Common timothy was present, and assorted wildflowers were doing well around the edges and at the bases of trees.

Bare mineral earth showing; Frissell 3.

Recommend replacing rope and sign.

**Site Two**

The rope and sign were both still up at this site, but the rope was very loose.

A late-lying snowbank was present, and its effect could be seen in the length of the growing season as it receded. This site has a very short summer, and, hence, is extremely delicate.

Common timothy was profuse, as was alpine timothy. Alpine timothy was in fruit while the common timothy was still very immature.

Bare earth, sparse plant cover in center of site, dense wildflower and grass cover away from center.

Recommend maintain rope and sign. This site has hope.

**Site Three**

Healthiest site of all! Rope and sign present until removed by USFS at end of summer.

Common timothy present, as were alpinetimothy and numerous native flowers.

Frissell 1, alas, as I fear it will not last. I saw this site on the day the rope was removed, and the healthy grasses were already flattened were people had been.



Site Four

Sign only.

Not in good condition. Very sparse plant cover, no reveg species. Mostly bare mineral earth, with roots of trees showing. Definite boundary to the site, beyond which vegetation flourishes. Within site, Frissell 4.

Recommend rope and sign.

Site Five

No sign, no rope. Frissell 3-4.

Vegetation sparse, with much bare earth.

Common timothy present, as was alpine timothy.

Recommend replace rope and sign.

Conclusions:

1. Native plants may re-establish themselves, but they need more than five years, and they need to be protected from human access. The most appropriate seed mix cannot survive being trampled.
2. Only one species, *Phleum pratense*, used as a revegetation species, has survived for five years.
3. Humans tend to use areas with either a) a sign and no rope, or b) no sign and no rope; however, if made aware, the public seems willing to comply, as evidenced by the health of those sites with both signs and ropes and the interest of people I talked with this summer.

Working on this evaluation helped me in my decision to return to school after 26 years and a family. I would like to acknowledge the following for their support and encouragement in this endeavor: the Colorado Mountain Club, Dr. James Halfpenny of INSTAAR, Neil Heywood of the Geography Department at the University of Colorado, the United States Forest Service, James Ehrets and Don Kissling, my employers at Jackalope Geological in Boulder, Gary Thor of Colorado State University in Fort Collins, and, especially, Edie Eilander, who set up these sites and was willing to spend time with me as I evaluated her "gardens." Any errors contained herein are solely my responsibility, and, as my work is yet incomplete, I hope to rectify any problems in 1988.

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We were pleased to have a total of 236 participants at the Eighth High Altitude Revegetation Conference. Representatives from five foreign countries as well as from twenty states attended the conference (Table 1). As can be seen from the data in Table 1, most of the participants came from Colorado, however people from both coasts and from Alaska to the Gulf of Mexico were present.

For all of you that came, thank you for your participation in the conference. Make your plans for attending in 1990, and pass the word to your fellow workers so that the 1990 conference will be a great success.

Editors

Table 1. Geographical distribution of participants at the Eighth High Altitude Revegetation Conference.

Geographic Entity	Number of Participants	Percent of Total Participants
AUSTRIA	1	0.4
CANADA		
Alberta	4	1.7
British Columbia	1	0.4
DENMARK	1	0.4
SWITZERLAND	1	0.4
UNITED STATES		
Alaska	2	0.8
Arizona	4	1.7
California	10	4.2
Colorado	147	62.2
Delaware	1	0.4
Georgia	1	0.4
Idaho	3	1.3
Indiana	1	0.4
Montana	9	3.8
Nevada	1	0.4
New Jersey	1	0.4
Ohio	2	0.8
Oklahoma	2	0.8
Oregon	1	0.4
South Dakota	9	3.8
Texas	1	0.4
Utah	8	3.4
Vermont	1	0.4
Washington	2	0.8
Wyoming	21	8.9
WEST GERMANY	1	0.4
TOTAL	236	99.4

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