Proceedings
High Altitude Revegetation
Workshop No. 10

Edited By
Wendell G. Hassell
Susan K. Nordstrom
Warren R. Keammerer
Jeffrey Todd

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Colorado Water
Resources Research Institute

Colorado State University

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HIGH ALTITUDE REVEGETATION WORKSHOP

NO. 10

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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 varous 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 Committee members cannot respond directly to participants' needs unless they are communicated. The Committee needs and solicits input. Addresses and phone numbers of Committee members are listed elsewhere in these Proceedings. Please contact any member with suggestions you might have. By collecting 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:

	Area Toured	Sites Toured
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 CO2 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	Teluride/Ouray/Silverton, CO	Ridgeway Reservoir, Telluride Mt. Village Resort, Idarado Mine, Sunnyside Mine
1989	Lead, SD	Terry Peak Ski Area, the glory hole and processing facilities of Homestake Mining Co., and Wharf Resources surface gold mines using cyanide heap leach.
1990	Colorado Springs & Denver Area, CO	Castle Concrete's limestone quarry, Cooley Gravel Quarry, Morrison. E-470 bridge and wetland near Cherry Creek. Littleton gravel pit restoration to parkland
1991	Central CO	Alice Mine, Urad Tailings, Pennsylvania Mine at Peru Creek. Yule Marble Quarry near Marble, and Eagle Mine tailings and Superfund clean-up, near Minturn and Gilman

PREFACE

The 10th biannual High Altitude Revegetation Workshop was held at the University Park Holiday Inn, Fort Collins, Colorado March 4-6, 1992. As always, the Workshop was organized by the High Altitude Revegetation Committee in conjuction 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.

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.

The Editors

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IMPLICATIONS OF REVEGETATION IN PARK MANAGEMENT

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INTRODUCTION

When I was asked to be the keynote speaker for this conference it delighted me because it came just when I was leaving my beloved Rockies for the eastern seaboard. For those of you who read the newsclips, the conditions surrounding that transfer are already quite public, but needless to say I left these mountains with a great deal of sadness. In the eleven and a half years as the Regional Director of the Rocky Mountain Region of the National Park Service, I grew to love and feel very protective of this fragile, unique area.

Perhaps it is because of that intense interest that I became very much involved personally in efforts to restore, reclaim and in general, promote the use of native plants in revegetation efforts in the parks in the Rocky Mountain Region of the National Park Service. That fact to my surprise, was observed and acknowledged by two awards in 1990 and 1991--the Award of Merit from the Colorado Chapter of the American Society of Landscape Architects, and the Federal Highway Administration's Commitment to Excellence Award. They are both hanging in prominent locations in my office in Philadelphia.

Now, I think you will understand, that the slides and examples I am going to show you of such efforts in the National Park Service, are understandably going to be from this Region. In my new Region my responsibilities range from sea level to a high of 3,000 feet (not described very often as "High Altitude"). In fact, in the Pinelands of New Jersey, of which I am currently a Commissioner, they are contemplating building an observation tower so people can oversee the whole area. They would build it at the highest point in the area (205 feet above sea level).

My address to you today is not a technical paper on the right or wrong way to perform high altitude revegetation. You are the experts. I am issuing a call to arms to Park Management, forest management, and etc., to become concerned and involved in this effort.

My experience has been that attention to this issue is good management and a strong public relations tool upon which to base park recommendations and decisions.

For instance, at Logan Pass in Glacier National Park, the need to provide a functioning comfort station became the catalyst for a major experiment in salvaging subalpine vegetation prior to the reconstruction of the comfort station and handicapped walkway.

Sod removal began the summer of 1985 and was cut short because of the lack of a contractor for the reconstruction work. This 1985 sod overwintered well, so the technique for removal and boxing the sod at the Pass was set. The remainder of the sod was removed in 1986 and set in wooden planter boxes at the Pass and on mirafi with log sides at Oberlin Bend (half mile west of Logan Pass). Initially the vegetation was dug out by hand and bobcat where feasible. As the result of changes in construction plans, an increase in the amount of sod to be removed, and the lack of time allowed before construction began on site, a front end loader was used to remove the remaining sod.

The 1987 season showed that the sod overwintered well. It was not necessary to use fertilizer because the sod, with only extra watering, attained sufficient vitality for replanting. Wooden sod boxes compared favorably to the roadcloth/log box. To ready the sod for the 1987 replanting, watering of the sod boxes began mid June. Rock landscaping was recommended before replacing the sod to stabilize the steep slopes and to aesthetically hide the culverts and the manhole cover. Transplants of native wildflowers from the back meadows were brought in and planted amongst the boulders.

The flagpole area was the first to be resodded, followed by the culvert pipe and the manhole area. An 18" border was left unplanted along the cement/rock walls and walkway to allow the construction crew room to work when pouring the cement walkway.

The revegetation project was very successful. But also as important as learning about revegetation techniques, was managing the funding. It all came from the construction project account. If your agency is similar to ours, you can wait forever for revegetation funding through normal channels. Funding for the revegetation has to start before the construction of the project begins.

Another real selling point of the on-site salvage and retention, is that it allowed us to interpret, for the public, what was occurring and educate them to the fragileness of the subalpine environment and consequent difficulty in restoring and reclaiming an area once it is affected by construction or human overuse.

At Glacier, the impending reconstruction of Going-to-the-Sun Highway necessitated the establishment of a preconstruction nursery to propagate native species for eventual replanting in the road cuts and disturbed areas. Here you will see collection of seeds to reproduce those species in the nursery. During the early years of my career, I was in charge of the budget for construction for the old Midwest Region of the National Park Service which then encompassed what is now the Rocky Mountain Region. As the person controlling the purse strings, I witnessed time and time again the lack of thinking ahead to provide for revegetation in advance of the project, and diverting limited funds that were provided for post construction revegetation to construction of the roads. Consequently, many of the road environments never were revegetated even after a 25-30 years. I was determined that we would not make that same mistake again. In our programming for roads in this Region, we have ensured that the necessary funds are acquired in the pre-construction period to gather and propagate native species, and then the provision of post construction funds for several years after construction, to provide for the necessary rehabilitation.

Many different types of revegetation are occurring in Rock Mountain National Park. At Lilly Lake, a former dump was acquired which required rehabilitation. "Regreen sterile wheatgrass" was seeded for cover until natural succession begins to occur at this site. Since this area was acquired to prevent development and restore the natural scene, it was extremely important to move quickly to revegetate it.

Excelsior netting was used to restore a denuded ski slope at Hidden Valley. One year later you can see a successful project with vegetation growing well. However, the grass used on the slope was not the ecologically appropriate plant for the slope, but the best to stabilize it. The ski area is currently closed. If it remains so, the slope will return to its natural condition. This is an example of protecting an area from recreation activities and stockpiling it until its future is absolutely determined. It stabilized the slope and deters runoff.

An example of revegetation techniques that can be employed to save money (or at least stretch it further) is the restoration of a ditch area. This particular ditch area is two miles into a proposed wilderness area. No soil existed in the area for back-filling the ditch and would have had to be hauled from elsewhere by helicopter or pack stock. Using the small constructed dams cost the park approximately $5,000 versus $50,000 if fill material were flown into the meadow by helicopter.

In road construction, at times it is impossible to lay back the shoulder gently enough to obtain revegetation. This calls for unusual techniques and solutions. On Trail Ridge Road we used an innovative technique of reducing the angle of repose on steep slopes. Complicating revegetation further, is that Trail Ridge Road is on the National Historic Register and any new walls have to resemble old CCC walls. The park cannot realistically or economically build retaining walls the way they were done by the CCC in the 1930's due mainly to prohibitive labor costs. So here the Maintenance Division came up with a cost effective (prefab-like) retaining wall that serves its purpose and yet preserves the integrity of the historic walls along Trail Ridge.

Whenever possible we use alternative methods to herbicides! Tame goats are being used to control the noxious weed--leafy spurge.

Those of you who have been to Rocky Mountain in the past few years, or those who go there this week, will see the use of different types of fences to control visitors in sensitive areas. These areas have, in many cases, come back on their own. Installation of the fences once again gives us the mechanism to preserve the resource and also educate the public to the fragileness and lengthy period of time it takes for areas to recover in alpine areas.

In Yellowstone you will find once again many of the techniques that have been employed in the aforementioned areas dealing with people impact and construction. I thought you would be interested in a series of fireline restoration techniques. This was an example of determining impacts even in a crisis so that disturbances are minimized. Forest Service crews and equipment installed these lines with guidance from the National Park Service. First, is a "before" photo of bulldozer line before rehabilitation began. It is curved and topsoil is windrowed to one side which greatly assisted revegetation work. The "after" photo shows three growing seasons later when the line is gone. The growth that has taken place is from the topsoil, nothing added. By conserving the seed sources and material the gene pools are not altered.

In a different part of the park, again the "before" slide shows disturbance, though it is carefully designed. Topsoil is windrowed and carefully removed. The "after" slide shows the same area three seasons later. The growth is from the material windrowed to the side. Nothing was added to the site. Heavy equipment was used to remove and replace the topsoil from the disturbed areas.

Hand fire-lines were also constructed using the same techniques. Deeper than bulldozer line and more extensively used, the technique is the same. The "before" slide shows the line in a disturbed state. The "after" shows the line three years later. Native plants are now covering the disturbances. Hand equipment was used to remove and replace the topsoil.

The lesson for park management is: In the haste of field decisions, during times of crisis, a little extra thought and care will lessen the immediate impact and hasten restoration after the crisis is over. It saves time, money, and is just a stellar example of protection and preservation of the natural resource under extremely trying circumstances.

In Grand Teton, the impacts of heavy backcountry use are becoming more and more of a problem every day. Various projects are ongoing, but I thought you might be interested in hearing about the Marion Lake area. Marion Lake is a popular high country lake visited by day hikers from the tram at Teton Village, by campers using the Teton Crest Trail, and by horse parties from valley dude ranches. The heavy use and short growing season have resulted in accumulated impacts. In 1980, we tried the installation of jute matting on several bare areas. In spite of the "Closed for Regrowth" signs, some visitors used the matting as blankets for sun bathing. So guess what, ten years later little vegetation was evident on the jute matted areas.

In 1989 and 1990, a major rehab effort was conducted at the lake by a Sierra Club work group. About 1100 feet of the Crest Trail was closed. Social trails were upgraded to be used as the Crest Trail and some new trails were constructed to connect pieces of trail. Fourteen campsites were scarified, three campsites had tent pads installed, and a borrow pit was opened. Over ten tons of soil were transported by mule to the site. Plugs were transplanted into the closed trail, and a gravity-feed irrigation system was installed using a gravity sock in a small stream. A borrow site for the fill was selected in a meadow just over the hill below the lake. It was a shallow draw carrying only surface water during heavy storms. Soil was excavated in such a way as to make the draw a little deeper but the sides were sloped so it would not be noticeable when revegetated. Impact of the mule trains was a concern so the work was done in August when the area was dry. One of the packers helped in avoiding disruption of the vegetation by his observation, "There are two kinds of plants--grass and weeds.

These are weeds, and you can't hurt weeds!" Sure enough, no mitigation such as sod saving or reseeding was necessary. The next summer you couldn't see any evidence of mule traffic. The lesson here is, park management should never close its ears to suggestions from anybody!

Also in Grand Teton, revegetation techniques and research were used as a public relations tool to sell to the public the need to relocate a segment of road. The outside Jenny Lake road had been initially constructed in an extremely straight tangent across sagebrush flats that were the home of major elk populations. When the need for reconstruction of that road occurred, we took the opportunity to examine the road alignment to determine if we could in some way make it less like a highway and more of an interpretive experience. We also took strongly into consideration the need for less interference by the road and traffic into the life of the elk herd. Successful reestablishment of sagebrush in the past had been very nominal. Consequently, we knew we had to convince the public that we **could** rehabilitate and revegetate the scar from the old alignment if we were to move to a different road alignment.

Four test plot sites were established along the Homestead Road, with similar topography and soil characteristics as the area to be revegetated, so we could translate our experience readily. Topsoil obtained from exposed lake bottom soils during construction of the Jackson Lake Dam was placed on the respective subplots to provide a more favorable plant growth medium. A motor grader was used to spread the topsoil and perform ripping activities. The ripping was used as a treatment to reduce compaction. Different methods of revegetation were experimented within the four plots.

The most successful plot treatment, of course, was selected to revegetate the road scar. It is a success story. Admittedly part of the success is related to utilization of extremely productive topsoil obtained from the lake bottom and good moisture supply at critical times. But we were able to demonstrate to those who did not want us to move the road that it could be done successfully.

This opportunity to be involved in the planning and restoration of my beloved Rockies has been the elixir of the Gods. I have used as my guide all these years, "The Ranger's Prayer"-

"Teach me O Lord not how to close gates but how to open eyes;

Let me not stand in exalted places gazing down upon my fellow men, but rather, give me the humility to speak on the level;

If I should lose sight of the arboreal ecosystem because of its constituent plant species, then Lord, show me the way whereby I may see the wood as well as the trees;

Though there be mud on my boots, may I still have stars in my eyes, yet my head not lost in the clouds;

Help me to acknowledge Lord, that awareness of my own ignorance is the beginning of wisdom, for if I possess knowledge but have not intelligence; if I have skill but lack understanding; if I represent Authority and Dominion--but have not charity; if I minister justice but have not mercy, then surely--I am as nothing."

by Malcolm Payne
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ECOLOGY OF THE GUNNISON VALLEY

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ABSTRACT

When entering the Gunnison Valley from Monarch Pass, an individual passes rapidly through the alpine, subalpine and montane zones into the cold desert and riparian zones. The valley bottom and slopes are quite similar to the starkness of Utah and Nevada. Perhaps the most noticeable differences are the cooler conditions associated with the Gunnison Valley, and the absence of the Pinyon Pine and Utah Juniper. However, as one leaves the river bottoms, the cold desert element loses its significance and more of the montane and subalpine elements are evident. Throughout the valley, an individual gets the impression of raw beauty and there is a tendency to develop the feeling of being associated with a pristine and untouched landscape. However, if a person leaves their vehicle and moves through the vegetation, it quickly becomes evident that virtually every hectare has experienced human intervention. The situation becomes difficult when attempting to provide reclamation which is directed to reestablishing original vegetation. Because succession is slow, however, much of the disturbance occurred prior to the turn of the century, there is limited evidence of how the vegetation was developed and distributed originally. An additional factor is associated with the evidence of climate change. The Gunnison Valley is beautiful, but one should recognize much of it is associated with management, rather than natural processes.

INTRODUCTION

When I was called to speak today, I felt honored, and I accepted. With some consultation with my inner self, I became a bit alarmed. What could I possibly discuss which you do not already know, or which you cannot handily access from the existing literature. Weber (1987) has provided a current listing of the flora of the Western Slope. Komarkova, Alexander and Johnston (1988) have described the Gunnison vegetation. Numerous theses and graduate manuscripts from Western State College have contributed bits and pieces to the Gunnison puzzle. Therefore, all I could provide is an inventory of all we do not know, and once you have read the literature, you would be aware of that as well. Therefore, upon considerable reflection, I felt what I could contribute are some of those reactions a person generates which are not documented, which may be based more on intuition rather than entirely on fact. This is the kind of information for which there is minimal data, but you will have a difficult time disproving me and, perhaps, I can help you enlighten the world by having you try to disprove me.

Also, another point came to mind. In 1955 I had the occasion to be befriended by Dr. Fred Wolf, a retired mycologist from Duke University.

He had recently written some rather controversial articles and he pointed out that upon retirement an individual could speak his mind because there could be no retribution. In March, 1990, I was diagnosed as having pancreatic cancer with four-six months to live, so I retired in May of 1991. When I was asked to speak today I decided I could unload some thoughts, none too profound, but for which I can receive no retribution.

In any case, I have devoted thirty years of my life, and the life of my family and students, to the joys and pleasures of gaining some academic and practical understanding of how the natural and unnatural biological systems function in the Gunnison Basin. I was paid for some of it and some of it was done because a student came along and said "Help me!". In all cases the results were rewarding. In my reference section I have cited those student productions because they are a part of me, and much of my knowledge stems from their labors.

The subject I address is motivated by several forces. First of all, the Gunnison Basin is the place I love and admire--if a person can love an inanimate object. Secondly, it is the place to which I have devoted my life. Thirdly, it is a place of stark, naked beauty, augmented by panoramas which are soothing, but breathtaking. I will show no pictures because you must see it to believe it.

I am an ecologist. Ecologists are sometimes confused with environmentalists, and it is true they may be one and the same, but often they are quite different. An ecologist is a realist and deals with the cards nature has dealt. An environmentalist is one who lives in fantasy, attempting to design a world which fulfills his dreams and goals of the moment.

The environmentalist goes over Monarch Pass from Salida and enters the Gunnison Valley. Tomichi Creek, trickling to the west, has associated with it a broad green valley. The first impression is that we must preserve such a work of nature. He sees the sagebrush and makes a note that we much change that. We must remove those phreatophytes, those symbols of mismanagement. Some logging trucks go by and the environmentalist is filled with disdain because the human has chosen to interfere with nature and is altering the pure and the pristine. How dare we remove those aspens to generate financial reward. How dare we cut the majestic old growth spruce so that we can have some lumber. How dare we interfere with nature. As he drives into town, a truckload of coal goes by, heading for Alamosa and the mushroom plant, and he is troubled by the thoughts of the coal mine operation rearranging the landscape. When he reaches Blue Mesa Reservoir he is stricken by the sight of the dam, where the turbines are generating electricity, and where the reservoir has covered the wildlife winter range for twenty miles and has destroyed some of the best trout fishing in the world, and, of course, trout fishing is truly a part of a natural system. The environmentalist looks at the mountains around him as he drives along and says to himself, "there is still something left and I will fight to preserve it".

The ecologist , the realist who is riding with the environmentalist, recognizes that all of what he and his partner have seen this day is a product of management. There is hardly a square foot of ground which has not been influenced by the action of a human - the beautiful and the ugly. Furthermore, the utilization of land is a function of priority. Wood must come from somewhere, the best management of forest ecosystems employs cutting and all of what the environmentalist has questioned, he is one of the recipients. His quality of life would be decidedly less without it.

The ecologist, the realist, must understand the natural systems, must be able to recognize that if they are going to be managed as they are being managed, that the management must be done to enhance the system and not destroy it. Perhaps the ecologist can promote the natural system, speed it up, but not destroy it. The ecologist must orchestrate and help the decision makers. Resources are to be conserved and not preserved.

Natural diversity can contribute to economic diversity. There must also be a place where the ecologist indicates no actions are appropriate. Perhaps the most obvious is the question of trans-mountain water diversion. The ecologist has noted for years that when a factor is limiting, the system has achieved its limits. If you supply the limiting factor, other factors are stressed and the system gets more and more management dependent. If the Front Range is out of water, I guess it is time to quit growing, or perhaps a time to start conserving. The solution is not to resolve today's Front Range stress by creating the Western Slope stress for tomorrow.

What I intend to do is examine the natural systems of the Gunnison Valley. I want to indicate to you how natural forces and human impacts have interacted to provide what you consider beauty, and what you consider unacceptable. Above all, I want to emphasize that human activity or management may contribute positively and it may contribute negatively. Much of the outcome is in the eyes of the beholder and virtually none of it has been subjected to any scientific test.

On April 1, 1962 (please note the date), I made my entrance to that part of the world known as the Gunnison Country. I rode the train from Pueblo to Salida, through the Arkansas River Canyon. The train stopped below the bridge near Canon City so the passengers could step out to observe the magnificence of the canyon. In Salida, Dr. Sidney Hyde greeted me and we drove across Monarch pass and into a raging blizzard. That should have provided me with some insight as to what this country is all about. The blizzard was only a part of it. Only U.S. 50 and Colorado 135 were paved. There was no housing available for our family of four children. Opportunities for conventional shopping were near nil. The forests of the Rocky Mountains I had envisioned did not extend to Gunnison. With a note of despair I called my wife to apologize for what I had done to her and our family, and promised that after a year of living in a faculty apartment with two bedrooms, we would seek employment elsewhere - you see the problem was that I had signed a contract in January. My first ecology lesson in the Gunnison Basis was in the area of human ecology.

A bit about the Gunnison Country. Gunnison County has about 10,000 permanent residents, living in a land area of 3238 square miles (three times the size of the state of Rhode Island; one and one-half times the size of Delaware). About 70% of the land is in public ownership. Land development has occurred to accommodate 50,000 people. The topography provides altitudinal variation of 4000 feet, in no regular pattern. The variety of altitude, aspects, atmospheric patterns, soil conditions, slope, moisture and temperature regimes result in such a variety of niches that the fauna, flora and vegetation are diverse. The primary limiting factors are a growing season which can be interrupted with a frost at any time, and a dry environment which may include temperatures as low as -50°F. The most effective precipitation is winter snow which provides winter insulation and a snowpack which provides the downslope with water during the growing season. The highest monthly precipitation occurs between July 15 and August 15, and is localized and of relatively short duration. Consequently, the summer precipitation is unpredictable, often devastating, and for the most part ineffective. Low night temperatures during the growing season result in low night moisture deficits accompanied by high daytime deficits. Summer day temperatures rarely exceed 85°F.

The combination of factors elaborated above provide groups of ecosystems which may be categorized as follows:

1. Valley
    a. Riparian
    b. Meadow
2. Cold Desert - Sagebrush
3. Woodlands
    a. Juniper
    b. Oak Woodland
4. Montane
    a. Ponderosa Pine
    b. Douglas Fir
    c. Aspen
    d. Lodgepole Pine
5. Subalpine
    a. Spruce-Fir
    b. Aspen
    c. Lodgepole Pine
5. Alpine Tundra

GUNNISON VALLEY ECOLOGY

In considering Gunnison ecology, there are many directions which one may take. First, there is the tourist assessment of our landscape as stark, overwhelming, pure, pristine, and the sense of the typical western wide open spaces, punctuated by heads of cattle and cowboys. Secondly, there is the recognition by the ecologist that there is much diversity, and virtually nothing has been written to provide an adequate appraisal of the ecological realities. Thirdly, there is the dilemma of the reclamation ecologist and the environmental engineers who are charged with returning disturbances to some original state. The tourist sees only the surface, and because our beauty has so much to offer, it successfully masks the blemishes, the disturbance, the mismanagement. The reclamation is equally difficult because there is no handle on what constitutes original. The landscape of the 1800's has been altered and not had the opportunity to reestablish the natural systems, even when impacts have been removed for a long time. Ecosystem stabilization takes longer than whatever history exists in our valley.

The initial thrust I will take is historical. The literature lacks historical accounts. On the East Coast surveyor reports provide considerable insights but much of our western land was surveyed after the impacts were initiated.

The literature lacks the historical accounts of what the Native American experienced, or how he managed the vegetation and fauna. The impression held by most people is that whatever the Native American did was next to godliness. They certainly lacked the technological advancements of our present time, however, they developed settlements with their attendant impacts. They moved about, but the impacts they provided at each site were not what you would like in your neighborhood. They hunted selectively and took advantage of large populations of game during the summer season. They utilized fire and there is reason to believe some of these fires got out of control and burned thousands of acres. Increment borings of scattered samples of forests and borings of wound tissue of burned trees indicate burns throughout the county 175 to 200 years ago. The introduction of grazing animals resulted in grazing impacts, which included localized overgrazing. The Ruffner Expedition in 1876 reported thousands of animals being maintained by the Utes along Tomichi Creek outside of Gunnison. With domesticated livestock we can assume there was selective hunting of predators such as wolves, coyotes and mountain lion. The urbanized Indian maintained gardens, although their gardening practices were radically different from ours. They ordinarily freely seeded without altering the native vegetation. Today, I believe we call this inter-seeding. They provided organic fertilizer by throwing food wastes from the front of their tepees.

The Native American utilized the high country for summer hunting and camped in the warmer areas of the low country during the winter. Therefore, the more fragile higher elevations received minimal winter disturbance. Because of minimal pressure, the large animals had uncontested winter range and over-wintered at lower elevations. With increased use of domesticated animals, the higher elevations were increasingly used by the Indian.

As early as the 1500's the Spaniards included the Gunnison environs in their exploration. Though the average Gunnisonite is reluctant to admit it, the Gunnison Valley was once a part of Spain, Mexico and Texas. During the 1850's assorted expeditions were commissioned to examine Colorado for a variety of reasons, and the Gunnison Valley was included. The native ecosystems were not appreciably affected by this activity. Early trappers provided localized impact. The annihilation of a species in one location only allowed the survival of overpopulation from another site.

The homesteader provided the first major alteration of the landscape. American law dictated that a parcel of land be identified and impacts were required to be concentrated on that parcel. Remaining public lands received the collective abuse of whoever got there first in any given season. Because of the need for water and the need for a flat and open place to manage livestock, the drainage basins, the bottomlands, became the sites for localization of housing, outbuildings, pasturage, hay meadows, family gardens, and whatever else was necessary for survival. Schoolhouses and churches were established and micro-communities emerged.

At the end of a day's wagon ride (nine to ten miles), people anticipated finding a place to eat, sleep, and to find care for their horses. This resulted in the establishment of small communities such as Parlin, Jack's Cabin, Powderhorn, Iola, etc.

The practice soon developed which concentrated livestock in the lands associated with the "home place", during the winter to allow care for the animals during brutal and bitter winter cold. The cowboy did not need to go far to carry out his early morning tasks. Predators could be managed, as they aggregated where their potential meals were grazing. This localization of animals allowed easy access for hay feeding and permitted the animals to be observed and protected during the vulnerable period of calving.

In Spring, after concentrated use of the bottomland during the winter, the cattle moved into less desirable areas where forage was not as concentrated as in the bottomland pasture, but where there were many square miles of grazing. The livestock were kept moving by the cowhands and shepherds from one patch of ungrazed land to another, always with water availability in mind. There was no organized grazing pattern because there were no allotments and therefore, when the animals reached an anticipated destination and the land was already occupied, they were moved to another location. The grazing areas nearest the homesteads were most susceptible to impact because they were often grazed in the Spring before plant species were well established and therefore subject to eradication. This resulted in an opportunity for the loss of herbaceous cover and increased erosion of topsoil, which reduced the potential for future productivity and species diversity.

Meantime, back at the ranch, the rancher needed to make hay to provide feed for the winter. He needed to get the livestock off the land as early as possible to obtain maximum herbage development. He needed to reduce any enclaves of non-productivity, so he irrigated to ensure good water distribution and to obtain vegetative uniformity. Marshy areas were unmanageable; dry sagebrush could not be mowed. Therefore, the multi-channeled, and often non-channeled bottomlands were channelized. The leveled lands were then scored with irrigation ditches to assure all of the land being inundated with the water from the spring melt of the high mountains. The high volume of water often placed the entire pasture under water. Standing water selected the anaerobic tolerant rushes and sedges, at the expense of grasses. Two weeks before Cattlemen's Days, irrigation ditches were shut off to allow the land to dry out so that the land surface would allow human and equipment activity. When the pastures were drained the herbaceous species achieved their maximum growth. After Cattlemen's Days (mid-July) haying started, and with limited mechanization this extended into September. Haying has always been a questionable venture because it occurs during the season of local showers. After haying, irrigation systems were once again opened to encourage a flush of growth. In October, the cattle were herded back to the home place for over-wintering and calving.

The homestead also provided impacts on forested lands. The need for fuel for cooking and for heating relatively well ventilated housing for large families or several families, was fulfilled from nearby forests.

Lumber to construct and maintain buildings was cut from the nearest forests and skidded out during the winter.

The homestead was a localization of high impact, with lesser use of less productive and more fragile public lands. The public lands were often abused because they were subject to waves of animal use as various ranchers moved through. Management plans were non-existent. Allotments were non-existent. However, early ranching was maximized by a period of high precipitation, high productivity and the opportunity to sell all livestock produced. This was followed, in the late 1800's, by a period of low precipitation, low productivity and poor markets, with resultant substantial overgrazing.

Concomitant with the development of a grazing industry was the recognition that the native rock was a source of valuable minerals. This stimulated the initiation of rail service. However, local travel was restricted to horse and wagon and this stimulated human habitation in close proximity to mineral deposits, hardly the kinds of environments which would encourage present-day planning commissions. Because of poor site selection, development was tentative, inflicting maximum impact. Water supplies were polluted and wildlife was exploited. Forests were decimated for the building of homes and mine development. The mines generated waste material, which often included toxic substances, in environments which often could least tolerate the waste. In addition, underground adits and shafts were effective in rearranging water quality, quantity and directional flow. By-products of human habitation were deposited wherever space was available. In any case, mining provided impacts in areas which ordinarily no one would select for living quarters, resulting in environmental disturbances of long enduring consequence because the disturbances were not readily healed. By the turn of the century mineral exploitation of the land decreased, but the scars endured.

Movement of mining and ranching supplies and the need to take cattle to market, and to take ore to smelters or for utilization, stimulated rail development. Taking the path of least resistance placed the rail service in valley bottoms, already the site of maximum impact. Gunnison and Crested Butte became viable communities by virtue of transportation logistics. Gunnison was located at the confluence of the Gunnison River and Tomichi Creek, the hub of the drainage system. Crested Butte provided the northern extension. In both cases the communities were not well sited. They were in a position where groundwater could easily be contaminated. Consider a housing lot had only 25 feet of frontage. The towns were centers of inversion patterns which provided highly polluted air from coal and wood stoves, and subjected people to extremely low temperatures. There are accounts of individuals living in tents with their bedrolls over the coals from daytime fires.

In 1880 Monarch Pass opened and provided an access which eased movement into the valley. Previous access was from the San Luis Valley by rail over Marshall Pass, or by wagon from Saguache and through the Cochetopa Canyon. Monarch Pass accelerated utilization of the valley.

At the turn of the century ranching was active, mining was waning and the U.S. Forest Service became an entity. A single ranger was responsible for the Western Slope. Some of the public lands became organized and managed, enabling the impacts to be reduced.

In the early 1900's a college became located in Gunnison. This provided an opportunity to increase economic diversity in the valley and to increase economic stability. However, it also encouraged population increase in a situation where it could only produce negative impact.

In the 1930's the Taylor Grazing Act helped the establishment of the Bureau of Land Management. This provided management of public lands which previously had not come under the control of the U.S. Forest Service.

The rugged beauty of the Gunnison Valley and its accessibility by rail, made the valley attractive to the rugged individualist who enjoyed fishing and hunting. Subsequently, fishing pressure has resulted in the disruption of the aquatic ecosystems to such an extent that sport fishing can be maintained only by a stocking program. Exotic species essentially eliminated native species. Fishing, along with big game hunting, provided considerable economic benefit but also influenced the wildlife species and habitat by a program which provides long term pressure on the hunted species.

Back country land utilization by recreationists, including hunting, fishing, horseback riding, 4-wheelers, backpackers, dogs, hang gliders, etc., has influenced the environment to the extent that virtually no species is living without direct or indirect interrelationship with the human. Historically, recreation by the local citizen was a minor event. After working 80 hours a week, an occasional trip to town, attending church, visiting with old friends, tippling a few at the bar or going to a dance, constituted recreation. A few minutes could be slipped in under the guise of "checking the place" to drop a line into the creek for a fish. A bit of hunting was permissible. A few people of means came from the outside to enjoy the rugged beauty and allowed themselves to succumb to their highly individualistic nature and partake of what our country has to offer. This has all changed. Use of leisure time is the nemesis of every employed individual. It has resulted in a recreational industry which draws untold dollars for many types of vehicles and uses. It has also developed a local industry in the valley which attracts untold dollars into the valley economy. Perhaps the most important consideration is that recreation has become a positive light in the eyes of the environmentalist. The movement can be opposed to grazing, timber harvest, watershed development, mining and any other occupational use, but they appear to be highly supportive of recreation. Is it perhaps something which most environmentalists enjoy doing and therefore being supportive is in response to their own interest. Or, perhaps, there is the feeling that this is one manner in which dollars for the local economy can be drawn from individuals who have the dollars to share in an environmentally painless manner. This of course means the environmentalist cannot see the destruction. In my own case, I live on 250 acres. The ranch across the street is for sale and I dread the thought that it will be sold for recreational use. I have so much better rapport with the cattle roaming on the property than the people I envision moving in across the street. By the same token, please recognize I have been a member of the Board of Directors of the Colorado Trails Foundation since its beginning.

Without attempting to belabor the subject, let me just give you the following statistics:

1. It is estimated that on any given day, 6273 people are visiting in the Gunnison Valley. This is not quite true - the number should be greater for the summer months and less for the winter.
2. It is estimated there are 3362 miles of roads under the jurisdiction of federal agencies.
3. It is estimated there are over 1300 miles of trails under the jurisdiction of federal agencies.
4. Nearly 30,000 hunters enter the valley, most over the six week seasons in October and November.

Because recreationist use is diffuse, there is less evident impact than what you see at a mining site or at a timber sale.

In the 1940's, mechanization was introduced to the rancher in his ranching operation and in the functioning of the household. The need to generate additional cash flow provided additional impacts on the land, as he attempted to draw more from the land. The 200 head operations which allowed family subsistence were inadequate to provide a lifestyle in keeping with the times. This encouraged borrowing and generating encumbrances from which some ranchers never recovered. It provided pressures to produce more animals on the same amount of land. Management programs effected by the U.S. Forest Service and Bureau of Land Management permitted some animal number increase without negative consequences, but not sufficiently to meet economic needs. Ranch land is increasingly subjected to receivership. Because the land is mortgaged on the basis of recreational or development values, it is considered too expensive for existing ranchers to expand their holdings. Potential ranchers are discouraged by development prices. As the ranch land undergoes a change in land use, no one can predict how the removal of irrigation will affect ecosystem quality. There are good indications the land will not support the original ecosystems.

Timber harvest has been an ongoing event. Wood was needed for homestead buildings, for poles and posts, for mine structure, and for railroad ties. Most of the impacts from cutting trees was associated with the proximity to the ranch or other human activity. Ultimately, as federal agencies had the opportunity to address forest management more seriously, more cutting became necessary. Considerable controversy has developed regarding any cutting practices. Someone must make a decision as to what constitutes management. Many environmentalists consider this to be de facto wilderness, not recognizing this is counter to the fundamental charge given to the federal agencies by Congress. The environmentalist must also recognize good management does not mean making money. Most of our federal lands are not highly productive forest lands. If they had been, most of the land would have been claimed and patented. For the sake of good management, it may reach the point where the federal agencies will need to pay someone to cart away that which is taken out of the forest. There is no question in my mind that in some cases of even-aged and over-aged stands, a series of small clearcuts represents the only manner in which a healthy forest can become established. In other cases, shelterwood cutting needs to be addressed. In some cases fire must be encouraged. In many cases, most of the trees cut will not be marketable, and therefore we cannot assume payment for them. My feeling always has been that the solution for forest management is to take the forester from behind the desk, where he is required to spend so much of his time, and have the forester, with a crew, cut the trees, bring them to roadside, and sell quality timber to the highest bidder. I dislike the idea about non-professionals being responsible for implementing good management. I say this with no evil spirit; the professional cutters must make a living and that is their first priority. The priority of the forester is sound management. In addition, I would urge blocks of land of all vegetation types being set aside to be treated as wilderness. However, I mean true wilderness - no cutting, no vehicles, no livestock, no trails, no recreationists. The concept of wilderness on the part of most environmentalists is too self-serving and results in many vegetation types repetitively represented on lands "protected." I believe the professionals in the federal agencies should set aside their fears of the environmentalists and do their job. If the environmentalist wishes to change the charge of the personnel of federal agencies, they should go to Congress and make the changes and not harass at the local level unless congressional directives are not being fulfilled. Professional forester-ecologists of the federal agencies should be interfacing with professional forester-ecologists who are representative of the environmental groups. I strongly advocate environmental groups. They have a distinct function in the system of checks and balances, and that role must be maintained. They, however, have a greater responsibility to deal with facts rather than fantasy. Because they have become powerful, some of the fantasy element is beginning to be incorporated into management as fact.

There has been periodic resurgence of mining. The valley lies in the Mineral Belt. Unfortunately, minerals can only be extracted where they are located. There is considerable resistance in the Gunnison Valley to mining because even under the best of circumstances, it provides some scarring. The old mining practices were devastating, but fortunately technology was not available to maximize the devastation. Today, we have regulatory agencies, the environmentalists, the ecologists, the engineers to "do it right." However, to many people, doing it right is not enough - it shouldn't be done at all. Many are legitimately concerned about the boom-bust cycling. I am supportive of a sustained mining industry in the valley. I believe the county government and the federal agencies should set aside a certain amount of resources (water, dollars, etc.) to maintain a particular sized mining force. When that operation is terminated, the next mining activity which is most environmentally sound would be the recipient of those resources. Other operations would not be precluded, but they would receive no inducements and would be taxed differently. Minerals and mineral need will exist forever. Forever is a long time and therefore there is no need to hurry. I do not wish to associate with the elitist who is a high consumer but only wants to mess up someone else's yard. I might add, that same elitist will buy his goods at the lowest price possible, which means the materials for those goods will originate where environmental laws do not exist or are not enforced, and where individuals who produce the material are underpaid and underfed. I believe a solution to the problem is, as a nation, not allowing any materials to enter our economy which have not been produced with the same environmental standards we employ. This means, of course, that the environmentalist and everyone else will be paying top dollar. I guess we need to put our money where our mouth is.

Our most recent large mining efforts have been associated with the Homestake Mining Company open pit near Marshall Pass and the anticipated molybdenum development at Mount Emmons near Crested Butte. There has been a small operational coal mine up Ohio Creek, which sells most of its production to a mushroom growing establishment in Alamosa. There is coal mining associated with Somerset, which is not in the upper valley. In Powderhorn there is a potential 100 year titanium-rare earth operation which is slowly evolving. Near Lake City there is a potential aluminum (alunite) deposit. Overall, there is no longer the mining fervor such as what was noted in the 1950's when every able bodied person who could afford a bulldozer went across the landscape gouging it, not replacing the divots and leaving it as a part of our heritage. Gold mining has attracted some, but it has been as elusive as ever.

I have left the most potential devastating impact to the end. The valleys in the mountains are being addressed and attacked by groups and individuals who wish to profit by removing water from ecosystems which already are maintained with a limited water supply and transport the water to the metropolitan areas of the state. They speak of taking only excesses and not altering the existing ecosystem. We have no excesses and our ecosystems will be altered. Our existing ecosystems are the product of the hydrological patterns which are in existence today. Changing those patterns will change the ecosystems. This is the time the environmentalists and the ecologists need to double team the individuals in the metropolitan area who feel they have the right to obtain whatever they wish with the use of a dollar. I say this when my personal political conviction is associated with conservative republicans. I wish to reiterate what I stated earlier - when a factor becomes limiting in an ecosystem, that ecosystem has reached its limits. If water is limiting on the Front Range, it has reached its limits. The Front Range should not expect our mountain valleys to sell their ecological soul so that the Front Range can destroy itself. My recommendation to the Front Range is conserve and recycle.

Originally I mentioned I was going to talk about the ecology of the Gunnison Valley. I have emphasized Human Ecology. Let me summarize natural ecosystem ecology, as a byproduct of human impact, in an environment which is so pure and pristine.

Valley Ecosystems

a. Channelization of what were originally meandering marsh-like expanses with ribs of sagebrush interdigitating with wetlands. Channelization permitted management and control.
b. Leveling topography to destroy sagebrush, enhance pasturage and increase harvestable meadows.
c. Removal of shrubs to increase hay production.
d. Development of elaborate irrigation systems to regulate water distribution.
e. Utilizing flood irrigation which modified species composition.

f. Raising the water table by extending the spring floods normally associated with snowmelt and reintroducing water after haying.
g. Establishment of a thick sod in response to flood irrigation.
h. Limited nutrient recycling in association with sod development and leaching.
i. Wildlife species have forage removed from winter range.
j. Streambank vegetation impacted by cows and fishermen.
k. Introduction of species to enhance hay production and wildlife.
l. Native flora and fauna impacted.
j. Humans have decided to utilize the environment for the construction of cities, towns, recreational cabins and homes.
k. As rancher survival is decreased, water rights will be sold to Front Range interests which will leave the previously saturated soils to assume the appearance and function of a shopping center parking lot.

Cold Desert - Sagebrush

The ugly beautiful sagebrush is the trademark of the Great Basin West. It provides a set of ecosystems which are apparently unyielding, obnoxious, overwhelming, subject to justifiable extinction (by some), but so tenacious it cannot be accomplished. It is the botanical equivalent to the coyote. The romantic sees the sage in a different light - the cowboy strumming a guitar in a full moon in the company of a sweet damsel. We also must recognize we could not enjoy the beautiful panoramas if the sage were trees. And there is the beautiful aroma after a rainstorm. Ecologically, we should be thankful for the sagebrush because there are not many organisms which can occupy the same niche. Consider then that the sagebrush is the one element that stands between us and a moonscape. The impacts we effected have resulted in:

a. Contouring to allow irrigation and increase in hay meadow.
b. Exposure to grazing before range readiness, selectively eliminating many grass species and contributing to the erosion of surface soil.
c. Application of 2,4-D to increase cattle and elk habitat.
d. Turn of the century overgrazing which resulted in habitat alteration (degradation).
e. Destruction of sagebrush because of its being a phreatophyte, and therefore a threat to ground water supplies.
f. Sites for unreclaimed mining exploration.
g. Site for increasing wildlife pressure.
h. Increased recreational use by numerous interest groups. There is very little respect for sagebrush habitat.
i. Virtually all sagebrush has been impacted. The U.S. Forest Service could not direct me to a single site when I was seeking an un-impacted research site in 1964.

Woodlands

The woodlands are not well developed in the Gunnison Valley. Scrub Oak is found at the western end of Blue Mesa Reservoir and west of Kebler Pass. It is not a major player in the ecosystem concerns of the valley. It is utilized primarily for wildlife habitat and for livestock grazing.

The Juniperus spp. in the upper Gunnison Valley lacks its normal partner, Pinyon Pine. The cedar occupies a rather nondescript niche which is evident in some valleys and virtually non-distinct in others. Because of its desirability for fence poles and because so many of the old fences still include cedar posts, there is a possibility it received unusual selection pressure.

Montane

Ponderosa Pine;

The Ponderosa Pine has an unfortunate ecological position. It grows in open stands with good livestock forage between the trees. The wood is excellent for lumber and the trees are large. It is the first tree species one encounters as one travels out of the sagebrush. It reproduces only sporadically (once every 20 years on the Kaibab Plateau of Arizona, even though it produces cones and viable seeds every year). There is also some indication the reproduction is limited because of climatic shift. Regardless:

1. Cattle grazing has resulted in pressure on the grass production.
2. Porcupines devoid of natural enemies selectively utilize Ponderosa Pine and can destroy a tree.
3. Lumbering has removed entire stands and particularly the isolated outliers. There is considerable evidence of stumpage still visible.

Douglas Fir;

The Douglas Fir ecosystem potential represents the majority of the valley. Trees grow close together and therefore easily carry a fire. It represents a commonly used household fuel. It dries out quickly in the Spring and does not receive substantial snowfall until October. Therefore, it has been most regularly burned and is best represented today by aspen and lodgepole pine ecosystems. The closeness of Douglas Fir trees results in physiological stress with reduced vigor and increased susceptibility to budworm. Fire is often the end result. Douglas Fir would profit from management which would space trees to about eight foot distances. This would allow maximum vigor.

Subalpine

Spruce-Fir;

Picea engelmannii and Abies lasiocarpa are the primary components of ecosystems which are the mainstays of watershed management. The snowmelt occurs late here and the first snows appear here. There is resistance to fire because of the extended moisture availability. The fir has limited timber value because the majority of the trees have heart rot. The forests are not easily traversed because of the considerable downed timber, which decompose slowly. Open stands may have grazing potential. The spruce-fir has been the location of some of the mining operations. There is considerable timber available, but it is questionable as to whether it can be economically harvested.

Lodgepole Pine;

This species is the dominant of ecosystems which are successional and the epitome of natural desolation. Lodgepole Pine is highly responsive to fires. High temperature opens the cones and allows the seed to spill out. Many thousands of seeds provide many thousands of seedlings which develop into many thousands of saplings. The horsehair or doghair stands result in many emaciated individuals which easily burn if a fire is available. Therefore, Lodgepole Pine can sustain itself for a long time. The straight and slender lines of a Lodgepole Pine make it desirable for poles, for construction, and for firewood. It provides excellent shelter for a variety of animals, but has limited utility for a food supply because of an almost total absence of an understory or underground cover. Lodgepole Pine stand always look impacted.

Aspen;

Despite the reports by some ecologists that aspen may be successional or climax, I personally have not seen a single stand which is anything but successional. Aspen is the occupant of moist sites which have been subject to disturbance such as fire, cutting, etc. There are a variety of Aspen ecosystems ranging from a Thurber Fescue understory to a Bracken Fern understory. During the summer, many ecosystem types are prone to fire whereas others, which are the moistest, seldom are combustible. The Aspen, along with the dry site Lodgepole Pine, will ultimately yield to Douglas Fir or to Spruce-Fir. The longevity of Aspen may be considerable, as a stand. The success of Douglas Fir or Spruce-Fir in replacing the Aspen appears to be associated with root system development. If you observe Aspen which has root systems which extend the full depth of the soil profile, the stand is in the process of being replaced. If the root system is shallow, the stand may appear to be climax. There is the impression the stand is choking itself out. In addition, the conifer seedlings which begin to appear have a bacterium on the roots which are pathogenic to aspen.

There is a great deal of controversy about Aspen cutting. Ultimately, if Aspen is to survive it must be subjected to disturbance. Periodic cutting, burning, or being sprayed with 2,4-D will help maintain the Aspen stands as a scenic component of our aesthetic demands, as well as a prime habitat for many of our animal species.

Alpine Tundra

The tundra ecosystems are scattered throughout the county as a part of the mosaic. The most accessible locations are at Cottonwood Pass and Cumberland Pass where you are permitted to drive to a parking lot, complete with a potty house, step out of your car and be in tundra. It is distributed from peak to peak where speciation has been allowed to take place over thousands of years. There are a variety of tundra ecosystems. Some are so dry that when you walk through them, there is a distinct crunchiness associated with them - others are quite moist. Miners have left their mark on the tundra. Sheep and shepherds utilized much of the tundra environment in the past; it is limited today. Tourists usually walk only a short distance from their cars. The air is thin, the hike physiologically demanding, the scenery is awesome, and quite often the unaccustomed feel downright intimidated. Persistent use of the tundra can cause long lasting impacts, but generally the overall seasonal and physical inaccessibility and its climatic mood swings tends to discourage overuse.

CONCLUSIONS

The Gunnison Valley is typical of the high altitude environments of the Central Rockies. The topography provides the basis for aesthetic appeal. Observers should recognize the country is vulnerable and what they see is a function of human management. Ranching can persist with the results being self-evident. Greatest threats are associated with water diversion and secondarily with human habitation, particularly developments which can remove the wildlife winter range. Less attention should be given to competitive use of summer range. Thirdly, recreational use of lands should be reassessed with some levels of reality. Timber cutting, if managed properly, can be a positive element but the federal agencies need to be more directly involved, rather than by proxy. Mining can be maintained without being an overwhelming element.

The entire set of systems have a variety of elements which must be orchestrated by an interested and aware conductor. We could lose it all; we can maintain a treasure.

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Environmental Mapping and Data Analysis Using a Geographic Information System

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ABSTRACT

Recent software developments as well as the reduction in price and increased power of computer hardware have led to advanced capabilities for processing geographic information. Sophisticated tools for collecting, managing, displaying, and analyzing environmental data are available to a larger number of scientists and decision-makers than ever before. The greatest challenge in solving current environmental problems is educating scientists and decision-makers to make efficient and cost-effective use of the new tools that are now available. This paper describes potential uses of the software tools provided by a Geographic Information System (GIS) for environmental mapping and data analysis.

Many environmental issues, including site characterization, impact assessment, and site restoration; modelling of surface and subsurface hydrology; analysis of soil and vegetation interactions; mapping and modelling of atmospheric events, fires, and other natural disasters or emergencies, and animal or population distributions can be effectively addressed using GIS methods.

A general description of systems which provide GIS capabilities including a brief description of data structures is provided, followed by an overview of environmental applications of GIS. Several examples demonstrating digital mapping and analysis of environmental problems using a GIS are presented to illustrate the expanding use of this technology in environmental and natural resource assessments.

INTRODUCTION

The use of Geographic Information Systems (GIS) has dramatically increased during the past 10 to 15 years from near obscurity to become relatively commonplace in many businesses, government offices, and universities. A wide variety of agencies, companies, and individuals use GIS for many diverse applications and consequently a wide range of systems and techniques have evolved to support these activities. This paper will focus on environmental applications and systems which provide GIS capabilities to address the needs of scientists and decision-makers involved in environmental and natural resource-related industries.

What is a GIS?

Many different techniques and systems have evolved to address a range of requirements for processing geographic information. This has led to a proliferation of software packages for mapping applications and confusion over an "official" definition of a Geographic Information System. One definition of a GIS which is comprehensive and widely accepted is stated as follows:

> An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. (ESRI, 1990)

This definition, although accurate, is somewhat difficult to grasp for those who are new to GIS and may be unfamiliar with the concepts of digital processing of spatial information. In the preface to their text, Geographic Information Systems - An Introduction, Star and Estes state:

> ... the essence of a geographic information system is its integration of the many different kinds of information we may be able to obtain about the spatial objects in an area. In other words, a user of a GIS should be able to work with many different types of data, bringing all the information relevant to a problem together in a consistent form, and should be able to bring to bear on the problem all the power of all the sophisticated analysis tools available. (Star and Estes, 1991)

This is perhaps not so much a definition of *what* a GIS is, but rather *why* a GIS is useful for a variety of applications in many different disciplines, particularly those dealing with environmental processes.

Current Systems for Processing Geographic Information

With the advent of lower-priced, higher performance computer hardware many data processing tools which were once only available to a few select individuals or researchers are now becoming commercially available and increasingly affordable. The general trend in the computer industry has been to migrate from large, centralized mainframe systems to a desktop environment utilizing networked, high-speed workstations with a multi-tasking (windowing), graphical user interface. Commercial software systems which incorporate a user-friendly interface and conform to recent data processing standards such as the Unix operating system and the X-Windows display environment are currently the industry leaders in the medium to high-end GIS market. PC-based systems running under the DOS operating system (and most recently, using MS-Windows) compete strongly for low-end market share due to the low cost, ease of use, and extremely high availability of PC clones.

A wide range of software packages, both commercial and public domain offerings, exist which may be considered a GIS. Often however, software which provides automated mapping or drafting capabilities, some with links to non-graphic tabular data, may be incorrectly classified as a GIS. Desktop mapping systems and Computer Aided Drafting (CAD) systems have existed for many years and are widely used, especially in the fields of civil and mechanical engineering, architectural design, and medicine. The primary distinction between these types of systems and Geographic Information Systems is the ability of a GIS to: 1) integrate data from a variety of source scales and formats into a common, geographically-referenced coordinate system, 2) maintain connections between spatial objects and tabular attributes and 3) provide analysis tools to manipulate those data. Table 1 provides an overview of the functional capabilities provided by a high-end GIS software package.

Table 1. Overview of ARC/INFO® Functionality

The following is a general categorization of the core functionality provided by the workstation version of ARC/INFO® and extended functions provided by the TIN, Network, GRID, and COGO modules which are fully integrated with workstation ARC/INFO®.

A. DATA MODEL

1. Arc-node topology.
2. Geo-relational (supports full RDBMS integration).
3. Double-precision storage available.
3. Image and other raster data formats supported.
4. CAD drawing support.

B. DATA CONVERSION (Import/Export)

1. DIME/Tiger (U.S. Census Bureau)
2. DLG/DEM (U.S. Geological Survey)
3. DXF (CAD Drawing Exchange Format)
4. IGES
5. MOSS
6. GRASS
7. ERDAS
8. Ascii (x,y,z and other tabular data)
9. others

C. CUSTOM PROGRAMMING [Arc Macro Language]

1. Full menu interface capability.
2. GUI (Graphical User Interface) widgets, etc.
3. High level programming language (AML) included in core product.

D. EDITING, DATA MANAGEMENT

1. Map Librarian
2. Sophisticated annotation
3. Map Projections (over 50 supported)
4. Symbol editing
5. Database cursors (one-to-many related records)
6. Coordinate Geometry (COGO) *

E. DISPLAY, QUERY, AND HARDCOPY OUTPUT

1. X-Windows-based user interface (Open-Look, Motif)
2. Attribute or spatial feature selection.
3. Typeset Quality fonts.
4. Graphs (x,y, scatter plots, bar charts)
5. Hardcopy device independence.
6. EPS (Postscript), other industry-standard formats

Table 1. Overview of ARC/INFO® Functionality (continued)

F. TABULAR DATA MANAGEMENT
1. Internal database management (INFO)
2. Report writing functions included.
3. Transaction management support.
4. External industry-standard RDBMS support.

G. SPATIAL ANALYSIS
1. Polygon Overlay
   a. Union
   b. Intersect
   c. Clip
   d. Erase
2. Attribute & spatial reselection
   a. Dissolve
   b. Reselect
   c. Erase/Eliminate
3. Statistics
4. Proximity/Distance
   a. Buffer zone generation
   b. Near
   c. Point distance

H. RASTER GIS, MODELLING* [GRID]
1. Cost surfaces
2. Zonal & neighborhood analysis
3. Map algebra (combinatorial, trigonometric, etc.)
4. Geostatistics (kriging, inverse distance weighting)
5. Watershed/drainage modelling
6. Interpolation & resampling
7. Analytical hill shading

I. SURFACE DISPLAY & ANALYSIS* [TIN]
1. Contouring
2. 3-D viewing and draping (including images)
3. Visibility and viewshed analysis
4. Stacked profile generation
5. Cut & Fill, Volume calculations

J. LINEAR MODELLING/GEOCODING [NETWORK]
1. Dynamic segmentation
2. Address matching *
3. Network Routing *
4. Resource Allocation *

* Available thru optional extension modules TIN, Network, GRID, or COGO

Data Models for Environmental Applications

A data model is an abstraction of reality used to represent objects. A map is a type of data model used to represent spatial objects on the Earth's surface such as roads, streams, or political boundaries. Within the context of a GIS, various types of data models are used to store, manipulate, derive, and display information about the spatial objects being analyzed.

The sources used to construct the data model may come in a variety of formats, scales, and projections. Disparate data types such as maps, photographs, and text can be cumbersome and costly to integrate using manual methods. A GIS provides the framework for assimilating spatial data from multiple sources into co-registered data planes or layers.

Data Structures

Storage and processing of environmental data in a GIS is directly dependent on the data structures used to represent spatial objects (i.e. the data model). Early systems which were developed for geographic analysis of natural resources were based on digital processing of remotely sensed imagery such as aircraft and satellite scanner data. Those systems were based on a raster, or grid-cell data structure **(Figure 1)** where each raster cell (pixel) is assigned a digital number representing the spectral reflectance of a rectangular patch of the Earth's surface.

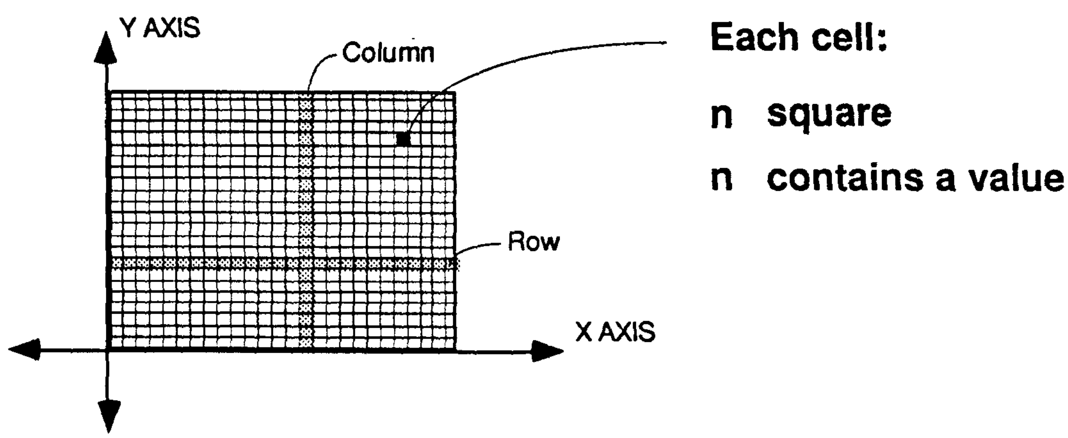

Figure 1. Raster or grid-cell data structure

This raster data structure became the foundation for early GIS packages since the value of a pixel could be used in a layered fashion (**Figure 2**) to represent some other characteristic of the same patch of ground (e.g. elevation, % vegetation cover, population density, or an encoded land use value).

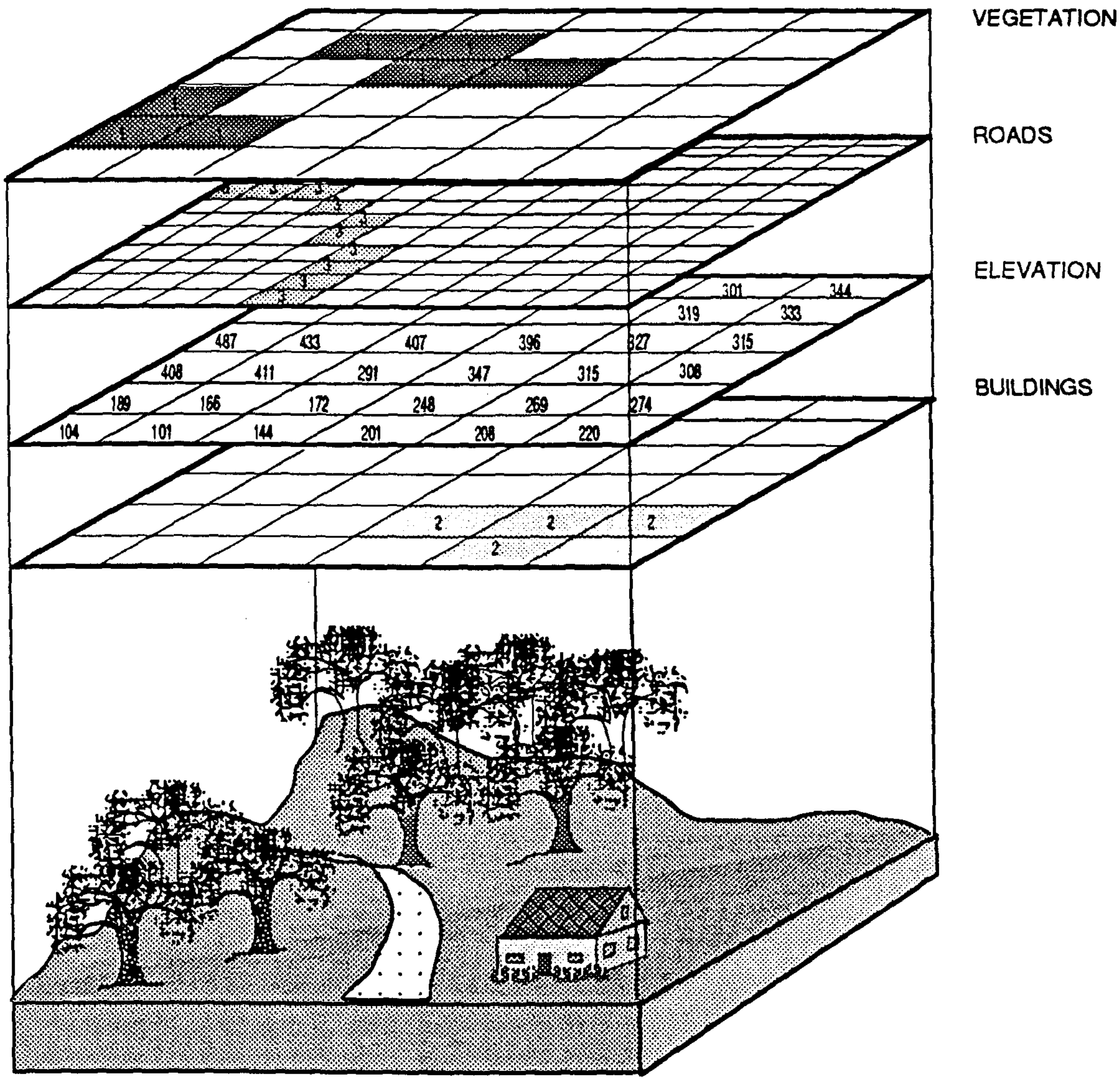

Figure 2. Raster GIS data structure

Later research in geographic data processing led to the recognition that vector data structures may be more appropriate or more accurate for describing and displaying various types of spatial objects. Specifically, point, line, and area features described by polygonal outlines (**Figure 3**) can be more effectively portrayed using X,Y coordinate pairs. Vector data structures also support topological encoding of spatial objects more efficiently than other data structures. Topological encoding means that relationships between objects such as connectivity, contiguity, adjacency, and proximity can be defined and manipulated mathematically.

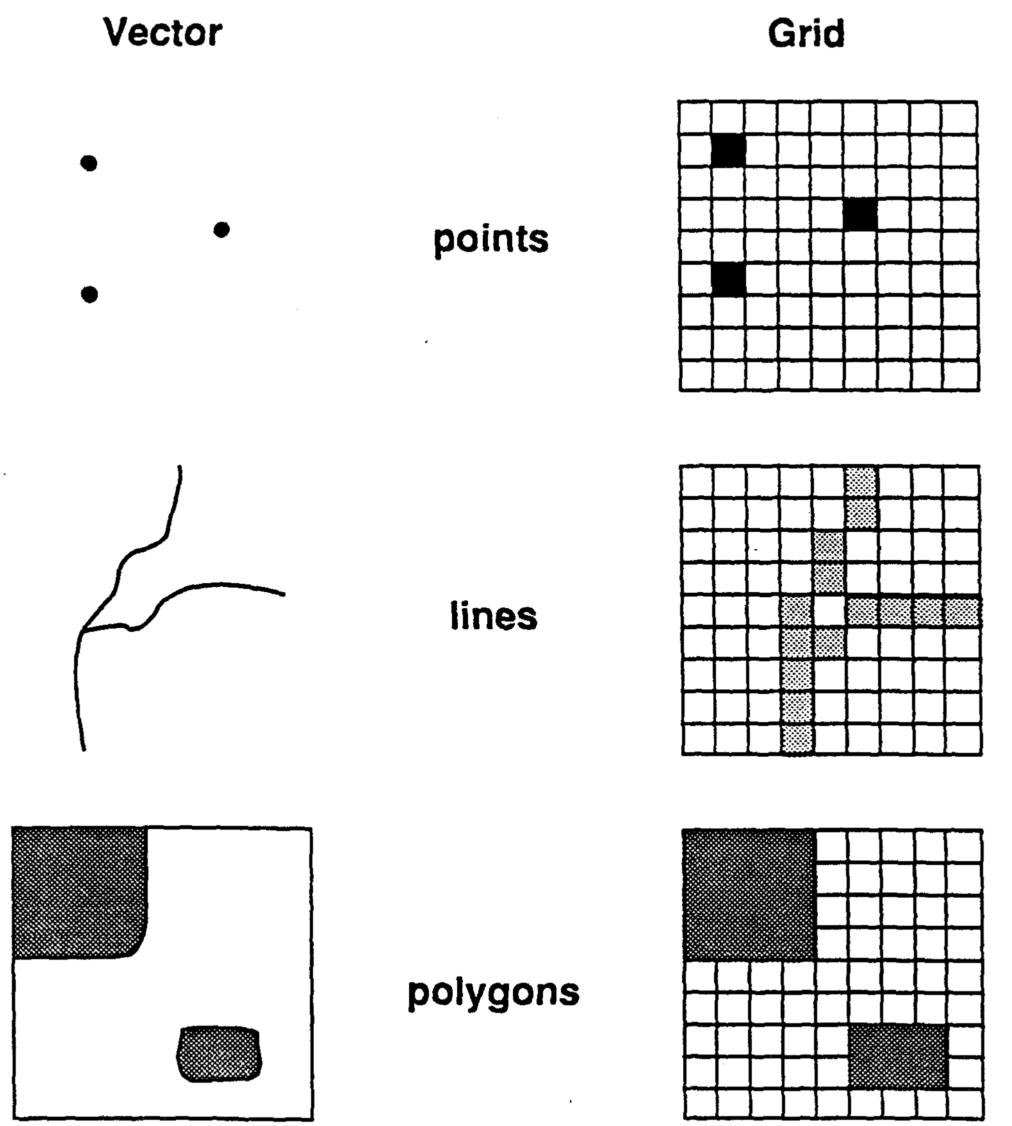

Figure 3. Vector vs. grid-cell encoding of spatial data.

Another general category of data structures which may be used to define spatial objects are termed tessellations of a plane. A raster grid is a regularly spaced, rectangular tessellation. Quadtrees are a hierarchical, irregularly spaced variation of a raster data structure. Triangulated Irregular Networks (TINs) are a triangular tessellation **(Figure 4)** which can be encoded as vectors (defining the sides of triangles) providing the ability to support topological encoding. TINs and other tessellations of a plane are most commonly used and are most effective at representing continuous surfaces such as topography or groundwater tables.

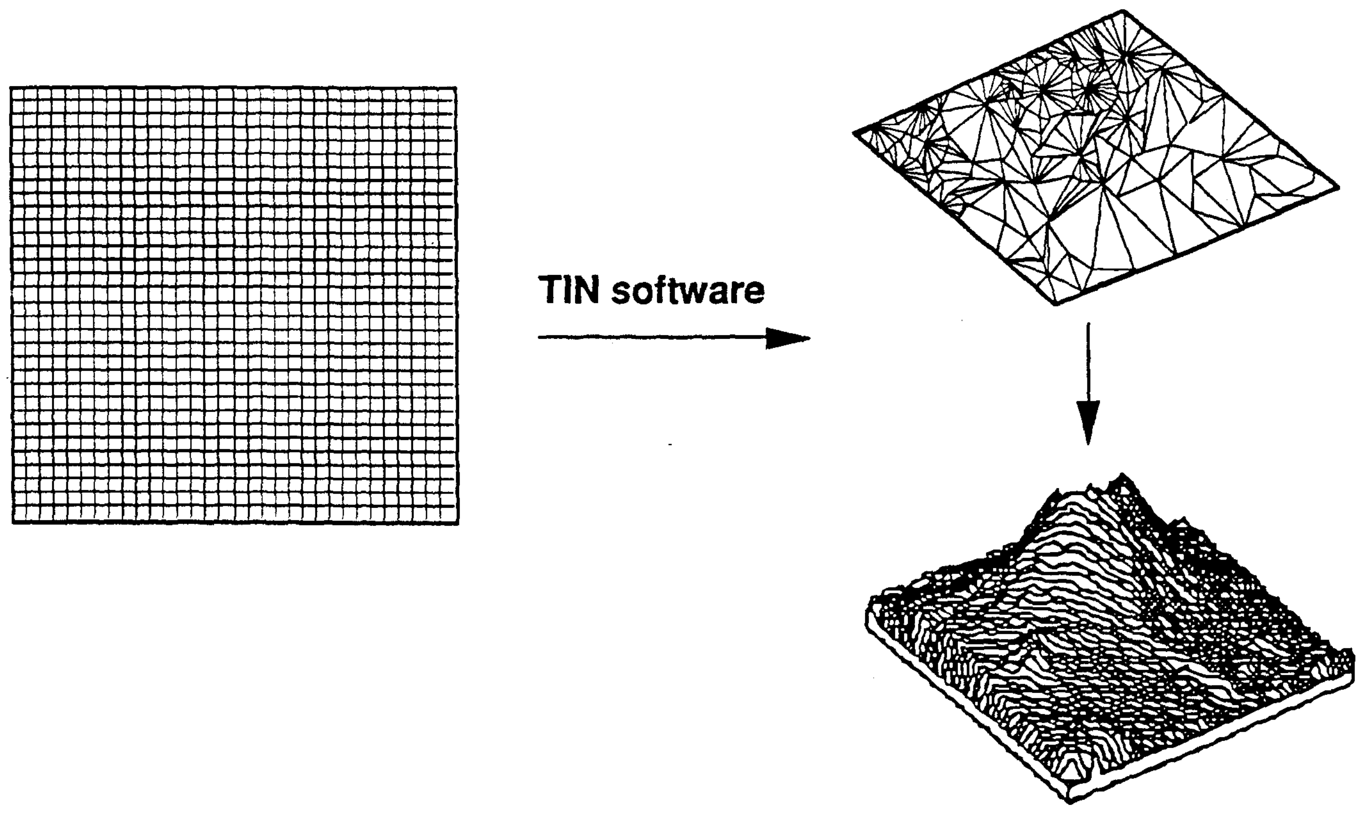

Figure 4. TIN representation of a continuous surface.

Sources of Data for Geographical Analysis

Many sources of spatial data are available, or can be obtained in a format suitable for automated processing using a GIS. Some of the most common sources include data which can be digitized either by manually tracing lines or by scanning off of stable base (e.g. mylar or paper) map sheets. A great deal of data in the U.S. is available in digital form through various federal agencies who have invested the time and resources to convert mapped information to computer media for automated use. Examples of digital geographic datasets provided at a nominal cost by the U.S. Geological Survey include Digital Line Graph (DLG) data which include roads, streams, political and administrative boundaries, and other cultural features, and Digital Elevation Model (DEM) data for most of the conterminous United States.

Other sources of natural resource information include areas delineated off of satellite images or air photos, either by manual methods or via digital image processing systems. Computer Aided Drafting (CAD) systems may also provide digital data such as building footprints, engineering designs, or locations of utilities such as sewers or electrical transmission lines which can then be converted for use by a GIS.

Errors in Environmental Databases

Two primary sources of error, inherent and operational, contribute to inaccuracies in products generated by a GIS. Inherent errors result from inaccurate mapping or poor delineation of features such as incorrect identification of land cover classes from satellite imagery, or outdated or improperly surveyed boundary information. When multiple data layers are combined using analysis tools provided by a GIS, operational errors may be introduced. For example, overlaying a poorly mapped vegetation strata with inaccurate political boundaries may result in a new data layer which incorrectly shows vegetation cover in areas where none in fact exists. It has been shown that combined inherent and operational error levels can be as high as 70 - 80% (Walsh, et al, 1987).

Recognition of the potential sources of such errors can help to minimize the total error present in a database. GIS users must be aware of and become knowledgeable about the limitations of the datasets they employ to solve a problem and should strive to utilize appropriate data for a specific application. This issue becomes especially critical when legal matters such as environmental cleanup criteria are based on decisions derived from GIS databases.

FUNCTIONAL USES OF A GIS

A GIS is useful for environmental mapping and data analysis because it: 1) provides a convenient mechanism for integrating spatial and tabular data; 2) provides tools to efficiently manage and update spatial information; 3) supplies capabilities to display those integrated data layers and produce high-quality cartographic output products; and 4) includes a unique suite of tools for the analysis of spatially oriented data.

For example, at a hazardous waste site large amounts of data are collected and scrutinized to determine the nature and extent of contamination and to identify and evaluate different remediation alternatives. Much of the data including laboratory analyses of soil and water samples, historical records, and other parameters describing the site are stored in tabular form as spreadsheet or database files, reports, or even as handwritten notes. Understanding the spatial patterns and areal distribution of toxic wastes, as well as the environmental properties affecting their fate and transport are critical factors in the decision-making process. Sophisticated methods are often necessary to correlate spatial patterns and locations of contaminated materials with the laboratory samples and other descriptive (tabular) data about the site. A GIS can greatly assist in many aspects of hazardous waste site data management, mapping, and analysis by offering the tools needed to assimilate the required information (Estes, et al, 1987).

The 4 Ms

Functional uses of a GIS for environmental applications can be broadly divided into four categories: Measurement, Mapping, Monitoring, and Modelling.

Measurement

Capabilities for measuring environmental parameters may include such tasks as capturing survey information and converting locations to a real-world coordinate system such as State Plane or UTM, calculating linear distances or areas, and determining slope and aspect from digital elevation models. However, the real value of a GIS lies in the ability to analyze multiple dimensions of data. In fact, according to one author:

> It is customary to visualize a GIS as analyzing a series of data planes, with the capability of analyzing data in a single plane and also showing the relations among selected sets of those data planes. Data in a single plane may be raw data or the results of previous processing, or they could have been created by the GIS. (Robinove, 1986).

The concept of measurement using a GIS is extended by the implementation of topologic data structures. Most spatial operators are based on the fundamental properties of distance, direction, and connectiveness. Boolean logic (set theory) can be combined with those properties to derive additional operators including adjacency, proximity, superposition, and containment.

Operators based on the principles of descriptive statistics can also be applied to the measurement of spatial objects. Finding the mean of a sample population provides a quantitative description of central tendency, while the standard deviation gives a measure of dispersion. These simple statistical concepts are often overlooked when attempting to analyze spatial information, yet they provide a basis for future analytical decisions.

Mapping

Both qualitative and quantitative information can be stored and mapped using a GIS. For example, areas representing mapped soil units may include a description of the texture and formation name, and may also contain permeability measurements. Any one of, or a combination of those descriptive features can be used to generate a soils map. Soil units can be shaded with varying shading patterns based on the permeability value where a darker shading represents lesser permeability. The shading color might be used to symbolize the texture classification, and a text label with the formation name can be drawn inside the area representing the soil type.

Mapping capabilities can also be used to refine or revise data collection and analysis efforts. At a hazardous waste site, Surface Management Units (SMUs) may be delineated by mapping sample locations where certain contaminants exhibit high concentrations, and by comparing those areas with historical information such as aerial photographs. New information such as additional historical records or new sampling may indicate that the boundaries of some SMUs need to be modified, or that previous sampling was inadequate for the area in question.

Other types of GIS mapping capabilities include those which can be categorized as simulation or visualization of environmental phenomena. A common example is the ability of some systems to produce three-dimensional perspective views of topographic surfaces. Extremely realistic portrayals of a study area can be achieved by draping a satellite image or scanned aerial photograph over the 3-D surface to simulate a viewer's perspective from any observation point. Other vector layers covering the same area such as roads or streams can also be draped over the surface.

Monitoring

Remotely sensed data including satellite imagery or aerial photography is also useful for monitoring changes in the landscape. Multi-temporal imagery can be imported into a GIS as separate layers representing "snapshots" of an area at several dates. Using the tools available in a GIS, changes which occur over time, such as the acreage of land converted from agricultural to urban use, can be easily computed and displayed or combined with other layers in the GIS for further analysis.

Other types of monitoring can be improved by applying GIS techniques. For example, soil penetrometers are often used to obtain readings of specific soil properties including contaminant levels at a hazardous waste site. By comparing changes in contaminant levels over time with other data layers in the GIS such as groundwater levels or vegetative cover, inferences can be made concerning the processes affecting contaminant migration.

Modelling

There are two primary ways in which a GIS can be used to assist in environmental modelling. The first method involves using the analysis functions provided by some GIS software packages to perform the modelling operations. An example of a GIS-based model might involve finding a suitable location for a landfill. In this instance, inputs to the model, as well as the actual computations required to implement the model, and the display of model results can all be performed using the capabilities provided by the GIS software.

The second method requires an interface between the GIS and an external model such as a finite difference groundwater flow model or an air dispersion model. The benefits of using a GIS in conjunction with an external model include the ability to effectively calculate and manage model inputs, and then display the model results in combination with other GIS data layers for an effective presentation. The GIS can also be used to perform additional analyses using the results from the model. For example, the plume generated from an air dispersion model could be combined with census data to determine the population that could potentially be affected by emissions from an incinerator.

EXAMPLE USES OF GIS FOR ENVIRONMENTAL APPLICATIONS

Atmospheric

A recent demonstration of GIS applications that was developed for use by members of the U.S. Antarctica Program included mapping and monitoring of the atmospheric ozone layer. A satellite-based sensor, the Total Ozone Mapping Spectrometer (TOMS), collects daily measurements of the atmospheric ozone layer by determining the amount of scattering of ultraviolet light through the Earth's atmosphere. Those measurements are stored as grids, where each grid cell represents a measurement of the ozone layer at a specific location above the Earth's surface.

A series of grids corresponding to monthly measurements of the ozone layer for the area surrounding the South Pole were converted for use in the GIS. By overlaying the outline of the Antarctic land mass on top of a series of color-coded displays of monthly ozone measurements it is clearly apparent where and when the variations or "hole" in the ozone layer occur. By combining this information with atmospheric circulation models and other data which provide clues to the depletion of the ozone layer, scientists can begin to understand and predict the processes which affect ozone levels in the atmosphere.

Hydrologic/Water Quality

A GIS was used by the U.S. Environmental Protection Agency and Arizona Department of Environmental Quality to support water quality modelling for the Arizona Rangeland Water Quality Project (Donovan, 1991). In this study capabilities of the GIS software were utilized to develop many of the input parameters to the Agricultural Non-Point Source Pollution (AGNPS) model, which was developed by the U.S. Department of Agriculture to simulate sediment and nutrient transport. Digital hydrography, elevation, soils, and landcover data were processed with the GIS to calculate model parameters such as per cent slope, slope length, channel slope, roughness coefficients, soil erodibility factors, soil texture, SCS curve numbers, and several others.

Errors discovered during model runs were corrected in the GIS database and re-loaded into the model. In addition, scenarios based on potential changes in snowpack or vegetative cover were easily simulated by modifying the data stored in the GIS and re-running the model.

Fire Prediction

The U.S. Forest Service, Bureau of Land Management, Bureau of Indian Affairs, and others are concerned with fire management on public lands. Many of these agencies already use a GIS for land management operations and are interested in applying more sophisiticated methods for fire fighting and prediction of wildland fire behavior. The BLM's Automatic Lightning Detection System (ALDS), maintained at the Boise Interagency Fire Center in Boise, Idaho, records the location of lightning strikes throughout the western United States and can provide those locations to their offices in real time.

Using the capabilities provided by a GIS, fire dispatchers can display the locations of lightning strikes in combination with other data layers such as fuel classes (derived from vegetation characteristics), locations of structures or populated areas, slope and aspect, meteorological conditions, and roads or other access routes. It is also possible to model the behavior of a wildfire that has already started burning using wind speed, wind direction, fuel classes, slope, and other parameters stored in the GIS database. This way, fire dispatchers can anticipate where a fire may spread and allocate resources accordingly.

CONCLUSION

Many additional uses of GIS technology for environmental applications are being implemented by researchers, consultants, technicians, civil servants, and others in a wide variety of disciplines around the world. A GIS offers a cost-effective method for organizing, interpreting, and displaying all forms of spatially referenced information. Significant cost savings can be recognized by implementing a GIS throughout all departments within an organization because a GIS: prevents redundancy in data storage and encourages data sharing, reduces the amount of time required to update and analyze information, and offers system users fast and relatively easy access to large databases derived from a variety of input sources.

Future developments may include the integration of expert systems approaches to environmental problems, taking the guesswork out of the operational use of this technology by incorporating the knowledge of experienced specialists. In the meantime, sophisticated tools are available now for those who are willing to exercise their imagination and apply creative thinking to solve the complex issues facing us.

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RESTORATION ECOLOGY: REPAYING THE NATIONAL ECOLOGICAL DEBT

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ABSTRACT

Restoration ecology is an emerging field focused on recovering and reinvesting ecological capital now being quickly spent by humanity, principally by habitat alteration. There is presently great confusion about what constitutes ecosystem restoration. Despite belief in the plasticity of nature, damaged ecosystems are not self-renewing, and the several options available to managers charged with restoring damaged systems range from re-creation of the original ecosystem to construction of entirely new, alternative ecosystems. The range of activities now called "reclamation" fall within this range. Several ecological factors constrain the probable success of habitat management and restoration. Biotic communities are dynamic. Colonization, followed by succession, results in changing species compositions and biotic functions. Any artificial habitat will accumulate species, but these species may not be those desired nor may desired species persist for long periods. Predicting the success of artificial habitat management is fundamentally simple. Desired and necessary species must be available to colonize the new habitat. Management capability must be available to monitor community development and take appropriate action, based on fundamental science, when needed. Management may be limited to rehabilitating a limited set of ecological characteristics or to enhancing particular ecological functions.

INTRODUCTION

The principles of ecology have been controversial when applied to the solution of practical problems. For example, it is relatively easy to arrange an argument between ecologists about competition or the role of predators in structuring communities, but it is unclear how these principles affect the restoration of natural communities and ecosystems. Many of the controversies in ecology arise because, despite well-known "physics envy" and the role of rigorous experimentation, many ecologically important variables cannot be controlled: ecology is often a "soft science" (Diamond, 1987). Still, a few ecological facts are not disputed: we have only one earth, and it is unlikely that the planet's ecological productivity will rise significantly. In fact, it is likely that productivity will decrease (Turner et al., 1990), principally because of human alteration of habitats, over-exploitation of soils and grazing lands, and the concomitant loss of species. Ecological capital is being spent at an alarming rate in the destruction and pollution of ecosystems - far greater than can be replenished by our currently meager restoration efforts. Ecological production that is co-opted by the human population (Vitousek et al., 1986) will not be available to the other several million species with whom we share the planet.

The challenge for the next century is to maintain ecological structures in a functioning condition while the human population rises toward ten billion (Cairns and Pratt, 1992). The landscape is already severely fragmented, and agricultural production appears to already be maximized (Ehrlich and Ehrlich, 1990). However, native ecosystems, often unmanaged, will continue to be a important source of food and fiber for humans. The question is whether human exploitation of ecosystems (and their underlying minerals) will happen in a sustainable way (Lubchenko et al., 1991) or whether management will continue to be fragmented, short-term, and short-sighted.

The scientists and managers participating in this conference have a grave responsibility. They must assure that their efforts are not simply justification for more rapid over-exploitation of ecological resources, and they must demonstrate that their efforts are both ecologically and economically sound. Reclamation, however defined, must be a road to a solution - especially a solution for ecosystem restoration - and not part of the problem. In this paper, we review the basic concepts of restoration ecology and pose questions and recommendations for scientists and managers who traverse the narrow line between basic science and its applications.

ECOLOGICAL CONSTRAINTS ON RESTORATION

A major question in the establishment of communities on artificial habitats is the rate and extent to which communities similar to natural communities develop. Despite considerable controversy about the adequacy of biogeographic models for predicting the rate and mechanisms of colonization, colonization of newly created habitats follows the dynamics predicted by MacArthur and Wilson (1967). Species arrival on barren habitat patches is a saturation process (e.g., Fig. 1).

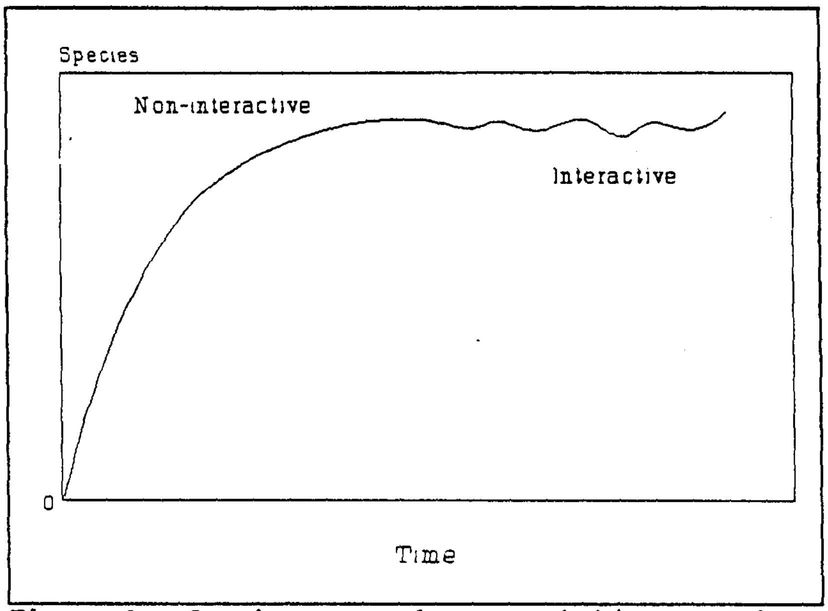

Figure 1. Species accrual on new habitat patches according to the MacArthur-Wilson (1967) equilibrium model. The noninteractive phase of colonization is species accumulation while the interactive phase is assortative and marked by species interaction.

Theoretical studies provide several predictions that apply to the design, sampling, and monitoring of artificial habitats (see Cairns, 1982). The number of colonizing species is limited by the size of the habitat and the distance of the habitat from the source of colonists. These predictions are intuitive, and the number of species that can be held by a habitat (the species-area relationship) depends on the taxa studied, as follows:

$$S = C A^z \quad (1)$$

where S is the number of species in the habitat, A is the area, and C and z are fitted constants. C is a constant determined by the richness and vagility of the colonizing taxa. The constant z has an empirically determined value of approximately 0.27 (MacArthur and Wilson, 1967).

As habitats accumulate species, the initially high rate of colonization falls, and some colonists become locally extinct. The rate of local extinction increases until the colonization and extinction rates are approximately equal, resulting in an approximate species equilibrium (Fig. 2). Predictions concerning the number of species at equilibrium give no clues about the composition of the colonizing community. In fact, because the rates of colonization and extinction do not fall to zero, there is continual turnover in the colonizing community, a turnover that differs in rate for differing taxa (Schoener, 1983).

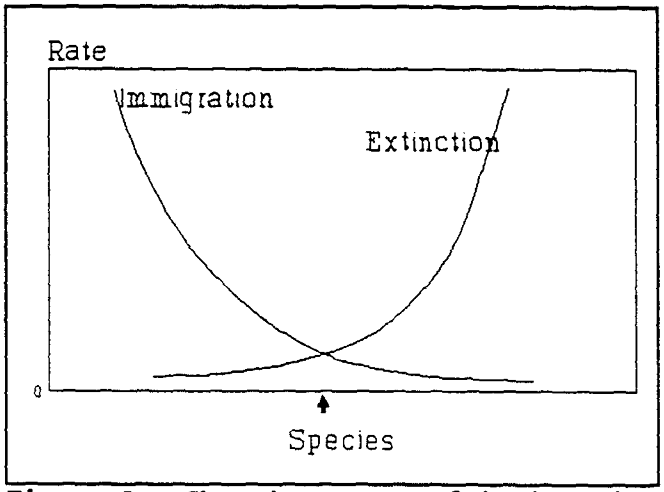

Figure 2. Changing rates of immigration and extinction in relation to species richness in habitat patches. The equilibrium number of species (arrow) is dynamic: continuing immigration and extinction result in species turnover.

The attainment of species equilibrium is primarily a non-interactive process (Simberloff and Wilson, 1969; Cairns and Henebry, 1982) in which species collect on the habitat. Once equilibrium is reached, however, assortative processes driven by interspecific interactions alter community composition (Fig. 1). This process is equivalent to the assortative processes of succession in terrestrial plant communities, although the driving mechanisms are principally autogenic (arising within the community). Previous studies have shown that occasionally allogenic forces such as invasion by a large, generalist predator affect the community (Henebry and Cairns, 1980).

The noninteractive portion of the colonization process can be modelled empirically by sampling for species richness through time. Time-dependent species richness data can be fitted to the colonization model to obtain a prediction of the eventual community richness at equilibrium. The colonization model

$$S_t = S_{eq}(1-e^{-Gt}) \qquad (2)$$

where S_t is the number species at time t, S_{eq} is the estimated equilibrium number of species, and G is the colonization rate. Iterative nonlinear regression techniques (Draper and Smith, 1981) or a variety of curve-fitting techniques can be used to estimate both the colonization rate and equilibrium species number. If an estimate of the species pool is available, then the degree to which the equilibrium species number approaches the size of the available pool of colonists can be determined.

The island biogeographic model of colonization is a simple community model that makes no predictions about the specific composition of the colonizing community. Often, specific composition (i.e., commercially important fishes) is extremely important to the success of a restoration or artificial habitat construction project. How can theoretical predictions be used to guide manipulations of artificial habitats? First, bigger is better. That is, larger habitats will have greater habitat heterogeneity and will hold more species, and (despite arguments such as those of May [1973]) more diverse habitats are likely to be more stable. Second, since the dispersal of propagules to new habitats is probably random, projects can manipulate the probability of successful arrival of species at the new habitat by seeding select taxa. For example, if a forest habitat is to be recreated artificially, planting trees in the artificial habitat will greatly enhance the rate of community development. This may seem platitudinous, but nature does not have an infinite ability to "naturally" recreate habitats. In the case of the forest, the presence of grazers (such as white-tail deer) may keep desired densities of natural recruits low unless planned manipulation is done. These principles are discussed more fully below.

RESTORING DAMAGED ECOSYSTEMS

The first step in restoring ecosystems is to state specifically the goals and objectives of the proposed work. It is now clear that a variety of objectives may be achieved, and participants in a restoration project may not all agree on the type of restoration being undertaken. The discussion that follows presents a theoretical framework of several restoration alternatives. Often, restoration to pre-disturbance condition is not practical or possible, and some projects will provide opportunities to create habitats and ecosystems different from (better than?) the original system. Establishing the goals of restoration may require a further understanding of the nature of the original ecosystem and an estimation of the future stability of the site. In other words, it is necessary to understand how quickly restoration is likely to occur by understanding the resistance of the original ecosystem and its ability to withstand and recover from the present and future perturbations.

In the United States, different laws and their promulgated regulations can limit the alternatives that can be considered. For example, under the Surface Mining Control and Reclamation Act (SMCRA), landscape patterns generally must be replaced (pre-miming forest with forest, streams with streams, etc.) but the species composition is not specified. However, under Florida statutes for the reclamation of surface phosphate mines, considerably more freedom is allowed in recreating post-mining habitats. Under the Uranium Mine Tailings Reclamation Act (UMTRA), the goal of reclamation is to stabilize low-level radioactive materials with little regard for the condition of the final disposal site which is regarded as permanently hazardous.

Restoration alternatives

Ecosystems often do not recover from anthropogenic stress without manipulation. The essential choices in restoration are shown in Fig. 3, but we now recognize that several options are available for restoring ecological structure and function following disturbance. The most fundamental question facing a team charged with restoring an ecosystem is "what should be restored?" Both structural and functional components of an ecosystem can be replaced, and approach to the pre-disturbance condition can be high, although this need not be the case. The original mixed forest of a mine site can be replaced by a stand of white pine.

In this case, the forest landscape (and some ecological function) is restored, but the pre-disturbance condition is not replaced.

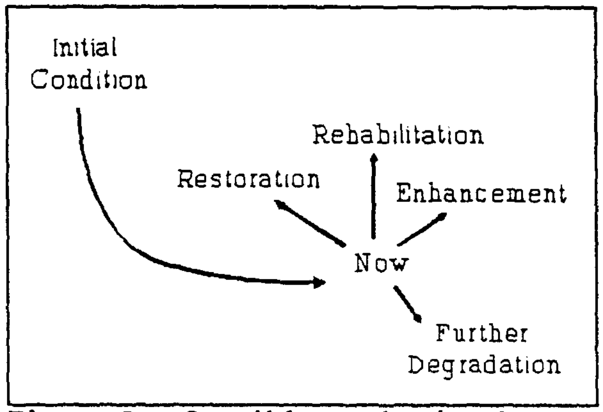

Figure 3. Possible paths in the restoration of damaged ecosystems (based on Magnuson et al., 1980).

Several terms are used imprecisely by scientists and managers charged with project oversight and ecosystem management. In this paper, we adopt definitions similar to those used by a committee of the National Academy of Sciences (NRC, 1992). Restoration means returning an ecosystem to a condition (or the successional state it would have had) had no disturbance occurred. This requires assessing both the structural and functional adequacy of the ecosystem. Rehabilitation means replacing some of the ecological features of the pre-disturbance ecosystem, but this is not restoration. The example of mitigating the impacts of coal mining, described above, is a familiar example of rehabilitation. Enhancement means the replacement of the original ecosystem with a different ecosystem. For example, phosphate mine pits in central Florida are not returned to original contour and the vegetation replanted. Rather, because mine spoils are somewhat hazardous and the water table is shallow, mine pits often become lakes. Clearly, the lake bears no resemblance to the former upland ecosystem. Enhancement can play a major role in providing otherwise-endangered habitats such as wetlands or marine reefs, even though the replacement is clearly not restoration.

Conspicuously absent from this list is the term reclamation. This term has several meanings including the three processes described above. In one sense, legislation such as the Surface Mining Control and Reclamation Act (SMCRA) has specified activities that include both rehabilitation and enhancement. Rarely is true restoration possible. Similarly, requirements under the so-called Superfund act (CERCLA) focus on restoration, even though some other endpoint would be practical and both scientifically and socially acceptable. Often, reclamation may mean simple stabilization of potential hazards, such as treating deep mine effluent or removing contaminated soil or sediment.

Several options and alternatives to restoration of the pre-disturbance condition are given in Table 1. Often, direct restoration is not possible because the pre-disturbance condition is unknown or imprecisely understood. This fact is often surprising and discouraging for managers and policy makers, but few ecosystems are sufficiently well characterized to establish baseline conditions. The exceptions are those systems studied to establish the ecological baseline prior to human actions. The paucity of structural and functional information is also troublesome for ecologists who often cannot make refined predictions about the goal of restoration efforts. General predictions about ecological productivity are available, as is information on the distribution of many familiar taxa. Because no systematic study of the nation's biotic resources (e.g., a biological inventory) has ever been attempted, expectations about the composition of biotic communities is rarely available (c.f., Ohio EPA, 1987) when determining restoration goals.

Table 1. Types of ecological restoration, based mostly on Cairns (1992).

Class	Common term	Definition
A	Restoration	Return to predisturbance condition
A1	Pre-emptive restoration	Restoration prior to damage occurring
Ex.:	Restoration with native, naturally occurring species	
B	Rehabilitation	Re-establishment of selected ecological attributes
Ex.:	Replacement of oak-hickory forest on mined land with stand of white pine.	
C	Enhancement	Establishment of an alternative ecosystem
Ex.:	Development of recreational lake following surface mining.	
D	"natural recovery"	Restoration left to natural processes
Ex.:	Unmanaged recovery of farmed land after abandonment.	
E	--[a]	Decommissioning hazardous waste sites
Ex.:	Managed confinement and capping of uranium mine tailings.	
F	--[a]	Restoration in an area with a high risk of ecoaccidents
Ex.:	Replacement of native species with rapidly growing "pioneers" in transportation corridors.	
G	--[a]	Restoration following contamination by genetically engineered organisms
Ex.:	Decontamination followed by reconstruction or restoration.	
H	--[a]	Restoration to protect adjacent ecosystems
Ex.:	Sealing of pyritic minerals in surface mines to prevent acid mine drainage.	

[a]Could be termed "reclamation"

A new option is pre-emptive restoration, also called habitat banking. That is, a restoration project might be undertaken to off-set expected or irretrievable damage to an otherwise unaffected portion of an ecosystem. In the example case, Russell (1991) used an artificial reef to replace habitat that was about to be destroyed. This process is particularly interesting because the original and replacement habitats can be studied (and expected restoration outcomes determine) simultaneously.

Managing the Recovery Process

The success of ecological recovery depends on several factors, some of which may require significant management to achieve any measure of success. Biological factors including the sources and transportability of propagules must be understood. The physical and chemical status of the recovering (or new) habitat must be known. Additionally, a management system must be in place to monitor and manage the biological, physical, and chemical habitat during restoration. For example, the lessons of biogeography suggest that colonization by some desired species cannot be left to "natural" processes, but that species with long life spans and poorly dispersing propagules will have to be introduced on the site. Such introductions need not be restricted to terrestrial plants alone. For example, we have routinely recommended inoculating new ponds and restored wetlands with material from other, similar aquatic ecosystems to assure that insect larve, worms, and microbes will effectively colonize the newly created habitat.

Some of the factors leading to ecological resistance to stress and to the ability of an ecosystem to recover from displacement are listed in Table 2. These factors can serve as a checklist for ranking different systems and situations or for determining the factors that may lead to successful (or unsuccessful) restoration.

Table 2. Factors important in ecosystem resistance and recovery. Lists are intended as checklists for identifying and rating environmental and management factors. Based on Cairns and Dickson (1975).

Resistance	Recovery
Biological	
Organisms accustomed to variable environment.	Nearby epicenters are sources of species.
System has high structural and functional redundancy	Propagules are highly mobile.
System is not near a major ecological threshold.	Physical structure of system is intact.
Chemical	
System has high flushing capacity.	Habitat has chemical-physical factors within normal bounds.
System has high pollutant buffering capacity.	Residual toxicants are not present.
Management	
Local management group has monitoring program in place.	Management has immediate and direct control of damaged area.

In the context of ecosystem restoration, monitoring means that management has the ability to sense when corrective action is needed and the authority to take that action. We see this as different from surveys and surveillance of systems (sensu Hellawell, 1978) in which data are collected without reference to expected ecosystem performance. This is described more fully below.

THE ECOSYSTEM PERSPECTIVE

The ecosystem is the functional ecological unit. Therefore, ecological restoration means more than simply replacing the dominant plant cover. Systems must be measured to assure that not only are the appropriate structures in place, but that these structures are functioning normally. Additionally, ecosystems are linked together, often in an interdependent fashion. Ignoring ecological linkages may result in poorly functioning restored ecosystems with low probability of persistence. For example, it does little good to restore a stream segment if the vegetated riparian zone that buffers and links the stream to the upland ecosystem is not also restored. Headwater streams are especially dependent on the riparian zone which shades the stream and which supplies energy to the stream in the form of leaves, needles, and wood.

The success of restoration efforts must be judged at the ecosystem level using objective criteria. That is, we need to pursue performance criteria for restored ecosystems to assess the results of restoration. Managing species colonization of new habitats only assures that species will arrive, but developing ecosystems, including restored systems, tend to increase in biological diversity as they mature (Odum, 1969). Changing diversity means much more than simple increases in species richness. That is, diversity increases at many organizational levels - landscape (spatial) heterogeneity, community richness, biogeochemical cycling, life cycles, food web complexity. For most ecosystems, patterns of organizational diversity are only qualitatively known, but these patterns (Table 3) provide a framework upon which criteria regarding the success (or failure) of restoration can be judged.

Table 3. Examples of developmental changes in ecosystems (based largely on Odum, 1969). Restored ecosystems should develop toward mature stages shown in the right hand column. Quantitative measures are needed to assess the adequacy of restored ecosystem development.

Criteria	Developing stages	Mature stages
Population life history		
Specialization	broad	narrow
Life cycles	short, simple	long, complex
Community structure		
Spatial heterogeneity	poor	well-organized
Species richness	low	high
Food chains	linear	web-like
Nutrient cycling		
Mineral cycles	open, leaky	closed, tight
Role of detritus	unimportant	important
Energetics		
Net production	high	low

The criteria presented above should be understood by those involved in the broad range of reclamation activities. For example, when a mine site is revegetated, a nurse crop of annual grasses is planted to stabilize soil. The life cycle of these grasses is short and simple, but they are not the ultimate goal. With just a nurse crop, erosion still occurs, leading to soil and nutrient loss (open mineral cycles). An adequately reclaimed (restored) ecosystem will minimize losses of mineral nutrients and will contain a community of perennial organisms with more complex life cycles. The standing crop biomass will increase, but annual yield will decline as the new ecosystem develops.

What is needed, then, is a set of quantitative measures that will define the endpoint of the restoration. These performance criteria should provide an objective answer to the question "when is restoration complete?" Performance criteria will differ according to the type of restoration undertaken and the physical setting (biome, physiographic province). Nevertheless, quantitative criteria will be essential for monitoring ecosystem development. Now, the performance criteria often are unspecified ("we'll know it when we see it") beyond design criteria (i.e., numbers of seedlings planted per hectare). The list of criteria in Table 3 is not exhaustive, but it could serve as the basis for an ecosystem-focused analysis of restoration success.

For an ecosystem approach to succeed, management must be capable of regularly measuring (monitoring) the state of the restored ecosystem. The list of measured criteria need not be long, but the list should include measures that will provide insight into system structure and function. Monitoring can then be diagnostic; it can tell managers what is working and what is not. Failure to monitor ecosystem performance (and to take action when measures are out of predetermined boundaries) can be viewed as a failure of quality control and can fail to prevent unintended impacts on adjoining ecosystems. By determining that restoration efforts are creating ecosystem structures that function like natural ecosystems, managers can be more sure that their efforts are ecological investments in the future.

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COVER, DIVERSITY, PRODUCTION AND METALS UPTAKE BY VEGETATION ON THE RECLAIMED URAD MOLYBDENUM TAILING

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ABSTRACT

The Urad Mine tailing ponds were reclaimed from 1974 through about 1979 by stabilizing with waste rock and mixing sewage and wood chips into the surface of the rock. This paper contains the results of subsequent monitoring studies conducted on the growth medium and vegetation.

Revegetation of waste rock material has been effective. Seeded grasses are well established and produced more forage in 1985 than in the control, an adjacent burned-over spruce-fir community. Vegetative cover on reclaimed tailing areas equaled or exceeded that of the control. The areas were dominated by a few species of grasses, and forbs occurred infrequently. Vegetation on the reclaimed areas was more diverse than the control when all species were considered, but less diverse than the control if only native species were considered. Invasion of the seeded stands by native species has occurred, and diversity may continue to increase with time.

Concentrations of the micronutrients zinc, iron, copper, and manganese in the waste rock growth medium were high. Nitrate nitrogen declined significantly through time. The pH was slightly alkaline and stable through time. If the growth medium were to become more acidic in the future, more metals may become available for plant uptake. The dominant legume, white clover, concentrated chemical constituents in foliage much more than did the dominant grass, smooth bromegrass. The clover had concentrations of molybdenum and fluoride, which might be considered dangerous to ruminant animals if grazing was restricted only to the reclaimed tailing areas.

INTRODUCTION

Molybdenum became a high priority item with the U. S. Government during World War I. The Molybdenum orebody within Red Mountain, about 50 miles west of Denver, Colorado near the Continental Divide, was first developed and mined by the Primos Exploration Co. from 1914 to 1919. Later, the Urad Mine (as it has always been known) was worked intermittently by the Molybdenum Corporation of America during World War II. The mine was closed for a number of years following the War. Climax Molybdenum Company purchased the property in 1963 and put the mine back into production in 1967. The orebody was depleted and the mine closed in 1974 after processing about 14 million tons of ore and producing 48 million pounds of molybdenum. Approximately four pounds of molybdenum were produced from each ton of ore mined.

Tailing produced in the milling process during World War I was deposited directly into Woods Creek. Most of the tailing was contained in a pond when mining was resumed during the World War II period. When Climax reopened the mine in 1967, the company agreed to stabilize, revegetate, and reclaim disturbed areas. Two tailing ponds totaling about 125 acres posed a most difficult reclamation problem for Climax when mining was completed in 1974 (Brown 1976). This was the first full-scale program to stabilize and reclaim hardrock tailing at a high elevation in the Rocky Mountains. Little was known about reclaiming sterile tailing at a 10,400 foot elevation and with a frost free growing season of only about 20 days per year. There were no precedents to follow, so the entire reclamation program was an experiment.

The company developed an innovative use of waste materials to reclaim the Urad tailing ponds. Three major waste products were used to reclaim the tailing: 1) waste rock from a nearby mine, 2) sewage sludge from a metropolitan center, and 3) wood chips from a sawmill in the area. The waste rock was generated during the development of the Henderson Mine. The source of rock was 4,000 to 5,000 feet underground where it was being excavated to develop access to the Henderson ore body. The granitic rock was a sterile growth medium that would require addition of organic matter and nutrients to create a plant growth medium. The Urad reclamation project utilized 1.5 million tons of waste rock, 4,200 tons of dry sewage sludge, and 24,000 cubic yards of wood chips to transform the surface material into a plant growth medium. Adding these amendments resulted in an increase in organic matter, nitrogen, and phosphorus, all essential for plant growth and development. The effort was quite successful, and the innovative reclamation program resulted in Climax Molybdenum Company receiving the 1981 National Environmental Industry Award from the Presidents' Council on Environmental Quality.

Both rock and tailing were initially sterile, but rock offered several advantages over tailing as a plant growth medium.

Waste rock provided a capillary barrier to potential migration of acids or salts from the tailing. The rock eliminated wind and water erosion, thus stabilizing the tailing and eliminating drifting and sand sheer of vegetation by tailing. Rock also provided a rooting zone for tap roots of trees and shrubs. Darker colored waste rock absorbed more heat and should maintain higher surface temperatures than white colored tailing. The rock material also acted as a mulch reducing water loss from the surface.

Wood chips mixed into the surface served as mulch, provided organic matter, and stored some of the excess nitrogen from the sewage sludge for future plant use. The sewage sludge added the necessary nutrients and more organic matter to form the complete waste growth medium. Because of the high C:N ratio of this organic matter, additional ammonium nitrate fertilizer was deemed to be necessary for some years, but in reality was only applied one time.

RECENT FINDINGS

At least 16 elements are known to be essential for plant growth. Of these, nitrogen, phosphorus and potassium are widely deficient in soils. Soil pH is also a common limitation to plant growth (Melsted and Peck, 1973). Secondary or micronutrient deficiencies are sometimes found, with sulphur, zinc and boron being the most common. Iron and zinc deficiencies are sometimes found in the western USA. However, plants differ widely in their susceptibility to micronutrient deficiency due either to their requirements or inability to extract the element from the soil or growth medium (Viets and Lindsay, 1973). There is usually a great increase in plant ability to uptake micronutrient cations as the soil pH decreases (Larcher, 1980).

Chlorine and molybdenum were only recently recognized as plant micronutrients (Johnson, 1966). However, during a fairly short period, molybdenum has been one of the most extensively studied plant and animal micronutrients. Most plant studies, however, have concentrated on molybdenum deficiencies rather than excesses.

Soil or growth medium testing is sometimes useful to determine whether nutrients are either deficient or excessive. Excesses of certain elements can be toxic to plants and animals, or contribute to pollution of surface and ground water. Testing soil for micronutrient concentrations may not always provide useful information because plant requirements for these nutrients vary among species, and availability of nutrients is dependent upon climatic factors and several chemical, physical, and biological processes (Reisenauer, Walsh, and Hoeft, 1973). To have significant predictive value, these tests should measure the amount of nutrients made available to plants under a variety of conditions.

The critical level for a nutrient is the concentration in a plant below which growth rate, yield, or quality declines significantly (Munson and Nelson, 1973). Of course, the critical level of an element can shift rather widely if an interfering or complementary element is present. Generally, though, good relationships between nutrient concentration, plant yield, and nutrient supply are obtained at a specific location in a year. However, year-to-year and location-to-location variation in these relationships are often quite wide spread and difficult to interpret. This, therefore, is a major problem in the general use of plant and soil analyses, and careful evaluation is needed.

Availability of nutrients to plants is determined both by factors which affect the ability of the soil or growth medium to supply the nutrients and by factors which affect the plant's ability to utilize the supplied nutrients (Corey and Schulte, 1973). Available nutrients in solution might be derived from a number of sources such as weathering of minerals, decomposition of organic matter, atmospheric deposition, application of fertilizer materials, etc. The nitrate anion is usually very soluble and generally does not form insoluble compounds with any of the soil constituents. As a result, it usually remains in solution until it is absorbed by plants or microorganisms, leached, denitrified, or otherwise disposed of (Corey and Schulte, 1973). Sulphate anions act in a similar manner in neutral or alkaline conditions but tend to be sorbed in acidic conditions. Most other nutrient elements form some type of relatively insoluble compound which tends to maintain an equilibrium concentration in the solution. Thus, water-soluble cations equilibrate with the cation exchange complex: cations such as copper and zinc form complexes with soil organic matter; ferric iron and aluminum form insoluble hydroxides or hydrous oxides; phosphorus forms iron, aluminum and calcium phosphates, etc.

Soil pH and temperature are important factors in determining solubilities of elements which tend to equilibrate with a solid phase. Solubilities of the hydroxy-oxides of iron and aluminum are directly dependent on the hydroxyl (OH^-) concentration and decrease as pH increases (Corey and Schulte, 1973). Hydrogen cations (H^+) compete directly with other Lewis acid cations for complexing sites and the solubilities of complex cations such as copper and zinc increase as pH decreases. The H^+ ion concentration determines the magnitude of the pH-dependent cation exchange charge and affects activities of all exchangeable cations to some extent. Solubilities of iron, aluminum, and calcium phosphates are markedly pH-dependent, as are solubilities of sorbed molybdate (MoO_4) and SO_4 anions. Another factor important in determining the concentration of nutrients in the soil or growth medium solution is the redox potential (Corey and Schulte, 1973). The redox potential is related to soil aeration, which in turn is dependent upon rates of microbial and root respiration and oxygen diffusion. It affects solubilities of nutrient elements which can exist in more than one oxidation state. These elements include C, H, O, N, S, Fe, Mn, and Cu.

Plants vary widely in their uptake and requirements for various macro- and micro-nutrients (Swaine, 1955). Some essential elements can also be taken up in excess and may become toxic to the plant (Lindsay, 1979). Some toxic elements or compounds can be taken up by plants even though they are not required for growth. Often uptake of toxic constituents are in proportion to their availability in the immediate environment of the plant. In other cases, plants may concentrate certain toxic substances to levels far in excess of their availability. We are only now beginning to understand the effects and fate of some potentially toxic chemicals as they move through food webs in ecosystems.

Whether an element or compound is limiting or toxic in many cases depends upon its availability and concentration (Lindsay, 1979). Although nitrogen is usually the most limiting nutrient, phosphorus is commonly the second most limiting. Phosphorus is often deficient in highly weathered soil, calcarious soils, or organic soils, but excesses may occur under acidic soil conditions. When phosphorus exceeds about 0.3% in plant dry matter, it may become toxic (Bingham, 1966).

Potassium is the third most likely element to limit plant productivity in natural communities. However, plants are capable of substituting sodium in part for potassium requirements (Ulrich and Ohki, 1966). The critical potassium level in leaves of many plants ranges from 0.7 to 1.5% on a dry weight basis. There have been few reported cases of excess or toxicity of potassium. Excess potassium may reduce absorption of other nutrients by the plant from the soil. For example, excess potassium may reduce the uptake of magnesium, manganese, zinc, and iron.

Zinc content in forage normally ranges from 20 to 10,000 ppm ($\mu g/g$) (Holmes, 1944). Therefore, plant leaves with less than 20 ppm zinc may be deficient in this micro-nutrient. Ample, but not excessive, levels commonly range from 25 to 150 ppm (Chapman, 1966). Amounts of zinc greater than 400 ppm may indicate zinc excess. Acidification of soils may bring about zinc toxicity in substrates that are high in zinc.

Iron was shown to be an essential element for plant life over a century ago and is required by plants in quantities larger than manganese, zinc, copper, and molybdenum (Wallihan, 1966). Iron toxicity has not been in much evidence under natural conditions. Concentrations of iron in foliage are usually in the order of 10^{-2} to 10^{-4} times that in the soil in which the plant grows. As a general rule, other elements known to be essential to plants achieve concentrations in the plant tissues that are approximately equal to or greater than that existing in the soil. In as much as most soils contain several percent iron, and plants require concentrations in dry matter in the order of 100 ppm or less, iron deficiency must result from low availability of soil iron.

Plants vary widely in their requirements for molybdenum and in their ability to extract this element from the soil (Reisenauer et al. 1973). Absorption of molybdate by plant roots is markedly influenced by pH, the amount of sulfate, soil organic matter content, and soil moisture (Gupta and Lipsett, 1981). Increased sulfate depresses molybdate uptake. Available molybdenum usually increases with soil organic content, as does that of most other nutrient elements. Additions of sewage sludge may also result in increased molybdenum uptake by plants (Soon and Bates, 1985; Pierzynski and Jacobs, 1986). Plant requirements for molybdenum are met at concentrations of 0.3 to 0.5 ppm in tissues of legumes, and at less than 0.1 ppm in tissues of most other plants. Molybdenum functions in the fixation of nitrogen by legumes, and its deficiency is most frequently observed in that group of plants. Molybdenum is essential in the reduction of nitrate in all plants and has also been implicated in other oxidation-reduction processes.

Molybdate as an anion is strongly adsorbed by soil and minerals and colloids below pH 6.0. Therefore, molybdenum availability in acidic soils may be limiting plant growth (Robinson and Alexander, 1953; Guputa and Kunelius, 1980). Under alkaline conditions, molybdenum is taken up much more readily by plants. Reductions in plant growth from excess levels of molybdenum can be expected when tissue concentrations exceed 200 ppm (Reisenauer et al. 1973). There have been several reports that legumes accumulate more molybdenum than do grasses (Barshad, 1951; Dye and O'Harra, 1959). However, there are a few reports that indicate that this is not always the case (Robinson and Edgington, 1954; Johnson, 1966; Gupta and Kunelius, 1980).

Forage containing more than 10 to 20 ppm molybdenum may produce molybdenosis of ruminants. Elevated molybdenum intake depresses copper availability and may produce a physiological copper deficiency in ruminants (Ward, 1978). Physiological copper deficiencies are produced when forage has: (1) high molybdenum levels (>100 ppm), (2) low copper/molybdenum ratios (<2:1), (3) low copper levels (<5 ppm), and (4) high protein (20-30%). Molybdenum toxicity in ruminants is, therefore, quite complex. It involves not only excess molybdenum but also low copper and high sulfate-sulphur concentrations in forage plants.

Copper supplementation in ruminant diets has been somewhat effective in controlling the disease (Dye and O'Harra, 1959).

It is now generally recognized that ruminants suffering from copper deficiencies have blood that is deficient in hemoglobin (Reuther and Labanauskas, 1966). In addition to copper's function in formation of hemoglobin, other deficiency symptoms are frequently seen in animals. Generally, animals on green forage containing greater than 5 ppm copper do not suffer from copper deficiency. Serious disease may occur when forage contains between 1 and 3 ppm of copper.

The free element arsenic is not considered poisonous. However, many of its compounds are extremely so. There is no evidence that arsenic is essential for plant growth although stimulation of root growth has been demonstrated in solution cultures (Liebig, 1966). Arsenic spray accumulation resulting from herbicide applications, however, has reduced productivity of soils. Arsenic does not usually accumulate to any appreciable extent in the aboveground portions of plants. Arsenic does, however, accumulate in roots. Arsenic levels in plants grown in uncontaminated soils rarely exceed 10 ppm (Liebig, 1966).

Presence of abnormally high concentrations of fluoride in aboveground parts of plants, with low concentrations in the roots, usually indicates that the atmosphere is the principle source of fluoride. High fluoride concentration in roots usually indicates absorption of fluoride from the soil. The usual fluoride content in foliage of plants grown in areas removed from possible sources of air pollution ranges from 2 to 20 ppm (Brewer, 1966). Animals may be detrimentally affected by eating forage containing 50 ppm or less of fluoride, whereas plants can tolerate concentrations greatly exceeding 50 ppm fluoride. Fluorine is not considered an essential element for plants, but it is essential for animals.

The soil system is extremely complex and our knowledge of exactly how various factors affect the availability and uptake of nutrients is still sketchy (Lindsay, 1979). Therefore, we can expect prediction values of soil tests to improve as our knowledge of these factors increases and as testing methods are improved as a result of new research findings.

OBJECTIVES AND PURPOSE

Rock waste materials placed on tailing ponds of the Urad Mine have been subjected to various physical and chemical analysis during the past 18 years. However, data and information had not been interpreted and integrated to determine whether chemical constituents of this plant growth medium had been greatly modified as a result of additions of sewage sludge, wood chips, inorganic fertilizers, and vegetation. Therefore, this study was conducted to answer these questions and to initiate a detailed monitoring effort for the waste rock growth medium. This information would also be used to determine if additional fertilization is desirable.

Waste rock used in reclamation of the Urad tailing was expected to be high in molybdenum (Mo) and some other metals as some of this material came from the orebody itself. High concentrations of Mo in plants can cause molybdenosis in ruminants and may cause molybdenum toxicity in plants. Forage with molybdenum levels as low as 5 ppm have been reported to cause molybdenosis in cattle. Generally, forage containing concentrations greater than 10 ppm Mo are considered toxic to cattle. Availability of Mo to plants is highly correlated with soil pH. Under the slightly basic conditions of the plant growth medium covering the Urad tailing reclamation areas, molybdenum solubility and uptake by plants could be appreciable. Since deer and elk sometimes utilize forage on the tailing reclamation areas, molybdenosis or other toxic chemical constituents could potentially become a problem to these ruminants. For these reasons, a study was initiated to determine if certain toxic compounds, elements, and heavy metals were being concentrated in vegetation established on the waste rock growth medium covering the Urad tailing. It was also possible to determine whether older plants with deeper root systems were concentrating more toxic constituents than were younger plants.

It was considered desirable to determine whether seeded species were increasing, decreasing, or simply maintaining themselves in stands. It is possible that introduced species might eventually be replaced with invading or planted native species on reclaimed areas. For these reasons, another study was undertaken to determine species composition, cover, diversity, and production on various reclaimed areas as related to length of time since seeding. This information was compared with data from a nearby native community to establish successional trends within the stands.

METHODS AND PROCEDURES

The two tailing ponds were covered with the waste mine rock from 1974 through 1978. The rock was spread at depths of three feet on the surface to 5 to 20 feet on the dam faces. Some small hills were created from the rock to break the flat contour of the surface and provide wind breaks. Twenty tons (dry weight) of wood chips and 30 tons (dry weight) of sewage sludge per acre were then applied and mixed (by ripping) into the rock surface with a dozer. Dead timber was also spread onto the surface for additional wind protection. Reclamation efforts followed the development of the plant growth medium with different areas being seeded from 1975 through 1979.

The tailing areas were seeded with a mixture of grass and forb seed at a rate of 50 lbs/ac. The seed mixture included smooth bromegrass, timothy, meadow foxtail, creeping foxtail, orchard grass, red top, red fescue, hard fescue, Kentucky bluegrass, cicer milkvetch, white clover, and an annual ryegrass. Seeded areas were irrigated during the first growing season to ensure good germination and plant establishment. One year after seeding, the areas were hand planted with trees and shrubs. Approximately 40,000 seedlings were planted through the years. Most seedlings were Engelmann spruce, lodgepole pine, bristlecone pine, limber pine, subalpine fir, aspen, and willows that occurred naturally in the area. Survival of tree seedlings has been poor, probably because of high winter winds that result in desiccation and injury caused by ice abrasion of exposed foliage and buds.

Growth Medium Samples

Samples of fractured (crushed) mine waste rock material were collected prior to addition of sewage sludge and wood chip amendments. Samples were also collected after additions of sewage, wood chips and seed. Therefore, samples of the growth medium were related to the year of seeding (1975 through 1979). Areas seeded earlier had greater plant cover and production (Trlica, 1989) and more time for soil development.

Growth medium sampling was done to a depth of 30 cm during the growing season. All samples were submitted to the Soil Testing Laboratory at Colorado State University for analysis. Analyses of this material were for pH, conductivity, organic matter (OM), nitrate (NO_3-N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and molybdenum (Mo). In addition, the 1979 samples were analyzed for arsenic (As), cyanide (CN) and fluoride (F). Cyanide analysis was conducted by the Front Range Lab, whereas fluoride was analyzed in the Range Science Laboratory at Colorado State University. All samples of crushed rock growth medium were air dried, ground to pass through a 2-mm sieve, and subsamples submitted for chemical analyses.

Plant Samples

Seedings made from 1975 through 1977 on Urad tailing ponds were sampled in August, 1979 and 1985. Plants were at about peak production at this time. The dominant grass, smooth bromegrass (<u>Bromus inermis</u>) and the dominant legume, white clover (<u>Trifolium</u>

repens), were clipped at ground level and placed in paper bags. Individual plants were sampled along transects over much of the reclaimed area. Each species that was collected from each year of seeding (1975, 1976, and 1977) was kept separately. Three samples (replications) of each species along separate transects and from each year of seeding were taken.

All samples were returned to the laboratory where they were washed in deionized-distilled water and blotted dry. Samples were then dried at 60° C, ground to pass through a 40-mesh screen, and stored in glass jars until analyzed. All samples were submitted to the Soil Testing Laboratory at Colorado State University (CSU) where they were analyzed for arsenic (As), aluminum (Al), zinc (Zn), iron (Fe), lead (Pb), manganese (Mn), copper (Cu), and molybdenum (Mo). Cyanide (CN) and fluoride (F) were determined by the Front Range Lab, Inc., in Fort Collins, Colorado, and the CSU Range Science Laboratory, respectively, in 1979.

Vegetation Samples

Data collected for vegetation on reclaimed and control areas included species composition, frequency, cover, and production. Sampling was done utilizing two different methodologies. A 0.1-m^2 rectangular quadrat (Daubenmire, 1959) was used to sample composition, cover, frequency and production. Individual species encountered within 50 quadrats in each of two replications per stand were recorded, cover and production estimated, and 10% of the quadrats were randomly chosen and clipped to determine actual production. This double sampling procedure (Pechanec and Pickford, 1937) for estimating production was employed to determine total community standing crop. The U.S. Forest Service paced transect technique (Range Analysis Handbook, 1979) was utilized as another measure of species composition and frequency of occurrence over larger areas of the stands. The 0.1-m^2 quadrats were utilized within 10x10-m plots on tailing ponds reclamation areas, whereas paced transects covered more total area of these stands. Urad tailings seeded in 1975, 1976, and 1977 were sampled.

In addition to reclaimed tailing ponds, one south-facing road cut near the Henderson Mine main office building that had been seeded in 1972 was sampled. A native community in the 1879 burned-over area above the Urad tailing ponds was also sampled as a control to compare vegetation of a native community with that on reclaimed sites.

Data Analysis

Data for the chemical constituents of the plant growth medium, the two species, and vegetation sampling were analyzed using standard analysis of variance and t-test techniques (Steel and Torrie, 1980). When significant differences ($p < 0.05$) were detected among variables or years of seeding, Duncan's New Multiple Range Test was used to separate these differences. When data were below detection limits of instruments, they were not analyzed statistically. Simple linear correlations between growth medium chemical characteristics and concentrations of elements in plant foliage were also made to determine whether growth medium (soil) chemistry influenced plant uptake of chemical constituents. Some data were not appropriate for statistical analyses (frequency and diversity), but were summarized and means calculated.

RESULTS AND DISCUSSION

Comparison of Urad Plant Growth Medium with Soil

Several potentially toxic chemical elements or compounds within the Urad plant growth medium were compared with concentrations in soil as reported in the literature (Table 1). Arsenic, copper, fluoride, and manganese concentrations in the waste rock growth medium were lower than that reported for soil. Lead and molybdenum were somewhat higher in the Urad growth medium than in soil. This was expected as these two elements should be high in ore from which much of the waste rock was derived.

Changes in Crushed Rock Growth Medium Through Time

Additions of wood chips and sewage sludge resulted in significant changes in the nutrient regime of the crushed rock growth medium. Dramatic increases in organic matter (0.7 to 2.4%), nitrate-nitrogen (NO_3-N) (54 to 137 $\mu g/g$) (ppm), phosphorus (P) (3 to 179 $\mu g/g$), and zinc (Zn) (14 to 100 $\mu g/g$) were found soon after addition of the amendments (Table 2). These data were all collected in 1976 and are mean comparisons of before and after the amendments were added to the waste rock on the tailing ponds. Although these differences appear great, they are not all significantly different ($p < 0.05$) because of large variances and the small sample size ($N = 2$).

Two to three years after the addition of sewage sludge, wood chips, and seed (1978 and 1979), some decline in conductivity (salts), nitrate-nitrogen, phosphorus and zinc were noted (Table 2). Leaching and plant uptake were probably responsible

Table 1. Average concentration ($\mu g/g$) of elements in soil as compared with the plant growth medium of the Urad tailing reclamation area.

	Urad plant growth medium		Soil		
Element	Mean	Range	Mean	Range	Reference
Arsenic (As)	<0.03	<0.03	10	0.3-38	Williams & Wheatstone (1940)
Copper (Cu)	14	2-37	45	10-200	Reuther & Labanauskas (1966)
Fluoride (F)	0.06	0.4-0.7	190	20-500	NAS (1971)
Lead (Pb)	27	11-44	16	2-200	Swain (1955)
Manganese (Mn)	20	5-52	600	200-3000	Swain (1955)
Molybdenum (Mo)	1.6	0.1-10	2.5	0.6-3.5	Robinson & Alexander (1953)
Zinc (Zn)	30	5-64	5-175	10-300	Swain (1955)

Table 2. Some average physical and chemical characteristics of crushed waste rock compared to crushed rock with addition of sewage sludge and wood chips in 1976. These data are compared with similar data for the amended growth medium that was collected in 1978 and 1979.

	Growth medium		
	Crushed rock w/o amendments	Crushed rock plus amendments	Crushed rock plus amendments 2 or 3 years later
	Year of collection		
	------------1976------------		---1978 & 1979---
No. samples	2	2	12
pH	8.3a[1]	7.2a	7.7a
Conductivity (mmhos/cm)	4.8a	3.6a	1.0b
Organic Matter (%)	0.7b	2.4a	2.4a
NO_3-N (µg/g)	54a	137a	8a
P (µg/g)	3a	179a	66a
K (µg/g)	200a	173ab	107b
Zn (µg/g)	14b	100a	30b
Fe (µg/g)	52a	75a	85a
Mn (µg/g)	--[2]	--	20.0
Cu (µg/g)	--	--	15
Mo (µg/g)	--	--	1.6

[1]Means in a row followed by a similar letter are not significantly different at $p < 0.05$.

[2]No data collected.

for most of these changes. Iron (Fe) concentrations and pH remained relatively constant between 1976 and 1979.

These results were not unexpected. One would suspect that additions of large amounts of sewage sludge and wood chips would cause an increase in organic matter, nitrate-nitrogen, phosphorus and zinc in the growth medium as these were quite high in the amendments. Thereafter, organic matter and potassium remained relatively constant, whereas nitrate-nitrogen, phosphorus and zinc declined somewhat. This probably reflects uptake and incorporation of these nutrients in plant biomass during later years or losses caused by leaching. The pH remained slightly basic during this entire period.

The plant growth medium (soils) data were then statistically analyzed to determine whether significant changes occurred after amendments had been incorporated with waste rock. Samples collected in 1978, 1979, and 1985 from the area that was seeded in 1976 were analyzed. These data indicated that pH, nitrates, potassium, and iron decreased through the nine-year (1976-1985) period of weathering (Table 3). Organic matter, phosphorus, zinc, manganese (Mn) and copper remained relatively constant. Salts (conductivity) and molybdenum (Mo) showed increases between 1978 and 1985. Weathering of waste rock and plant growth and development on these seeded areas probably account for most of the changes observed in growth medium chemistry. Leaching may have also removed some of the ions from the 0- to 30-cm surface layer.

Comparison of Year of Seeding

Data for both smooth bromegrass and white clover were combined when analysis of variance was made to determine whether differences existed in vegetation growing in the areas seeded over a three-year time period (1975 through 1977). This allowed for more observations (N=6) for each year of seeding. These analyses revealed that vegetation growing on the newer seeding (1977) had higher concentrations of both arsenic and molybdenum in 1979 (Table 4). However this trend had disappeared by the time the areas were resampled in 1985 (Table 5). This might indicate that younger plants in the 1979 sampling of the area that had been reclaimed in 1977 took up more of these elements, or the elements became less available as the growth medium aged.

These results contradicted our hypothesis that older plants with root systems that exploited more of the growth medium would concentrate elements to a greater extent than would younger plants. It may be that older root systems, with greater preexisting concentrations of elements, were more selective in uptake and translocation of arsenic and molybdenum to the aboveground foliage than were plants with younger root systems.

Table 3. Average characteristics for the plant growth medium from 1978 through 1985 on the Urad tailing pond reclamation area (N=6).

Chemical constituent	Year of sampling 1978	1979	1985
pH	8.1a[1]	7.2b	7.1b
Conductivity (mmhos/cm)	0.5b	1.4a	1.4a
Organic matter (%)	2.0a	2.9a	2.5a
NO_3 - N (μg/g)	12a	5b	2b
P (μg/g)	62a	72a	34a
K (μg/g)	112a	101a	71b
Zn (μg/g)	22a	39a	29a
Fe (μg/g)	78a	93a	41b
Mn (μg/g)	17a	23a	34a
Cu (μg/g)	7a	22a	7a
Mo (μg/g)	1.5b	1.8b	9.4a
As (μg/g)	--[2]	<0.03	--
F (μg/g)	--	0.61	--
CN (μg/g)	--	<1.00	--

[1]Means in the same row followed by a similar letter are not significantly different at $p < 0.05$.

[2]No data collected.

Table 4. Average elemental concentration in forage samples of smooth bromegrass and white clover collected from Urad tailings seeded in 1975, 1976, and 1977. All sample collections were taken in August, 1979.

Year of seeding	Species	Chemical constituent (μg/g)										
		As	Al	Zn	Fe	Pb	Mn	Cu	Mo	Cu/Mo	CN	F
1975	Both	.07b[1]	81a	47a	128a	<5	224a	10a	104b	.21a	2.45a	22.2a
1976	Both	.15a	152a	39a	186a	<5	181a	11a	155ab	.16a	7.87a	30.0a
1977	Both	.20a	97a	62a	134a	<5	203a	12a	258a	.14a	5.37a	38.9a
1975-77	Smooth bromegrass	.11a[1]	48b	38b	89b	<5	195a	11a	42b	.29a	2.04b	18.0b
1975-77	White clover	.18a	171a	60a	209a	<5	219a	11a	303a	.04a	8.41a	42.8a

[1]Means in the same column followed by a similar letter are not significantly different ($p<0.05$).

Table 5. Average elemental concentration in forage samples of smooth bromegrass and white clover collected from Urad tailings seeded in 1975, 1976, and 1977. All sample collections were taken in August, 1985.

Year of seeding	Species	Chemical constituent (µg/g)								
		As	Al	Zn	Fe	Pb	Mn	Cu	Mo	Cu/Mo
1975	Both	.16a[1]	122a	73a	242a	<5	266a	6a	182a	.11a
1976	Both	.05b	34b	72a	84b	<5	148a	8a	235a	.16a
1977	Both	.05b	59b	82a	103b	<5	141a	7a	223a	.17a
1975-77	Smooth bromegrass	.05b[1]	36b	71a	60b	<5	189a	7a	30b	.28a
1975-77	White clover	.12a	107a	80a	226a	<5	181a	7a	397a	.03b

[1]Means in the same column followed by a similar letter are not significantly different ($p<0.05$).

Arsenic levels in plants were within the normal expected range of 0 to 10 $\mu g/g$ (Williams and Wheatstone, 1940); whereas, molybdenum levels were exceedingly high and surpassed most levels previously reported (Kubota, 1976; Gupta and Lipsett, 1981).

Comparison Between Species

The legume, white clover, had significantly higher concentrations of aluminum, zinc, iron, molybdenum, cyanide and fluoride in foliage than did smooth bromegrass in 1979 (Table 4). This same trend was also still apparent in the 1985 samples (Table 5). This was expected as legumes are known to concentrate several elements more than do grasses. The exceedingly high average concentrations of molybdenum (303-397 $\mu g/g$) and fluoride (43 $\mu g/g$) in white clover would certainly not make this species desirable forage for a ruminant animal. Fluoride concentration in plant foliage normally ranges from 2 to 20 $\mu g/g$ (NAS, 1971). The concentration of molybdenum in smooth bromegrass would also limit its utility for use by livestock (Tables 4 and 5). With the high concentration of molybdenum and the low but normal concentration of copper in both species, the copper-to-molybdenum ratio was dangerously low for ruminants. Copper-to-molybdenum ratios less than 2:1 can produce copper deficiencies in livestock (Miltimore and Mason, 1971), and ratios in this study were often less than 0.1. Sustained grazing by ruminants on the reclaimed areas might result in molybdenosis; however, the ponds do not appear to be used in that manner.

Plant Chemical Constituent Correlation With Growth Medium Parameters

Simple linear correlation analysis of chemical constituent concentrations in smooth bromegrass and white clover with plant growth medium parameters indicated low correlations among most variables (Table 6). This was anticipated as there usually is not a simple linear relationship between soil variables and the uptake and concentration of elements in plants. The concentration of copper in smooth bromegrass was highly correlated with the molybdenum concentration in the same plant and in the growth medium (Table 6). The concentration of molybdenum in smooth bromegrass was also highly correlated with the molybdenum concentration of the growth medium. Therefore, smooth bromegrass is a good indicator of molybdenum levels of the substrate, whereas weaker correlations were found for copper and molybdenum levels in white clover with concentrations found in the growth medium.

Diversity

Species diversity was estimated by recording invading species occurrence along transects through the study areas. Species that were planted at each particular site were not included in diversity determinations. The data indicated that the spruce-fir area that was burned in about 1879 (which served

Table 6. Simple linear correlation coefficients (r values) of plant growth medium parameters with chemical constituents in foliage of plants. All samples collected on the Urad tailing ponds reclamation area in early August, 1979 and 1985 (data sets combined).

Parameter	Plant Cu	Plant Mo	Plant Cu/Mo	Medium Cu	Medium Mo
	- - - - - - - Smooth bromegrass - - - - - - -				
Plant Cu	-	-	-	-	-
Plant Mo	.97	-	-	-	-
Plant Cu/Mo	.24	.07	-	-	-
Medium Cu	.34	.36	.08	-	-
Medium Mo	.95	.95	.16	.33	-
Medium pH	.64	.66	-.42	.29	.66
	- - - - - - - - White clover - - - - - - - -				
Plant Cu	-	-	-	-	-
Plant Mo	.33	-	-	-	-
Plant Cu/Mo	.66	-.87	-	-	-
Medium Cu	.60	-.32	.63	-	-
Medium Mo	.70	-.21	.49	.33	-
Medium pH	-.47	.91	-.83	-.51	-.13

as a control) was the most diverse community (Table 7). Twenty-six species occurred along the transects through this community in 1979 and 30 species were recorded in 1985 (Table 7). The Urad tailing ponds seeded in 1975 had 19 invading species in 1979 and was thus slightly less diverse, but frequency of occurrence of these species was low. Species diversity of other stands was low, but increased between 1979 and 1985. No invasion of stands seeded in 1977 was noted in 1979. By 1985, however, 15 species had invaded the 1977 seeded area. Some of these species are considered as weeds, however.

Table 7. Number of naturally occurring species found in 1979 and 1985 on reclaimed tailing areas and road cut in the Henderson-Urad mining area.

	Number of species					
	Grasses & sedges		Forbs & shrubs		Total	
Study area	1979	1985	1979	1985	1979	1985
1975 seeding - tailings	4	2	15	20	19	22
1976 seeding - tailings	0	1	8	9	8	10
1977 seeding - tailings	0	2	0	13	0	15
1972 seeding - road cut	6	4	4	12	10	16
Control - 1879 burn area	5	7	21	23	26	30

These data indicated that invasion was fairly rapid within five years of seeding and improvement continued through 1985. Also, invasion was directly related to length of time since seeding of the reclaimed tailing ponds. It will be interesting to determine whether the invading species increase in cover and production in the future, as their importance was still fairly low in 1985. If both invading and planted species are considered, then diversity of reclaimed areas may exceed that of the control.

Frequency of Occurrence

Plants were found more frequently in 1979 as the length of time since seeding of tailings increased (Table 8). However, using the U.S. Forest Service pace transect method (Range Analysis Handbook, 1979), rock and litter were also frequently encountered on the reclaimed tailings. Bare soil and moss cover was not encountered on transects through these seeded stands in 1979. Moss was encountered on seeded areas by 1985 and plant occurrence was quite similar to that of the control area. Litter disappearance in seeded areas was also evident by 1985.

Table 8. Frequency of occurrence of various characteristics in stands on seeded areas of the Henderson-Urad mine as compared with a native burned-over spruce-fir stand.

	Percentage of hits											
	Bare soil		Erosion pavement		Rock		Moss		Litter		Plants	
Study area	1979	1985	1979	1985	1979	1985	1979	1985	1979	1985	1979	1985
1975 seeding - tailings	0	2	4	8	21	15	0	4	35	25	40	46
1976 seeding - tailings	0	2	8	5	31	12	0	3	31	12	30	66
1977 seeding - tailings	0	2	7	4	26	10	0	0	52	15	15	69
1972 seeding - road cut	12	5	12	12	6	15	2	10	41	8	27	50
	2	2	15	6	22	14	1	2	12	11	48	65

With an increase of occurrence of vascular plants and moss in 1985 on seeded areas, there was a corresponding decrease in the occurrence of rock on the surface (Table 8). The amount of erosion pavement and bare soil did not vary greatly between 1979 and 1985. The pattern of frequency of occurrence on seeded areas compared much more favorably with that of the 1879 burned area (control) by 1985, indicating that seeded areas had definitely improved between 1979 and 1985.

Aerial Cover

Aerial cover for grasses and forbs of each stand was sampled utilizing the Daubenmire (1959) technique. Total cover on seeded areas was very similar to that of the burned-over spruce-fir community in both 1979 and 1985 (control) (Table 9). Hard fescue (Festuca ovina) was the only seeded species common to both seeded stands and the control. Of the various areas sampled, total cover was greatest in 1979 on the tailing ponds area that had been seeded in 1976. However, by 1985 total cover on all areas of the tailing ponds reclamation were fairly similar. Forbs were more prevalent on the burned area in both 1979 and 1985 than within any of the seeded stands. Forb cover was less than 2% on all tailing ponds reclaimed areas compared with more than 13% on the control area.

Smooth bromegrass (Bromus inermis), hard fescue (Festuca ovina), and timothy (Phleum pratensis) dominated the cover of the seeded areas in 1979 and 1985 (Table 9). These three seeded grasses may be expected to dominate at higher elevations with ample water and high nitrogen fertility. One might theorize that the two taller grasses would eventually shade out the shorter stature species, such as hard fescue. This could cause the shorter stature species to decrease in importance and, theoretically, might lead to a situation similar to that of intensively managed mesic meadows or irrigated pastures. Conversely, it might be theorized that withholding nitrogen fertilizer would actually allow for better expression of shorter stature species. What has actually occurred is that hard fescue increased in cover between 1979 and 1985 on the seeded areas as supplemental nitrogen was not applied after 1979. Also, we suspect that further decreases in the taller grasses have occurred since 1985.

Production

The seeded Urad tailing ponds and the road cut area were producing significantly more aboveground biomass than were the burned-over spruce-fir community (control) in 1979 (Table 10). Production on reclaimed tailing ponds was much greater than for the control area in 1985. In general, there was an increase in

Table 9. Aerial cover (%) for grasses and forbs on various seeded areas of the Henderson-Urad reclamation area in 1979 and 1985 as compared with a stand in a burned-over spruce-fir community.

	Tailing ponds seeded in											
	1975				1976				1977			
	Unfertilized		Fertilized		Unfertilized		Fertilized		Unfertilized		Fertilized	
Species	1979	1985	1979	1985	1979	1985	1979	1985	1979	1985	1979	1985
Agrostis alba (redtop)	0.3	0.0	0.4	0.0					0.4	0.0	0.4	0.0
Alopecurus arundinaceus (creeping foxtail)					0.1	0.0			0.3	0.0	0.1	0.0
Alopecurus pratensis (meadow foxtail)	0.0	1.0	0.0	3.2			0.0	1.8	0.0	1.0	0.0	0.9
Bromus inermis (smooth bromegrass)	12.5	3.1	9.3	0.9	19.6	7.4	27.2	4.0	12.1	7.6	10.9	7.2
Dactylis glomerata (orchard grass)	5.7	0.8	2.8	0.5	3.0	0.0	0.8	0.1	5.2	1.2	8.1	1.4
Festuca ovina (hard fescue)	7.0	10.6	2.4	9.0	29.4	22.0	20.7	11.8	9.4	15.0	5.4	17.0
Festuca rubra[1] (red fescue)	1.1	0.0	1.5	0.1	1.6	0.0	1.5	0.0	1.3	0.0	0.0	0.4
Phleum pratensis (timothy)	5.0	0.6	7.2	0.2	5.2	0.1	4.5	0.0	8.4	1.4	1.3	0.5
Poa pratensis(Kentucky bluegrass)	12.2	12.9	30.6	15.0	2.1	1.2	5.8	2.3	0.0	2.4	7.2	3.8
Secale cereale (Balboa rye)									2.4	0.0	7.0	0.0
Other grass	0.1	0.0							1.0	0.0	1.8	0.0
Trifolium repens (white clover)	0.1	0.2					0.0	0.3	0.1	0.0	0.1	0.1
Other forbs	0.1	0.2	0.9	1.8	0.1	0.0	0.0	0.1				
Total grass	43.9	28.9	54.2	28.8	61.0	30.7	60.5	20.0	40.5	28.4	42.2	31.2
Total forbs	0.2	0.4	0.9	1.8	0.1	0.0	0.0	0.3	0.1	0.0	0.1	0.1
TOTAL COVER	44.1	29.3	55.1	30.6	61.1	30.7	60.5	20.3	40.6	28.4	42.3	31.3

[1]Young *Festuca rubra* plants may have been identified as *Festuca ovina*.

Table 9. Continued.

	Road cut				Control burn			
	East		West		Uphill		Across hill	
Species	1979	1985	1979	1985	1979	1985	1979	1985
Agrostis alba (redtop)								
Alopecurus arundinaceus (creeping foxtail)								
Alopecurus pratensis (meadow foxtail)	0.3	0.1	0.0	0.7				
Bromus inermis (smooth bromegrass)	4.0	0.1	5.4	4.2				
Dactylis glomerata (orchard grass)	0.4	0.1	6.2	0.5				
Festuca ovina (hard fescue)	24.7	6.7	27.2	12.4	1.2	0.6	0.6	1.1
Festuca rubra[1] (red fescue)								
Phleum pratensis (timothy)	7.4	4.5	11.2	1.4				
Poa pratensis(Kentucky bluegrass)	0.0	0.2	0.0	0.5				
Secale cereale (Balboa rye)								
Other grass	0.3	0.0	6.8	0.0	19.2	4.4	19.4	3.3
Trifolium repens (white clover)	2.4	1.5	0.6	0.8				
Other forbs	0.1	2.7	0.5	1.9	24.4	20.1	13.0	15.8
Total grass	37.1	13.5	56.8	19.7	20.4	5.0	20.0	4.4
Total forbs	2.5	4.2	1.1	2.7	24.4	20.1	13.0	15.8
TOTAL COVER	39.6	17.7	57.9	22.4	44.8	25.1	33.0	20.2

[1]Young *Festuca rubra* plants may have been identified as *Festuca ovina*.

Table 10. Average aboveground standing crop of vegetation for various seeded areas compared with a burned-over spruce-fir community (control).

Stand sampled	No. samples	Standing crop (g/m^2) 1979	Standing crop (g/m^2) 1985
Tailing ponds (seeded in 1975, 1976, and 1977)	300	61a[1]	127a
Road cut (seeded in 1972)	100	65a	76b
Control (1879 burned area)	100	24b	59b

[1]Means in a column followed by a similar letter are not significantly different ($p < 0.05$).

production on the tailing reclamation area between 1979 and 1985 even though vegetation cover declined somewhat. Production on the tailing ponds and road cut area was similar to that of shortgrass prairie; whereas production of the control area was more like that of a desert grassland or sagebrush-grassland type (Sims, Singh, and Lauenroth, 1978).

Applying inorganic nitrogen to the tailing ponds seeded areas during the 1979 growing season did not significantly increase the aboveground standing crop in 1979 or 1985 (Table 11). However, vegetation that received the added nitrate fertilizer had a dark green color and appeared more vigorous in 1979 even though production was not increased.

The tailing ponds that were seeded in 1976 had significantly more standing crop in 1979 than did tailings seeded in either 1975 or 1977 (Table 11). This same area also had greater aerial cover of vegetation (Table 9). The reason for the better stand that existed on the 1976 seeded area in 1979 may be that more care was taken to achieve proper distribution of the amendments, better germination from better irrigation management, etc. In addition, the area planted in 1975 received 20 tons/acre of sewage, whereas those areas seeded in 1976 and 1977 received 30 tons/acre of sewage sludge. Similar seeding mixtures were used in 1975, 1976 and 1977. Climatic conditions could also have favored plant establishment on the 1976 seeding. However, by 1985 there were no differences in production among sites seeded in 1975, 1976 or 1977.

Table 11. Effects of seeding year and 1979 application of inorganic nitrogen fertilizer on aboveground standing crop of vegetation in 1979 and 1985 for the Urad tailing reclamation.

	Standing crop (g/m^2)				Average standing crop in 1979 and 1985 (g/m^2)	
	Unfertilized in 1979		Fertilized in 1979			
Year of seeding	1979	1985	1979	1985	1979	1985
1975	46	121	58	112	52b[1]	117x
1976	76	67	82	110	78a	89x
1977	55	191	47	160	51b	176x
Average	62a[1]	126x	59a	127x		

[1]Means in a row or column followed by a similar letter are not significantly different ($p<0.05$).

SUMMARY AND CONCLUSIONS

Fertility Level of Urad Tailing Reclamation

Only five nutrients have been found sufficiently deficient to limit agronomic crop production in Colorado (Soltanpour, Ludwick, and Reuss, 1979). They are nitrogen (N), phosphorus (P), potassium (K), zinc (Zn) and iron (Fe). Nitrogen is the macronutrient most frequently found deficient.

It appears that nitrate-nitrogen is becoming limiting again on the reclaimed sites (Table 3). Therefore, one or more applications of 33 lbs/acre of nitrate-nitrogen is recommended to return the vegetation to a reasonable vigorous condition. If nitrate fertilization is to be used, ammonium nitrate rather than ammonium sulfate is recommended as sulfur is already high in the waste rock and ammonium sulfate might also cause a reduction in growth medium pH through time.

Phosphate levels are presently very high in the growth medium. Potassium levels are moderately high at the present time. Therefore, additions of these two fertilizers are not recommended.

Concentrations of the micronutrients zinc, iron, copper, and manganese were all considered very high (Soltanpour et al. 1979) (Table 3). Certainly no additions of these elements should be considered. Soil organic matter was high and pH was only slightly alkaline. Therefore, the plant growth medium should readily supply elements for plant uptake. Salts were not excessive and should not reduce plant growth. As more organic matter enters the humus fraction, soil water relations and cation exchange capacity should improve.

Calcium and magnesium appeared to be marginally low in the growth medium (Table 12). However, both elements had high concentrations in waste rock material (Table 2). Therefore, we might expect availability of these two elements to increase with time, so fertilization is not warranted unless an inexpensive source of $CaCO_3$ is available.

Table 12. Suggested ranges of optimum concentrations (μg/ml) of elements in nutrient solutions for plant growth as compared with concentrations in the plant growth medium from Urad tailing ponds reclamation. Optimum concentration values taken from Bowen (1966).

Element	Optimum nutrient solution concentrations (literature values)	Urad plant growth medium concentrations (CSU Soil Testing Lab values)
B	0.1 - 1.0	---
Ca	50 - 350	12 - 46+
Cl	1 - 300	---
Co	0.001 - 0.01	---
Cu	0.01 - 0.1	2 - 37*
Fe	0.5 - 50	30 - 182
K	100 - 600	73 - 205
Mg	20 - 60	0.5 - 1.6+
Mn	0.1 - 1.0	5 - 52*
Mo	0.01 - 0.1	0.1 - 10*
N	70 - 250	90 - 180
Na	0.06 - 350	4 - 19
P	30 - 150	1 - 305
S	50 - 270	---
Se	<1	---
Si	<0.09	---
V	0.01 (-10)	---
Zn	0.02 - 0.2	5 - 175*

+Indicates values lower than optimum concentration.
*Indicates values greater than optimum concentration.

Toxicity of Elements

Of the various elements that were more than twice as concentrated in waste rock material as in native soil, six (Be, Co, Pb, Ni, and Sn) are considered potentially very toxic (Bowen 1966), whereas most of the others are considered potentially moderately toxic. Although availability of these elements for plant uptake is not known at present, slight toxicity problems may presently exist or may become more evident with continued weathering of the rock material. If growth medium pH should become more acidic in the future, more of these toxic elements may become available for plant uptake.

Microorganism populations may also be affected by these toxic elements. Bacteria, fungi and algae are often sensitive to toxic elements. Therefore, if microorganisms are less effective in decomposition of dead plant material, nutrient cycling and humus production may be slowed.

The dominant legume (white clover) concentrated chemical constituents in foliage much more than did the dominant grass (smooth bromegrass) on the Urad tailing reclamation areas. Younger plants in 1979 appeared to have greater concentrations of both arsenic and molybdenum in foliage than did older plants, but these differences were no longer evident in 1985. This may be related to greater availability of these elements in recently seeded areas or to the older plants' ability to reduce uptake of these two elements.

White clover had concentrations of both molybdenum and fluoride which were high. Molybdenum levels in smooth bromegrass were also high, but not nearly as high as that in white clover. Concentrations of these constituents may decline in foliage as the plant growth medium weathers, or as these metals become incorporated into organic litter on the surface. The present study indicated little change in uptake of molybdenum in 1979 and 1985 by plants growing on the reclaimed tailing. If pH of the plant growth medium (soil) becomes more acidic with time, this could cause molybdenum to become even less available for plant uptake.

Cover, Diversity and Production

Reclamation of waste rock material over Urad tailing utilizing sewage sludge and wood chips has been effective. Seeded grasses are well established and produce more forage than in a nearby burned-over spruce-fir community. Cover of vegetation on reclaimed tailings equals or exceeds that of the native plant community. Therefore, wind and water erosion of tailing has been effectively mitigated.

Vegetation on the tailing ponds and road cuts is not as diverse as naturally-occurring communities, unless seeded species are included in the number of species encountered. Reclaimed areas are dominated by a few species of grasses, and forbs occur infrequently. However, species diversity has increased significantly with time since the areas were seeded in 1974-1979. Invasion of the seeded stands by native species is occurring and diversity may be expected to continue to increase with time. Fertilization with inorganic nitrate fertilizer should be used sparingly to prevent the tall introduced grasses from becoming more dominant and competing with native invading species. A more natural community might thus be obtained in a shorter period of time.

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PRAIRIE RESTORATION ACTIVITIES AT ROCKY MOUNTAIN ARSENAL

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ABSTRACT

Prairie restoration has been conducted at Rocky Mountain Arsenal since 1989. Species mixes for four prairie types, short grass, tall grass, mixed grass, and sand prairie are being seeded. The program involves one to two years of control of undesirable vegetation by a combination of burning, chemical application, mowing, and tilling. Vegetation control is followed by soil preparation, fertilization, seeding and application of grass hay mulch. Results have been variable, but typical of revegetation efforts reported for semi-arid environments. Cool season grasses have generally established quickly. Warm season grasses have required a longer establishment period with vegetation control during the first and second growing season. Precipitation distribution during the growing season appears important for establishment and growth of all warm season grasses. Above average precipitation during July and August of 1991 resulted in excellent establishment and growth of all warm season grasses. Even with optimum precipitation, establishment of shrubs from seed has been very limited.

INTRODUCTION

Rocky Mountain Arsenal (RMA, the Arsenal) is located at the western edge of the High Plains Section of the Great Plains Province. Topography of the Arsenal is gently rolling, with an elevation range from 1,622 meters at the southeastern boundary to 1,566 meters along the northwestern boundary.

RMA is an Army installation covering about 70 square kilometers (27 square miles) in southern Adams County, Colorado, about 15 kilometers (9 miles) northeast of downtown Denver. Before the Arsenal was established, the area was used primarily for dryland and irrigated farming and rangeland, mostly as small farms and ranches. Evidence of this past is still apparent on RMA, and this land use currently dominates areas to the north and east of the site.

Rocky Mountain Arsenal was originally established in 1942 as a facility for the manufacture of chemical and incendiary munitions. The Army continued to produce, store, and demilitarize chemical agents at the Arsenal through the Vietnam war era. Concurrently, beginning in 1947, facilities in the South Plants area of the Arsenal were leased to private chemical manufacturing companies. The most extensive of these operations was pesticide manufacturing. The majority of contamination of the site resulted from disposal of waste material in surface basins.

At present, most activity at RMA is limited to four categories: (1) administration, maintenance, and security; (2) technical investigations related to remediation of the site; (3) interim actions to contain various contamination sources; and (4) activities related to habitat improvement and wildlife management.

METHODOLOGY AND RESULTS

A program to diversify the prey base and restore prairie areas on Rocky Mountain Arsenal was initiated in 1989 as mitigation for expansion of a runway onto RMA land from Stapleton International Airport. Several areas were designated for prairie restoration. This paper will focus on one site, although results were similar among all areas.

The sand prairie restoration site is located in the southeast portion of RMA. It is characterized by Bresser Sandy Loam soils and was dominated by cheatgrass (Anasantha tectorum) and weedy annual and perennial forbs.

The site was burned in early April and sprayed with glyphosate in early May 1989. A seed bed was prepared and a sterile sorghum seeded in mid-June. A dense stand of sorghum established by August and provided forage and cover for wildlife through the winter. In spring 1990, a dense growth of cheatgrass occurred under the standing sorghum. The sorghum was therefore mowed in mid-April to facilitate a second application of glyphosate in mid-May 1990. The site was seeded with warm season grasses (Table 1) and grass hay mulch applied at a rate of two tons per acre.

Precipitation data is collected through the year. Data for vegetation cover is collected each fall by the point transect method using the ocular sighting device. Data is summarized with Revegetation Information Monitoring and Analysis, Version 2.0 (Keammerer Ecological Consultants, Inc.)

Table 1. Species mix for sand prairie sites at Rocky Mountain Arsenal.

SPECIES	COMMON NAME	VARIETY	LBS/ACRE
Chondrosum gracile	Blue grama	Hachita	0.75
Calamovilfa longifolia	Prairie Sandreed	Goshen	1.0
Andropogon hallii	Sand bluestem	Woodward	5.0
Sporobolus cryptandrus	Sand dropseed	Native	0.1
Panicum virgatum	Switchgrass	Nebraska 28	0.3

In the fall of 1990, the only seeded grass to appear in the data collected (Table 2) was sand dropseed (Sporobolus cryptandrus). This species is a common early successional species at the Arsenal. It has subsequently been deleted from most seeding projects because is volunteers readily from seed in the soil seed bank. No change in the vegetation was observed through the spring of 1991. The seeding was considered a failure and it was decided to reseed in the fall of 1991 after further vegetation control. Glyphosate was applied for a third time in late May and 2,4-D was applied in June.

Table 2. Sand prairie site vegetation summary for 1990. Based on data from 6 50 meter line-point transects.

Warm Season Perennial Grasses	Mean Cover %	Relative Cover %	Percent Frequency
Buchloe dactyloides	0.40	0.87	20.00
Sporobolus cryptandrus	2.40	5.22	40.00
Sub-total	2.80	6.09	
Annual Grasses			
Anisantha tectorum	13.20	28.70	100.00
Eragrostis cilianensis	0.80	1.74	20.00
Sub-total	14.00	30.43	

During summer 1991, the precipitation pattern diverged greatly from the long range averages. For the period of June, July, and August a total of 5 inches of precipitation greater than the long term average was received at RMA (Table 3). Precipitation events were gentle and lasted for days instead of the high intensity, short burst thunderstorms more typical of the summer months.

By fall, the results in terms of warm season grass establishment were very different than that observed in the spring. All of the species seeded provided some amount to the total vegetation cover for the site, and warm season grasses provided 33% of cover by all species. Cover by cheatgrass was reduced from a mean of 13% in 1990 to only 3% in 1991 (Table 4).

The trend of vegetation succession at the site was considered positive. The idea to reseed the area was abandoned and replaced by an over-seeding effort to try and increase cover by switchgrass, sand bluestem, and prairie sandreed.

CONCLUSIONS

1. Warm season grasses may require at least two growing seasons before significant cover is provided by these species.

2. During summers of precipitation amounts equal to or less than the long range average, irrigation to supplement natural precipitation during June, July, and August may be desirable for establishment of warm season grasses in this region.

Table 3. Precipitation long term means, totals and variance from long term mean for 1989, 1990, and 1990 for Rocky Mountain Arsenal.

MONTH	1989	+/-		1990	+/-		1991	+/-		MEAN
APRIL	1.00	-0.8		1.01	-0.8		1.94	0.1		1.81
MAY	3.83	1.4		1.51	**-1.0**		2.43	0.0		2.47
JUNE	2.04	0.5		0.21	**-1.4**		2.2	**0.6**		1.58
JULY	1.64	-0.3		3.57	1.6		4.11	**2.2**		1.93
AUGUST	1.28	-0.3		1.96	0.4		3.69	**2.2**		1.53

Table 4. Sand prairie site vegetation summary for 1991. Based on data from 6 50 meter line-point transects.

Warm Season Perennial Grasses	Mean Cover	Relative Cover	Percent Frequency
Andropogon hallii	0.01	0.01	0.00
Calamovilfa longifolia	0.67	1.03	16.67
Chondrosum gracile	4.33	6.70	66.67
Panicum virgatum	0.01	0.01	0.00
Sporobolus cryptandrus	16.67	25.77	83.33
Sub-total	21.67	33.50	
Annual Grasses			
Anisantha tectorum	3.00	4.64	33.33
Cenchrus longispinus	0.33	0.52	16.67
Eragrostis cilianensis	2.00	3.09	16.67
Panicum capillare	2.00	3.09	33.33
Sub-total	7.33	11.34	

OPERATIONAL AND FINAL RECLAMATION ACTIVITIES AT THE THUNDER MOUNTAIN MINE

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ABSTRACT

Because the location of the Thunder Mountain Mine is in a congressional exclusion area surrounded by the Frank Church River of No Return Wilderness, reclamation and drainage control practices were implemented based on an interim program that was modified annually following approval of the Reclamation Plan. Implementation of the program began in 1984 during exploration activities and followed through operations and final closure of the mine. Goals of the interim reclamation and drainage stabilization program were to control non-point source runoff on disturbed land and restore vegetation cover, where possible, as soon as practicable to protect water quality of adjacent creeks tributaries to anadromous spawning streams.

Results of annually modifying the interim reclamation program indicated early on that runoff could be successfully dispersed by preventing it from concentrating on mine facilities and directing it to undisturbed land. Initiating facility reclamation as soon as practicable significantly reduced the time required to close the mining operations. The final closure processes consisted of contouring, grass and forb seed planting, planting native and climatized lodgepole tree seedlings and establishing stable drainage conditions. The end result has been accelerated bond release and positioning the mine to deal with storm water regulations.

INTRODUCTION

The Thunder Mountain Mine is located in central Idaho adjacent to the River of No Return Wilderness. Thunder Mountain is situated at an elevation of approximately 8,000 feet at the headwaters of two primary tributaries to the Middle Fork Salmon River. The location of the mine enhanced concerns and interest within the regulatory and public sectors regarding operations and reclamation activities proposed by Coeur d'Alene Mines. Primary concerns associated with project development and operations were related to sediment impacts to local anadromous fisheries resources, and use of cyanide in the recovery process and potential impacts to surrounding water resources.

Thunder Mountain was operated as an on-off heap leach gold mine. Leached ore was treated with alkaline chlorination to destroy residual cyanide in the heaps. Following the cyanide destruction process, spent ore was disposed of by off loading individual pads and placing the material in approved waste disposal facilities. The mine was decommissioned during the field season of 1991; final reclamation activities were completed by October. On-going reclamation monitoring will continue for three years based on an agreement made with the Idaho Department of Lands (IDL). Post closure monitoring will consist of slope stability inspections, revegetation success (self perpetrating plants), erosion control and water quality monitoring.

Water quality monitoring for selected parameters was conducted on a weekly and/or monthly basis at monitoring wells, springs and adjacent streams. Water quality parameters of most interest to state and federal agencies include: Ph; cyanide (weak acid dissociable form); turbidity; chloride; and key heavy metals. Table 1 provides a summary of the water quality parameters evaluated as part of the water quality monitoring program.

Coeur d'Alene Mines developed an innovative surface water management plan to address issues and concerns identified as a result of the permitting process for the Thunder Mountain Mine. Plan development was initially designed based on evaluating potential flood events associated with rainfall and snowmelt characteristics representative to the project region. Following review of several hydrologic model results, a combination of rain-on-snow was selected as the design storm event for drainage control facility. This approach provided maximum protection from typical snowmelt runoff events plus an additional conservative safety factor for the occasional rain-on-snow runoff events.

The intent of the surface water management plan was to develop a cost effective method to control non-point source runoff from land disturbances due to mine construction and operation. Facilities at the mine that generated the most non-point source runoff were the haul road system and waste rock disposal sites. The water management plan developed by Coeur was based on best management practice techniques incorporating interim drainage stabilization for erosion control with revegetation of disturbed surfaces at the soonest practicable opportunity.

TABLE 1

WATER QUALITY MONITORING PARAMETERS

Parameter	Units	Procedure	MDL**
Antimony	mg/l	Graphite Furnace AA	0.002
Arsenic	mg/l	Graphite Furnace AA	0.005
Mercury	mg/l	Graphite Furnace AA	0.0005
Zinc	mg/l	Flame AA	0.01
Copper	mg/l	Graphite Furnace AA	0.001
Iron	mg/l	Flame AA	0.01
Chloride	mg/l	Mercuric Nitrate-Titration	0.1
Chlorine (free)	mg/l	Colorimetric	0.05
Calcium	mg/l	Flame AA	0.02
Magnesium	mg/l	Graphite Furnace AA	0.01
Nitrate N	mg/l	UV Screen, Cd Reduction	0.1
pH Units		Electrode	
Spec Cond (umho)	umho	Conductivity Bridge-Meter	0.1
Cyanide (WAD)	mg/l	Method C	0.005
(TOTAL)	mg/l	Distillation	0.005
(FREE)	mg/l	Colorimetric	0.005
Turbidity	FTU		0.5
TSS*	mg/l	Gravimetric	1.0

* TSS - Total Suspended Solids
** Dependent on sample size, dilution

SEDIMENT CONTROL DURING EXPLORATION

Sediment control facilities were constructed during the fall of the first exploration season. Early stormwater runoff management structures were designed to prevent concentrations of water from building on areas cleared of vegetation for exploration purposes. Dispersion terraces were constructed based on design parameters including; total drainage area; slope; soil scour velocities; and runoff potential per acre of drainage area.

Location of dispersion terraces was initially conducted by use of site contour maps generated from typical aerial mapping of the mine. Watershed drainage areas contributing runoff to exploration sites were divided into sub-drainage areas to control the amount of runoff entering to any one dispersion terrace. After preliminary design of drainage control facilities were completed, dispersion terraces were located in the field by surveying their alignments as laid out on site maps. All terraces were surveyed at a constant slope of one percent. Establishment of this design criteria prevents runoff collected in the dispersion terraces from exceeding a flow velocity of 2.0 to 2.5 feet per second. Grade control of terraces was accomplished by placing a stake every 50 feet along the length of the facility during the surveying process. Scour of the terrace surface is prevented and deposition of settleable solids is enhanced by aligning terraces at this gradient. Additionally, dispersion terraces act to collect settleable solids due to the one percent grade they are constructed at.

DRAINAGE STABILIZATION/EROSION CONTROL DURING CONSTRUCTION

As a result of creating large cleared areas, soil was exposed to the erosion-transport-sediment deposition process over approximately 200 acres. This exposure of soil to the erosion process on steep slopes created the need for an intensive drainage stabilization and erosion control plan to be developed for protection of local water resources from sediment impacts. Disturbed areas were divided into small sub-drainages with a maximum size of approximately five acres. Additionally, all runoff from upland watershed areas was diverted around project facility sites to minimize the contributing area of drainage to project facility sites under construction.

The small sub-drainage basins were identified by use of aerial mapping of the entire project area. At the base of each sub-drainage area a dispersion terrace was developed at a one percent slope. Dispersion terraces collected all surface stormwater runoff and routed it off and away from the project facility's area of disturbance.

Actual alignment of dispersion terraces was modified in the field to incorporate existing exploration road cuts to the extent practicable. Utilization of existing exploration roads minimized the amount of additional disturbances required as part of the drainage stabilization and erosion control plan implementation for the construction phase project development.

Dispersion terraces were developed such that the upper terrace extended further into the forested area adjacent to the cleared zone than the next downslope terrace (Figure 1). By aligning terraces in this manner runoff from the upper most terrace would disperse out over forest ground cover vegetation with concentrating runoff with the next downslope terrace. This technique was applied to all terraces as they were constructed down the slope of a cleared area, thereby enhancing the dispersion of runoff by preventing it from re-concentrating into gully flow conditions.

Due to the large areas of disturbance associated with project construction additional sediment trap facilities were incorporated at the end of all dispersion terraces. Two similar sediment trap techniques were applied based on the anticipated flows expected from each terrace. The primary sediment trap technique incorporated consisted of placing silt fence structures at the outfall point of dispersion terraces (Figure 2). Silt fences were incorporated due to minimal costs associated with the material and the life expectancy of the product, which was anticipated to be in excess of the project life.

Placement of the silt fence structures was based on forming the fence material in an arch pattern such that runoff entering the fence would not spill around the uphill edge (Figure 3). Forming an arch out of the silt fence structure in this manner forced runoff to pond prior to spilling over the top of the material at the central point of the arch. Rocks were placed on the downslope side of the silt fence arch at the point where runoff spilled over the fence. Use of rocks in this location prevents additional scour of soil minimizing sediment impacts.

A combination of silt fence and log barriers were incorporated as the alternative sediment trap techniques for the construction phase of the project. Use of log barriers in conjunction with silt fences was applied to the drainage stabilization and erosion control plan to evaluate the efficiency of the two techniques, and determine if cost savings could be realized by increased applications of log barrier sediment traps.

Figure 1 Dispersion Terraces and Silt Fence Structures

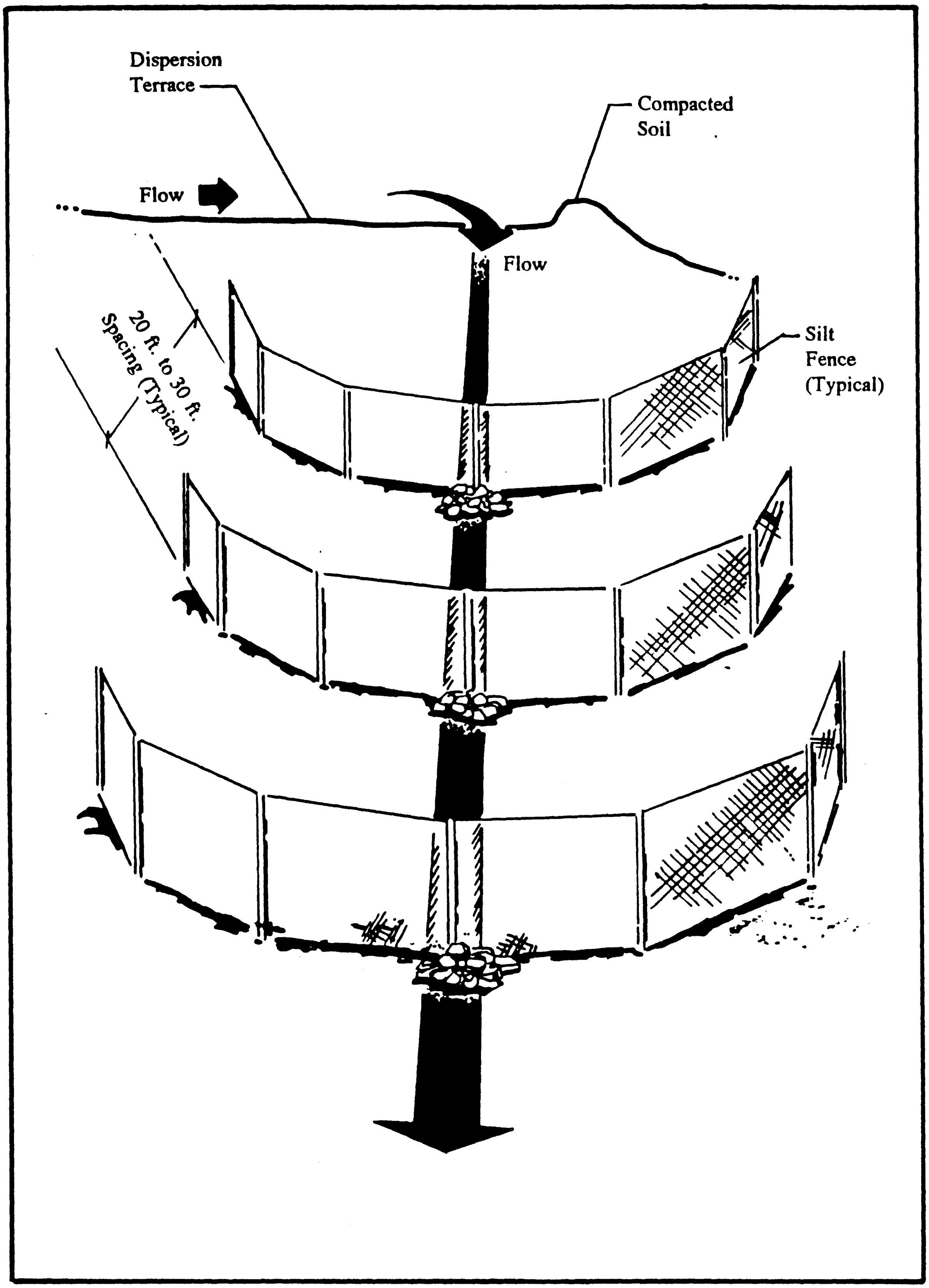

Figure 2 Silt Fence Structures

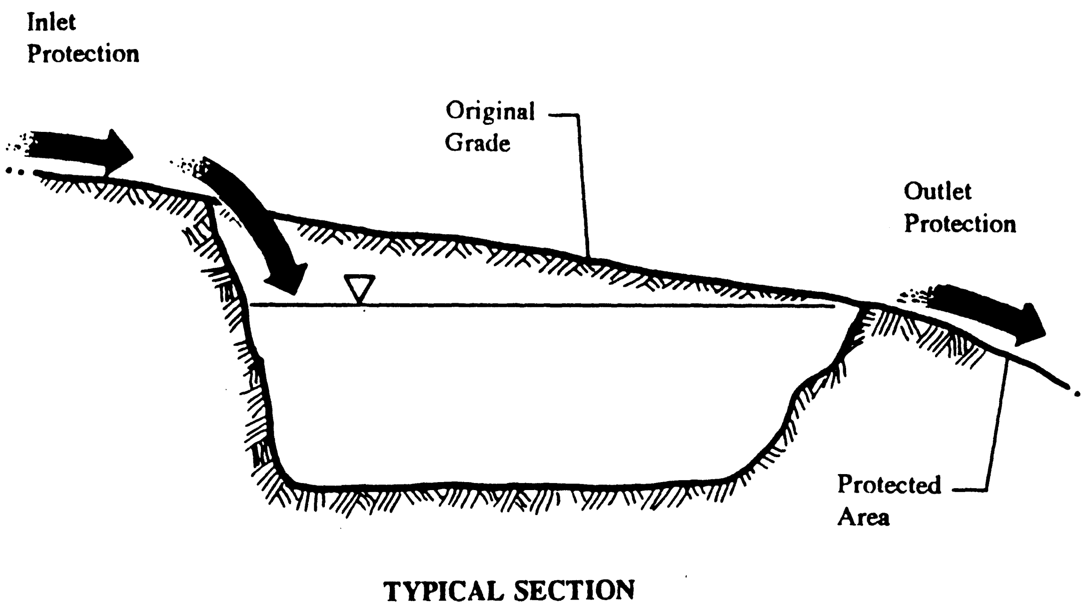

Figure 3 Sediment Sumps

The conclusion of evaluating the efficiency of the silt fences versus the log barriers resulted in increased use of silt fences. This was due to the long life span the silt fence material has in field applications at elevations similar to Thunder Mountain and the flexibility of reusing the materials at different sites once an area became stabilized or project development precluded the need for future drainage control.

INTERIM WATER MANAGEMENT PLANNING DURING OPERATIONS

During the operating life of Thunder Mountain, water management planning and reclamation progressed on an annual basis. This allowed the operations to expand yearly incorporating surface runoff control measures where needed. Reclamation of disturbed sites was conducted when practicable based on short and long-term stabilization needs.

Interim water management control measures utilized dispersion terraces, silt fences and several new techniques developed in response to drainage conditions generated from major mine facilities. The primary source of runoff from mine facilities were mine haul roads. Haul road compaction and road gradients combined to create large flow rates during major snowmelt, rain-on-snow and rainfall events.

In order to control the sediment load resulting from project facilities, incorporation of sediment sumps, rock filter sediment traps, roadside culvert sediment traps and protection of culvert outlets were added to the water management plan (Figures 4, 5 and 6). These additional sediment control structures were combined with existing and new water management facilities.

Sediment sumps were located at the end of dispersion terraces prior to runoff entering the silt fence or along haul road drainage ditches. Sufficiently large amounts of sediment was trapped in sediment sumps that annual cleaning was necessary along the length of dispersion terraces. Sediment sump placement approximately every 50 feet along terraces acted to extend the functional life of silt fences at the end of the terraces before maintenance of the fences was required.

PROJECT DECOMMISSIONING AND FINAL CLOSURE

In accordance with the approved Reclamation Plan, all buildings and ore processing facilities were dismantled and removed from the site. Leach pads were reclaimed by removing the final ore heaps after their detoxification and rinsing the

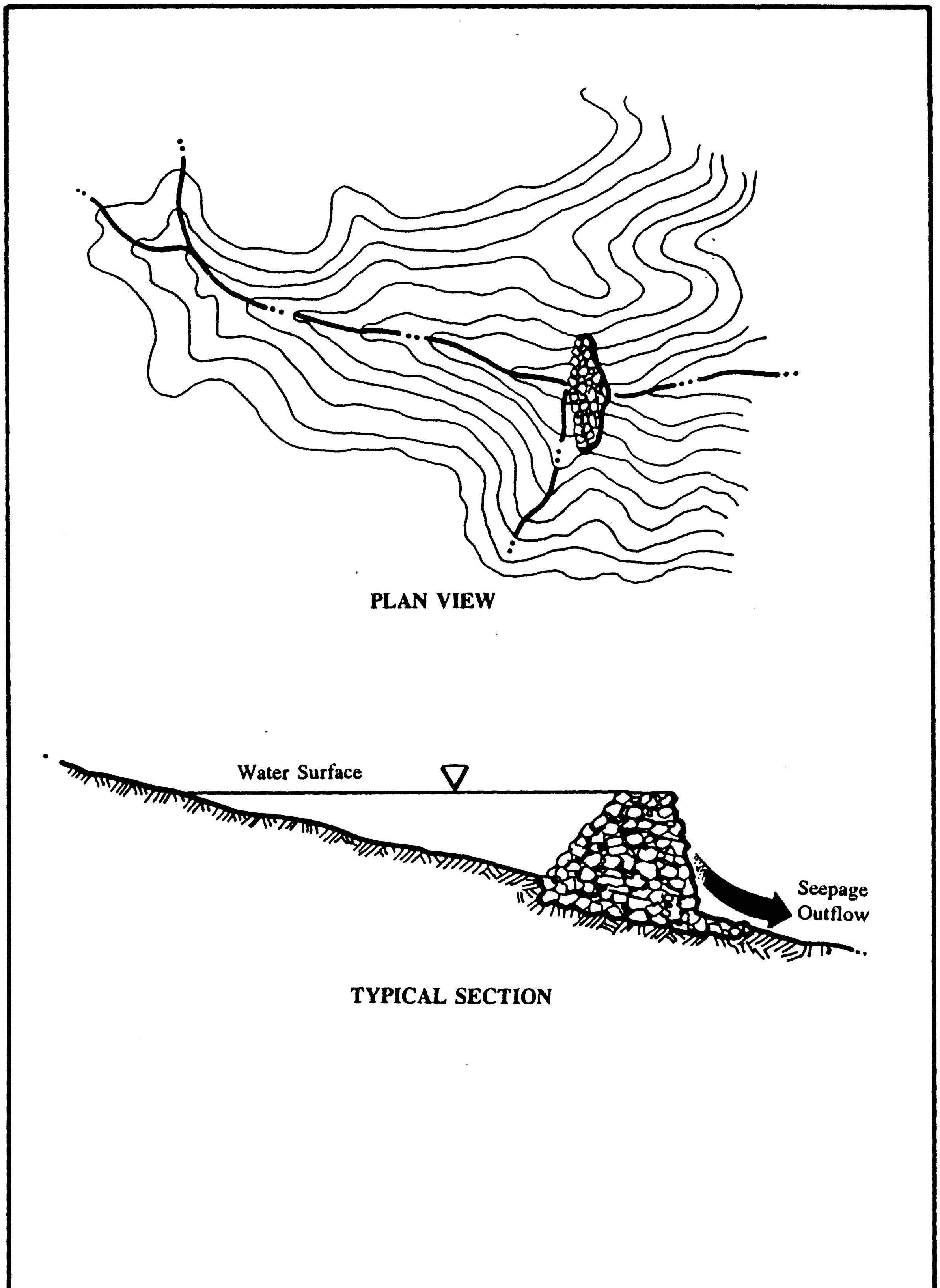

Figure 4 Rock Filter Sediment Trap

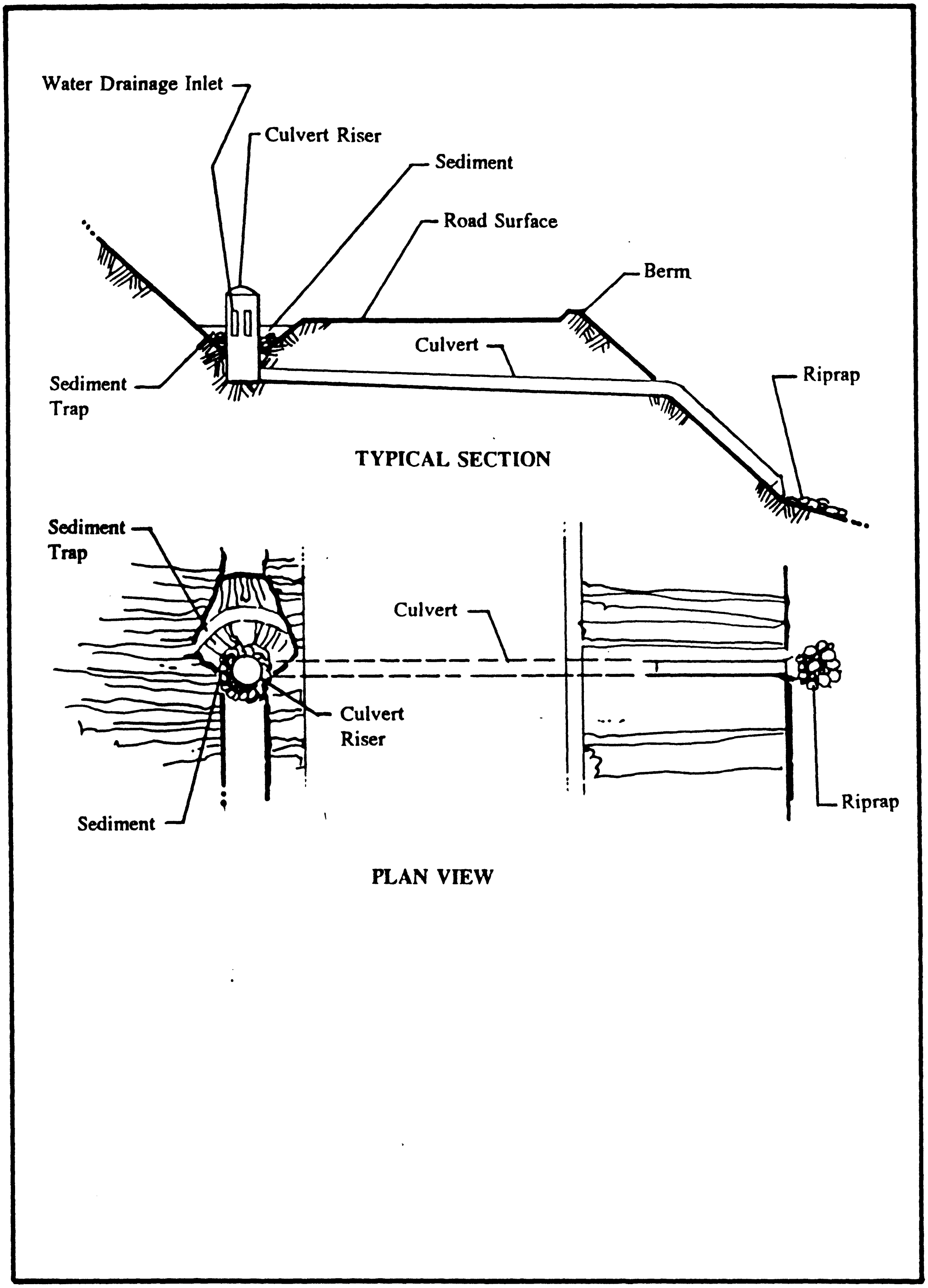

Figure 5 Roadside Culvert Sediment Trap

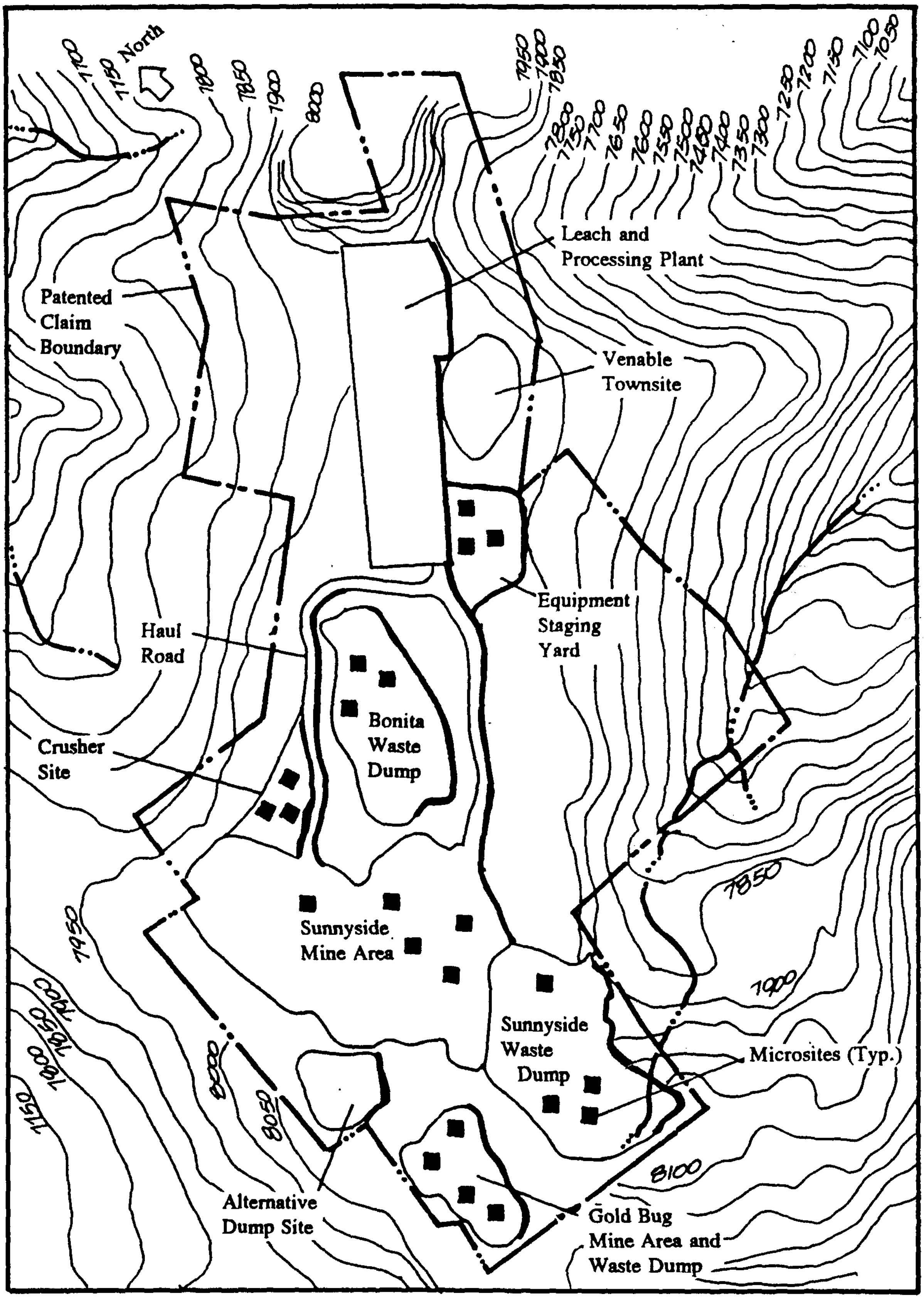

Figure 6 Soil Microsites

asphalt surface to remove any residual cyanide. The asphalt was then ripped and hauled to a disposal site and buried. Leach pad subbase material was then treated with chlorine to remove any residual cyanide prior to capping the pad area with 2 feet of stockpiled topsoil.

Solution collected in the process ponds from leach pad detoxification was treated with chlorine and disposed of at the wastewater land application facility. Following the disposal of all water collected in the process ponds the ponds were reclaimed by placing an 80 mil HDPE liner over the existing pond liners and filling the ponds in with clay material. The final reclaimed surface of the ponds was left crowned with an approximate slope of three percent. Crowning the pond surfaces will ensure that water does not pond by allowing storm water to runoff, away from the reclaimed pond facilities.

Following decommissioning and dismantling of all process related facility, offices, laboratory and personnel camp foundations were ripped and harrowed. All other compacted surfaces including roads and backfilled pit areas were ripped to enhance infiltration potential and establish vegetation. Soil that had been stockpiled during project construction was placed as scattered clumps throughout the project facilities including the equipment yard, crusher site, haul roads, waste rock disposal sites and backfilled mine pits to create microsites for establishing vegetation.

Coeur d'Alene Mines implements a revegetation test plot program on spent ore during the operating life of the mine. Vegetation species evaluated as part of the program included grasses, forbs and trees. In addition, mulch, fertilizer, lime and gypsum were tested as part of the program to assist in developing an efficient restoration process of the disturbed land from mining activities. Table 2 provides a summary of vegetation species use for broadcast seeding over surfaces to be reclaimed. Table 3 provides a summary of the reclamation techniques used at the mine. Coeur also collected lodgepole pine seeds during the clearing process of developing one of the mine pits and had the Forest Service grow the seeds at a tree nursery. Approximately 5,600 two year old seedlings are available for planting during the spring of 1992. An additional 18,500 seedlings have been purchased to plant throughout the mine along with the native tree stock. To date approximately 11,000 trees have been planted at facilities reclaimed as part of the interim reclamation program (Figure 7).

At the end of the 1991 reclamation season the entire mine site, totaling in excess of 200 acres, was planted with a grass and forb seed mixture at a rate of 50 lbs per acre. Following seed application the area to be reclaimed was harrowed and mulch with approximately 1.5 tons per acre of straw. Fertilizer will be applied during

TABLE 2

TEST PLOT SEED SPECIES
THUNDER MOUNTAIN MINE PROJECT

COMMERCIAL SEED SPECIES
Coeur-Thunder Mountain Grass Seed Mixture Bromar Mountain Brome Revenue Slender Wheatgrass Potomac Orchardgrass Timothy
Forb Mixture 1 Western Yarrow (Achillia millefolium) Arrowleaf Balsamroot (Balamhoriza saggitta) Mountain Lupine (Lupinus alpestris) Rocky Mountain Penstemon (Penstemon strictus "Bandera") Fireweed (Ephilobium angustifolium)
Dry Shrub Mixture 1 Antelope Bitterbrush (Purshia tridentata) Wax Currant (Ribes cereum) White Rubber Rabbit Brush (Chrysothmnus nauseosus albicaulis)
Wet Shrub Mixture 1 Wood's Rose (Rosa woodsii) Blue Elderberry (Sambucus cerulea) Choke Cherry (Prunus viginiana melanocarpa)
HAND-COLLECTED NATIVE SEED SPECIES
Forb Mixture 1989 Lupine Rock Penstemon Goldenrod
Tree Mixture 1989 Lodgepole Pine Spruce Timber Pine

TABLE 3

RECLAMATION TECHNIQUES
THUNDER MOUNTAIN MINE PROJECT

Revegetation Method	Application Method	Constituent Distributed	Goal	Reclamation Component
Soil Amendment Application	Five Gallon Shaker Bucket	Calcium Carbonate Gypsum	Provide soil nutrients & pH adjustments	Interim and/or long-term
	Broadcast Seeder	20-10-10 Fertilizer	Provide soil nutrients	Interim and/or long-term
Scarification	550 John Deere with 5 seven-inch ripper bars attached	Growing Medium	Aerate growing medium and relieve compaction	Long-term
Topsoil	Dump truck followed by Caterpillar D-7, or 550 John Deere bulldozer spreading material	Native Topsoil	Provide growing medium	Long-term
Commercial Seed	Broadcast Seeder	Grasses	Revegetate Disturbed Land	Interim and/or long-term
	Broadcast Seeder	Forbs Shrubs	Revegetate Disturbed Land	Long-term
Native Seed	Broadcast Seeder and Hand Thrown	Forbs Trees	Revegetate Disturbed Land	Long-term
Mulching	550 John Deere bulldozer pulling a 10 ft. flatbed trailer followed by a gasoline powered mulcher	Oat Straw Barley Straw	Provide seed cover, insulation and retain moisture	Long-term and/or short-term
Transplanting	Shovel and Bucket	Trees Shrubs	Revegetate Disturbed Land	Long-term

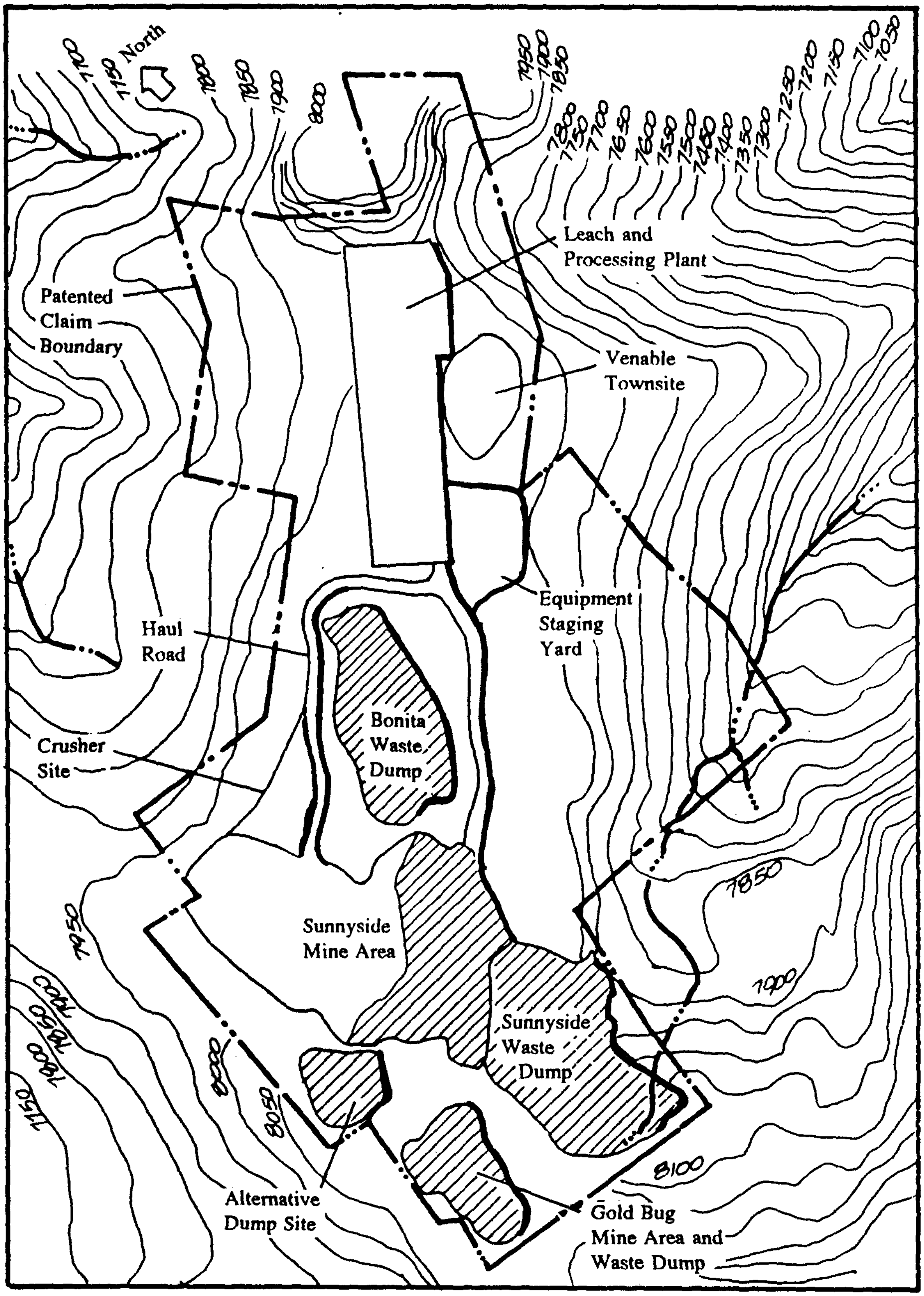

Figure 7 Tree Planting Sites

the spring of 1992 on all areas planted with grass and forb seed.

POST CLOSURE MONITORING

Monitoring will continue for a period of approximately 3 years following project decommissioning activities that occurred in 1991. The three main aspects of the project that will require monitoring include: 1) slope stability; 2) water quality; and 3) establishment of vegetation. Coeur d'Alene Mines will be responsible to provide the State and Federal agencies reports summarizing the results of field monitoring and hold field meetings with the agencies annually to evaluate the results of the reclamation activities.

In addition to the post closure monitoring requirements, Coeur will have to provide water quality monitoring to the EPA relating to the new storm water discharge requirements. The Company will have to either prove that there are no direct point source discharges from project facilities or obtain an NPDES Permit from EPA. The permit will have to be an individual permit due to the fact that there are no similar mines in the State that could be placed into a group permit status.

The reclamation bond held on the project by the State and the Forest Service will be evaluated for release in 3 years. The criteria for release of the bond will be the acceptance of the monitoring results collected over the next 3 year period. However, the EPA will potentially require storm water monitoring associated with the NPDES Permit for an indefinite period of time.

UPDATING PEGASUS GOLD'S RELIEF CANYON MINE RECLAMATION PLAN 1984 VERSUS 1990 STANDARDS

Nancy Logue

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Florida Canyon Mine
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Imlay, NV 89418

ABSTRACT

The Relief Canyon Mine in Pershing County, Nevada was first permitted in 1984. Pegasus Gold acquired the property in 1986 and the ore body was exhausted in 1990. When reclamation of the property began, Pegasus wanted to upgrade the standards in the 1984 permit to better match Pegasus' operating practices. The Winnemucca office of the BLM was asked for their input, both State and Federal BLM suggestions were obtained, and the plan was cooperatively upgraded.

The actual field work on the waste dumps in many cases exceeded the upgraded reclamation plan. Special efforts were made to reshape the dumps to blend with the existing topography. Various dozing and seeding techniques were used to achieve optimum results. All exploration roads in the pit area were recontoured.

The results of these efforts were publicly recognized when Pegasus received the Nevada 1991 Excellence in Mining Reclamation award "in recognition of outstanding achievement in final reclamation of mine waste dumps and in exceeding prior plan requirements". This award is presented by a group of State and Federal regulatory agencies who regularly deal with the mining industry.

INTRODUCTION

The Relief Canyon Mine operated from 1984 to 1990 producing in excess of 120,000 ounces of gold. The mine was permitted during the infancy of BLM's 3809 surface management regulations and consequently had a very abbreviated reclamation plan. When production ceased and closure began, the standards recognized by industry and regulatory agencies for reclamation had been upgraded.

Through cooperation with State and Federal agencies, a modified reclamation plan was written providing reclamation goals and objectives. Actual reclamation of the waste dumps exceeded those goals.

Earthwork under the new guidelines began in June, 1990 using a small dozer. A contractor with larger equipment, J.D. Welsh & Associates, was retained in September, 1990 and the last of the earthmoving was completed in January, 1991. After spring seeding and one growing season in essentially drought conditions, many small plants of the seeded species were found in the reclaimed areas. These results are encouraging.

The remainder of reclamation and closure should be completed by October, 1993.

RELIEF CANYON MINE

Location

The Relief Canyon Mine is located 17 miles east of Lovelock in Pershing County, Nevada, 100 miles northeast of Reno. The mine pit areas are at elevations up to 5700 feet; the process area is at 4650 feet. The vegetation ranges from sage with sparse juniper at the higher elevations to sage in the flat.

History

The Relief Canyon property was originally explored for high grade limestone in 1978 by Falconi & Associates. At that time, it was expected that the MX missile project would proceed and limestone for cement would be needed in this area. However, it soon became evident that the limestone contained too many metals to meet purity requirements.

Duval Corporation discovered gold in the limestone exploration area in 1979 and following a two-year drilling program announced reserves of 6-10 million tons with an average grade of .04-.06 ounces per ton (opt) Au.

Lacana Gold Corporation optioned the property in 1982 and calculated reserves at 9.2 million tons with an average grade of .032 opt Au. A 9,000 ton test leach was run in 1983 with favorable results. Full scale mining and processing started shortly after and continued through August 1985 when the project shut down due to lower-than-expected gold recovery.

Pegasus Gold Corporation purchased the property in July, 1986 and resumed production in December, 1986 after adding a crushing and agglomerating circuit to enhance metal recovery.

Ore was mined and crushed through September, 1989 with leaching completed by September, 1990.

	Oz Au	Ore Tons	Waste
Pegasus	119,374	5,823,000	8,918,000
Lacana	1,253 *	530,000 *	1,000,000 *
TOTAL	120,627	6,353,000	9,918,000

* 1984 production estimates; no estimates for 1985.

Reclamation

The original reclamation plan contained 3 pages of text outlining plans for soil handling, revegetation methods, and seeding of specific sites. Reshaping some areas was addressed, but no reference was made to overall reclamation goals or how to evaluate success. It appears that for plans written and approved in the early 1980's more emphasis was placed on operating the mine than mine closure. Through the intervening years, reclamation planning and completion have been integrated into the early stages of mine planning.

Initial reclamation was completed at the end of mining in August, 1989. All dump surfaces and haul roads were ripped, several berms were removed and the entire mine pit area was aerial seeded. No reclamation was started in the process area because of continued leaching and rinsing activities.

Six months later it was agreed by BLM and Florida Canyon Mining, Inc. that further reclamation would be necessary to meet the current guidelines for successful reclamation.

The operating plan was modified to address planned reclamation. The updated plan discussed reclamation of the roads, heaps, pits, and waste dumps; proposed final slope angles; revegetation; and a monitoring program.

Reclamation under the updated plan was initiated in June, 1990 using a John Deere 550 dozer. Five process plant operators split their time between operations and reclamation. The dozer was used to remove berms, grade exploration roads and regrade flat areas near the pits. Approximately 25 acres were recontoured.

A Komatsu track-mounted excavator was used to reclaim 17,250 linear feet (approximately 6 acres) of exploration roads on steep slopes at a cost of $1.05 per linear foot. The road cuts were filled in and the textured surface left by the bucket teeth retained moisture for plant growth and minimized erosion.

A motor grader was used to remove berms and shape road cuts in the flat exploration areas.

The waste dumps were reshaped and contoured using a D8N and D9N dozer. See Relief Canyon Mine diagram for waste dump locations.

After mining and initial reclamation, the dumps were left with flat surfaces and angle-of-repose slopes too steep for vegetation growth and livestock use. After further reclamation, the slope angles range from 2¼:1 to 4:1. In most places the dozers pushed straight downslope and completed the reshaping by cutting down the dump crests and extending the dump toes with the fill material. The waste dump toes were blended onto the next lower waste dump or to the existing topography to approximate natural contours.

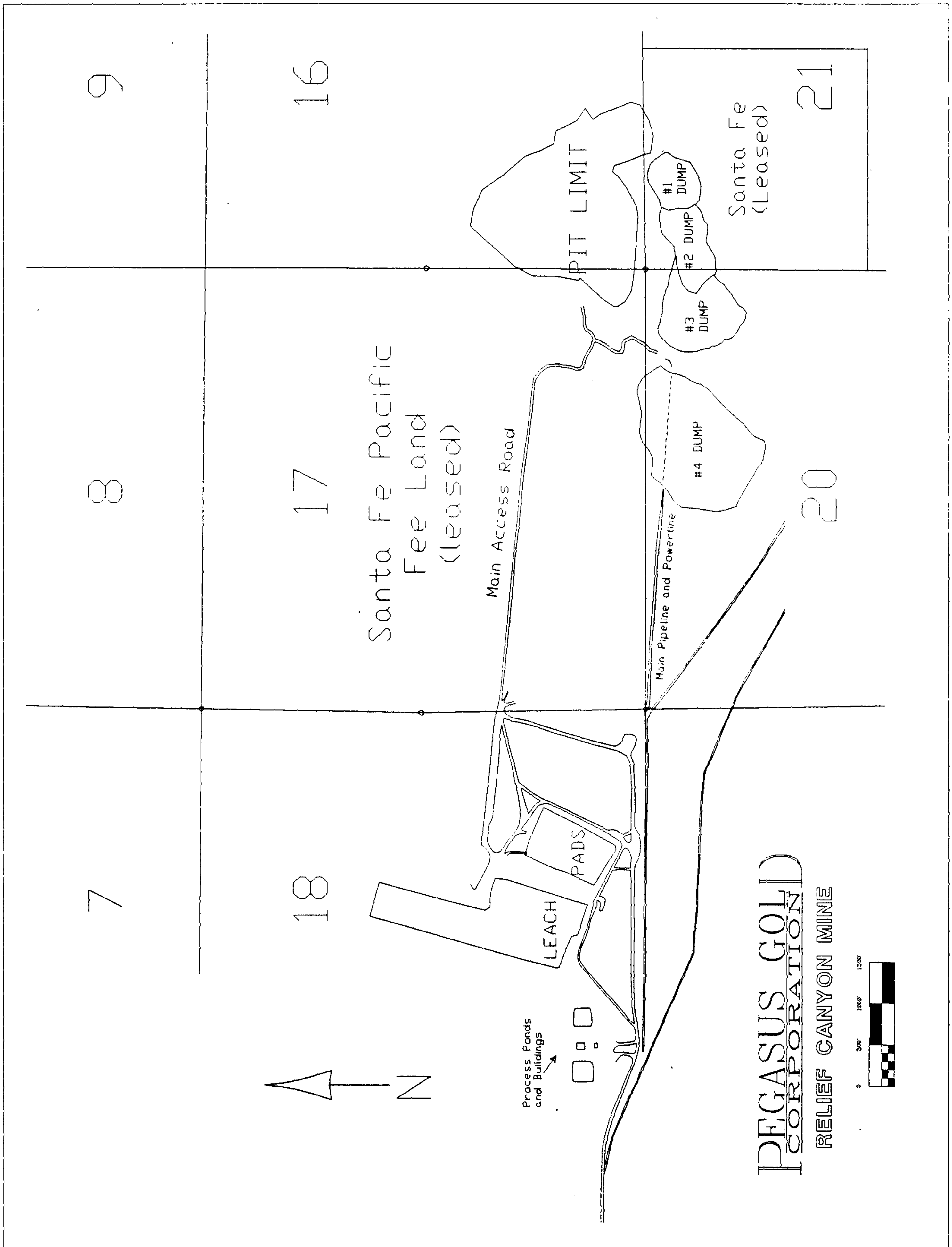
Dumps 1, 2, and 3 required dozing of the slopes from crest to toe and attention to blending the toes to the natural ground surface. The dump tops were smoothed to break down the furrows left by the earlier deep ripping.

Dump 4, the largest waste dump, also needed shaping of the entire dump top, approximately 17 acres. At the end of mining in 1989, more than half the dump was covered by end dumping run-of-mine material. The piles were approximately 10 feet high and composed of large rocks. Fine material was markedly absent and very little plant growth was noted in that area.

On dump 4, the D9N dozer was used to move the large rocks into the depressions on the surface. Finer material, found in places on the surface or trucked in from a haul road by scraper, was used to cover the rocks. The resulting dump surface has many levels created by rounding over the lifts, hillocks and low spots. Fine material now covers most of the surface and piles of large rocks have been scattered for small animal habitat.

The resulting landforms from dump reclamation are low hills with irregular shapes and slopes. The flat dump tops were minimized by rounding over the crests. The vertical color patterns from waste dumping were blended to a uniform neutral color. The shaping has been approved by the BLM and will be monitored for 2 years for erosion or slope failure.

After the reshaping was completed, 400 tons of manure was spread on approximately 40 acres of dump slopes and tops on dumps 2, 3, and 4. The targeted application rate was 10 tons/acre. Manure was tried because it was readily available and it could act as mulch and fertilizer.



9
16
21
Santa Fe
(Leased)
PIT LIMIT
#1 DUMP
#2 DUMP
#3 DUMP
#4 DUMP
8
17
20
Santa Fe Pacific
Fee Land
(leased)
Main Access Road
Main Pipeline and Powerline
7
18
LEACH
PADS
Process Ponds and Buildings
N
PEGASUS GOLD
CORPORATION
RELIEF CANYON MINE
0
500'
1000'
1500'

Seeding was completed in 3 phases. The flat exploration roads and waste dump 1 were seeded with a snowcat modified with 2 broadcast seeders mounted on the front and a harrow dragged behind the machine. The exploration roads on steep slopes were seeded by hand. Dumps 2, 3, and 4 and the remaining areas near the pits were seeded with a Caterpillar Challenger agricultural tractor. The Challenger is a rubber-tracked vehicle which was equipped with a large seed box on the front and harrow dragged behind. The Challenger was run on contour in all areas except the mile-long haul road to the crusher site. The seed mix consisted of:

Species	lbs pls/acre
Immigrant kochia	1
Shadscale	2
Fourwing saltbush	2
Crested wheatgrass (Nordan)	6
Alfalfa (Ladak)	2
TOTAL	13

The seed was broadcast at approximately 15-20 pounds per acre by the various methods. The snowcat and hand seeding was done in September, 1990 and the Challenger seeding was completed in mid-April, 1991.

The BLM performed seven plant transects in June, 1991. Of the seven transects read, five had between 4 and 23 seeded plants per meter and two had no plants of seeded species. Vegetative success for this project is defined as 3 plants per square meter.

The site monitoring plan requires at least quarterly monitoring for two growing seasons after an area has been reclaimed and seeded. This will result in a staged release and closure of the plan.

Florida Canyon Mining, Inc. (FCMI), a subsidiary of Pegasus, received Nevada's Excellence in Reclamation award, for the reclamation completed at Relief Canyon. The award is sponsored by two federal and three state regulatory agencies and was presented at the Nevada Mining Association annual convention in September, 1991. The award recognizes FCMI for outstanding achievement in waste dump reclamation and for exceeding plan requirements.

Continuing Reclamation

The heaps and process area were idle for 1 year before reclamation was begun in September, 1991. Final reclamation for the area has included heap rinsing, general site clean-up, and equipment removal. The chemistry of the heap rinse solution is being monitored and soluble metals have been reduced through use of the carbon columns. The size of the lined pad area has allowed heap benches to be laid back and ripped for better rinsing. The reshaped heap slopes are at an angle of 3 : 1. Various disturbances around the process site have been shaped and scarified and will be seeded in early spring, 1992. Projected completion for all reclamation is October, 1993.

BIOLOGICAL WEED CONTROL IN HIGH ALTITUDE SITUATIONS

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ABSTRACT

Biological control is the utilization of living organisms to suppress the population of a pest to levels considered as tolerable to man. Conventional biocontrol of exotic weeds utilizes natural enemies from the native land to reestablish that balance of nature that maintains the density of the target pest in the native land as a mere member of the plant community. Approaches to biocontrol of native weeds are considerably more complex, utilizing augmented native bioagents.

Biocontrol of exotic weeds at high elevations must utilize those organisms that do well at high elevations in the native country, providing that conditions such as soil type and texture, aspect, vegetation complex, and climatic regimes are considered and possibly matched before releases are made.

The concept of "islands in the sky" may explain why some high elevation localities have native weed problems while other areas do not. This same concept provides a possible solution. Other aproaches may be dangerous.

(Paper not available)

Soil Conservation Service Projects Impacting High Altitude Revegetation

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ABSTRACT

Seven western Plant Material Centers (PMC's) conduct projects leading to new varieties and important technology for high elevation land reclamation. 'High Elevation' criteria differs for each PMC.

High altitude projects fall into the following categories 1) reclamation associated with mining, 2) critical areas associated with roads, recreation, urban buildup, 3) wildlife habitat/food, and 4) wetland/riparian developments. All categories impact water quality.

Many important native species have been identified. SCS collects seed/plants, selects through extensive testing, and develops production technology. Species candidates are selected based on priorities and potential for positive impact.

Soil Conservation Service (SCS) divides the U.S.A. into Major Land Resource Areas (MLRA's). Approximately 18 MLRA's deal with revegetation problems associated with high altitude sites. You can access this informational resource by knowing 1) the MLRA, and 2) the PMC servicing the MLRA covering your project.

An old program nemesis haunts the success of most new high altitude varieties. The market is generally specific and limited. Commercial production is not attractive, consequently reasonable priced products will not be readily available. The bottomline is this, without a strong market, high altitude species are confronted by an extremely specialized, restricted, commercial market.

INTRODUCTION

This presentation has two purposes. The first is to acquaint you with the types of high altitude projects conducted by the SCS Plant Materials Program. The second will guide you in obtaining information from SCS that correlates to your specific interests. Tables are used to capsulate the most important information for you.

The System and You:

The PMC's are strategically located throughout the west. Each has experience helpful to you.

You are invited to call upon our PM specialists, PMC managers and their staff for information about plants and reclamation technologies for your purpose (Table 1 and 1A).

You are extremely important to the success of the plant selection program. We know if you are knowledgeable about our species during the testing period you will contribute to the success or failure of the plant as a released variety.

Plant material activities in SCS are designed to provide a vegetative remedy for a defined conservation issue. An issue requiring plants is WATER QUALITY degradation from land disturbing activities in High Altitude environments. Many of you have suggested plant species with potential to solve the problem. You've helped us set priorities, make collections, and test the plants. We are grateful for your support and involvement.

SCS concludes the exercise by selecting and naming a superior variety, and making long term commitment to the product by providing seed for its commercial production.

Plants are selected for release based on their ability to perform, their environmental acceptability, and their economic importance. Sixty years of SCS experience in plant materials teaches us economics will rule the acceptance and success of any new variety.

Gene Pool Issues

SCS traditionally has explored the value of all plants with attributes contributing to the solution of a specific conservation problem. Today some conservation problems can be resolved only by utilizing very specific naturalized gene pools. Prime program benefits are directed at soil and water protection on private lands. So for most conservation issues we explore and screen all genetic sources for the most beneficial plants.

Accessing The Data

Correlation to Major Land Resource Areas

To correlate your project to SCS information I encourage you to key your sites and soils to the framework used by SCS. SCS uses Agriculture Handbook 296, titled "Land Resource Regions and Major Land Resource Areas of the United States." This handbook, in limited supply, is the only source providing descriptions for each MLRA (Land Resources 1981). An updated map with abbreviated descriptions is more readily available. If you have difficulty obtaining the information you need please request a copy from me.

The MLRA is a broad brush concept grouping similar environments, soils, and vegetation with brief discussions of each component. Its not important whether you agree with the MLRA concept, what is important is that your project be identified with one of the MLRA's and the PMC or PMC's servicing the MLRA. This information allows you to correlate your project to the documented SCS projects.

It is important to communicate in similar terms taxonomically. SCS utilizes PLANTS DATABASE and its list of accepted names in an effort to unify the system (PLANTS 1992).

High Altitude Projects

There's a multitude of SCS projects complimenting high altitude revegetation from Colorado to California, and New Mexico to Alaska. They are primarily listed in Table 2 and Table 3 (Bridger PMC 1991 [2], Corvallis PMC 1991, Lockeford PMC 1991, Meeker UCEPC 1991 [2]).

TABLE 1. USDA, Soil Conservation Service Funded Plant Material Centers servicing High Altitude sites in designated Major Land Resource Areas (MLRA) and related National Parks.

Plant Material Center	*MLRA's
Upper Colorado Environmental Plant Center Attn: PMC Manager Box 448 Meeker, Colorado 81641	48A, 48B,49, 51 National Parks Rocky Mountain Grand Teton
Los Lunas Plant Material Center Attn: PMC Manager 1036 Miller Street, SW Los Lunas, NM 87031	48A, 51 National Parks Grand Canyon
Montana (Bridger) Plant Material Center Attn: PMC Manager Route 1, Box 1189 Bridger, MT 59014-9718	43, 44, 46 National Parks Glacier Yellowstone
Idaho (Aberdeen) Plant Material Center Attn: PMC Manager P.O. Box AA 1693 South 2700 West Aberdeen, ID 83210	12,13,43,44,47
Oregon (Corvallis) Plant Material Center Attn: PMC Manager 3415 NE Granger Avenue Corvallis, OR 97330	1, 3, 6 National Parks Crater Lake Mount Rainier
Alaska Plant Material Center Attn: PMC Manager HC 02 Box 7440 Palmer, AK 99645	Multiple MLRA's Major Regions Arctic West Alaska Interior
California (Lockeford) Plant Material Center Attn: PMC Manager P.O. Box 68 21001 N. Elliott Road Lockeford, CA 95237	22 National Parks Yosemite

*MLRA definition
(1) Northern Pacific Coast Range, Foothills, and Valleys
(3) Olympic and Cascade Mountains, Western Slope
(6) Cascade Mountains,, Eastern Slope
(12) Lost River Valleys and Mountains
(13) Eastern Idaho Plateaus
(22) Sierra Nevada Range
(43) Northern Rocky Mountains
(44) Northern Rocky Mountain Valleys
(46) Northern Rocky Mountain Foothills
(47) Wasatch and Uinta Mountains
(48A) Southern Rocky Mountains
(48B) Southern Rocky Mountain Parks
(49) Southern Rocky Mountain Foothills
(51) High Intermountain Valleys

TABLE 1A. USDA, Soil Conservation Service Plant Material Specialists and the states they serve as of March 4, 1992.

ALASKA	Calvin Miller 201 East 9th Avenue, Suite 300 Anchorage, AK 99501-3687 Phone 907-271-2424
CALIFORNIA	Robert D. Slayback 2121-C 2nd Street Davis, CA 95616-5475 Phone 916-449-2857
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TABLE 2. List of high altitude related species being studied, reproduced,(1) in blocks producing from a few ounces to hundreds of pounds, or (2) as live plants.

Names used are found in the USDA Soil Conservation Service PLANTS DATABASE, Jan. 16, 1992.

Genus	species
Acer	circinatum
Achillea	millefolium
Agrostis	exarta
Agrostis	variabilis
Agrostis	scabra
Alnus	sinuata
Anaphalis	margaritacea
Antennaria	alpina
Arnica	cordifolia
Arnica	latifolia
Artemisia	arbuscula
Artemisia	tridentata
Aster	laevis
Blepharoneuron	tricholepis
Bromus	marginatus
Bromus	vulgaris
Calamagrostis	breweri
Calamagrostis	canadensis
Carex	aperta
Carex	exserta
Carex	haydeniana
Carex	mariposana
Carex	microptera
Carex	phaeocephala
Carex	rossii
Carex	spectabilis
Carex	straminiformis
Carex	utriculata
Danthonia	intermedia
Deschampsia	atropurpurea
Deschampsia	cespitosa
Elymus	elymoides
Elymus	glaucus
Elymus	trachycaulus (Ag. trachycaulum)
Epilobium	alpinum
Erigeron	peregrinus
Eriogonum	umbellatum
Erythronium	grandiflorum
Fagopyrum	jamesii (species not in PLANTS)
Festuca	viridula
Geranium	viscosissimum
Juncus	mertensianus
Juncus	parryi

Table 2 continued

Genus	species
Lupinus	argenteus
Lupinus	confertus
Lupinus	covillei
Lupinus	grayi
Lupinus	latifolius
Lupinus	lyallii
Luzula	hitchcockii
Melica	spectabilis
Muhlenbergia	montana
Oryzopsis	kingii
Oxyria	digyna
Penstemon	fruticosus
Phacelia	hastata
Phacelia	sericea
Phleum	alpinum
Poa	alpina
Poa	cusickii
Poa	gracillima
Poa	nervosa
Poa	pattersonii
Populus	tremula
Pseudoroegneria	spicata (Ag. spicatum)
Purshia	tridentata
Ribes	lacustre
Ribes	montigenum
Rubus	idaeus
Secale	cereale
Sibbaldia	procumbens
Shepherdia	canadensis
Solidago	multiradiata
Stipa	viridula

TABLE 3. Projects carried out by Plant Material Centers dealing with complexities of High Altitude revegetation and associated environmental problems.

NEW MEXICO

Molycorp-Evaluate molybdenum concentrations and copper/molybdenum ratios in above ground parts of native plant species used to revegetate molybdenum tailings.

Assist the New Mexico Highway and Transportation Department in establishing and maintenance of roadside vegetation in order to prevent erosion.

Pegasus 1-Stabilize waste rock dump using coniferous tree species native to the site in order to reduce the visual impact of disturbed land surrounded by pinyon-juniper woodland. Accelerate growth of trees using drip irrigation with soluble nutrients.

Pegasus 2-Evaluate whether constructed wetlands can be used to degrade cyanide and nitrate in waste waters from gold mining operations.

Cold soil cover crops for agricultural cropping systems and erosion control on critical areas (both Colorado and New Mexico).

COLORADO

Grand Teton National Park-Seed and plant production of species for roadside revegetation.

Rocky Mountain National Park-Seed and plant production of species for roadside revegetation.

In cooperation with the Colorado Mined Land Reclamation Division.

1. Revegetation of abandoned coal mined land and graded overburden near Steamboat/Milner.

2. Riparian area recovery on abandoned mined land near Steamboat/Milner.

3. Development and vegetation of a wetland system designed to modify low pH water and remove heavy metals near Carbondale.

4. Forb and shrub establishment at Colowyo Coal site near Meeker.

Maintain foundation seed for releases of 1) 'Peru Creek' tufted hairgrass, and 2) 'Summit' louisiana sage.

TABLE 3. Continued

MONTANA

Glacier National Park-Seed and plant production for road revegetation.

Yellowstone National Park-Seed and plant production for road revegetation.

IDAHO

Field plantings to resolve problems on mines, ski slopes, and road cuts.

CALIFORNIA

Yosemite National Park-Trail, campsites, critical area and roadside revegetation.

Lake Tahoe-Wetland revegetation.

WASHINGTON/OREGON

Crater Lake National Park-Seed production for revegetation of roadsides, clearcuts, and burns.

Mount Rainier-Seed production for revegetation of roadsides, clearcuts and burns.

Field trials for acid soils, nutrient uptake, wetlands, and drawdown zones.

Tables 1 and 1A list A) PMC's with their exact locations enabling you to contact them directly, B) MLRA's, and their brief definitions for each PMC, and C) National Parks with plant material projects conducted by each PMC.

As you can see in reviewing Table 2, many of your "wish list species for high altitudes" are being explored in detail through the SCS cooperative agreement with the National Park Service (NPS). Mr. Wendell Hassell, an active member with this High Altitude Committee and now Plant Materials Technical Advisor to the NPS, provided some insight into the NPS/SCS projects. Mr. Hassell says "this activity targets the development of park indigenous plants for revegetation in the park. Preservation of native plants within their natural ecosystem is a high priority in the NPS. NPS recognizes that historical and cultural landscapes are important and worth protecting."

"NPS is confronted with the need to restore acceptable vegetation on damaged meadows, lake shores, along roads, campsites, and on construction sites. Cooperative plant material projects have primarily focused on road related revegetation work. Twenty nine projects have been developed nationally in this cooperative program. An estimated 150 park indigenous ecotypes have been collected and are now in the process of being reproduced and conditioned for use on park projects."

The cooperative effort explores the values of new species and develops essential technologies for their successful use. The agencies are working on an agreement to make these public land originating ecotypes available for inclusion in the plant material testing program.

Each PMC carries out a multitude of formal and informal projects. Not listed in Table 3 are trials to determine the plants area of adaptation, phenology, seed collection, establishment, seed culture, seed production, live plant production, seed conditioning, germinations, storage, and effective use. This information is available through individual PMC technical reports. Table 3 lists formal projects carried out by PMC's dealing with the complexities of high altitude revegetation and the associated environmental problems (Los Lunas PMC, 1991).

Details of these projects for each state can be provided by directly contacting the SCS personnel.

CONCLUSION

SCS has more detailed information about high altitude adapted species than ever before (Table 2 and 3). A few varieties are now in commercial production and available. Identify your resource information within a specific MLRA and inquire with the correct state and plant materials personnel listed in Table 1 and 1A.

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THE GALLOPING FORESTER'S COOKBOOK
RECIPE FOR VEGETATIVE PROPAGATION

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ABSTRACT

Vegetative propagation can be a very easy and inexpensive way to obtain woody plants for revegetation projects, particularly for wetland sites. It allows the selection of the most vigorous and site specific plants and ready availability of species not commonly found on a commercial basis.

Planning is important as it can take upwards of two growing seasons to obtain and prepare sufficient cuttings for use. Planting site evaluation is critical as it will dictate the success of uprooted cuttings and dictate alternative propagation techniques.

A simple cookbook method is described for the most readily rooted species of plants.

Vegetative propagation can be a simple and efficient method of growing woody plants for revegetation projects. All the grower is doing is exposing stem, root, or leaf tissue to favorable growing conditions which induces the development of shoots and roots.

The advantages for revegetation projects are the minimal use of space, can be done on site, it's quick and simple to do, and is very inexpensive.

In addition, it can increase the use of lesser known native willow and poplar species, and collections can be made from sources in the immediate area.

While there are several different types of vegetative propagation, this presentation will focus on hardwood stem cuttings with a short discussion on root cuttings.

Hardwood stem cuttings are taken from the wood of the previous seasons growth. These cuttings can be collected after the parent plant has lost its leaves in the fall or early spring. Depending on the situation, you can spend time locating source stock in the field or cultivate your needs from a few individual plants (stooling blocks). While it's always fun to get away from the office, a lot of time can be needlessly spent locating an adequate amount of material to propagate.

To keep this simple, the stooling block method is preferred. This is accomplished by cutting down five to six or more mature specimens in the spring before bud break. This removal of the parent stem forces the development of root suckers. These suckers can then be collected the coming fall season and planted the next spring.

The big advantage here is that it allows you to select specific plants at a known location and have a large number of sprouts available for use. Once the sprouts are collected, they can be cut into lengths, commonly referred to as "sticks".

These sticks can be anywhere from four (4) to thirty (30) inches long, and one-quarter inch (1/4") to one (1) inch in diameter. The tips of sprouts should not be used and discarded. The central and basal parts are best.

The most common length is six (6) to eight (8) inches long. In any event, make the sticks a convenient size. This will be dictated by the soil texture of the planting site (ease of planting) and depth to water. Unless supplemental watering is going to occur, it is critical to keep the sticks moist until roots develop.

The cuts for the sticks should be made two ways, the basal portion should be cut at a slight angle and made just below a node. The angle serves as a point to ease the planting. The node, the point where buds originate, is the area where root development will occur. The sticks can then be bundled and stored in dark, cool, moist conditions till spring. This can be done either indoors in a refrigerator or outdoors in the ground. If indoors, I recommend one of the old units that does not have the frost free improvements. Temperature should be kept at 32-40• F.

The sticks should be packed in a box with moist sawdust or a combination of 2 parts sand to 1 part peat moss. This will allow you to keep the sticks moist, yet well drained to prevent fungal buildup. The bundles may be placed horizontally or vertically.

The sticks can also be buried in a small pit outdoors. Again, use a well drained backfill mix such as the two described above. However, the bundles should be placed upside down, several inches below the soil surface. Placing the basal end closer to surface promotes root initiation at the base and retards bud development at the tip. Water as needed to keep the area moist, not allowing the wood sticks to dry out.

Finally, plastic bags can be used to store the cut sticks. Again, keep the temperature down, moisture up and light down. Because of the lack of aeration in the bag, the loss to fungi can be high. In any event, it takes about two months for the cuttings to differentiate stem tissue to root tissue.

The rooting hormone, indolebutyric acid or IBA, may be used to speed up the differentiation process, but is not necessary. The poplars respond to this treatment much more than the willows. Once spring arrives, the individual sticks may be planted. Just push them into the ground, points first, leaving one bud just above the surface. They may be spaced as close as 3-4 inches.

If there is no water available to keep the individual sticks moist, survival will be low. The cutting once planted, starts to develop and extend out actual roots. This is the most critical period for moisture, so plan a backup watering system.

In addition, preventative fungal treatment may be wise. Benomyl, at a 3 ounce-50 gallon mixture can be used as a dip treatment just prior to planting. After planting, it is necessary to maintain adequate soil moisture so the cuttings can become established. In some cases, removing competing vegetation may be all that is needed. Because of the succulent tissue and the unpredictable explosions of bugs, insects, and disease, control may be needed.

Root cuttings are very similar to stem cuttings. Obviously, it is much more labor intensive and material in some cases cannot be easily gathered. But, if a lot of earthwork or site disturbance is being done, a large number of roots may be available for propagation. Obviously the reclamation team needs to coordinate closely with the site development so as to capture this resource.

In addition, root cuttings allow propagation of some species that do not propagate well as stem cuttings, such as trembling aspen.

Again, younger plants are the desired source for root cuttings. They can be collected in winter or early spring. Storage conditions remain the same. The big difference is in preparation, as the root cutting cannot be planted upside down. To avoid this, the proximal end (the end nearest the crown) receives a straight cut. The distal end (furthest from the crown) receives an angled or pointed cut. The cutting is planted vertically or may be planted horizontally, one to two inches deep. Post planting maintenance is identical to stem cuttings.

Again, propagation of plants through vegetative cuttings should not be overlooked in preparing a revegetation plan. Due to its ease, with a little preplanning, it can become a large source for planting stock in reclamation efforts.

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THE EROSION CONTROL INDUSTRY - A LOOK AT ITS PAST, PRESENT AND FUTURE

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ABSTRACT

Erosion control started centuries ago primarily as a component of agricultural techniques. It remained mostly an agricultural oriented practice until the 20th century, when other land disturbing activities created a need for preventing soil and wind erosion. The last 30 years have seen the development of specialized products, methods and research that have focused on ways to prevent erosion as well as to control sediment, the major product of erosion. Erosion costs society in many ways. From the loss of productive soils to the premature filling of reservoirs, development tends to accelerate natural erosion rates and create numerous environmental problems. Today, in addition to the technological advances in the erosion control industry, regulatory programs, from federal agencies down to the municipal level, are increasing to help reduce environmental degradation caused by erosion and sediment transport. In addition to the progress being made on the technological and regulatory fronts, the erosion control industry is currently preparing standards for product performance which will give professionals better tools for the design and evaluation of erosion and sediment control measures.

INTRODUCTION

Erosion and high altitude revegetation are directly related, since revegetation is a key component to controlling erosion on disturbed sites. Many of the Western U.S. river systems begin at high elevations where water quality is usually quite good. However, if sediment from erosion enters waterways at high elevations, it can pose a variety of problems throughout the course of the stream or river including deposition, impaired water quality, habitat damage and flooding.

Erosion control is the best prevention for the impacts of off site sediment transport. Keeping sediment on site and controlling erosion at the heart of the disturbance can dramatically reduce the amount of sediment entering our waterways. Regardless of elevation, the impacts of erosion and sediment transport can have serious consequences.

EROSION CONTROL DATELINE

As an industry, erosion control has its roots in agriculture. One of the earliest forms of water control (and therefore erosion control) was the construction of terraces to harvest and collect water necessary for the production of crops such as rice. Terraces have been used in most continents as agriculture developed and vestiges of ancient terraces can be seen in southwestern U.S. in areas once occupied by the Anasazi Indians.

Much of the technological and cultural advancements in erosion control has occurred in the past 100 years. During this time, agricultural equipment has improved dramatically, offering farmers better tools with which to cultivate the land. Along with better equipment, agricultural practices such as crop rotations, strip planting and contour planting have helped in reducing the amount of soil lost to wind and water erosion.

In the late 1950's and early 1960's, the first erosion control products made their appearance. One of the first products, used in 1958, was a plastic "cloth" (known today as a geotextile) which served as a separating layer underneath shoreline rip rap (Richardson and Koerner, 1990). By preventing wave action from washing away soil upon which the rip rap was placed, the cloth effectively prevented undermining of the rip rap and kept the shoreline from eroding. Several years later, a state soil conservationist discovered that the material used for baling cotton, jute, could be draped over bare ground and reduce soil loss from rainfall. With an open mesh construction, the jute checked the movement of soil while permitting vegetation to establish. About the same time, another product made of wood fibers (excelsior) was introduced as an erosion control blanket. Another product developed in this early era was wood fiber mulch used for hydraulic mulching applications.

In 1965, W.H. Wischmeier of the USDA Agricultural Research Service in conjunction with Purdue University developed the Universal Soil Loss Equation (USLE) (SCSA, 1977). This mathematical model gave researchers and conservationists the first tool with which to evaluate and predict soil loss. Based on a combination of site factors, the USLE is still used to assess erosion potential.

The USDA Soil Conservation Service, in 1977, compiled the first erosion assessment of cropland in the U.S. The study placed the rate of excessive erosion from cropland at 1.7 billion tons/year (USDA SCS, 1977). Therefore, it has only been in the last 15 years that we have even had a baseline of erosion rates from which to assess our current situation. It has also been within the past 15 years that erosion and sediment control has developed as a distinct and viable industry. While accurate figures are difficult to come by, the sales of erosion control products and services represents an estimated $ 500 - 750 million per year. Over 200 products now exist and more appear each year.

What benefits does an industry provide? Several positive values can be associated with an industry. First is the awareness of a given cultural problem or need. The erosion control industry has developed in response to the need for soil conservation. With the growth of the industry has come a greater recognition, by the general public, of the impacts of erosion. The industry has also supported and sought research - notably product testing and evaluation. With the growth of the erosion control industry comes opportunities for new business ventures. Trade associations and their publications highlight the current technology and offer business incentives for the entrepreneur and established companies looking for expansion opportunities.

A significant, but less tangible, benefit from an industry is the development of an ethic that can be promoted throughout its constituents. In the case of erosion control, it is hoped that the ethic of responsible environmental stewardship can become a common pursuit of those within the industry.

THE SCOPE OF EROSION

Is erosion good or bad? On the good side, erosion has produced some of the world's natural wonders, producing the economic benefits associated with tourism. Sediment, the product of erosion, when deposited on floodplains has always contributed to the fertile and productive agricultural lands associated with floodplains.

More often than not, however, erosion is viewed as a problem, not a benefit. It should be noted that erosion is a natural process that has been operating since land was formed. And society should not expect to completely control *natural* erosion. It is a dynamic component of any ecosystem. However, *accelerated* erosion, usually caused by man's activities, is a concern. Accelerated erosion puts unnecessary strains on our air and water resources, reduces our ability to produce food and costs society in numerous ways.

The amount of worldwide erosion occurring each year is staggering. The Worldwatch Institute has placed the annual rate of soil erosion at approximately 25 billion tons (Brown and Wolf, 1984). This rate is based on soil loss from croplands and does not include soil from construction, forestry, mining or other industrial activities. In the U.S., the most recent Natural Resources Inventory, conducted in 1982 and administered by the USDA Soil Conservation, places the rate of erosion from cropland at nearly 3 billion tons/year (USDA SCS, 1982). If erosion from other non-agricultural sources is included, the annual rate of erosion in the U.S. probably exceeds 3 billion tons/year.

What are the sources of erosion? Agriculture accounts for roughly 60% - 70% of the annual soil loss, which is not surprising, since agriculture is the major land disturbing industry in the U.S. and most other countries as well. The next category of erosion is associated with construction and urban runoff, accounting for about 15% of the erosion "pie." Mining and forestry combined may contribute 10%.

CONSEQUENCES OF EROSION - THE COSTS TO SOCIETY

The costs of erosion are usually not well perceived by society. One reason is that soil loss is typically a gradual process, with the consequences not appearing soon in time, or close in geography. Regardless of perceptions, erosion has definite costs, both economic and ecological to all societies.

Perhaps the most obvious consequence of erosion is the loss of soil. Losing soil reduces biological diversity, not just from the organisms found within the soil but also from the plant and animal life the soil supports. Simply, the loss of soil leads to the loss of biological diversity - a serious ecological impact.

With the loss of soil comes a reduction in the capacity to produce food. Even if there is a soil material left after erosion has occurred, this "soil" requires increased inputs to produce the same amount of food, typically in the form of greater amounts of fertilizer, water and other amendments. Given the exponentially growing world population, the additional strain of less soil to produce more food will continue to place a great burden on societies, and unfortunately, most of the burden will be borne by those countries who can least afford it.

Another consequence of erosion is the degradation of water quality. The "by-product" of erosion is sediment. Sediment is classified as a pollutant by the U.S. Environmental Protection Agency (EPA). In fact, sediment accounts for more than 2/3 of all pollutants entering the U.S.'s water systems. Not only is sediment alone a pollutant, but it serves as a carrier for harmful and toxic chemicals that enter waterways. The EPA estimates that erosion related pollutants cost the U.S. from $ 3 - $ 13 billion annually (U.S. EPA, 1985).

Wildlife habitat is also adversely affected by sediment. Increased sediment loads in lakes leads to increased turbidity which reduces photosynthesis activity in aquatic plants, which impacts associated animal life. Siltation destroys breeding habitat for fish and fowl as well.

A third important consequence of erosion is the loss of water as a resource. Sediment finds its way into streams and rivers, which when slowed by reservoirs deposit their silt loads. Siltation has serious impacts. Economically, for example, the U.S. spends $ 500 million a year for removing sediments from harbors and waterways (U.S. EPA, 1985). Dredging of the lower Mississippi continues to be one of the U.S. Corps of Engineers largest budget items (Brown and Wolf, 1984).

Though difficult to measure in dollars, siltation of reservoirs has numerous other serious consequences. First, as a reservoir fills up, less water can be stored. This in turn reduces the capacity for flood control, reduces the water available for irrigation and may impact wildlife habitat. Siltation of reservoirs also reduces recreational opportunities. Should a reservoir fill up completely, the unique site for the reservoir is lost. Given the fact that dams can be built in only so many places, this is a consequence often overlooked.

INCENTIVES FOR EROSION CONTROL

The desire to control erosion stems from a variety of reasons. Optimally, it would be best if people were conscious enough of the consequences of erosion to undertake control measures on their own. Unfortunately, this is an uncommon approach and today's incentives for erosion control are based on monetary or regulatory principles, not those of ecologically wise land use.

And to this end, we have regulations - laws that force us to practice responsible stewardship with our soil resources. In 1972, the U.S. federal government established the Clean Water Act, legislation intended primarily to reduce pollution from concentrated or "point" sources. Compliance with the Clean Water Act did significantly lower pollution rates from point sources. However, by the early 1980's, data showed that, while point source pollution was declining, pollution from other sources was not subsiding. The other sources became known as "non-point" sources.

In 1987, Congress enacted the Water Quality Act to address the pollution arising from non-point sources. Non-point sources include urban runoff, agricultural practices, construction activities, mining and atmospheric fallout of dust and other particulates. Sediment accounts for 60% - 80% of the non-point source pollution. Currently, implementation of the National Pollutant Discharge Elimination System permit program, as administered by the U.S. Environmental Protection Agency, has many municipalities scurrying to develop erosion and sediment control plans or face stiff federal fines.

At the state level, there are an increasing number of ordinances and enforcement policies aimed at controlling erosion on site and protecting the state's water resources. Michigan, Georgia, Maryland and South Carolina are examples of states who have developed erosion and sediment control regulations (sometimes called stormwater management) that are being applied to a growing list of land disturbing activities. And where state laws do not exist, some communities are developing their own ordinances as environmental and development issues continue to conflict.

One incentive for erosion control, therefore, is the regulatory incentive - there is a law and a consequence for not complying with the law. And it is this incentive that most people will respond to. Less obvious incentives, though, exist and may offer a greater impetus for developing erosion control as part of any land management policy.

The damage or loss of property as a result of erosion or sedimentation opens the door to a favorite American recourse - lawsuits. The off site impacts of sediment laden water silting in a privately owned pond or lake have resulted in numerous lawsuits to compensate the affected party for the neglect of the developer to keep sediment on site. Alterations of the movement of off shore sand from the construction of jettys, dikes, weirs and wall, though done with good intentions, has caused a variety of beach problems for areas like Florida. With the natural nourishment of beach sand interrupted by man made structures, high energy storms often scour beach front property, removing the precious sand and even destroying or threatening homes, hotels and other high value buildings. It has been reported that replenishing beach sand along the Florida coast can cost upwards of $ 1 million per mile (IECA, 1991). Property protection, therefore, is another incentive for erosion control.

An incentive that is difficult to appreciate but has worldwide implications is the need to support our societies. With the world population presently at 5 billion people, another billion could be added in less than a dozen years, if the current growth rates continue. Less land is available to support more and more people. The issue of protecting our limited soil resources to produce food for the world's societies is not a complex one. Developing effective policies to insure conservation of our soil is a complex issue. Nevertheless, this should be viewed, ultimately, as our most important incentive for controlling erosion.

WAYS TO CONTROL EROSION

Erosion control is simple in concept - keep soil where it is by preventing the forces of water and wind from transporting away. And the measures available to implement effective erosion control are relatively simple as well. The challenge lies in developing a society that understands these concepts, accepts them and acts to implement them.

Basically, erosion is controlled by either vegetative or non-vegetative means. Vegetation has long been the key component of successful erosion control works, providing a long term, flexible system to hold soil in place. Where vegetation is not strong enough to resist the forces of erosion, structural components and other non-living materials may be required.

The erosion control industry offers the greatest variety of techniques and products yet known to society. Natural products to protect the soil range from mulches made of straw, hay, wood fiber, recycled paper to tackifiers made of glue-like solutions to blankets and mats made of straw, jute, paper and coconut. Synthetic products abound and are used for filtering sediment (silt fences), stabilizing slopes (geogrids and cellular confinement systems) and reinforcing vegetation (turf reinforcement mats). Relatively new to the U.S. but used extensively in Europe are a variety of biotechniques that utilize a combination of living plant material and structural elements such as retaining walls and geotextiles to control erosion and stabilize soil. Agricultural practices such as conservation tillage (planting a new crop in the previous years' stubble), grassed waterways and buffer strips have made a significant impact in reducing the amount of soil lost from farmlands.

The tools exist to control erosion. Actually, the technology is far ahead of the perceived need for erosion and sediment control. The challenge is to develop a sense of "soil stewardship" that can fully utilize the technology, both low and high tech, that is currently available.

THE FUTURE OF THE EROSION CONTROL INDUSTRY

The erosion control industry will see increasing growth in the future for a number of reasons. First, government regulations, state programs and local ordinances will continue to force developers, farmers, construction and mining companies and a host of others to make erosion control an integral part of site development activities. Without the threat of monetary penalties and/or project closure, erosion control will probably not work on a strictly voluntary basis, at least not for the immediate future. Therefore, look for a continued presence of government involvement to insure protection of our soil resources.

Secondly, continued advancements in the development of product technology as well as the refinement of current methods will produce a wealth of tools to deal with erosion related problems. For example, the ability to trace sediments to their source by "magnetic fingerprinting" may help identify sediment production zones, and, thereby, offer target areas for remedial action. The development and propagation of new varieties of plant material is already producing erosion control benefits and is particularly helpful in developing countries who cannot afford expensive erosion control treatments. Vetiver grass is one example of a plant that has great utility for controlling erosion in tropical and subtropical areas (IECA, 1992). Vetiver grass tolerates drought well, develops extensive roots systems and persists under a wide range of environmental conditions.

The erosion control industry will gain greater recognition in the future as a result of continued specialization by professionals in this field. Programs such as the Certified Professional Soil and Erosion Control (CPESC) specialist program will offer credibility and cohesiveness to a somewhat diffuse group. Sponsored by the Soil and Water Conservation Society, the American Society of Agronomy and the International Erosion Control Association, the CPESC program offers erosion control professionals a means to establish their proficiency in the field of erosion and sediment control. As municipalities and other industries confront an ever growing array of erosion/sediment control regulations, people with the CPESC designation will continue to play a greater role in the development, implementation and enforcement of erosion control programs.

Another future trend for the industry is the establishment of standards. The specifier or engineer using specialized erosion control products today has little concrete information to use for accurately selecting a product based on composition or performance. Without a standardized set of criteria, based on construction and/or performance, consistency and reliability from the product side of the industry will be difficult to achieve. The International Erosion Control Association is pursuing the development of standards which will apply initially to a basic core of erosion control products and will expand in time to cover a broad spectrum of products. Ultimately, the goal is to establish standards which can help specifiers design by how products actually perform rather than how they are made.

The use of specialized erosion control nomenclature and symbols will develop in the future. Without a "language" specific to the industry, communication will continue to be awkward and incomplete. Development of an international set of engineering symbols, for example, can help all erosion control professionals recognize specific treatments, products and applications regardless of the origin of the erosion control plans or documents.

The erosion control industry has a bright future ahead. Environmental awareness is growing, although for more political and newsworthy reasons such as toxic spills, radioactive accidents, and ozone concerns, than for the concern over losing our soil. Nevertheless, people in all countries are beginning to realize that man's impacts are serious and life threatening. Erosion control is one small component of our environmental responsibility. But it is an important one - without it we lose ecological stability, resilience and the ability to feed ourselves.

If we suddenly lost our oil reserves, or our automobiles, or our medicines, the world would pay immediate attention to these crises. We are losing soil, gradually and steadily. It will be a crisis and a significant one, someday. The erosion control industry can help avoid this crisis. Through education, action and political cooperation, the industry can help focus societies on the problems of erosion and the solutions available. And if the world's societies someday view erosion control as a necessity, rather than a compliance, then the erosion control industry will have played its best role in the world game of environmental action.

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COMPARATIVE EVALUATION OF EROSION CONTROL PRODUCTS

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ABSTRACT

Many erosion control products have been developed which have proven to be successful in controlling sediment. What is not readily available is information concerning their long term durability, applicability in a semi-arid environment, ability to assist with dry land grass establishment without irrigation, and so forth. In order to evaluate product potential limitations, over 40 erosion control materials were tested in the semi-arid environment of Parker, Colorado including hydraulic mulches, organic blankets, tackiness and synthetic mats. Sediment was collected from plots having 3:1, 2:1 and 1.5:1 slopes and statistically compared to product parameters. Biomass production from slopes having an easterly and westerly aspect were evaluated and also compared statistically to product parameters. It was concluded that as long products do not fail, they appear to reduce sediment from steep slopes at least 96%. In addition, product thickness appears to be important for controlling sediment. Finally, biomass production varies with slope aspect and appears to be impacted by product thickness and product color.

INTRODUCTION

Since 1987, HydroDynamics Incorporated (HDI) has tested erosion products in the semi-arid environment of Parker, Colorado on land owned by the Parker Water and Sanitation District (see Fifield et al., 1988, 1989 and 1990). This paper presents an analysis of data collected and provides results of statistical evaluations as to why products reduce erosion and assist with dry land grass establishment without irrigation. Finally, results are presented identifying which product parameters appear to be best in controlling sediment and assisting in establishment of dry land grass without irrigation.

EVALUATING SEDIMENT CONTROL PROPERTIES

Thirty two erosion control products were tested on 3:1, 2:1 and 1.5:1 slopes to evaluate their ability for controlling sediment. All testing was completed during the growing season of May to September with three products having data collected during the snow melt season. Dimensions and aspects of the test plots are identified in Table 1.

Table 1. Test Plot Dimensions and Aspects for Different Slopes

Slope	Width	Length	Aspect
3:1	3.0 m (10 ft)	9.1 m (30 ft)	Easterly
2:1	3.0 m (10 ft)	12.2 m (40 ft)	Easterly
1.5:1	3.0 m (10 ft)	7.6 m (25 ft)	Westerly

A collection system captured runoff at the downstream end of each plot. Captured runoff then entered an 18 gallon "sludge" bucket placed within a 250 gallon overflow tank, both of which were calibrated for volume. In this manner, sediment-laden water samples were collected after each significant rainfall event. Additional information on the collection system and how sediment samples were obtained can be found in Fifield et al. (1988).

Erosion Control Products Tested

Table 2 identifies erosion control products tested in Parker, Colorado since 1987. Detailed statistical analysis of product parameters can be found in Fifield and Malnor (1990). Figure 1 illustrates a summary of their findings on how natural products and tackifiers control sediment from the test plots. Figure 2 illustrates how natural products and tackifiers impact runoff from the plots. Finally, Figure 3 illustrates how effective geotextile products were for controlling sediment and runoff.

Based upon evaluation of the above referenced figures, as well as a statistical evaluation of product parameters, the following were observed concerning erosion control products.

1. When erosion control products were installed by May 15, sediment yield appear to be reduced by at least 96% when compared to bare ground conditions.
2. When an erosion control product reduces runoff, it appears sediment yield is reduced.
3. For natural products and tackifiers, sediment yield appears to increase as volume density increases. However, increasing the product thickness may decrease sediment yield.
4. Increasing the areal density of a geotextile material appears to reduce sediment yield.
5. Increasing the product thickness and volume density of a geotextile material may reduce sediment yield.

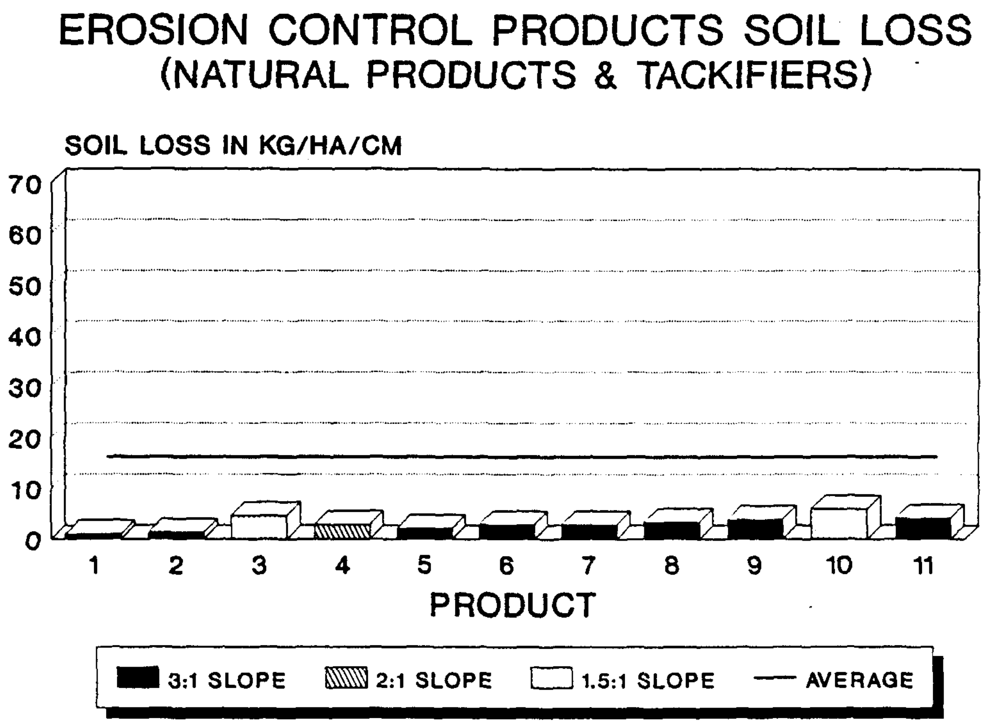
DRY LAND GRASS ESTABLISHMENT WITHOUT IRRIGATION

One of the most important aspects of using erosion control products lies with their ability to assist with dry land grass establishment with no irrigation. If erosion control products are to be successfully used in a semi-arid climate, they must meet two fundamental criteria. First, they have to retain their integrity and continue to

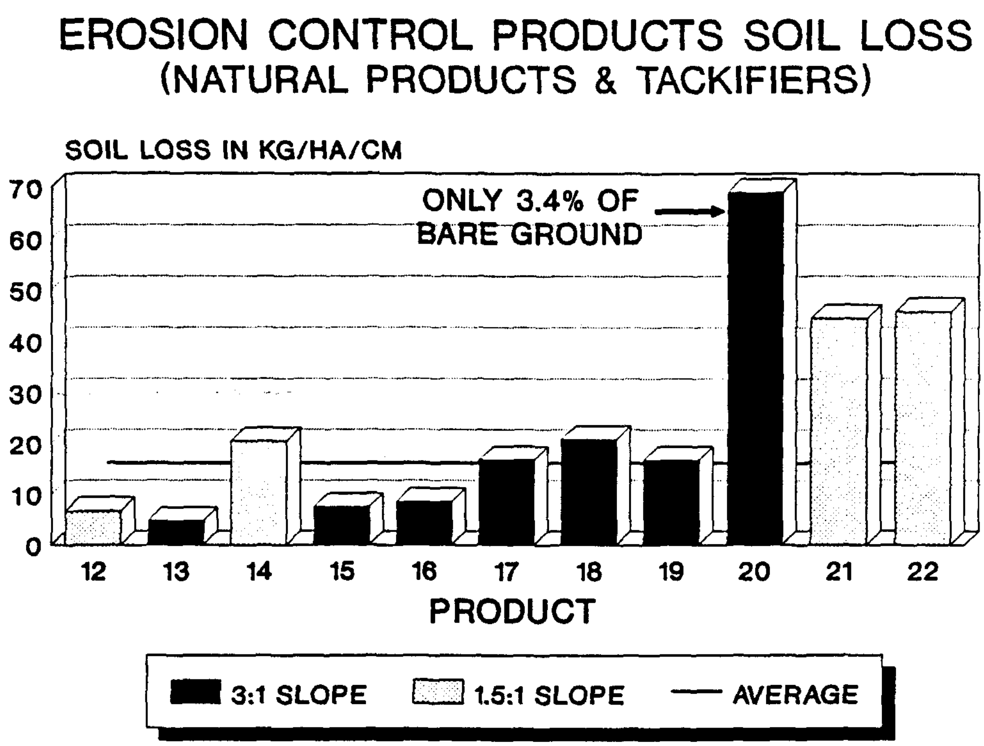
Table 2. Erosion Control Products Tested During 1987 through 1989.

PLOT NUMBER	COMPANY AND PRODUCT	YEAR TESTED	SLOPE	AVERAGE SEDIMENT KG/HA/CM	AVERAGE RUNOFF CU-M/HA/CM
NATURAL PRODUCTS AND TACKIFIERS					
1	N. Amer Green-S150	1987	3:1	1.28	1.12
2	N. Amer Green-C125	1987	3:1	1.68	1.07
3	U.S. Gypsum-AIRTROL	1989	2:1	5.87	1.47
4	Belton-COIR DEKOWE 900	1988	1.5:1	3.53	1.71
5	N. Amer Green-SC150	1987	3:1	2.60	2.35
6	Henry Boot-BEMNET	1987	3:1	3.53	1.22
7	PROSEED-BIOFABRIC	1987	3:1	3.53	1.30
8	Soil Saver-Jute	1987	3:1	4.24	1.18
9	ESSI-SM WR:1 T/AC HAY	1987	3:1	4.85	2.60
10	ESSI-SM WR:2 T/AC HAY	1988	1.5:1	7.41	3.40
11	ESSI-SM WR:2 T/AC HAY	1987	3:1	5.16	4.86
12	Belton-Jute	1988	1.5:1	8.43	2.85
13	PNG-Wood Hyd Mulch	1987	3:1	5.96	3.77
14	PNG-Wood Excelsior	1989	1.5:1	25.7	4.27
15	PNG-Wood Hyd Mulch/Tack	1987	3:1	9.49	3.66
16	Cellin-Paper Hyd Mulch	1987	3:1	10.7	1.85
17	Est. Dry Land Grass	1989	3:1	21.1	2.34
18	Terravest-801K/BIOSOL	1988	3:1	26.1	1.94
19	Est. Dry Land Grass	1988	3:1	21.1	3.44
20	Terravest-801K/BIOSOL	1989	3:1	86.7	5.09
21	Generic Wood Hyd Mulch	1988	1.5:1	55.9	5.14
22	Generic Paper Hyd Mulch	1988	1.5:1	57.6	5.14
GEOTEXTILE PRODUCTS					
1	HOECHST-Trevira, No Slits	1987	3:1	2.65	3.06
2	Delaware-Tenamat	1987	3:1	2.87	2.41
3	TENSAR-NS2000	1987	3:1	3.79	1.31
4	HOECHST-Trevira, Slits	1988	1.5:1	5.78	2.67
5	TENSAR-NS3000	1987	3:1	4.06	3.74
6	MIRAFI-Maramat 1800	1987	3:1	4.46	2.39
7	MIRAFI-Maramat 2400	1987	3:1	5.25	3.23
8	HOECHST-Trevira, Slits	1988	3:1	11.1	1.90
9	PNG-Red Plastic Mat	1989	2:1	19.5	2.76
10	PNG-Clear Plastic Mat	1989	2:1	22.2	2.71
11	TENSAR-NS1100	1987	3:1	7.63	6.45
12	PNG-Inorganic Mat (East)	1989	3:1	15.2	3.90
13	PNG-Inorganic Mat (West)	1989	1.5:1	49.3	14.1

NOTE: KG/HA/CM = Kilograms of Sediment/Hectare/Centimeter of Rain
CU-M/HA/CM = Cubic Meters of Runoff/Hectare/Centimeter of Rain
PNG = Permission Not Given to use names

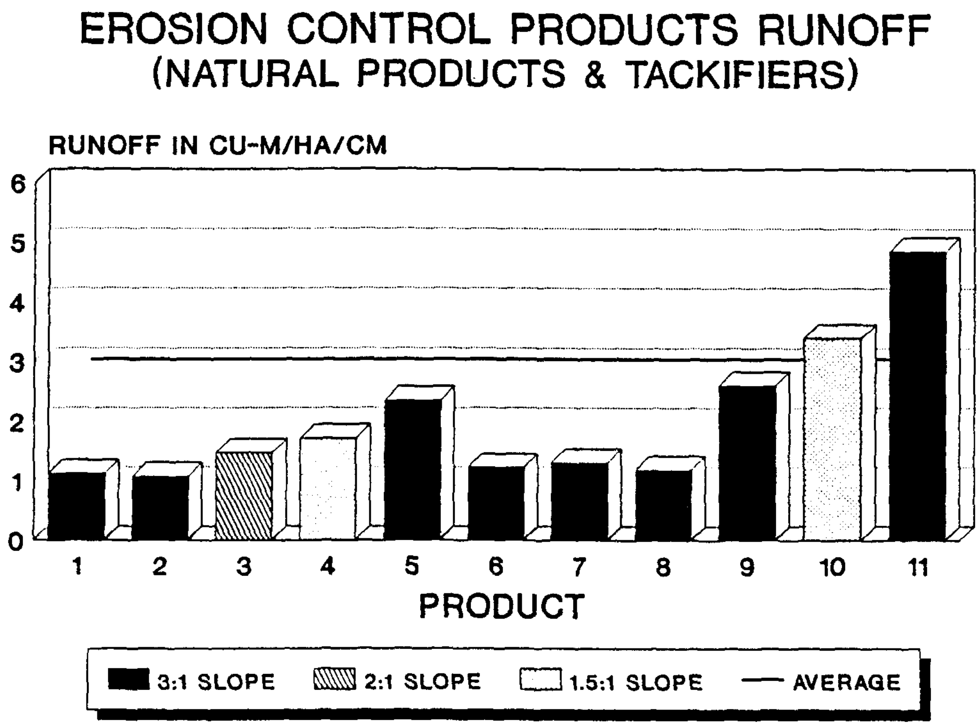


1 KG/HA/CM = 0.35 P/A/I
AVE BARE GROUND LOSS = 2048 KG/HA/CM

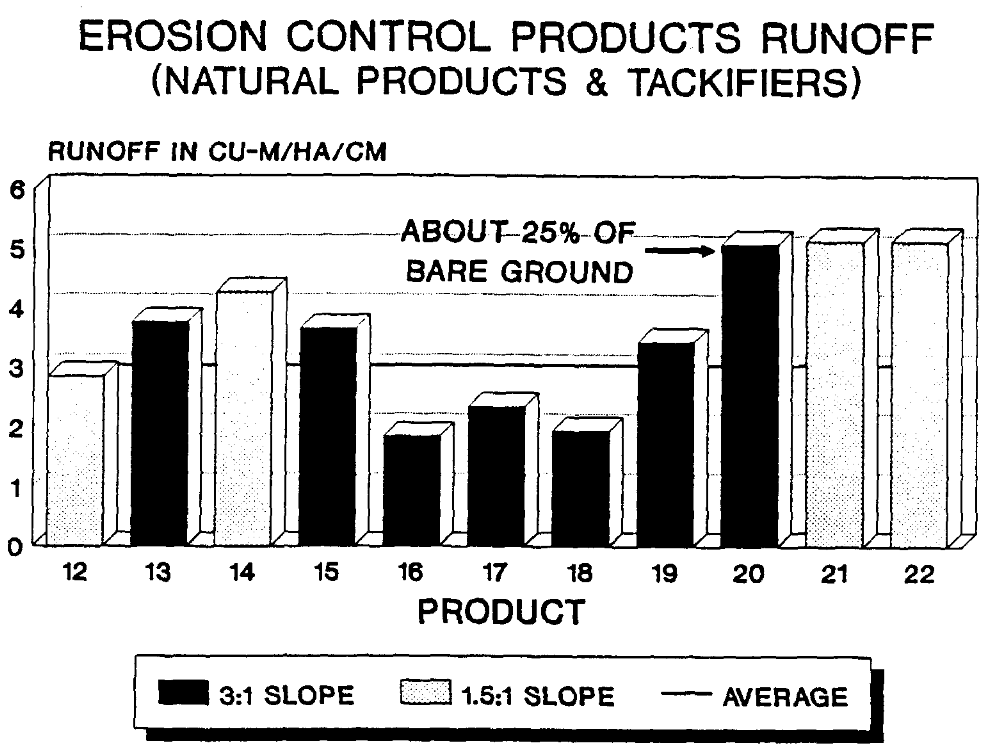


1 KG/HA/CM = 0.35 P/A/I
AVE BARE GROUND LOSS = 2048 KG/HA/CM

Figure 1. Natural Products and Tackifiers Soil Loss.



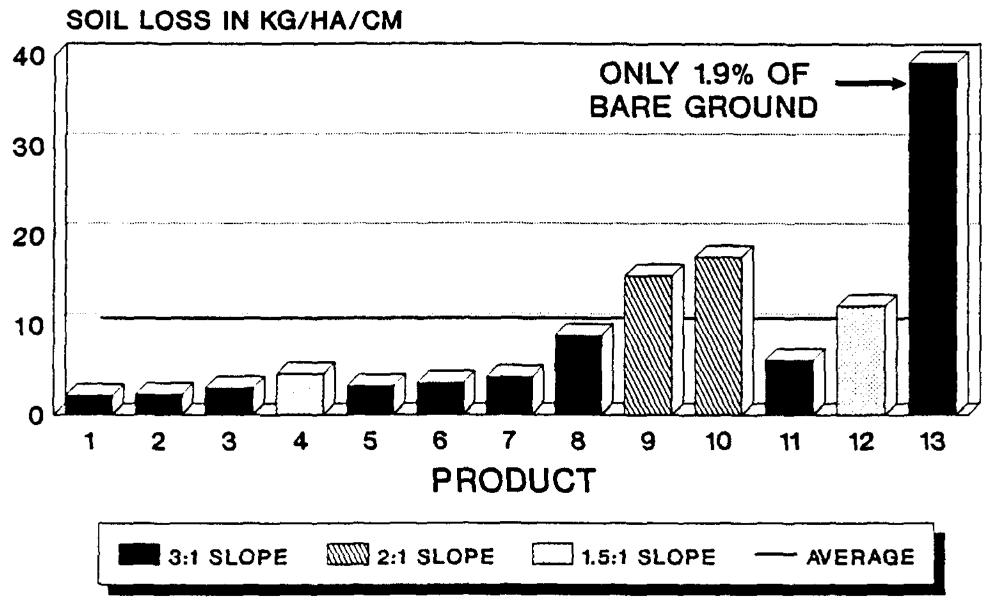
1 CU-M/HA/CM = 0.028 CF/A/I
AVE BARE GROUND RUNOFF = 11.3 CU-M/HA/CM



1 CU-M/HA/CM = 0.028 CF/A/I
AVE BARE GROUND RUNOFF = 11.3 CU-M/HA/CM

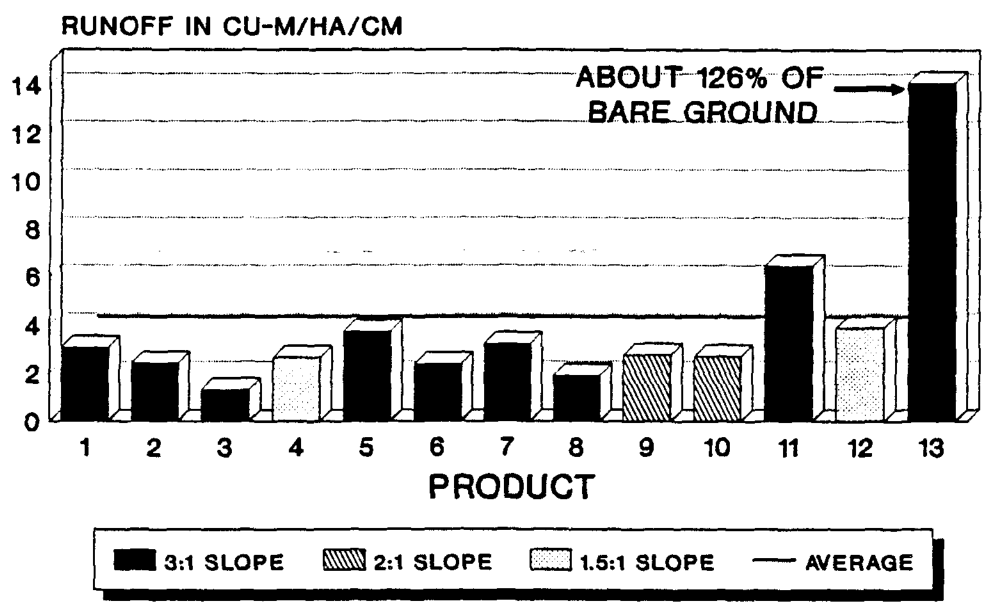
Figure 2. Natural Products and Tackifiers Runoff.

EROSION CONTROL PRODUCTS SOIL LOSS
(GEOTEXTILE PRODUCTS)



1 KG/HA/CM = 0.35 P/A/I
AVE BARE GROUND LOSS = 2048 KG/HA/CM

EROSION CONTROL PRODUCTS RUNOFF
(GEOTEXTILE PRODUCTS)



1 CU-M/HA/CM = 0.028 CF/A/I
AVE BARE GROUND RUNOFF = 11.3 CU-M/HA/CM

Figure 3. Geotextile Products Soil Loss and Runoff.

protect soils from erosion for at least two growing seasons. Second, erosion control products have to provide an optimal environment to allow for adequate dry land grass establishment.

A detailed analysis of 13 erosion control products used to assist with dry land grass establishment with no irrigation was completed for biomass production during one growing season in Parker, Colorado (see Fifield, 1992). The products are identified in Table 3. All products tested involved three replicates having an easterly aspect and three replicates having a westerly aspect.

The 1991 testing program not only evaluated biomass production but also allowed for a collection of data on soil temperature and moisture. In addition, a statistical analysis of product parameters was completed that evaluated which product parameters appear to be important for assisting in biomass production.

Rainfall

Figure 4 illustrates how precipitation at Parker, Colorado varied during 1991. Notice, for three months out of five, total precipitation exceeded anticipated monthly averages. However, upon reviewing daily precipitation values, it becomes evident that after about August 4, little precipitation fell on the test plots. This proved to be detrimental to biomass production.

The variability of climatic events in a semi-arid environment is important to consider for vegetation establishment. Due to the unpredictability of rainfall events, establishing dry land grass without irrigation can be difficult. Hence, it is important erosion control product parameters be developed in a manner that provides maximum benefit for establishing vegetation.

Soil Temperature

Figure 5 illustrates the impact products have upon soil temperature. Although only one day is illustrated, the variability of each product remained nearly the same throughout the summer of 1991. Review of Figure 5 indicates that early morning temperatures are relatively constant for all products. However, by afternoon it becomes evident each product impacts soil temperatures differently. Finally, by evening hours, it appears the products are having less influence on heating of soil.

In summary, it appears use of erosion control blankets impacts the daytime heating of soil. Where blanket materials were not installed (e.g., tackifiers and Turf Reinforcement Mats), heating of soil appears to be in the same manner as occurred with no products applied.

Table 3. Description of Erosion Control Products Tested During 1991.

PLOT	COMPANY NAME & PRODUCT	AREAL DENSITY (GM/SQ CM)	THICKNESS[A] (MM)	COLOR
1	Research Prod-EARTH GARD	0.035	1.10	Brown
2	PND-Wood Excelsior	0.053	8.81	Lt Wheat
3	PND-Wood Excelsior	0.088	8.58	Lt Wheat
4	CONTROL (Bare Ground)			
5	PNG-3 dim TRM[B]	0.026	3.90	Black
6	Synthetic-3 dim Poly.	0.024	2.34	Green
7	Synthetic-3 dim Poly.	0.034	4.00	Black
8	Bonterra-Straw/Coconut	0.027	2.61	Brn/Yel
9	Bonterra-Straw	0.027	1.91	Yellow
10	Bonterra-Straw	0.041	3.70	Yellow
11	ESSI-Soil Master WR			
12	CONTROL (Bare Ground)			
13	Synthetic-3 dim TRM[B]	0.041	4.06	Black
14	Midwest-SOIL SEMENT			
15	Polyester Blanket (not included due to installation problems)			

A: Thickness measured with a micrometer while product was sandwiched between two rigid metal plates

B: TRM = Turf Reinforcement Mat

PRN = Permission Not Given to use Name

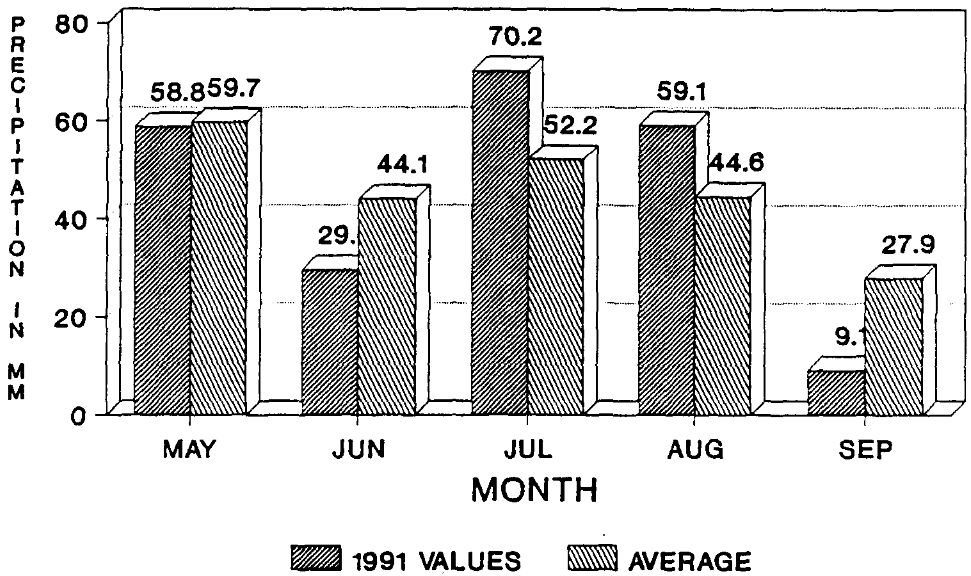
Soil Moisture

Figure 6 illustrates how the soil moisture varied throughout a typical day. As with soil temperature, it appears the products have an impact on soil moisture. What is interesting to note is that soil moisture within five centimeters (two inches) of the surface appears to increase during daylight hours.

Dry land Grass Production

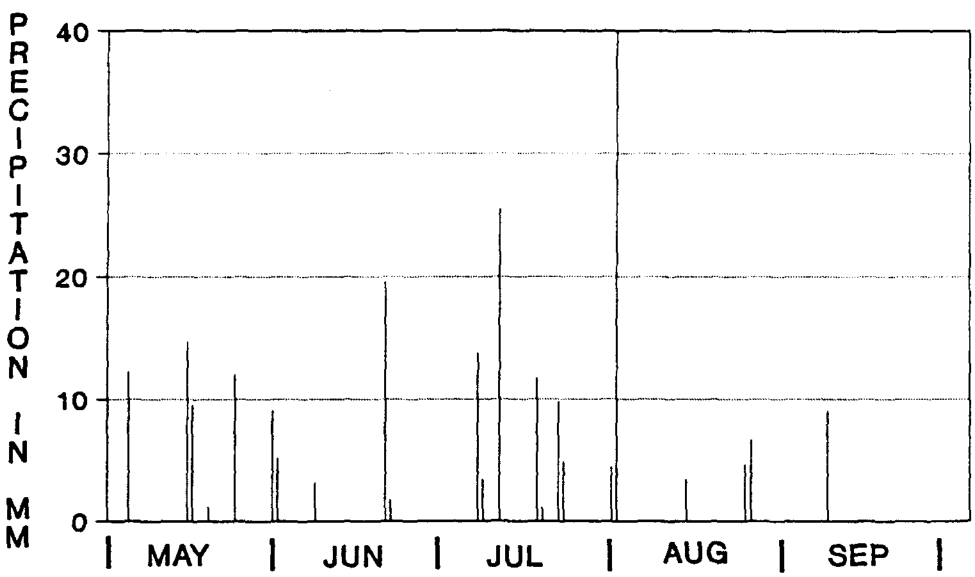
As indicated previously for semi-arid environments, it is important an erosion control product provide optimal conditions for dry land grass establishment without irrigation. By broadcasting a cool season grass (Smooth brome) and a warm season grass (Sideoats grama) and harvesting all biomass produced after one growing season, it was possible to evaluate the ability of erosion control products to assist with biomass production.

PRECIPITATION AT PARKER, COLORADO
(1991 AND AVERAGE)



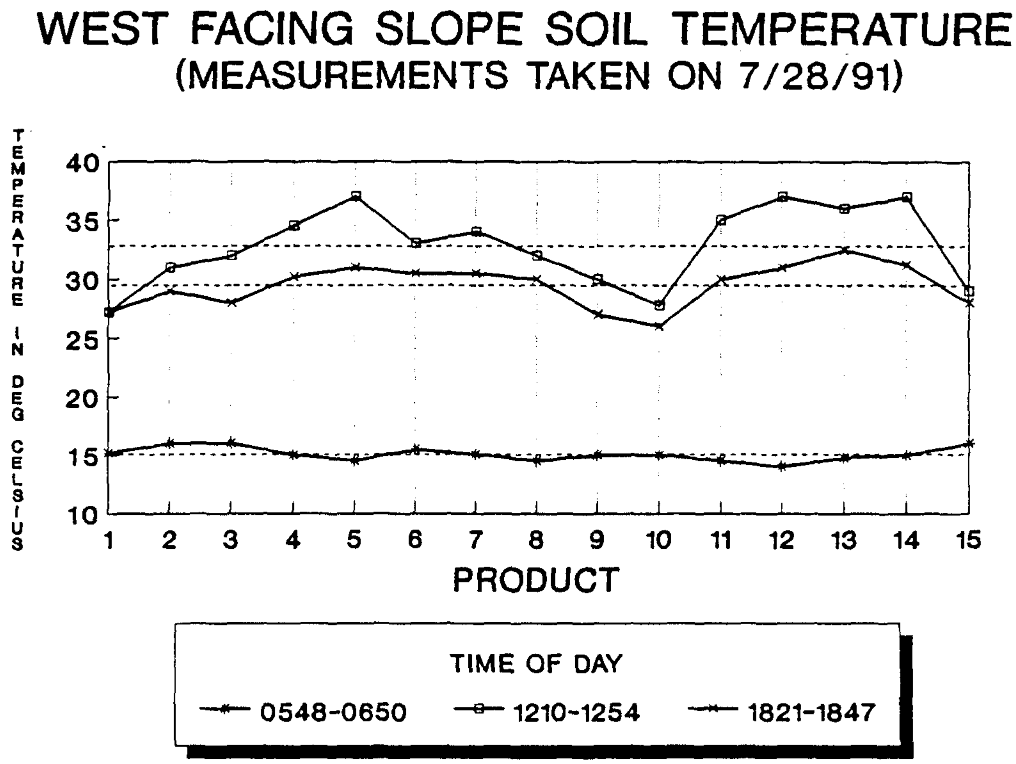
NOTE: 1 INCH = 25.4 MILLIMETERS

DAILY PRECIPITATION AT PARKER, COLORADO DURING 1991

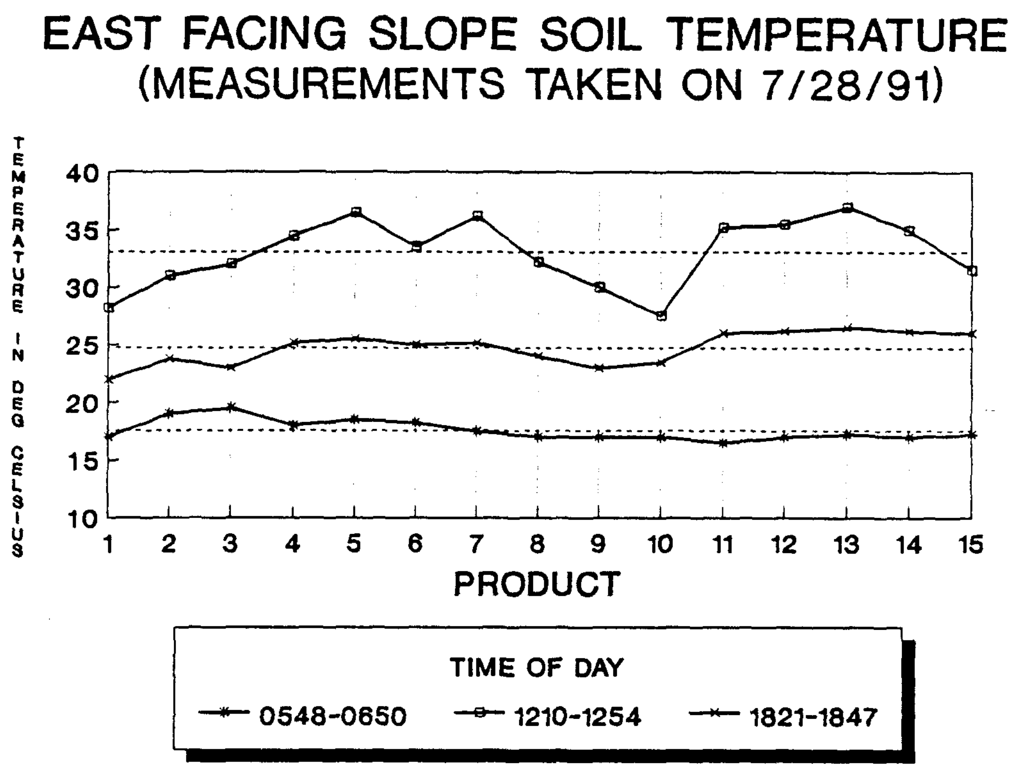


NOTE: 1 INCH = 25.4 MILLIMETERS

Figure 4. Precipitation Collected at Parker, Colorado During 1991.

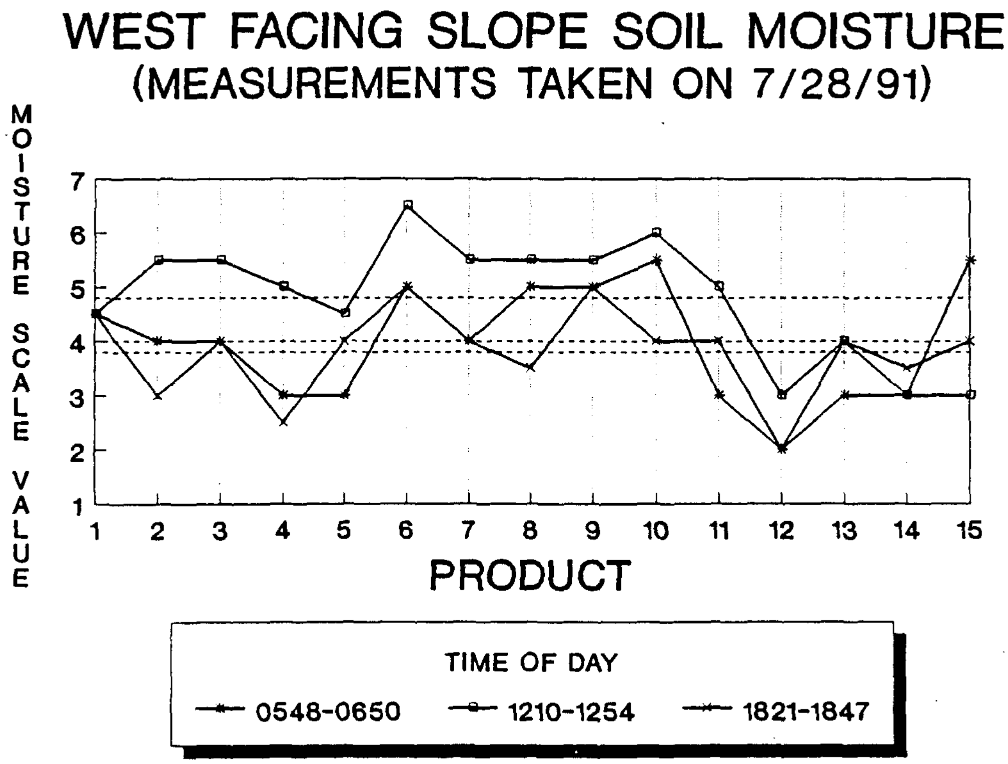


NOTE: DASHED LINES REPRESENT AVERAGES

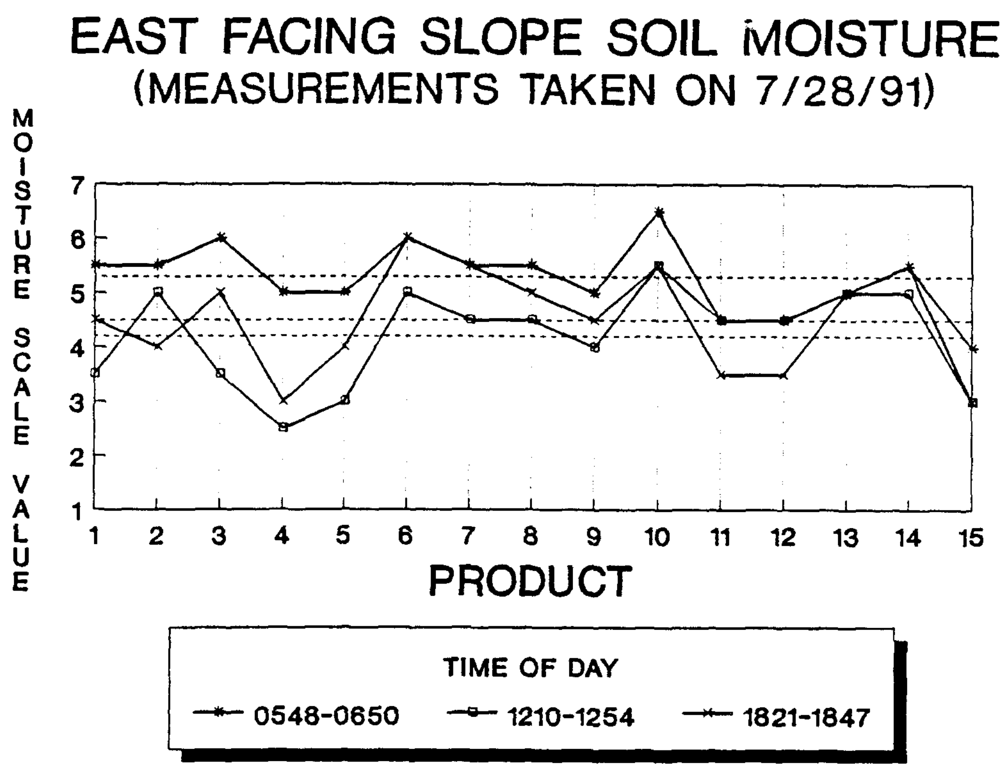


DASHED LINES REPRESENT AVERAGES

Figure 5. Soil Temperature Within Five Centimeters (Two Inches) of the Surface.



DASHED LINES REPRESENT AVERAGES



DASHED LINES REPRESENT AVERAGES

Figure 6. Soil Moisture Within Five Centimeters (Two Inches) of the Surface.

Figure 7 illustrates how the biomass production from each plot varied when west facing slopes are compared to east facing slopes. It is interesting to note that some products actually produce less vegetation than what was observed from untreated slopes. It must be kept in mind that harvesting of biomass from each test plot occurred after only one growing season. What would have happened after two growing seasons is not known.

Figure 7 also illustrates that products having an easterly aspect appear to produce approximately 30% more biomass when compared to products tested having a westerly aspect. It is speculated the difference in biomass production may be attributed to the extensive heating westerly aspect slopes experience. It is not known if similar conditions would have occurred on slopes having a northerly and southerly aspect.

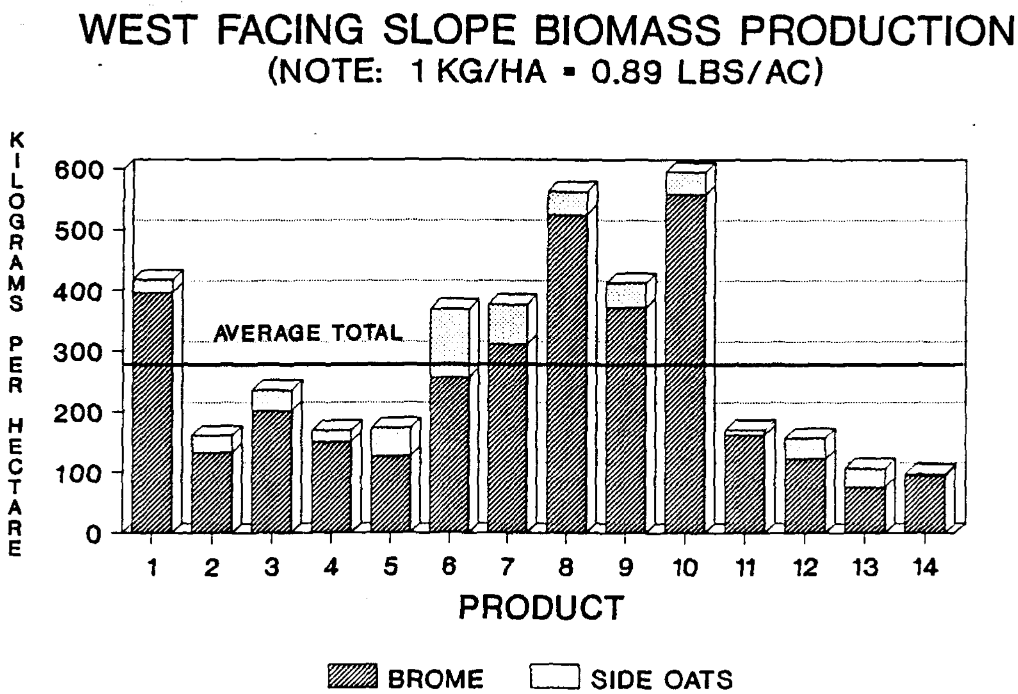
Finally, in order to evaluate production of specific species, biomass from treated plots were compared to vegetation produced on the control plots (see Figure 8). Notice the variability of different species produced depended upon the type of treatment each plot received. For example, it appears the synthetic products may favor germination of warm season grasses when compared to natural products such as straw.

Statistical Evaluation of Biomass Production

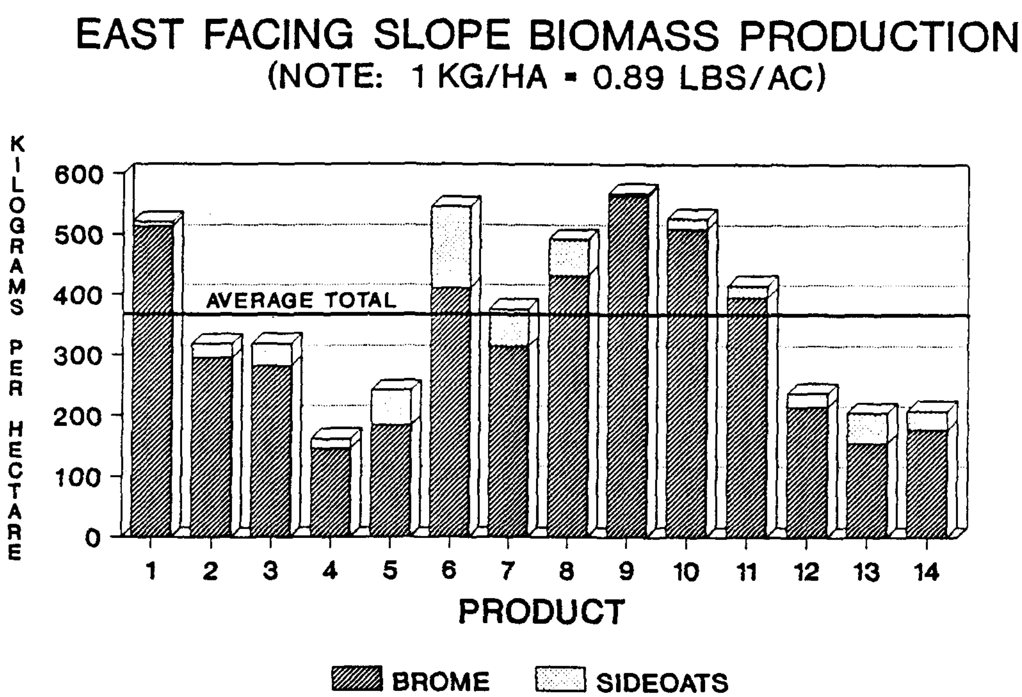
The obvious question that needs to be answered now is which product parameters appear to be important for biomass production without use of irrigation? Previously, it was found that thickness appeared to be important in controlling sediment from treated slopes. A similar type of analysis was completed for biomass production with the results illustrated in Figure 9. Notice, Figure 9 illustrates that product thickness may actually reduce biomass production (i.e., the longer graph). However, upon evaluating actual biomass production, it becomes evident this trend contradicts what actually happens.

Analysis of data yields the fact that wood excelsior products created a set of data separate from other products. When data associated with wood excelsior products were removed from the analysis, it became evident (i.e., the shorter graph) product thickness alone did not account for biomass production. It is speculated wood excelsior products had an impact on the first year growth of vegetation perhaps due to adsorption of scant precipitation experienced in the latter part of the growing season.

In order to evaluate another product parameter, color was introduced utilizing information from the additive primary colors of red, blue and green found in a light spectrum (see White, 1956). This resulted in the following ranking concerning color.

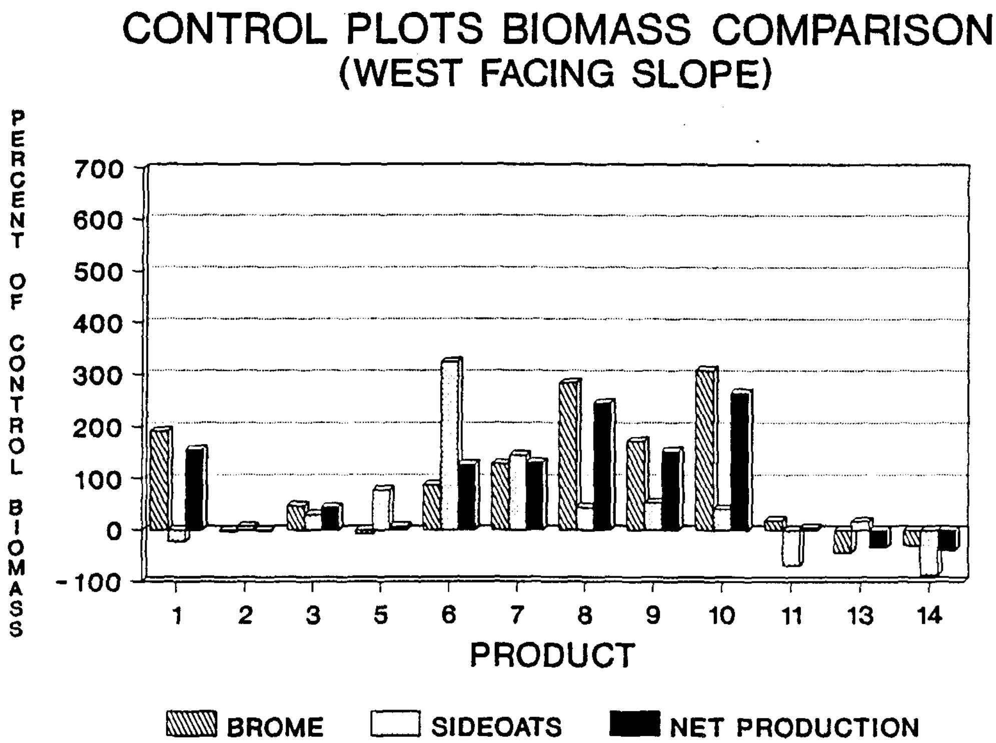


AVERAGE BROME = 247 KG/HA (220 LBS/AC)
AVERAGE SIDEOATS = 37 KG/HA (33 LBS/AC)
AVERAGE TOTAL = 284 KG/HA (253 LBS/AC)



AVERAGE BROME = 328 KG/HA (292 LBS/AC)
AVERAGE SIDEOATS = 39 KG/HA (35 LBS/AC)
AVERAGE TOTAL = 367 KG/HA (327 LBS/AC)

Figure 7. Biomass Production and Product Comparison.



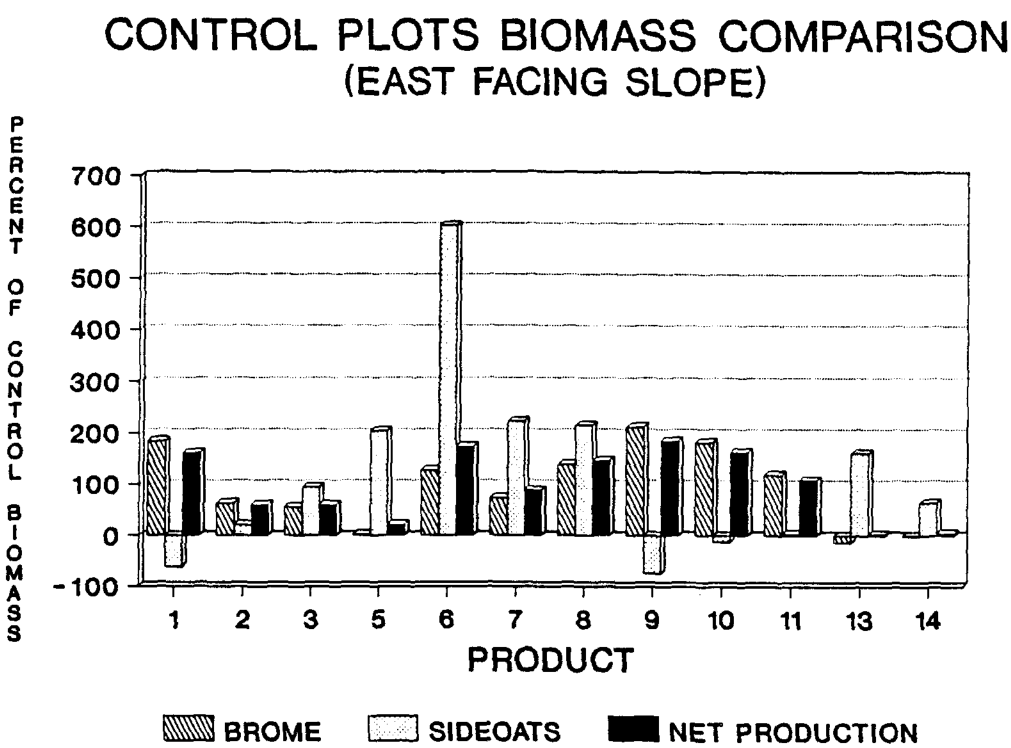


Figure 8. Control Plot Biomass Production Comparison.

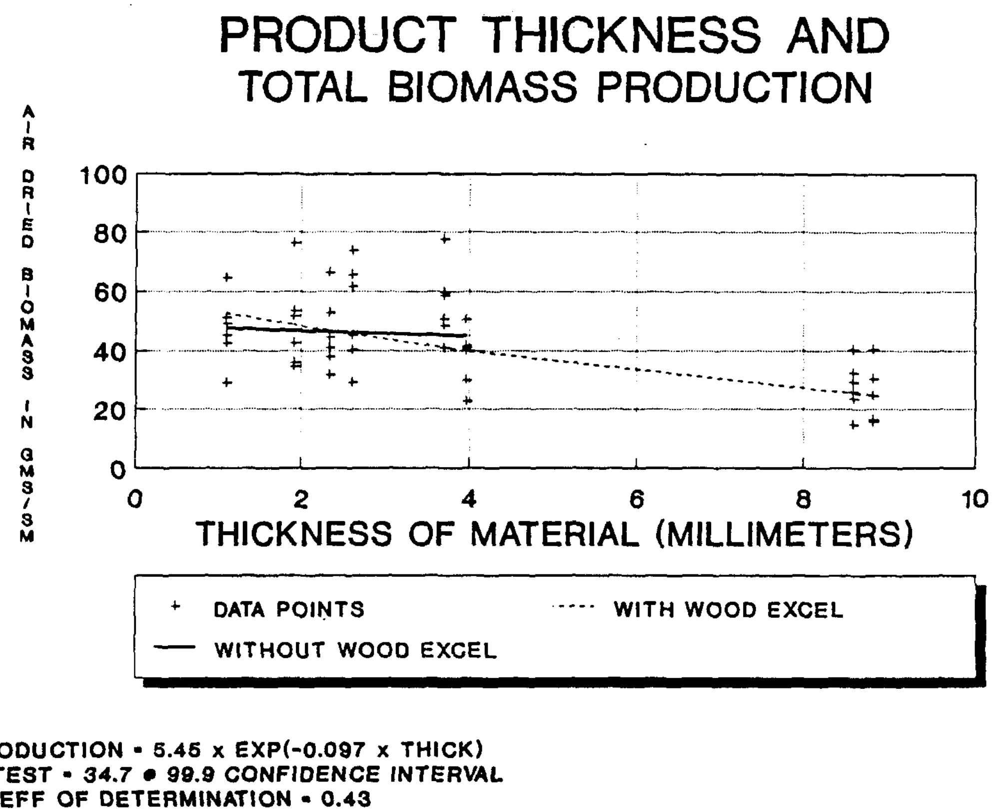


Figure 9. Product Thickness and Biomass Production Comparison.

1 = no color (i.e., black)
2 = green
3 = yellow
4 = brown
5 = all colors (i.e, white)

Once this new parameter was introduced, it became statistically evident that both product thickness and color appear to impact biomass production. The results are summarized below.

Net Biomass Production

LN(Prod) = 0.93 + 0.23 x LN(thickness) + 0.37 x LN(color)

F-Test: 7.52 @ 99.8% Confidence Interval
Coefficient of Determination: 0.31
Number of Data Points: 36

West Facing Slope Biomass Production

Prod = 1.22 + 0.98 x thickness + 1.09 x color

F-Test: 3.12 @ 92.6% Confidence Interval
Coefficient of Determination: 0.29
Number of Data Points: 18

East Facing Slope Biomass Production

LN(Prod) = 1.26 + 0.10 x color

F-Test: 3.46 @ 91.9% Confidence Interval

Coefficient of Determination: 0.18

Number of Data Points: 18

Smooth Brome Net Biomass Production

LN(Prod) = 0.24 + 0.14 x thickness + 0.27 x color

F-Test: 7.52 @ 99.8% Confidence Interval

Coefficient of Determination: 0.31

Number of Data Points: 36

Sideoats Grama Net Biomass Production

No correlation existed

***** Note: LN = Natural Logarithm

Except for Sideoats grama, it appears as product thickness increased and product color became lighter, biomass production increased. It must be noted these conclusions were determined for a semi-arid environment. While similar results may apply to arid conditions, it is not known if they apply to humid regions.

As a summary, twelve erosion control products were tested to evaluate their ability to assist with establishment of dry land grass in the semi-arid environment of Parker, Colorado. After one growing season, the following observations were made.

1. Erosion control blankets appear to impact heating of the soil. The other products appear to fluctuate as air temperature changes.

2. Erosion control blankets appear to maintain higher soil moisture content.

3. Erosion control blankets generally increased biomass production when compared to slopes not treated. An exception to this observation was wood excelsior products.

4. Tackifiers and TRM's did not substantially increase biomass production. However, if both had been used in conjunction with a mulch, it is anticipated greater biomass production would have occurred.

5. It appears natural erosion control blankets increase production of cool season grass and synthetic products increase the production of warm season grass.

6. It appears product thickness and color influence the production of dry land grass in a semi-arid environment for one growing season.

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"THE EXPANDING ROLE OF GEOSYNTHETICS IN EROSION AND SEDIMENT CONTROL"

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ABSTRACT

The use of geosynthetic erosion and sediment materials continues to expand at a rapid pace. From their early beginnings in the late 1950's, geosynthetic materials today are the backbone of the erosion and sediment control industry. Geosynthetic components are an integral part of erosion and sediment materials ranging from temporary products such as hydraulic mulch geofibers, plastic erosion control meshes and nettings, erosion control blankets and silt fences to high performance turf reinforcement mats, geocellular confinement systems, erosion control geotextiles, fabric formed revetments and concrete block systems. This paper provides a brief overview of these materials and concepts, and how they may be designed and incorporated into cost effective applications.

INTRODUCTION

We are entering a new environmental era where concern for the protection of our planet's natural resources will reach global proportions. Continued technological advances have led to improved monitoring of Earth's vital signs. As such, prior theoretical modeling of environmental concerns such as the "Greenhouse Effect", ozone depletion, rising sea levels, deforestation, drought, accelerated erosion, sediment loading of waterways, species extinction and the eventual downfall of mankind appear chillingly realistic.

Slogans such as "Think Globally, Act Locally", "Love Your Mother" and "Someone Always Lives Downstream" are spearheading the efforts of numerous preservation groups. With the continued demise of oppressive governments, optimism for world peace and an unprecedented feeling of global unity, a spirit of environmental cooperation is beginning to prevail.

The term "non-point pollution" hopefully is heading toward obsolescence with "watch dog" groups such as Stream Watch sloshing their way up muddy creeks to pinpoint sources of unchecked sediment. Improved methods to detect and monitor rates of erosion and sedimentation via high tech satellite imagery or even the actions of the Stream Watchers of the world lends credence to the old saying "you can run but you can't hide." Generators of sediment and other pollutants can and will be identified.

Cumulative research suggests excessive **sediment** in our waterways **is the planet's most prevalent contaminant.** The amount of world wide erosion is staggering. The Worldwatch Institute has placed the **annual** rate of soil erosion from crop lands at approximately 27.5 billion metric tons or 25 billion US tons (Brown and Wolf, 1984). Agriculture accounts for roughly 60% - 70% of the annual soil loss with construction and urban runoff accounting for about 15% of the erosion "pie". Mining and forestry combined may contribute up to 10%. All sources combined, the annual rate of erosion in the U.S. alone probably exceeds 3.3 billion metric tons/year (Northcutt, 1992).

Sediment accounts for more than 2/3 of all pollutants entering U.S. waterways. It is estimated up to $13 billion per year are spent in the U.S. to directly mitigate the offsite impacts of erosion and sediment. Increscent economic and social losses from reductions in arable farmland, timber production, fishery yields, species diversity and navigable waterways exceed those caused by pollutants in the public eye such as nuclear and hazardous wastes, oil spills, air pollution or ground water contamination. Worse yet, the problem is exasperated as one moves downstream toward our coastlines and population centers.

Recently a number of laws have been mandated in the United States to combat excessive erosion. Such legislation ranges from local erosion and sediment control ordinances to numerous state and federal agricultural, waste containment and surface mining acts, to the broadly encompassing Environmental Protection Agency's 1972 Clean Water Act and The Farm Bill administered by the Department of Agriculture.

In October of 1992 The Clean Water Act will mandate projects disturbing more than two hectares (five acres) of land to obtain a National Pollutant Discharge Elimination System (NPDES) permit to help identify and quantify release of pollutants into our watersheds. This act is up for further review in 1992. With environmental groups pushing for numerical standards for sediment discharge, next year inspectors may be measuring the turbidity of your runoff in parts per million, just like heavy metals or hazardous waste. Landfills, surface mines, commercial real estate developments, even our public agencies such as DOT's, county and municipal entities will be scurrying to develop erosion and sediment control plans or face stiff federal fines. These actions are only the tip of the iceberg as more and more government agencies and entities get with the program.

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 an economical manner (Theisen, 1988).

In this era of shrinking budgets, decision makers are hard pressed to reclaim disturbed sites at minimum costs. Given site conditions such as slope angles, climate, runoff, soil profile and ultimate land use; a specifier must select with confidence a technique she (he) feels will perform up to expectations at the lowest cost. Over the past 25 years the erosion control industry has experienced rapid growth and is becoming more sophisticated. Materials developed for erosion and sediment control (E & SC) are becoming increasingly effective. Improved design and installation guidelines are directing the use of E & SC products toward more specific and cost effective applications. The industry has evolved from the seed drills, straw blowers, hydroseeders, excelsior, jute, concrete channel liners and rip rap of the sixties into a diverse hierarchy of techniques and materials. It seems as if every month a new product is introduced to control erosion and sediment in more specific situations. Numerous materials have come and gone in the survival of the fittest, most cost competitive products.

Historical Perspective

Geosynthetics may broadly be defined as synthetic materials or components used with soil, rock, earth or other geotechnical engineering related materials as an integral part of a man made product, structure or system. Benefits include reinforcement, stabilization, separation, drainage, filtration, containment, and erosion control. Related materials include geotextiles, geogrids, geomembranes, geomeshes, geonets, geomats, geofibers, geocomposites and the newest term, "geoappurtenances" to cover the myriad of materials being developed for geotechnical applications.

Many of us perceive the use of geosynthetic materials for erosion and sediment control as a new horizon. However, geosynthetics have played a major role in the E & SC industry for over 30 years, particularly in the case of rolled goods. In 1958, a geosynthetic component was incorporated into an erosion control system which has changed the course of slope, channel and embankment protection. A "plastic cloth" was used in lieu of a granular filter to prevent sand from washing out behind concrete blocks used for shoreline protection (Richardson and Koerner, 1990). The significant cost savings realized when a 0.4 millimeter thick plastic filter cloth could replace up to a meter of soil peaked the interest of the U.S. Army Corps of Engineers. Subsequent successful installations of woven plastic cloth filters in coastal structures led to the birth of the geotextile industry as is practiced today. Through the years tens of millions of square meters of woven and non woven geotextiles have been installed as a critical component of hard armor systems.

Another geosynthetic breakthrough was initiated about 10 years later. In the mid 1960's only one type of erosion control blanket existed. A state soil conservationist discovered the material used for wrapping cotton bales could be used to prevent soil erosion. The material was jute, a woven mesh of thick natural yarns, which when applied on the soil surface provided thousands of tiny check dams to help keep soil from washing away. Jute blankets allow vegetation to become established on steeper slopes and in higher flowing swales than traditional hydraulic straw and hay mulches. A similar material remains in use today.

However, jute has drawbacks: its open weave construction leaves soil exposed, the organic material tends to shrink and swell under changing moisture conditions, and it is extremely flammable. To achieve optimum results straw or hay mulch still must be placed beneath the jute.

What was needed was a one step, roll out mulch blanket. The first attempts involved a very dense mat of curled, barbed aspen wood (excelsior) fibers. The material stayed together but was too dense to allow vegetative growth. Next, a twisted kraft paper net was placed above a thinner mat of excelsior fibers. Vegetation grew through the blanket but performance of the paper netting was very inconsistent; often breaking down too quickly and being lifted by the vegetation or worse yet, allowing the blanket to be washed away before vegetative establishment. A stronger, non-moisture sensitive, more durable netting was needed. Polypropylene netting was the answer.

Combining a dense mat of excelsior with a plastic netting lead to the first successful excelsior erosion control blankets. Field trials with various nets, fiber lengths and glue patterns resulted in essentially the same blankets we see today. The key to the improved performance of excelsior over jute blankets is the plastic net backbone of the product.

Biaxially Oriented Process Nets

Biaxially oriented process (BOP) nets are typically manufactured from polypropylene or polyethylene resins. BOP nets are extremely versatile in that composition, strength, elongation, aperture size and shape, color and ultraviolet stability can easily be designed into the product for specific site requirements.

Because they do not absorb moisture, these nets do not shrink and swell like kraft paper nets and jute blankets. BOP nets have proven to be so adaptable they are being used to create more complex products and are even used alone to anchor loose fiber mulches such as straw, hay and wood chips. The lightweight nettings placed over mulches come in rolls which are 3 to 4 1/2 meters in width, weigh only about 55 kilograms and will cover 0.4 hectares (one acre) or more. Installation of these products is less labor intensive than traditional netting products.

Erosion Control Meshes

A step up from BOP nettings are woven polypropylene geotextile erosion control meshes. In fact, the newer twisted fiber erosion control meshes can provide comparable performance to natural fiber erosion control blankets. These photobiodegradable, natural looking, high strength polypropylene meshes protect the soil surface from water and wind erosion while accelerating vegetative development. Four meter, lightweight rolls facilitate installation on slopes and channels. Erosion control meshes may be used alone, with dry mulches or as a stabilizing underlay for sod reinforcement. They also show promise as an open weave geotextile facing for fostering vegetation on geosynthetically reinforced steepened slopes or bioengineering installations where establishment of woody plant species is desired. Displaying rapid photobiodegradation in one direction, these meshes allow woody vegetation to freely sprout and emerge through the installation with little potential of girdling.

Erosion Control Blankets (ECB's)

BOP nettings or woven meshes of varying characteristics are now placed on one or both sides of finely tuned erosion control blankets adapted to anticipated site conditions. These one to two meter wide biodegradable fiber erosion control blankets (ECB's) are composed of straw, excelsior, cotton, coconut, polypropylene or blends thereof. Nettings or meshes may contain UV stabilizers for controlled degradation or long chain interrupters to accelerate photodegradation. Colors vary from clear, tan, green to black. Methods of holding the fibers in place range from glues and glue strips to more superior parallel lock stitching with cotton, polyester or polyolefin threads. Applications for the wide variety of blankets range from protection of gradual to steep slopes to low or moderately flowing channels. The top of the line blankets may provide temporary resistance to short duration flow velocities of up to nearly three meters per second.

Finally and perhaps of most concern to the environment, these meshes and nettings may ultimately become biodegradable. As photodegradation progresses the plastic chains are cut into shorter and shorter segments down to a plastic "sand" which becomes part of the soil. These short segments become biologically degradable and are attacked by soil microorganisms and converted to carbon dioxide and water (Guillet, 1974). It is unfortunate that emotional, uninformed anti-plastic stigmas sometimes preclude the use of these extremely cost effective temporary materials in lieu of costly exotic fibers or hard armor solutions.

TERMS vs PERMS

At this point an important distinction must be presented regarding the intended use of E & SC materials. For many installations vegetation alone will provide adequate long term erosion protection. However, getting vegetation established requires a variety of techniques. Materials of a temporary nature which facilitate vegetative establishment, then degrade, may be termed **TERM's** or **Temporary Erosion and Revegetation Materials.**

Basically TERM's consist of degradable natural and/or synthetic components which provide temporary erosion control and aid in the growth of vegetation. In only a few instances are TERM's "totally organic". Remember vital geosynthetic components often include netting, stitchings and adhesives. These short term materials degrade leaving only vegetation for long term low to medium flow resistance. TABLE 1 lists various TERM techniques.

TABLE 1
GENERAL TERM TECHNIQUES

Straw, Hay and Hydraulic Mulches

Tackifiers and Soil Stabilizers

Hydraulic Mulch Geofibers

Erosion Control Meshes and Nets (ECMN's)

Erosion Control Blankets (ECB's)

Fiber Roving Systems (FRS's)

Site conditions requiring the higher performance of reinforced vegetation or revetment systems will require **PERM's** or **Permanent Erosion and Revegetation Materials.** PERM's may be subdivided into **Biotechnical Composites** when vegetation is reinforced or **Hard Armor Systems** when nonvegetated inert materials are installed.

Biotechnical Composites are composed of non-degradable materials which furnish temporary erosion protection, accelerate vegetative growth and ultimately become synergistically entangled with living plant tissue to extend the performance limits of vegetation. This reinforced vegetation provides "permanent" medium to high flow resistance provided Biotechnical Composites are protected from sunlight via shading by vegetation and soil cover. TABLE 2 outlines examples of Biotechnical Composites.

TABLE 2
BIOTECHNICAL COMPOSITES (PERM's)

UV Stabilized Fiber Roving Systems (FRS's)

Erosion Control Revegetation Mats (ECRM's)

Turf Reinforcement Mats (TRM's)

Soil and Sports Turf Geofibers

Vegetated Geocellular Containment Systems (GCS's)

Vegetated Concrete Block Systems

Hard armor systems generally employ inert materials used to provide high to maximum flow resistance where conditions exceed performance limits of reinforced vegetation systems. Listed in TABLE 3 are systems used to provide permanent erosion protection of areas subject to high flows, wave action and/or scour attack.

TABLE 3
HARD ARMOR SYSTEMS (PERM's)

Geocellular Containment Systems (GCS's)

Fabric Formed Revetments (FFR's)

Concrete Block Systems (CBS's)

Gabions

Rip Rap

Composites and Hybrids

Fiber Roving Systems (FRS's)

Fiber roving systems (FRS's) are another geosynthetic concept providing moderate erosion protection. Developed in the late sixties, rovings are applied in a continuous strand for protection of drainage swales and slopes.

Fiberglass roving is a material formed from fibers drawn from molten glass and gathered into strands to form a single ribbon. Polypropylene roving is formed from continuous strands of fibrillated yarns wound onto cylindrical packages such that the material can be fed continuously from the outside of the package. Use of fiberglass roving has been declining due to its carcinogenic properties and is being displaced by more versatile "environmentally friendly" polypropylene roving.

Erosion control roving is unique because of the flexibility of application, allowing for any width or thickness of material to be applied (Agnew, 1991). Other erosion control materials, such as blankets or mats require the user to apply the width or thickness of material supplied. Fiber rovings may be viewed as an "in situ" erosion control geosynthetic with reduced labor and material costs over traditional blanket materials. The continuous strand concept provides ease of installation with minimal waste factors from overlap.

Using compressed air, roving is rapidly applied through a nozzle over the seeded surface and then anchored in place using emulsified asphalt or other natural or synthetic soil stabilizers. Photobiodegradable polypropylene roving may be used for temporary applications (TERM) or when UV stabilized is appropriate for extended use situations (PERM). In addition, these polypropylene roving systems may be colored to match substrates or improve visual aesthetics.

The use of fiber roving systems is rapidly expanding. Key markets include highways, surface mines and landfills. The future in FRS's lies in the development of a one step application apparatus which will further accelerate installation efficiency. The concept of developing an on site mat or blanket is certainly appealing and extremely cost effective.

TRM vs ECRM

Turf Reinforcement is a method or system by which the natural ability of plants to protect soil from erosion is enhanced through the use of geosynthetic materials. A flexible three dimensional matrix retains seeds and soil, stimulates seed germination, accelerates seedling development and most importantly, synergistically meshes with developing plant roots and shoots. In laboratory and field analyses, biotechnically reinforced systems have resisted flow rates in excess of four meters per second for durations of up to two days, **providing twice the**

erosion protection of unreinforced vegetation (Carroll, Rodencal and Theisen, 1991). Such performance has resulted in the widespread practice of turf reinforcement as an alternative to concrete, riprap and other armor systems in the protection of open channels, drainage ditches, detention basins and steepened slopes.

Permanent geosynthetic mattings are composed of durable synthetic materials stabilized against ultraviolet degradation and inert to chemicals normally encountered in a natural soil environment. These mattings consist of a lofty web of mechanically or melt bonded polymer nettings, monofilaments or fibers which are entangled to form a strong and dimensionally stable matrix. Polymers include polypropylene, polyethylene, nylon and polyvinyl chloride.

Geosynthetic mattings generally fall into two categories: **Turf Reinforcement Mats (TRM's)** or **Erosion Control Revegetation Mats (ECRM's).** Higher strength TRM's provide sufficient thickness and void space to permit soil filling/retention and the development of vegetation within the matrix. TRM's are installed first, then seeded and filled with soil. Seeded prior to installation, ECRM's are denser, lower profile mats designed to provide long term ground cover and erosion protection. By their nature of installation TRM's can be expected to provide more vegetative entanglement and long term performance than ECRM's. However, denser ECRM's may provide superior temporary erosion protection. Geosynthetic mattings occupy one of the fastest growing niches of the erosion and sediment control industry.

Geocellular Containment Systems (GCS's)

Geocellular Containment Systems work in a unique fashion in that strength or stabilization by confinement is achieved by a series of three-dimensional cells up to 20 centimeters deep. When expanded into position, the polyethylene or polyester cells have the appearance of a large honeycomb, one of nature's most efficient structures. The cells are then backfilled with soil, sand or gravel depending upon application. For revegetation, the soil-backfilled cells are seeded, fertilized and covered with a variety of TERM or PERM techniques. The mulches provide surface protection while the cells greatly reduce the chances of subsurface failure and act as a deeper rooted biotechnical composite. Shallow lateral root development is precluded by the nearly impermeable geocell walls. As such vegetated GCS's are limited to flow velocities of two to three meters because of the tendency of the cells to sustain scouring under high flow velocities or shear conditions (Chen and Anderson, 1986).

For higher flow conditions GCS's may act as an easy to install form which is filled with concrete or grout to create a hard armor system. Typically a geotextile will be placed beneath the expanded web to provide separation and/or filtration. Erosion control applications for GCS's are many including steep slope revegetation, channel liners, shoreline revetments, retaining walls, boat ramps, and low flow stream crossings.

Fabric Formed Revetments (FFR's)

Fabric forming systems are mattresses typically constructed of water permeable, double layer woven geotextiles which are positioned on the area to be protected and filled with a pumpable fine aggregate concrete (structural grout). The two layers of geotextile are joined at discrete points to create a form which when filled with grout will conform to most subsoil conditions. Thickness and geometry are determined by internal spacer threads woven into the upper and lower sheets of fabric. In many cases the mattresses may be installed for less cost than conventional armor systems since all construction is conducted in place with no heavy equipment or skilled labor required (Richardson and Koerner, 1990).

FFR's are generally available in three styles. Filter point mats are formed with a double-layer woven fabric, joined together by interwoven filter points which relieve hydrostatic pressure. Uniform section mats are formed with a double-layer woven fabric, joined together by spacer cards on closely spaced centers. Relief of hydrostatic uplift pressure may be provided by inserting plastic weep tubes through the mat at specified centers. Articulating block mats are formed with a double-layer woven fabric, joined together into a matrix of rectangular compartments each separated by a narrow perimeter of interwoven fabric. High strength cables may be threaded between the two layers of fabric to interconnect the concrete filled compartments (blocks), and provide for block articulation. Hydrostatic pressure relief is achieved by slits cut between adjacent blocks and/or inserting plastic weep tubes. A filtration geotextile is recommended beneath all fabric formed revetments.

Installation of FFR's consists of four basic steps:

1. Site Preparation
2. Geotextile and Panel Placement/Field Assembly
3. Structural Grout Pumping
4. Inspection of Field Seams, Zipper Connectors and Lap Joints

Concrete Block Systems (CBS's)

Concrete block systems consist of prefabricated concrete panels of various geometries which may be attached to and laid upon a woven monofilament or non-woven geotextile. Bending and torsion are accommodated by having the concrete blocks articulated with joints, weaving patterns or connection devices. Concrete block systems may be subdivided into three groups: non-tied interlocking blocks, cable-tied blocks, or in-situ concrete (Hewlitt, Boorman and Bramley, 1987).

Concrete block revetments incorporate cellular concrete blocks, either open or closed, and are underlain with a properly designed filtration geotextile. The blocks are held on the slope by anchors placed at the top of the slope and/or by friction between the slope and the blocks. The blocks can be assembled into fabricated mats either at the factory or on site. Sections of precabled concrete blocks may be placed by using a special spreader bar, which may lower costs on large projects. Or the blocks may be handplaced with or without the cable subsequently installed.

Articulating concrete block revetment systems combine the favorable aspects of lightweight blankets and meshes, such as porosity, flexibility, vegetation encouragement, habitat enhancement, and ease of installation, with the nonerodibility, self weight, and high tractive force resistance of rigid linings. These specially designed interlocking precast concrete grids are a proven cost-effective, aesthetic, and functional alternative to dumped stone rip rap, gabions, structural concrete, and other heavy-duty, durable channel protection systems. Additionally, these systems offer enhanced flow efficiencies, nurturing of vegetative cover and safe access (Koutsourais and Sprague, 1992).

Gabions

Gabions are compartmented rectangular containers made of galvanized steel hexagonal wire mesh or rectangular plastic mesh and filled with hand-sized stone. Cells of equal capacity are formed by factory-inserted plastic or wire netting diaphragms or partitions which add strength to the container and help maintain its shape during the placement of stone. In highly corrosive conditions a polyvinyl chloride coating is used over the galvanized wire.

Advantages of gabions include flexibility, durability, strength, permeability and economy versus rigid structures. The growth of native plants is promoted as gabions collect sediment in the stone fill. A high percentage of installations are underlain by woven monofilament and nonwoven geotextiles to reduce hydrostatic pressure, facilitate sediment capture and prevent wash out from behind the structure.

Rip Rap

Rip rap consists of stone dumped in place on a filter blanket or prepared slope to form a well graded mass with a minimum of voids. Stone used for rip rap is hard, dense, durable, angular in shape; resistant to weathering and to water action; and free from overburden, spoil, shade and organic material. The rip rap material is generally placed on a gravel bedding layer and/or a woven monofilament or nonwoven geotextile fabric.

Performance of Erosion Control Materials

Several test procedures have been proposed to quantify performance of erosion control materials. Initial concern for vegetated systems is temporary erosion protection prior to and during seed germination and seedling development. Typically, this level of performance is measured by the material's ability to minimize soil loss when subjected to various flow rates and/or rainfall amounts. Temporary erosion protection is important but the long term goal of any vegetated erosion control matrix is to provide permanent erosion protection via permanent vegetation and/or subsequent root reinforcement. The more rapidly vegetation becomes established the more rapidly long term erosion control may be accomplished. Thus, the material's ability to facilitate vegetative establishment is equally important. Too much emphasis on an erosion control product's temporary protection may inhibit the growth of newly emerging seedlings.

Perhaps the most critical parameter in an engineering design is flow resistance before, during and long after vegetative establishment. Some erosion control materials may be washed away before the vegetation takes hold while others may temporarily exhibit excellent flow resistance only to lose their effectiveness as they degrade or decompose over time. Specifiers must take into account immediate and long term flow resistance based upon longevity of the material when designing grassed slopes and waterways.

Two basic design concepts are used to evaluate and define a channel configuration that will perform within accepted limits of stability. These methods are defined as the permissible velocity approach and the permissible tractive force (shear stress) approach. Under the permissible velocity approach the channel is assumed stable if the adopted velocity is lower than the maximum permissible velocity. The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between flowing water and the materials forming the channel boundary (Chen and Cotton, 1988).

The permissible velocity approach uses Manning's Equation where with given depth of flow, D, the mean velocity may be calculated as:

$$V = 1.49\, R^{2/3}\, S^{1/2}/n$$

where V = average velocity in the cross section;
n = Manning's roughness coefficient;
R = hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P; and
S = friction slope of the channel, approximated by the average bed slope for uniform flow conditions.

The tractive force approach uses a simplified shear stress analysis which is equal to:

$$\tau = \gamma DS$$

where τ = tractive force;
γ = unit weight of water;
D = maximum depth of flow;
S = average bed slope or energy slope.

Design criteria based on flow velocity may be limited because maximum velocities vary widely with channel length (L), shape (R), and roughness coefficients (n). In reality it is the force developed by the flow, not the flow velocity itself, that challenges the performance of erosion control systems. Tractive forces caused by flowing water over the ground surface create shear stresses which can be used as a design parameter independent of channel shape and roughness. Moreover, the higher stresses developed in channel bends or other changes in stream channel geometry can be quantified by simplified shear stress calculations, providing a higher level of design confidence than otherwise possible (Chen and Cotton, 1988).

Critical shear stress determinations are meant to be used with velocity calculations for prescreening of channel lining designs. Manning's Equation remains the primary hydraulic research and design tool. However, as everyday practice has determined, a simplified screening criteria such as maximum shear stress is necessary to ensure properly engineered design of channel lining erosion control systems. Figure 1 combines cumulative research for several erosion control materials and attempts to group categories of erosion control materials into their cost effective design niches (Theisen, 1992).

LONG TERM PERFORMANCE GUIDELINES

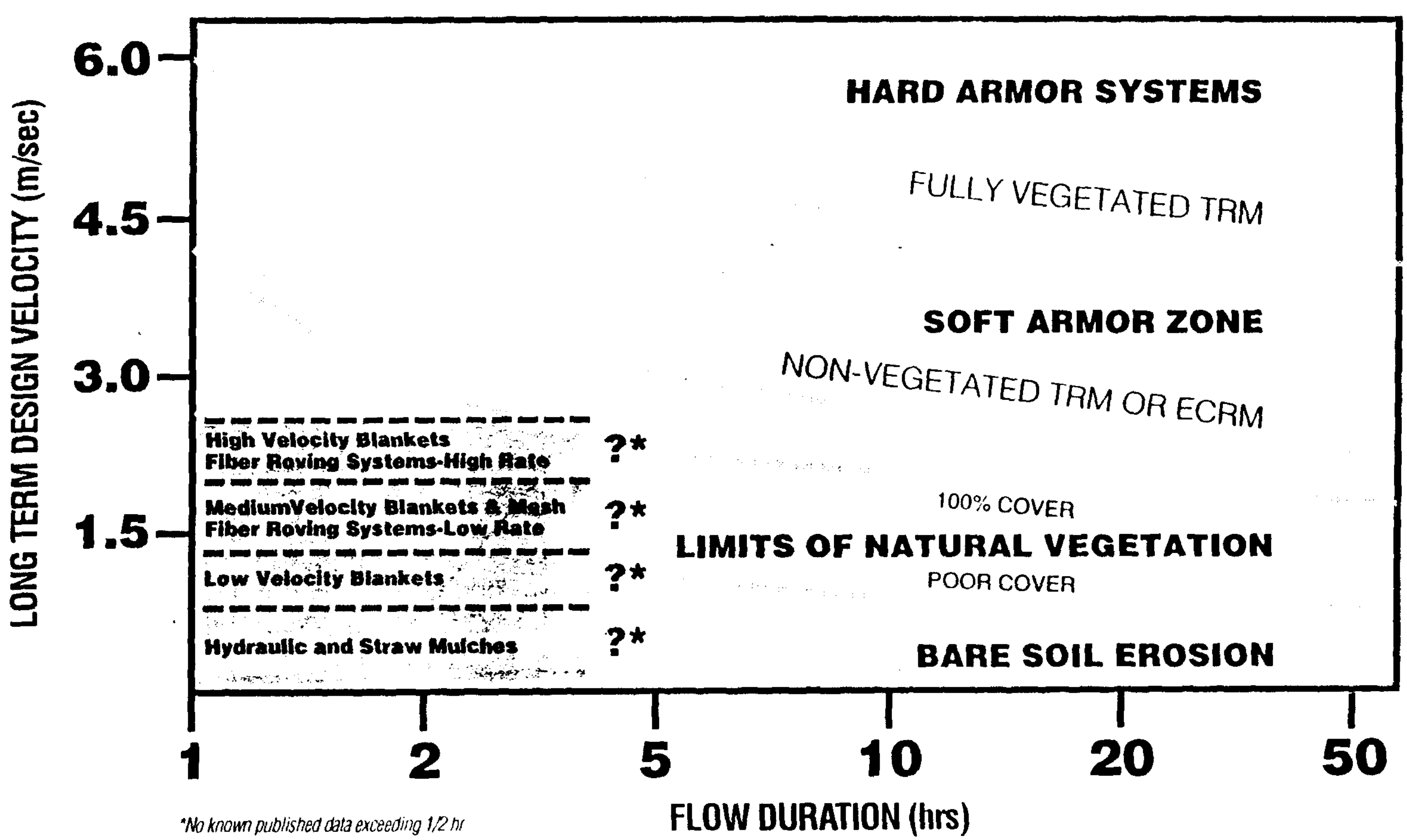

FIGURE 1

Maximum permissible velocities for vegetative techniques are illustrated under vegetated and non-vegetated conditions. Thus a designer will have performance guidelines from the time a material is installed to when it becomes fully vegetated. As additional data becomes available from field and laboratory analysis perhaps a design guide chart utilizing maximum permissible shear stress may be developed. The reader must be cautioned, velocity and tractive force are not directly proportional. Under certain conditions, a decrease in velocity may increase depth of flow, thereby increasing shear stress.

Flow Duration

Of key importance is the significance of duration of flow. Note from Figure 1 that allowable flow velocities decrease with flow duration. This is a critical point. Manufacturers of both organic, natural and synthetic erosion control products often express the erosion resistance of their materials in terms of maximum allowable flow velocity or permissible shear stress. Though unstated, these flow limits are typically for very short durations (minutes rather than hours). They do not reflect the potential for severe erosion damage that results from moderate flow events over a period of several hours. Ironically, many manufacturers, designers and users do not consider duration of flow when evaluating and selecting erosion control measures (Theisen and Carroll, 1990).

Typically, a major precipitation event will produce significant flow velocities with durations lasting hours or days . . . not minutes. The two day design duration was selected because in grass waterways, high velocity flow events should be no longer than about two days duration, following which grass recovery and subsoil drainage should be able to take place (Hewlett, Boorman and Bramley, 1982). As Figure 1 illustrates, duration of flow will reduce the erosion resistance of a grassed surface. It is critical that design of grassed waterways take this into account.

Flow values for the various temporary erosion control mulches, blankets, meshes and rovings have been truncated and placed into a gray area because extended flow duration trials for these materials have not been reported. Their long term performance may either go up or down as vegetation becomes established and ultimately will fall into the niche for natural vegetation as the product degrades. Short term performance of fully vegetated surfaces is impressive at nearly four meters/second. However, as duration of flow progresses, long term performance drops off sharply to two meters/second (six feet/second) with 100% vegetative cover to only one meter/second (three feet/second) with poor cover.

The "Soft Armor Zone" begins just above the limits of natural vegetation. Performance data for reinforcing mats ranges from unvegetated TRM's and ECRM's (which exceed performance of natural vegetation) to the upper curve which delineates maximum recommended design velocities obtained from field and laboratory evaluation of vegetated TRM's (Carroll, Rodencal and Theisen, 1991; Hewlett, Boorman and Bramley, 1987; Theisen and Carroll, 1990; Western Canada Hydraulic Laboratories, 1979; Hoffman and Adamsky, 1982; Theisen, 1992). Fully vegetated, geosynthetic mattings may withstand short term (1/2 hour) flow velocities of six meters/second and flow rates of in excess of four meters/second for durations of up to two days.

The upper end of the graph is comprised by the niche for hard armor materials. The graph is not intended to establish performance limits for these materials, but rather to define the upper limits of "soft armor" (reinforced vegetation). Performance for hard armor materials will be considerably higher and upper limits are beyond the scope of this paper.

Sediment Control

Going hand in hand with aggressive erosion control measures should be a well conceived sediment control plan. Erosion control measures are an offensive strategy to attack potential sedimentation while sediment control practices are a stop gap defensive strategy. In erosion and sediment control planning, the old sports axiom that a strong offense is the best defense is certainly apropos. Vegetation is clearly the finest sediment control product on the planet!

Geosynthetic silt fences have become a standard construction practice over much of the United States replacing straw and hay bales, brush layers and rock check dams. Silt fences are generally installed at the beginning of the construction project and usually consist of woven slit tape geotextiles mounted on prefabricated fence.

A well designed silt fence must initially screen silt and sand particles from runoff. A soil filter is formed adjacent to the silt fence and reduces the ability of water to flow through the fence. This leads to the creation of a pond behind the fence which serves as a sedimentation basin to collect suspended soils from runoff water. To meet such needs, the geotextile must have properly sized openings to form the soil filter and the storage capacity of the fence must be adequate to contain the volume of water and sediment anticipated during a major storm (Richardson and Koerner, 1990).

Porous sediment control structures are one of the newest geosynthetic approaches to sediment control. A three-dimensional moldable mass of crimped polypropylene fibers may be placed in rills or gullies to provide passive sediment control. Placed by hand with its size and shape determined by the installer, applications include rill and gully repair, ditch checks, sediment traps, and perimeter berming. Moreover, the fibers may be encapsulated in a polypropylene mesh to create prefabricated check dams for swale and ditch protection during new construction. Table 4 lists a few sediment control techniques.

TABLE 4
EXAMPLES OF SEDIMENT CONTROL TECHNIQUES

Vegetation

Straw and Hay Bales

Brush Layers

Silt Fences

Porous Sediment Control Structures (PSCS's)

Rock Check Dams

Sediment Traps, Basins and Ponds

The Importance of Geosynthetic Materials

While accurate numbers are difficult to come by, sales of erosion control products and services are estimated at $500 - $750 million per year (Northcutt, 1992). The Industrial Fabrics Association International (IFAI) estimates that during 1992, "organic" erosion-control materials (including mulches, mats, tackifiers and emulsions) will compose 55% to 65% of the erosion control industry. Synthetic mats will make up the remaining 35% to 45% of the total market of 65 million square meters (Jagielski, 1992).

Assuming a market share of 40% for synthetic mattings at an average selling price of $6.00 per square meter, sales of these materials would total $156 million per year. Considering only "organic" erosion blankets to comprise the remaining 60% of the market and selling at an average price of $0.60 per square meter, only $23 million in annual sales would be generated. Add the annual sales of erosion control geotextiles, fiber roving systems, fabric formed revetments etc. to the equation and the disparity becomes even larger.

Then consider all but two or three types of degradable blankets utilize geosynthetic components. At most only 10% of the "organic" side of the market really is completely organic. Accurate assessment of geosynthetic materials used for E & SC quickly becomes an extremely complicated endeavor. The author personally believes that market share of synthetic mattings is over estimated. The point is not to belabor numbers but to identify the expanding role of geosynthetics in erosion and sediment control. Without the plethora of "geo" materials available, the rapidly evolving E & SC industry would be pretty "slim pickins".

Other Geosynthetic Opportunities

Ideas for geosynthetic erosion and sediment control materials abound. Certainly new ideas have been omitted or are being developed at the time of this publication. Odds are high that geosynthetics will work their way down the ladder into more traditional applications such as hydraulic mulches and degradable erosion control blankets. Hydraulic mulch geofibers (which improve the tenacity of wood fiber and recycled paper mulches) and recycled plastic fiber blankets and mats have already entered the market. Geofibers are being used as part of sports turf systems in major athletic stadiums providing both ground stabilization and a root reinforcing matrix.

The future of geosynthetics for E & SC lies partly in the recycling of waste plastics generated from other applications. Polymer specifications for E & SC applications may not be as stringent as other geosynthetic materials such as geomembranes, geogrids and geotextiles. It's an environmentally friendly gesture in an environmentally friendly industry. And recycled plastics are cost effective.

The Resource Conservation and Recovery Act (RCRA, amended in 1984) requires the EPA to designate items which can be produced with recovered materials, then prepare procurement guidelines to assist Federal agencies in complying the Section 6002 of RCRA. Section 6002 requires that agencies using Federal funds to procure those items must revise their specifications and purchase such items containing the highest percentage of recovered material practicable. Currently, the EPA is studying the feasibility of developing procurement guidelines for construction products, including materials used as erosion control materials.

More research on erosion and sediment control effectiveness of the myriad of materials is mandatory. Questions regarding resistance to extended flow durations and long term performance for all materials must be answered. Systems must be developed for standardizing product descriptions, sanctioning uniform test and evaluation procedures, and creating a market reporting system to insure broad acceptance of E & SC industry. Organizations such as the International Erosion Control Association (IECA), Erosion Control Technology Council (ECTC), American

Society for the Testing of Materials (ASTM), Industrial Fabrics Association International (IFAI), and the Geosynthetics Research Institute (GRI) must lead the way.

Another hurdle to overcome or trail to blaze, depending upon how you look at it, is the issue of biodegradable plastics for short term applications. This is an area of very important research. Members of the industry as well as the general public must be educated. The performance advantages of man made fibers over natural fibers is recognized in many sectors of the textile industry. The E & SC industry is quite possibly a sleeping giant for man made fibers. Keep your ear to the ground and your eyes wide open because "you ain't seen nothin' yet". The future of geosynthetics in erosion and sediment control is bright!

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STREAM RESTORATION IN BOULDER, COLORADO

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ABSTRACT

Urbanization, gravel mining, and channelization cause major impacts to stream corridors. Flooding characteristics, water quality, aquatic and terrestrial habitat values, and stream channel stability are adversely affected by these activities. Like other cities, the City of Boulder, Colorado contains many reaches of altered stream channels. Numerous stream reaches pass through the city's busiest commercial areas and most densely developed residential neighborhoods, while other reaches remain relatively pristine. The City of Boulder has recognized that these streams provide unique opportunities for creating a comprehensive greenway system for the community. They can be creatively developed to function as storm drainage and flood channels, efficient bicycle and pedestrian transportation systems, open space and wildlife corridors, and attractive recreation areas.

Sensitively designed improvements enhance the value of each stream corridor as wildlife habitat, as a place for in-town opportunities for both active and passive recreation, as major links in both existing and proposed trails and bikeways, and as improved flood carrying channels.

This paper describes the rationale, approach, and progress by the City of Boulder in restoring its stream corridors.

(Paper not available)

SLEEPER MINE
TEMPORARY WETLAND ENHANCEMENT PROJECT

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ABSTRACT

A cooperative effort between the Nevada Department of Wildlife, the U.S. Bureau of Land Management, and Amax Gold Inc. has transformed a desert playa in northwest Nevada into a 3,500 acre wetland oasis for wildlife and livestock. Dewatering of the open pit operation at the Sleeper mine has afforded the opportunity to create a temporary resource that benefits the community, local ranchers, wildlife and the mine. The cooperative development of the temporary wetland was an in-depth education for all involved. Extensive studies of the hydrology of Desert Valley, hydro-chemistry of near surface groundwater and pumped water from deeper portions of the aquifer, soil chemistry, and geomorphology of the lake bed sediments were conducted prior to construction of the conveyance canal and ponds.

The actual design, permitting, construction and operation of the temporary wetlands drew on both mining and wildlife habitat management disciplines. Use of the temporary wetlands has exceeded the expectations of all involved; hopefully, other similar cooperative efforts will be initiated to maximize multiple use of public land.

INTRODUCTION

Cooperative Management of Mine Dewatering

The high-desert setting of Amax Gold Inc.'s Sleeper Mine, with it's shadscale/greasewood vegetation and desiccated alkaline flats, did not allude to the world class ore body beneath or to the huge volumes of near-surface groundwater. The discovery of the Sleeper Mine was a surprise to the buckaroos who pushed cattle and horses across the desolate miles of the Desert Valley located in northern Humboldt County, Nevada; but, the vast volumes of groundwater really astonished and baffled the experts.

The initial groundwater levels at the mine site were 9 to 12 m (30 to 40 ft), consequently requiring the drilling of dewatering wells in the pit and on the perimeter of the ore body to create a cone of depression for mining.

In order to achieve effective and efficient dewatering of the ore body, different approaches were evaluated; lowering the water table below the workings is typical of open pit operations and control of flow beneath the water table is common in underground mining and tunneling. The Sleeper deposit is currently being mined as an open pit operation, which requires interceptor wells, peripheral wells and in-pit wells to lower the water table. Initially, pre-drainage of the working area was accomplished with cutoff channels, collection ditches and drains and drain holes.

The successful dewatering system required a thorough understanding of the local geology, correct interpretation of hydrologic and engineering data, choice of the most cost-effective dewatering methods, efficient design, and optimum beneficial use of pumped water. Sleeper Mine's program blends a thorough understanding of high ground water permeability (high flow rates) of the alluvial material with a combination of interceptor and peripheral wells to achieve continuous dewatering of high wall gravels. Effective dewatering of the high wall gravels is critical to safe mining conditions. The progressive lowering of the water table as the pit is deepened and minimal drawdowns of the water table away from the mine has been accomplished by optimizing well siting by groundwater modelling.

Initially, the Sleeper Mine dewatering program was viewed as a source of process water with the remaining small volume to be infiltrated or reinjected in another portion of the valley. Dewatering began in April of 1985, with total pumped water volumes reaching close to 5,000 gallons per minute by the completion of the overburden stripping in the fall of 1985. As mining has progressed and a more refined understanding of the aquifer has been achieved, the volume of pumped water has increased and is projected to level off at approximately 20,000 gallons per minute.

Regional Groundwater System and Sleeper Mine Water Quality

Amax Gold Inc. entered into a cooperative agreement with the Nevada Division of Water Resources to partially fund a U.S. Geologic Survey (USGS) study of the groundwater resources of the Desert Valley and the affects of dewatering on the aquifer. By sharing data generated through operation of the dewatering program, Amax Gold is assisting the USGS in identifying the dominant aquifer units, regional flow patterns, impacts of dewatering on regional flow, groundwater storage and natural and induced recharge.

Coinciding with the USGS survey are water quality and hydrochemical studies at the Sleeper Mine. Continuous water sampling is necessary to thoroughly document pumped water quality and age, in addition to delineating variations in water quality within the region. Groundwater flow paths and estimations of water quality changes with time will enable Amax Gold to develop further strategies for the protection of the water resources and to identify post-mining conditions.

Beneficial Uses of Pumped Water

Discharge of the excess pumped water onto the desert playa for infiltration created a lush marsh area with extensive use by migratory waterfowl, terrestrial wildlife and livestock. The rapid conversion of desert vegetation to aquatic and wetland species (seeds brought in by waterfowl), unfortunately, reduced the open water, limiting the amount of suitable habitat necessary to optimize the propagation of waterfowl.

The Nevada Department of Wildlife (NDOW) approached the Sleeper Mine in the fall of 1988 with the request to make use of the excess pumped water, in conjunction with the Bureau of Land Management (BLM), and create a new and manageable wetland habitat for wildlife. Realizing 82% of Nevada Wetlands have been lost over the last 100 years, Amax Gold Inc. - Sleeper Mine entered into a cooperative agreement with the Nevada Department of Wildlife to engineer and construct the temporary wetlands in the center of Desert Valley.

Geotechnical investigation of the proposed site began in early 1989 and design engineering continued into 1990. The Cultural Resource Survey and Environmental Assessment were completed and approved in November of 1990, allowing construction to commence during the last week of November. The temporary wetlands project, located approximately 3½ miles west of the mine site, is jointly managed by NDOW and BLM to optimize the multiple use of the area resources. The new temporary wetland area consists of a conveyance canal and two separate shallow ponds with a combined total of 3,509 acres. Construction of pond No. 1 was completed and water introduced at the end of February, 1991, in time for the spring waterfowl migration.

Since completion of pond No. 1, numerous species have nested and raised broods. Construction was completed on pond No. 2 during the first week of September, 1991, and has provided additional open water during the fall migration.

An additional 2,000 acres of the original discharge area is proposed for use as pond No. 3, after an amendment to the Environmental Assessment is submitted and approved. The individual ponds will be utilized until approximately 50% of the water has been encroached upon by wetland vegetation. At that point, the pond will be dried up, the local ranchers' cattle allowed to graze the area, and the remaining stubble burned off before the water is re-introduced. Alternate use of the three ponds will allow for developing nesting habitat and maintenance of large areas of open water to ensure maximum utilization of the area by all types of migratory birds.

The Nevada Department of Wildlife has provided the following potential use pattern for waterfowl. This estimate does not include increased use by non-game birds, shorebirds, raptors, or passerines. Based upon previous records for the Quinn River Lakes, the area can probably be expected to provide for migrating populations of between 500 and 800 Canada geese and up to 200 whistling swans. Peak duck numbers during the fall and spring periods should vary between 10-15,000 birds consisting primarily of mallard, pintail, widgeon, green-winged teal, redhead and canvasbacks. Waterfowl use-days during the fall migration period will probably be between 600-900,000, if past records are any indication of expected use. This part of the state is seriously lacking in migration stopover points for waterfowl and the creation of a relatively stable area such as this is a significant asset for these birds. Currently, no such type of area exists on a regular basis in the far northwestern part of the state. In addition, since the area will be receiving warm water, there will be an increase in the number of wintering waterfowl in this part of the state.

So far, usage in the temporary wetland has exceeded NDOW's preliminary estimate of use-days. NDOW will conduct population surveys in the spring and fall of 1992 and provide a more accurate use-day estimate.

The number of shorebirds utilizing the new temporary wetland is phenomenal, with American Avocets, Black-necked Stilts, Killdeer, Plovers, Sandpipers, Ibis, Curlew, Godwits, Dowitchers and Egrets common throughout the spring, summer and fall. Raptor populations have increased significantly to include Golden Eagles, Red-tailed Hawks, Northern Goshawk, Kestrel, Swainson's Hawks, Prairie Falcons and a variety of owl species. Terrestrial animal populations have multiplied with increased numbers of Kit Foxes, coyotes and antelope, to mention but a few.

Amax Gold Inc. - Sleeper Mine and the Nevada Department of Wildlife have succeeded in making the temporary wetland a reality, due to the personal dedication of the staff and management of both entities throughout the three-plus years of the permitting process. Staff from the Nevada Department of Wildlife were instrumental in convincing and uniting all of the government agencies to the merits of the temporary wetland project.

Although Amax Gold Inc. - Sleeper Mine and NDOW are the principle parties involved in the project, the cooperation between other state and federal agencies involved has been extraordinary. The Winnemucca District of the U.S. Bureau of Land Management, the Nevada Divisions of Water Resources and Environmental Protection, U.S. Fish & Wildlife Service, and U.S. Geologic Survey are all cooperators and have a bona fide interested in the systematic development of the temporary wetland area. Conversion of vegetation from desert shrub to aquatic-marshland species, water quality data, and aquifer recharge quantity and quality data are just a few of the areas these agencies are evaluating.

The Sleeper Mine Temporary Wetland Enhancement Project will have a tremendous impact on the propagation of wildlife in the Desert Valley, increased grazing for livestock in the area, and provide the public with associated recreational uses. Culmination of the project is the result of numerous state and federal agencies cooperatively working with private industry for a project that will benefit the entire State of Nevada. The project is a winner for everyone involved.

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STORMWATER MANAGEMENT IN SOUTH LAKE TAHOE, CALIFORNIA USING VEGETATIVE AND ENGINEERING SOLUTIONS

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Introduction

Lake Tahoe is famous for the clarity and purity of its water. It is one of the clearest lakes in the world. Yet, over the past 20 years, the transparency of its waters has been declining at the rate of 1-1/2 feet per year. In other words, a visitor to the lake today can see about 30 feet less far down into the water than he or she could 20 years ago. During this same period, the measured growth rate of algae in the lake has more than doubled.

Much of this decline in water quality is due to the effects of land development. When land is disturbed for road building or construction, the erosion rate increases from two to 2,000 times the natural rate. It has been estimated that the amount of sediment now entering Lake Tahoe each year is 20 times above the natural rate. The eroded soil contains a mixture of nitrogen, phosphorus, iron, and other nutrients that stimulate algae growth, which is directly responsible for the diminished clarity of the lake.

The Tahoe Valley Erosion Control Project is one of many projects designed to reduce the discharge of sediment and nutrients to Lake Tahoe. It was funded by the California Tahoe Conservancy, a seven-year-old state agency which protects and restores environmentally sensitive lands on the California side of the Tahoe Basin. In 1986 the Conservancy gave the city a grant of $249,000 to buy privately-owned land along the Tahoe Valley drainageway, and, in 1987, a grant of $405,000 to construct the project.

As a local government, the city's primary concern was providing adequate storm drainage to protect life, limb, and property. The city also wanted to minimize maintenance costs. The primary objective of the funding and regulatory agencies was to prevent sediment and nutrients from reaching Lake Tahoe. In addition, the agencies wanted to preserve and restore riparian areas and to make the drainage improvements aesthetically appealing. As with most erosion control projects in the Tahoe Basin, this dichotomy of objectives created conflict throughout the implementation of the project.

Site Description

Tahoe Valley is a heavily urbanized area in the City of South Lake Tahoe, located near the intersection of U.S. highways 50 and 89 (Figure 1). The watershed is 838 acres, of which approximately 250 acres are commercially and industrially developed, with up to about 90% hard coverage (referred to as "Industrial" on Figure 2). The upper watershed contains steeply-sloping, forested land. At the base of the slopes is a large expanse of pavement where the city's industrial park, a trailer park, a shopping center, and other commercial development is located. This area is drained by a conventional storm drain system, consisting of curb and gutter, drop inlets, and underground pipe. A 48-inch pipe collects the runoff from the industrialized and forested portions of the watershed and discharges it into a natural riparian area that runs through the city. Such areas are referred to in the Tahoe Basin as "stream environment zones" or "SEZs." Portions of this stream zone are still natural-looking, containing a dense cover of native and introduced riparian plants. Other portions of the stream zone have been channelized to convey storm flows through the residential lower watershed and prevent flooding of adjacent homes. Most of the channel is still earthen, but one section, through a power company corporation yard, was paved with asphalt, and there are culverts at all the street crossings. Below Tahoe Island Drive, the channel has open space along both sides of it, but it is confined in a ditch about four feet deep. Most of this section of channel is stable, except for a few bare outside bends and some scour holes. The channel eventually drains into Tallac Lagoon, a constructed water body behind the Tahoe Keys development. The lagoon, which suffers from algae blooms and stagnation, drains into Pope Marsh, located on the shore of Lake Tahoe. During wet years, the marsh overflows into the lake. At other times, there is only a connection through groundwater.

Design Issues

A variety of design issues were debated during the design process, including location of the channel, type of channel lining material, use of pipe versus open channel in urbanized areas, grass seeding versus salvage and re-establishment of native plants, and sediment basins versus restored wetlands.

Determining the location of the channel and the drainage easements to purchase was a major issue. In the area between Tata and Glorene (Figure 2), the channel passes between two closely spaced homes, then cuts across several backyards. The flooding which has occurred in this area had prompted property owners to construct berms to keep the water away from their homes, driveways, and parking areas. Although the agencies involved in the review process (the Conservancy, the Tahoe Regional Planning Agency, and the Lahontan Regional Water Quality Control Board) desired to maintain the existing stream zone wherever possible, the city and its engineer consultant sought to re-route the stream along property lines. This approach would give the owners maximum use of their property, but would require piping and riprapping the channel, and forcing it to make a series of 90 degree turns. Through an iterative process of plan review and revision, the piping and riprapping were eliminated and the stream was left to follow its natural

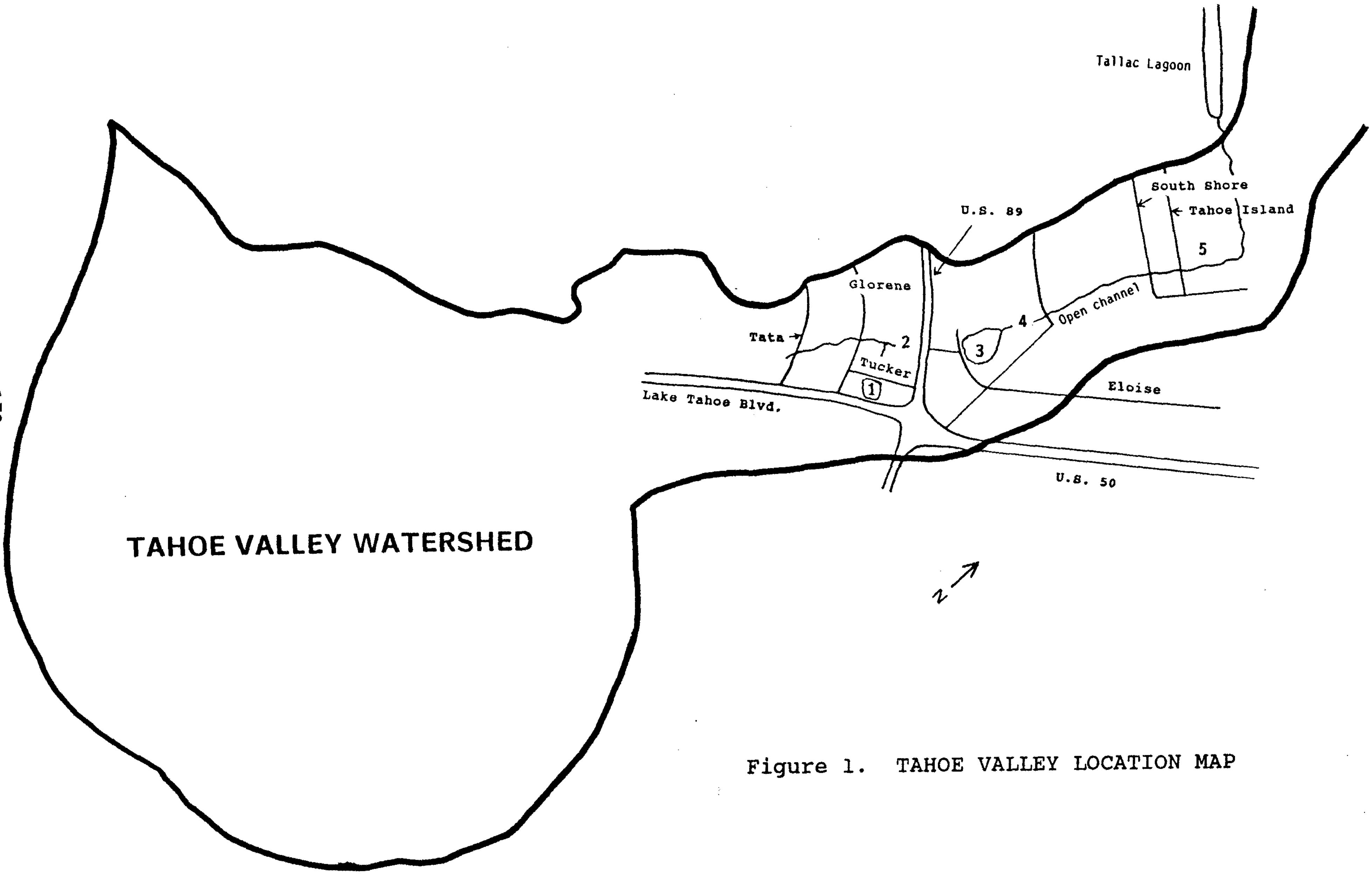


Figure 1. TAHOE VALLEY LOCATION MAP

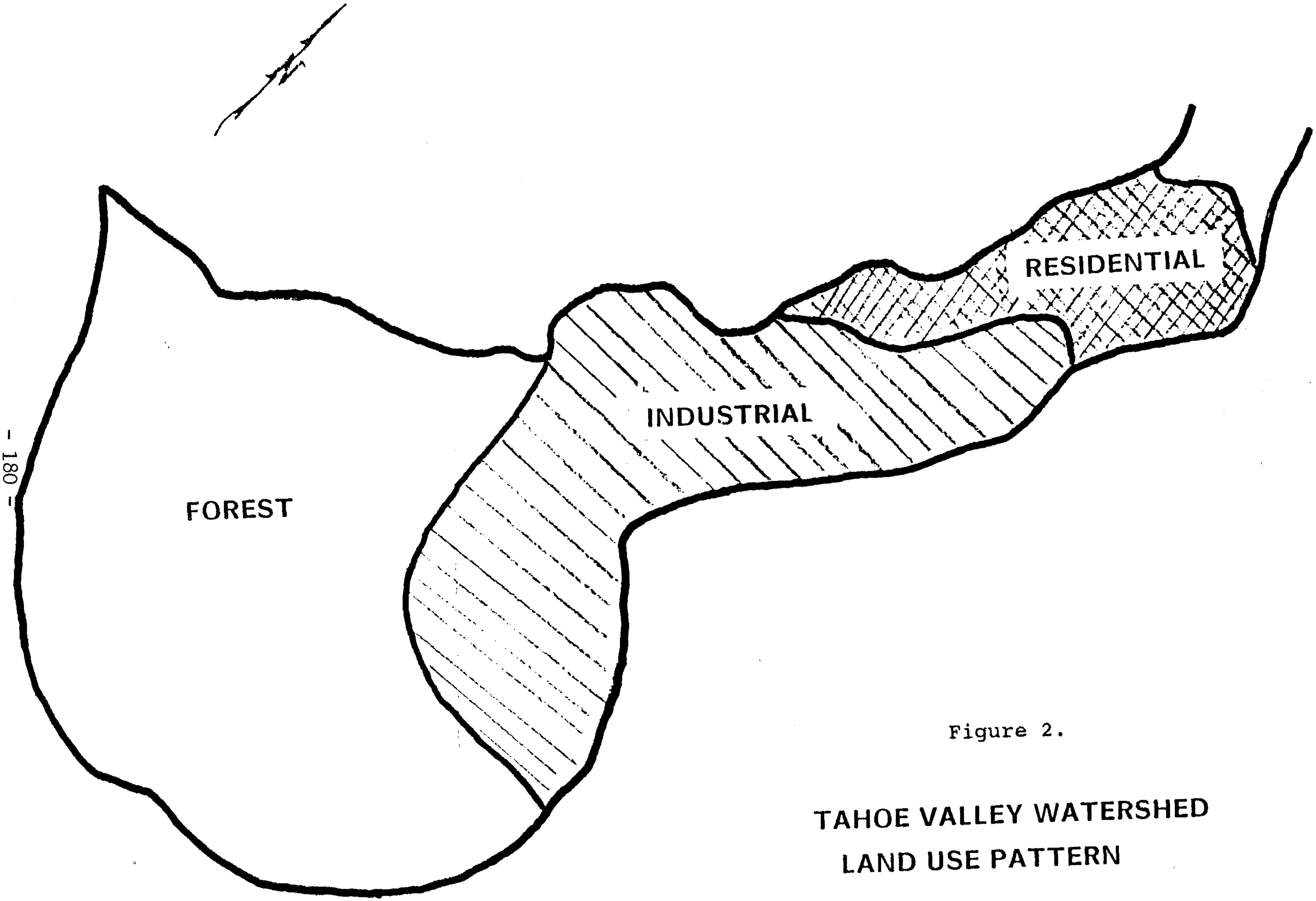


Figure 2.

TAHOE VALLEY WATERSHED
LAND USE PATTERN

course. Vegetative treatments were substituted for rock linings, except at culvert outlets.

The city proposed to create sediment basins at two sites along the drainageway. Both sites were low-lying areas which were prone to flooding and contained wetland plants. The Tucker Street site (#1 on Figure 1) was about three-fourths of an acre and the Eloise Avenue site (#3 on Figure 1) was slightly over an acre. The city wanted the basins to trap sediment to keep the downstream portions of the channel clean. Thus, the city initially proposed excavating the basin sites, then seeding them with grasses. The agencies wanted, in addition to trapping sediment, to absorb nutrients and restore wetlands.

To meet these objectives at the Tucker basin site, earth berms were proposed around the basin to allow it to retain more water and to avoid excavation, which would disturb the existing plant cover on the site. In contrast, the Eloise basin required excavation to remove fill that previously had been deposited on the site. Much of the Eloise site was unvegetated or was covered with non-native grasses. Native wetland plants were located in one small area on the site, and this area was targeted for salvage prior to excavation. The Eloise basin also required excavation to allow it to store more runoff, since it was located on the main channel, as opposed to the Tucker basin, which was on a small tributary channel.

The most critical erosion area on the site occurs where the stream channel crosses Highway 89 (#2 on Figure 1). This area is about 500 feet downstream from the point where the 48-inch culvert from the industrial area enters the channel. The critical factor is the elevation of the bottom of the highway culvert, which is about three feet below the elevation of the natural stream zone. As the water approached the culvert, it dropped three vertical feet over a short distance, causing severe gullying. One hundred feet upstream of the culvert, the principal drainage path through the stream zone has a cross-section about two feet wide and one foot deep. During high flows, the entire stream zone becomes flooded, and there are several small flow paths through it of similar size. However, in the last 100 feet to the culvert, the main channel enlarged to a gully about three to four feet deep and three to four feet wide.

The original design for improvements in this area called for a rock cascade leading into a rock- and willow-lined basin in front of the culvert. The theory behind this design was to drop the elevation of the water quickly, over a short horizontal distance protected by rock, then to have a settling area before the culvert entrance.

However, a few months prior to construction, this section of the project was re-designed according to the teachings of Dave Rosgen, a prominent stream restoration specialist. The rock cascade was left as proposed, but the basin was eliminated. In place of the basin, a two-tier drainageway was designed, consisting of a shallow low-flow channel meandering down the center of a level floodplain. The low-flow channel was two feet wide, and each half of the floodplain was three feet wide, making a total width of eight feet (conveniently, the same width as a front-end loader bucket). This design is based on the assumption that during low flows, water will be confined in the small channel, but during high flows, the water will rise and spread across the floodplain. Because the floodplain is wide and well vegetated, water should flow at a slow, non-erosive velocity.

Construction

Reconstructed channel and floodplain (site 2)

The new floodplain channel at site 2 was constructed by carefully lifting blocks of native sod from the stream zone and storing them on-site while the channel was excavated to the designed width and depth. The channel bottom was given a slope of about 0.8% over the 100 feet approaching the culvert. Then blocks of sod were placed on either side of the channel center line to form a vegetated floodplain with a two-foot-wide low-flow channel in the middle. The sod pieces were carefully fit together, with gaps chinked in with native soil or small sod plugs to create a continuous, stable surface.

On either side of the new floodplain was a vertical cut bank about 1-1/2 to 2 feet in height, which required some protection from erosion. Since the top portion of sod is more resistant to erosion than the sides of the root mass, the sod on top of the bank was collapsed at an angle using the following technique. A small, horizontal trench was cut into the base of the bank with a square-point shovel, just above the surface of the new floodplain. Then, the sod above the bank was forced downwards at an angle by stomping on top of it. Then the sod was anchored with six-inch staples.

The outside curves of the new channel were armored with willow brush matting. Willow brush matting also was used to protect unvegetated portions of the channel banks below Tahoe Island Drive. If properly constructed, the willow will root from top to bottom of a bank, along the entire length of the cuttings. The willow thus will provide long-term stability for the entire bank. Willow brush matting has been used very successfully along other creek banks in the Tahoe Basin.

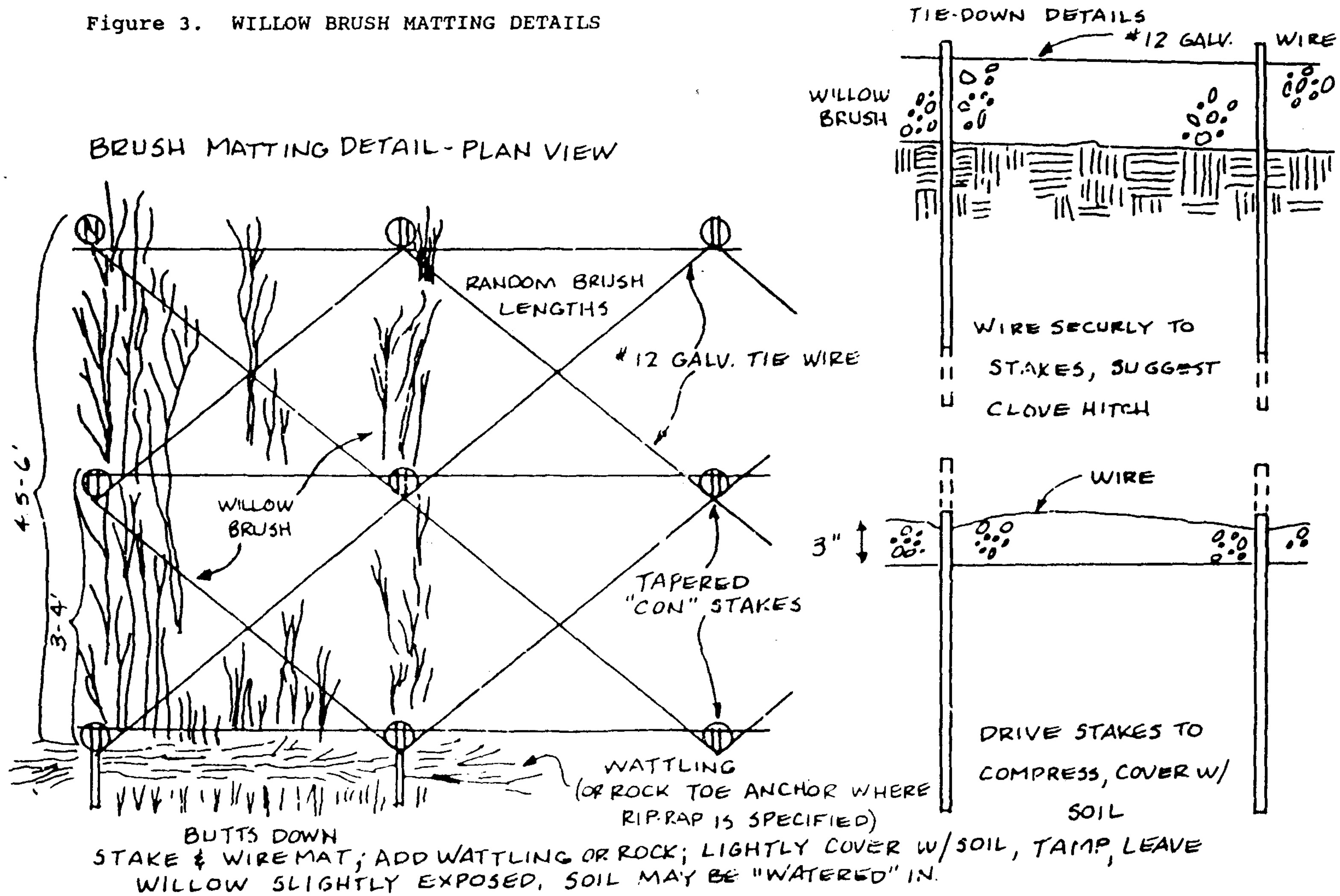
The matting consists of a dense cover of willow branches (Figure 3). The branches are cut to the height of the bank and placed with butt end down in a footing trench at the base of the bank. The trench is covered with rock or willow wattling to hold the butts in place. Rock was the preferred alternative in this case, since a heavy growth of willows in the channel bottom can cause debris jams. Wood stakes are pounded into the bank through the willow brush, and wire is wrapped around the tops of the stakes and strung from stake to stake. When the stakes are hammered further down, the wire draws the brush tightly against the ground. Finally, soil is placed over the top of the brush to cover it, which helps the willow to root.

Remaining areas of disturbance were seeded with a native mesic-hydric mix including Tufted hairgrass (Deschampsia caespitosa), 'Pennlawn' Red fescue (Festuca rubra), 'Sherman' Big bluegrass (Poa ampla), Kentucky bluegrass (Poa pratensis) and 'San Luis' Slender wheatgrass (Agropyron trachycaulum). This mix was applied throughout the project area. Fertilizer was not used. Following seeding and raking, straw mulch was applied at 1.5 tons/acre and anchored by hand punching and tackifying with an organic glue.

Sediment basins/wetlands (sites 1 and 3)

The techniques used to construct the basins at Tucker Street and Eloise Avenue were very similar. Before construction of the Tucker

Figure 3. WILLOW BRUSH MATTING DETAILS



basin, native sod that would have been covered by the berms was salvaged and stored on a nearby lot. Branches were removed from willows at the berm locations, and these were saved for later use throughout the project. A low-flow channel through the basin was hand dug, after salvaging native sod. Surplus fill from excavating the Eloise basin then was used to create the berms around the Tucker basin. The salvaged sod was divided into four-inch diameter plugs and was planted on one foot centers. The sod was concentrated near the basin outlet, where the most erosion and wetness was anticipated. Willow cuttings then were planted in between the sod plugs. Willows salvaged from the Eloise basin excavation were planted in the berms for stabilization, screening, and aesthetics. The remaining disturbed areas were seeded and mulched, then anchored with an organic tackifier. Native containerized stock (Aspen, Chokecherry, Woods rose, Lemmon's willow, and Creek dogwood) were planted in clusters according to the species' water requirements. Slow release fertilizer (17-7-12) was placed in the planting holes before planting.

The Eloise basin was planted late in the fall, requiring some modifications to the specifications and the order of work. Salvaged sod was planted in continuous blocks along the low-flow channel and around the basin inlet. It was felt that smaller plugs would not become established so late in the growing season (ground freezing was beginning to occur), and would be more likely to be uprooted during high flows. Seeding and mulching was not completed due to the onset fall storms, which brought snow. Revegetation of the basin was rescheduled for spring, and irrigation will be required throughout the growing season. The Conservancy has requested that additional wetland plants, vegetatively propagated from native wetland species, be planted throughout the basin, as was called for in the original specifications.

Channel stabilization (sites 4 and 5)

After exiting the Eloise basin through a corrugated metal pipe, the channel traverses a power company's storage yard. The channel was originally lined with asphalt, but to allow more treatment of runoff, as requested by the regulatory agencies, the asphalt was removed and the side slopes were laid back to about 1.5 to 1. Two-to-one slopes had been specified in the plans, but due to a miscalculation, this slope could not be achieved without removing a significant portion of the pavement in the storage yard. The re-shaped channel was seeded with a standard grass mix, then covered with a heavy duty excelsior blanket. Since the channel made an almost 90 degree bend before exiting the yard, riprap was used to armor the outside of the curve.

Below the storage yard, the channel crosses a parcel owned by the Conservancy. This portion of the channel will be restored in 1992, as a separate project.

The remaining portion of the channel, below South Shore Drive, was re-graded where needed and stabilized using hand labor and native materials. Willows growing within the channel that had caused debris jams were cut to their bases, but left in place so as not to further de-stabilize the channel. The remaining cut stems then were hand painted with concentrated glyphosate herbicide. These willow clumps may require application of more herbicide in the spring, since they were almost dormant when treated, and thus unlikely to be killed by the herbicide.

Overhanging banks were undermined by hand digging, and the sod was collapsed to reduce the slope and armor the banks (similar to what was done at site 2). Several sections of bare channel bank were stabilized with willow brush matting or by seeding and covering with excelsior blanket. Unfortunately, fall storms prevented completion of this work.

Results

On October 26, 1991, Tahoe Valley experienced a very heavy rainstorm. About 3-1/2 inches of rain fell in a 12-hour period. At the time, the new floodplain channel had been completed only three weeks before, revegetation work was nearing completion in the lower channel, and the Eloise basin and storage yard channel had not been revegetated or mulched.

The floodplain channel worked reasonably well, but some damage occurred there. Discharge from the 48-inch pipe flooded the stream zone and water flowed in several small channels across its full width. When these small channels reached the banks of the new floodplain channel, the water plunged downwards two to three feet in a horseshoe-shaped waterfall and at several points where there was no rock to protect the banks. The result was gullying of the bank at one location and undercutting of the willow brush matting at another spot. Where the water came over the side of the rock cascade at one end of the horseshoe, some scouring occurred behind the rocks at the top of the bank. At the center of the waterfall, which was also the apex of the rock cascade, about two linear feet of rock was displaced downstream. The rocks that moved were up to about six inches in diameter.

Another gullying problem occurred next to the highway, where unaccounted for roadside drainage from a small section of highway and adjacent commercial areas entered the stream zone and flowed down to the new channel. Part of the filled and seeded area on top of the bank was gullied, which will require smoothing and reseeding after the roadside drainage is properly controlled.

The Tucker basin performed well. It filled with water during the storm, and the water exiting through the riser outlet was running clear. The Eloise basin was another story. The basin had not been revegetated or mulched, loose soil had been stored inside it, the riser was missing its top section, and the surface area of the basin was too small relative to the inflow to trap small soil particles. As a result, the water leaving the basin was very turbid. The basin drained directly into the earthen channel through the power company storage yard, which had not been seeded or blanketed at that time. Significant erosion occurred in the channel at this location.

It should be noted that a basin similar to the Eloise basin, which was constructed in the City of South Lake Tahoe in 1988 and 1989, has performed extremely well. The bottom of that basin (at Sierra Boulevard and Chris Avenue) now supports a nearly 100 percent cover of sedges, rushes, and other native wetland plants. The willow clumps that were transplanted around the basin perimeter are thriving, and the appearance of the basin has been greatly enhanced by their presence.

The lower portion of the channel, below Tahoe Island Drive fared reasonably well, except for pockets of scour near grade breaks in the channel bottom. Most of the willow brush layering and erosion control blanket remained intact. However, some of the transplanted sod was displaced, because of lack of establishment or inadequate anchoring with staples. In addition, much of the sod had not been properly watered and was in poor condition prior to the storm. Thus, it was particularly susceptible to damage during high flows.

Additional work already has been proposed to address the problems that have been observed this winter. The entire project will be evaluated in the spring after snowmelt. Following the evaluation, the Conservancy will work with the city to design and install further improvements.

Conclusions

The following conclusions can be drawn from our experience with the Tahoe Valley project and other similar projects:

1. Project participants, including sponsor, designer, and funding and permitting agencies need to agree, preferably in writing, on a project's objectives before design begins. The permitting agencies should state, in no uncertain terms, what the bottom line is for approval. In the case of the Tahoe Valley project, the bottom line was no pipe through the stream zone. But the firmness of this position did not become clear until after draft plans had been prepared.

2. The designer should have a thorough understanding of a watershed's characteristics before beginning design work. A stream through an urbanized area like Tahoe Valley is neither a natural stream nor a flood control channel. It exhibits some elements of both types of systems and varies from reach to reach. The designer needs to know not only the peak flow during a major storm event, but typical flows that occur on a yearly basis, since these frequent flows will shape the low-flow portion of the channel. A channel which is designed only to handle a flood may be unstable during lower flows. Abrupt changes in elevation of the channel, particularly where culverts are located, are critical points which require careful consideration. Merely armoring culvert inlets and outlets and other erosion spots usually will not cure an erosion problem. The problem will be transferred somewhere else.

3. Timing is critical for a project that requires establishment of vegetation for stability. Planting must be done early enough so that plants can become established before erosive storms typically occur. In the Sierra Nevada mountains of California, the best planting time is spring or early summer. Little precipitation occurs in summer and early fall storms tend to be light. However, by late October, the probability of an erosive storm occurring is high. At Tahoe Valley, disagreements over design issues caused delays in completing plans. As a result, the project was bid in mid-summer and construction extended into November, so that the site was not stable before heavy rains occurred.

4. Stabilizing bare soil should be a top priority when construction is conducted late in the season. At Tahoe Valley, pipe installation was given priority over revegetation and mulching, which led to erosion that could have been avoided.

5. Salvaging and re-establishing native plants is effective and beneficial, both from a water quality and an aesthetic standpoint. Additional plants may be required, especially if planting is not done at the optimum time of year.

6. Full-time supervision is required of the erosion control, revegetation, and restoration portions of projects such as the Tahoe Valley project, particularly when work is performed in riparian areas. Few contractors are experienced with the techniques employed in this and similar projects, and they cannot be expected to complete a satisfactory job without assistance from a revegetation specialist. In addition, site conditions may dictate alterations in project specifications. Project owners, designers, and contractors must be flexible, within contracting limits.

7. Post-construction inspections are essential to ensure project improvements are working properly. Inspections should be made during or immediately after major storms. A portion of a project's funds should be reserved for follow-up work, so that necessary corrective work can be be designed and implemented as quickly as possible.

NEARLY THREE YEARS AFTER THE SPILL: AN UPDATE ON THE CONDITIONS IN ALASKA

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ABSTRACT

The tanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound, Alaska on March 24, 1989. The result was a spill of nearly 11 million gallons of crude oil, some of which moved through Prince William Sound into the Gulf of Alaska, oiling shorelines in the western Sound, along the Kenai Peninsula, and in the Kodiak Island area.

Under the direction of federal and state authorities, Exxon initiated and continued intensive cleanup activities during the months of April through mid-September of 1989, in 1990, and in 1991. Additional work may be done in the summer of 1992 if conditions warrant it. This cleanup was the largest and most expensive oil spill cleanup program ever done in the world.

Ecological recovery is well under way in areas impacted by the spill, thanks to nature's own cleansing power and man's efforts. Much has been learned about how to prevent and respond to such an event in the future.

(Paper not available)

NOMINATIONS TO THE NATIONAL PRIORITY LIST - WHAT DOES THE EPA'S MASSIVE OVERHAUL OF THE HAZARD RANKING SYSTEM MEAN TO YOU?

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ABSTRACT

You have just learned that the Environmental Protection Agency (EPA) plans to investigate your property to decide whether it should be a Superfund Site, i.e., placed on the National Priorities List. Is there anything you can do? Is it already too late? How does the EPA decide whether to place your site on the National Priorities List?

Must there be an actual release before your site can be placed on the National Priorities List? Does the EPA have to consider current conditions in evaluating your site or only the initial conditions? Will the EPA use all available data in evaluating your site? How are large volume waste sites, e.g., mining waste sites, evaluated?

What are sensitive environments? What is a surface water? Is a fishery a place where the fish are actually caught? What is an intense or concentrated spawning area? What is a maximally exposed individual? Do people actually have to drink from a water body before it can be considered a drinking water source? What is an observed release of hazardous substances? Finally, how does the recently revised Hazard Ranking System actually work?

This paper will address these questions, as well as others which have arisen due to the EPA's recent revision of the Hazard Ranking System.

INTRODUCTION

Under the Superfund law,1 the EPA can list sites2 on the Superfund list (National Priorities List3 (NPL)). This can literally determine the survival of the public or private entities, as well as the economic survival of individuals. It can mean the difference between thousands or millions of dollars (or possibly even billions as is currently being discussed with the Rocky Mountain Arsenal).

Recently, because of the Superfund Amendments and Reauthorization Act of 1986 (SARA)4, the EPA promulgated final regulations5 (hereinafter referred to as the "Final Rule") in which it revised the HRS (Revised HRS). SARA required the HRS to be amended so that it "assure[d], to the maximum extent feasible, that . . . the relative degree of risk to human health and the environment posed by sites and facilities subject to review"6 was accurately assessed.

The purpose of this paper is not to go through the HRS in detail. Rather, it is to explain that an understanding of the Revised HRS may allow a potential NPL site owner/operator to influence whether or not a site is placed on the NPL.

Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)7 (commonly known as Superfund), Congress required the United States Environmental Protection Agency (EPA) to determine priorities among releases8 or potential releases of hazardous substances9 using established criteria.10 The criteria were to be based upon the relative degree of risk to human health and the environment posed by the releases or
potential releases.

To meet this priorities requirement, the EPA developed a scoring system, the HRS,11 which it uses to determine whether sites should be placed on the NPL. The HRS was designed so that it could be uniformly applied to sites in order that they could be evaluated relative to each other.12

SARA REQUIREMENTS

As mentioned, SARA required that the Revised HRS accurately assess sites "to the maximum extent feasible." The EPA has interpreted this provision as one which allows it to evaluate a site based solely upon preliminary assessments and site investigations.13 Specifically, in the preamble to the proposed rule to revise the HRS14 (hereinafter referred to as the Proposed Rule), the EPA quoted the Congressional Conference Report, which provides that:

> This [provision] does not [] require the [HRS] to be equivalent to detailed risk assessments . . . such as might be performed as part of remedial actions. The standard requires the [HRS] to rank sites as accurately as the Agency believes is feasible using information from preliminary assessments and site inspections * * *. [Additionally,] this [provision] does not require long-term monitoring or an accurate determination of the full nature and extent of contamination at sites, or the projected levels of exposure, such as might be done during remedial investigations and feasibility studies. [Rather, t]his provision is intended to insure that the [Revised HRS] performs with a *degree of accuracy appropriate to its role in expeditiously identifying candidates for response actions* . . . .15 (Emphasis in original.)

As will be discussed below, the EPA's incorporation of this provision into the Revised HRS may have a substantial impact on a site's evaluation, and possible score, under the Revised HRS.

SARA also focused on surface water and drinking water contamination. Specifically, SARA required the EPA to accurately assess:

> the human health risks associated with the contamination or potential contamination (either directly or as a result of the runoff . . . from sites or facilities) of surface water . . . where such surface water is, or can be, used for recreation or potable water consumption. In making th[at] assessment . . . the [EPA was required to] take into account the potential migration of any hazardous substance or pollutant or contaminant16 through such surface water to downstream sources of drinking water.17

Additionally, SARA required the EPA to "give a high priority to facilities where the release of hazardous substances or pollutants or contaminants ha[d] resulted in the closing of drinking water wells or ha[d] contaminated a drinking water supply."18 Further, SARA required the HRS to include a method to assess the "damage to natural resources which may affect the human food chain . . . [as well as] the contamination or potential contamination of the ambient air."19

Before turning to how the EPA incorporated the SARA requirements into, and the specific revisions which the EPA made to the Revised HRS, it is important to briefly discuss how a site gets to the point of having the Revised HRS applied to it.

PRE-RANKING

If a site is to be placed on the NPL based upon its HRS score,20 the EPA must first conduct a preliminary assessment and a site investigation of the site. Preliminary assessments are site studies which are meant to give a complete picture of the site using existing information.21 This information is typically obtained from local or state governmental records.22 Based upon the preliminary assessment, the EPA will decide whether the site needs further investigation.23 If so, the EPA will initiate a site investigation.

One of the site investigation's purposes is the collection of "sufficient data to enable the site to be scored using the HRS."24 The data collected during the site investigation is data which can be incorporated into the HRS based upon a single visit, or which is otherwise readily available.25 Basically, the site investigation augments the data collected during the preliminary assessment with sampling of appropriate media and wastes at the site.26 Based on the site investigation data, the EPA will determine whether or not to apply the HRS to the site. If the EPA decides to apply the Revised HRS to a site, both the site investigation and preliminary assessment data will be used.

THE REVISED HRS

Basic revisions

Although the EPA kept the original HRS's basic structure, it made substantial changes to particular areas.27 Specifically, every factor in the revised HRS is either new or has been modified. In some instances, the modification is substantial. Additionally, under the original HRS,28 a site was evaluated based upon five pathways: air, ground water, surface water, direct contact, and fire and explosion. Under the Revised HRS, a site is now evaluated based on only four pathways: air, groundwater, surface water (the three migration pathways), and soil exposure (a new exposure pathway).

Structure of the Revised HRS

Each pathway is made up of different factors.29 Factors, which are the "primary rating elements internal to the [Revised] HRS,"30 are divided into the same three categories for each pathway: (1) likelihood of release for the three migration pathways (or likelihood of exposure for the soil exposure pathway), (2) waste characteristics, and (3) targets.31

Likelihood of Release (or Likelihood of Exposure) Category:

The likelihood of release category is a measure of the likelihood that a site has or will release hazardous substances to the environment.32 Similarly, the likelihood of exposure category (for the soil exposure pathway) is a measure of the likelihood that either people or sensitive environments will be directly exposed to "wastes and contaminated surficial materials at a site."33

Additionally, the likelihood of release category is composed of two components, only one of which will be evaluated for each pathway: (1) observed release, (i.e., "has been" a release) or (2) potential to release (i.e., "likelihood that there will be" a release). Observed releases always result in a higher score than potential to release.34 The likelihood of exposure category is only evaluated based upon observed contamination; there is no component for potential to release.

Waste Characteristics Category:

The waste characteristics category is made up of two components which measure the hazardous wastes (or hazardous substances) at a site. Those two components are (1) hazardous waste quantity (which will be discussed below) and (2) a combination of toxicity, ecosystem toxicity, persistence, bioaccumulation, and/or mobility factors.

Targets Category:

Within the targets category, a site is evaluated based on four primary factors: (1) human individuals (this factor name varies by the pathway and threat), (2) human population, (3) resources, and (4) sensitive environments (this factor applies to all pathways except the groundwater pathway)35.

Scoring a site:

On a pathway by pathway basis, the values for each of the three categories are multiplied together and the product is divided by a constant figure; this results in the particular pathway's score. This is done for each pathway evaluated at a site. Based upon the pathway's scores, an HRS score for the site is calculated.36 It is important to note that any one pathway can cause a site to score above the cutoff level of 28.5, which the EPA uses to determine whether a site should be placed on the NPL. Therefore, depending upon a pathway's score, it may be unnecessary to evaluate the other pathways. This is in part due to the fact that the Revised HRS is not intended to be the equivalent of remedial investigations and feasibility studies, but rather is to be used as a tool to determine whether a site warrants further investigation.37

Major Changes in Revised HRS

As previously mentioned, every factor in the Revised HRS is either new or is in a substantially revised form from the old HRS. While it is beyond the scope of this paper to discuss each of those revisions, there were a substantial number of major revisions which can or do have a dramatic impact upon a site's score.

Among the revisions which will be discussed in this paper, however, are: consideration of removal actions; using a tiered approach to determine a site's hazardous waste quantity factor38; addition of dilution and distance weightings to the groundwater and surface water pathways; additions to the sensitive environments' list; addition of factors for evaluating maximally exposed individuals; addition of a human food chain threat to the surface water pathway; consideration of potential to release factor within the air pathway; addition of benchmarks for evaluating actual or potential contamination of targets; and inclusion of a new on-site exposure pathway.39

Clarification of Information to be Used in the Revised HRS

In the preamble to the Final Rule, the Agency stated that while it was required to amend the HRS to assure "to the maximum extent feasible, that the [HRS] accurately assesses the relative degree of risk to human health and the environment,"40 there are limitations on what information it must consider. Specifically, it cited the Congressional Conference Report on SARA for the proposition that it need only use "information from preliminary assessments and site inspections".[41] In light of the substantial changes made in the Revised HRS, this position becomes critical.

For example, if a potential NPL site owner or operator knows that the EPA plans on conducting a site investigation at its site, and understands the Revised HRS, the potential NPL site owner or operator should know the media (or pathways) which are cause for concern. If so, depending upon the particularities of its site, it may be possible to gather data which would not otherwise be collected during the EPA's site investigation. Depending upon how this data was collected, it may then be submitted to the EPA either prior to or during the site investigation.

As will be discussed, this could influence the score for all three categories. In particular, with regard to the likelihood of release (or likelihood of exposure) category, the background of hazardous substances for the particular pathways being evaluated at the site must be established before the likelihood of release (or likelihood of exposure) category score can be calculated. Similarly, with regard to the waste characteristics category, the amount of hazardous substances, total quantity of hazardous wastes, volume of source(s),[42] or area of source(s) must be determined to obtain a waste characteristics category score. Finally, many of the targets category factors are evaluated based upon whether there has been an observed release (or observed contamination for the soil exposure pathway) or whether there is only the potential to release. Thus, a determination of the background of hazardous substances at the site again becomes critical.

Basically, pre-site investigation sampling or studies by a site owner or operator could help answer these questions. In many cases, due to the constraints of the EPA, and the fact that site investigations are usually one-time sampling activities, these questions could be better answered with more sampling or studies which a site owner or operator could conduct prior to the site investigation. In turn, depending upon the results of the sample analysis and studies, the site's score could be influenced so that it would meet or exceed the 28.5 cut-off level.

SCORING THE LIKELIHOOD OF RELEASE (OR LIKELIHOOD OF EXPOSURE) FACTOR CATEGORY

As previously mentioned, the likelihood of release category is scored based upon whether there has been an observed release, or there is the potential to release, of hazardous substances from source(s) at the site. This applies to all three migration pathways. However, the soil exposure pathway likelihood of exposure category is only evaluated based upon whether there has been observed contamination. Therefore, it is critical to understand how observed release (or observed contamination) or potential to release values are calculated under the Revised HRS.

If there has been an observed release of any hazardous substance, the potential to release value is not calculated. It is only if there has been no observed release of any hazardous substance(s) that a potential to release value will be determined. In all pathways, the potential to release value, if calculated, will always be less than the observed release value.43

Observed Release/Observed Contamination

"[A]n observed release [is established] either by direct observation of the release of a hazardous substance into the media being evaluated . . . or by chemical analysis of samples appropriate to the pathway being evaluated . . . ."44 Direct observation occurs when a material which contains a hazardous substance has been deposited into or been observed entering either an aquifer45 (groundwater migration pathway), surface water46 (surface water migration pathway), or air47 (air migration pathway).

Specifically, in the surface water pathway, an observed release may be established by direct observation not only by knowledge that a hazardous substance has been seen entering surface water, but also if:

> a source area has been flooded at a time that hazardous substances were present, and one or more hazardous substances were in contact with the flood waters[. It can also be established w]hen evidence supports the inference of a release of a material that contains one or more hazardous substances by the site to surface water 48

Similarly, in the air pathway, an observed release by direct observation can also be established based on the inference of a release to the atmosphere.49 Observed contamination in the soil exposure pathway cannot be established by direct observation.50

In all four pathways, an observed release can be established by chemical analysis. Basically, this requires a showing that "the concentration of hazardous substance[s] has increased <u>significantly above the background concentration</u> for [the particular type of sample being evaluated for] the site."51 (Emphasis added.) Specifically, it:

> is established when a sample measurement equals or exceeds the sample quantitation limit [] <u>and</u> is at least three times above the background level[. Additionally,] available information must attribute[] some portion of the release of the hazardous substance to the site. (The [sample quantitation limit] is the quantity of a hazardous substance that can be reasonably quantified, given the limits of detection for the methods of analysis and sample characteristics that may affect quantitation (e.g., dilution, concentration).) When a background concentration is not detected (i.e., below detection limits), an observed release is established when the sample measurement equals

> or exceeds the [sample quantitation limit]. Any time the sample measurement is less than the[sample quantitation limit], no observed release is established.52

Establishing that there has not been an observed release lowers, if not totally negates, a likelihood of release category score. The reason for this is that if there is no observed release of a hazardous substance from source(s) at the site, then the site's source(s) are evaluated based on a potential to release (even assuming there is a potential to release score, it is always lower than an observed release score53). Additionally, if there is no observed contamination established, the soil exposure pathway is not evaluated.54 As will be discussed below, establishing that a source does not have an observed release also has a dramatic affect on scoring the targets category.

Calculation of Potential to Release Factors/Availability to Migrate

The critical factor about the three migration pathways' potential to release factor is the determination of whether hazardous substances are "available to migrate from the sources at the site to the [particular] pathway."55 Only hazardous substance which are "available to migrate" can be used to evaluate a source's potential to release. Basically, hazardous substances are considered to be "available to migrate" if they meet one of two requirements.

First, they are considered to be "available to migrate" if they meet the criteria for an observed release to the particular pathway, e.g., groundwater, surface water, or air.56 However, as previously mentioned, if there has been an observed release of hazardous substances to the pathway being evaluated, then the potential to release value is not calculated. Second, and perhaps most important in terms of calculating a potential to release value, hazardous substances are considered to be "available to migrate from the source(s) at the site to the pathway" being evaluated if the source(s)' particular containment factor value is greater than zero.57 Basically, a source is said to be "contained" (and thus, has a zero value) if it meets certain stringent criteria.

For example, in the groundwater migration pathway, before a source can have a containment factor of zero it (1) must be "inside or under [a] maintained intact structure that provides protection from precipitation so that neither runoff nor leachate is [or would be] generated, [(2) can have no] liquids or materials containing free liquids [at the] source area [or in containers or tanks], and [(3) must have a] functioning and maintained run-on [and/or run-off] control."58 Similarly, in the air migration pathway, before a source can have a containment factor of zero it must (1) be "covered with [an] essentially impermeable, regularly inspected, maintained cover" or (2) be covered by substantially vegetated, uncontaminated, soil which is greater than three feet thick and have very little exposed soil.59

Therefore, as a practical matter under the Revised HRS, regardless of what chemical state a hazardous substance is in, it will be considered to be "available to migrate" if the above conditions are not met. The ramifications of this are significant. If, for example, a source did have a containment factor of zero, not only would the likelihood of release category factor value be zero for the pathway being evaluated, but the entire pathway score would be zero.

The reason for this is that the potential to release factor is only evaluated if there is no observed release. Additionally, because the containment factor value is multiplied by the other potential to release factors (e.g., net precipitation (ground water pathway), runoff (surface water pathway), or gas or particulate source type (air pathway)),60 if it is zero, the potential to release factor value will also be zero. Consequently, if the potential to release value is zero, the likelihood of release category will be zero. Because the likelihood of release category is multiplied against the waste characteristics and targets category, the pathway score would also be zero. All this does not mean, however, that the site could not be scored based on another pathway; it simply means that particular pathway score would be zero.

Consideration of Potential as well as Actual Release to Air

In response to the SARA requirements to consider potential as well as actual releases to air, the Agency incorporated into the Revised HRS an evaluation for:

> source potential to release separately for gases and particulates. Only those sources containing gaseous hazardous substances are evaluated for gas potential to release, and only those sources containing hazardous substances that can be released as particulates are evaluated for particulate potential to release.61

The potential to release for either gas or particulates, is only evaluated if an observed release cannot be established.62

SCORING THE WASTE CHARACTERISTICS FACTOR CATEGORY

Hazardous Waste Quantity

Consideration of Removal Actions:

Under the old HRS, only a site's initial conditions63 were considered for purposes of applying the HRS. However, in keeping with the SARA requirement that sites be accurately assessed, the EPA solicited and received public comment64 on the question of whether the Revised HRS should consider "the effect of response actions, such as the removal of some quantity of the waste,"65 in calculating the waste characteristics factor category score. In response to those comments, the EPA revised the HRS so that a site's current conditions will be considered if two basic requirements are met.66

First, the EPA must be able to determine, with reasonable certainty, the amount of hazardous substances remaining in sources at the site.67 It must also be able to determine the amount of hazardous substances that have been released to the environment.68 In essence, this means that site owners or operators "will have the primary responsibility for collecting any data needed to support the determination of the quantity of hazardous constituents remaining. [They may also] need to conduct sampling and analyses to determine the extent of hazardous substance migration in soils and other media in order to estimate with reasonable confidence the quantity of hazardous constituents remaining."69

Second, the waste must actually have been removed "from the site for proper disposal or destruction in a facility permitted under the Resource Conservation and Recovery Act (RCRA),70 the Toxic Substances Control Act (TSCA),71 or by the Nuclear Regulatory Commission."72 The EPA has also made it quite clear that it will not consider any other types of response actions. Specifically, in the preamble to the Final Rule, the EPA stated that it "will not consider the effects of response [actions] that do not reduce waste quantities . . . ."73 That includes those instances when "alternate drinking water supplies to populations with drinking water supplies contaminated by the site" have been provided.74

Since the amount of hazardous waste at a site, or the amount of hazardous constituents in the waste, is one of the two components in determining the waste characteristics factor category value,75 it is clear that if a response action is taken which meets the EPA's two requirements, the waste characteristics category value for a source at the site will be reduced. Depending upon the amount of waste removed, it may be possible for a source (or site) to fall well below the cutoff level (if the source scores at all). This consideration of current conditions, assuming the two requirements are met, applies regardless of which pathway is being evaluated.

Revised Hazardous Waste Quantity Factor Allowing a Tiered Approach:

Each source at a site is evaluated separately based on the available data for the particular source.76 Under the Revised HRS, the hazardous waste quantity factor for source(s) at sites can be calculated in one of four ways (in descending order of preference), based on the: (1) source(s)' hazardous constituent quantity; (2) source(s)' total quantity of hazardous wastes; (3) source(s)' volume, or (4) source(s)' area.77 The intent behind this tiered approach is to evaluate the threat related to a site as accurately as possible.78

If there is enough data available to properly determine the amount of hazardous substances (constituents) allocated to a source, the other three tiers are not evaluated.79 Similarly, if the hazardous waste constituent quantity value cannot be calculated, the next preferred approach is to calculate the source(s)' hazardous waste quantity factor based on its total quantity of hazardous wastes. If that can be done, then neither the source(s)' volume or area are calculated. Finally, if none of the three tiers above the area can be calculated, a source(s)' hazardous waste quantity factor is calculated based on its area.

The hazardous constituent quantity factor value is determined based upon the entire mass of all CERCLA hazardous substances80 allocated to the source. Depending upon whether the source being evaluated is a hazardous waste listed or exhibiting the characteristics identified under RCRA, the hazardous constituent quantity factor will be determined differently. If the source is a hazardous waste listed pursuant to RCRA, and is listed solely for a toxic waste, the hazardous constituent quantity factor value is calculated based only on the hazardous substances at the source.81 If the source is a hazardous waste listed pursuant to RCRA and is listed for some reason other than as a toxic waste, then the mass of the entire hazardous waste is included in calculating a hazardous constituent quantity factor value.82

Similarly, if the source is a hazardous waste which exhibits the toxicity characteristic, only the hazardous substances in the source are used in calculating the hazardous constituent quantity factor. If the source has any characteristic other than toxicity, then the entire mass of the hazardous waste is included in the hazardous constituent quantity factor value.

Depending upon whether the hazardous waste quantity factor value is determined using either the hazardous constituent quantity, total quantity of hazardous wastes approach, or based upon volume or area, the characterization of the source is critically important. Both the hazardous constituent quantity and the total quantity of hazardous waste factors are calculated based upon the pounds of hazardous substances or hazardous wastes, pollutants and contaminants in a source. However, if the hazardous waste quantity factor value is calculated based upon either a source's volume or area, the source must be classified as either a landfill, surface impoundment, drums, tanks (and containers other than drums), contaminated soil, pile, land treatment, or other.

The important point here is that the EPA has not defined the terms "landfill", "surface impoundment", or "pile" in the Revised HRS. However, the National Contingency Plan (NCP),83 to which the Revised HRS is an appendix, does provide that "terms not defined in this section have the meaning given by CERCLA or the CWA [Clean Water Act]."84 While these terms are not defined in either the CWA or CERCLA, the EPA has recently promulgated regulations,85 pursuant to the CWA, which do define these terms.

A landfill is defined as "an area of land or an excavation in which wastes are placed for permanent disposal, and that is not a land application unit, surface impoundment, injection well, or waste pile."86 A surface impoundment

> means a facility or part of a facility that is a natural topographic depression, human-made excavation, or diked area formed primarily of earthen materials (although it may be lined with human-made materials), that is designed to hold an accumulation of liquid wastes or wastes containing free liquids and that is not an

injection well. Examples of surface impoundments are holding storage, settling, and aeration pits, ponds, and lagoons.87

A waste pile or "pile means any noncontainerized accumulation of solid, nonflowing waste that is used for treatment or storage."88

For particular types of industries, this distinction is critical. The hazardous waste quantity factor, when calculated based on the volume of the source, may increase 200 times depending upon whether the source is classified as a landfill, surface impoundment or pile.89 Similarly, if the hazardous waste quantity factor value is determined based upon area of the source, the value may increase over 260 times, depending upon whether the source is classified as a landfill, surface impoundment or pile.90

An example of this critical distinction can be seen when looking at the significant number of abandoned mining sites which are located in many areas of the western United States. Depending upon the type of ore deposit being mined, the tailings, and waste materials, may contain hazardous substances. When those mines were operating, tailings, as well as other waste material, were deposited in valleys which were not designed to hold the tailings or waste material. Further, many times there were no structures whatsoever to hold the tailings, or where there were structures, they were merely wooden frames which allowed water, but not the tailings, to flow through.

Applying the definitions in 40 C.F.R. Part 257, it appears that those tailings should not be classified as a pile, because they were not put there for treatment91 or storage92. Additionally, it appears the tailings should not be classified as a surface impoundment, because the valleys were not designed to hold the tailings, even assuming that the tailings contained free liquid. Thus, the only term which applies is a "landfill", since the valleys could be considered to be "area[s] of land . . . in which wastes [were] placed for permanent disposal, and that [are] not . . . surface impoundment[s] . . . or waste pile[s]."93

It is noteworthy that the EPA itself has stated that it:

> generally equates the CERCLA area of contamination with a single RCRA land-based unit, usually a <u>landfill</u>.94
>
> The reason for this is that the RCRA regulatory definition of "landfill" is generally defined to mean a land disposal unit which does not meet the definition of any other land disposal unit, and thus is a general "catchall" regulatory definition for land disposal units. As a result, a RCRA "landfill" could include a non-discreet land area on or in which there is generally disbursed contamination.
>
> * * *

Thus, EPA believes that it is appropriate generally to consider a CERCLA area of contamination as a single RCRA land-based unit, or "landfill."95 (Emphasis added.)

SCORING THE TARGETS FACTOR CATEGORY

Generally, "[t]he factor value for most types of targets depends on whether the target is subject to actual or potential contamination for the pathway and whether the actual contamination is Level I or Level II."96 Actual contamination "is associated either with a sampling location that meets the criteria [i.e., chemical analysis] for an observed release (or observed contamination for the soil exposure pathway) for the pathway or with an observed release based on direct observation for the pathway . . . .97"

Level I concentrations are present when the "media-specific concentrations98 for the target meet the criteria for an observed release (or observed contamination) for the pathway and are at or above media-specific benchmark values."99 Level two concentrations occur when the "media-specific concentrations for the target meet the criteria for an observed release (or observed contamination) for the pathway, but are less than media-specific benchmarks."100 Benchmarks are "selected specific criteria based on applicable or relevant and appropriate requirements (ARARs), excluding state standards, that have been selected for the protection of public health and then environment . . . ."101

Potential contamination is associated with a target which "is subject to a potential release (that is, [the] target is not associated with actual contamination for that pathway or threat)."102

Addition of Dilution and Distance Weightings to the Groundwater and Surface Water Pathways

Groundwater migration pathway:

The groundwater targets category has four factors: (1) nearest well103 (essentially a factor for a maximally exposed individual); (2) population104; (3) resources105; and (4) well head protection area106. However, of the four targets, only two (nearest well and population) are evaluated for potential contamination and thus, are the only two which are distance weighted. Distance weighting is basically a method of reducing a targets factor value based upon the distance the target is from a site's source(s) to more accurately assess the risk to that target. However, the factors are only distance weighted if there is potential contamination (this means background for the particular hazardous substance being evaluated must be determined).

The nearest well factor value is calculated based upon the "drinking water wells drawing from the aquifer being evaluated and those drawing from overlying aquifers . . . ."107 Wells are counted even if they are only used for a drinking water supply once a year.108 The population factor value is calculated based upon "those persons served by drinking water wells within the target distance limit109."110

Residents, students, and workers who regularly use the water are counted, but transient populations such as customers and travelers passing through the area are not.111

If there has been an observed release to a drinking water well, both the nearest well and population factor values are evaluated based on actual contamination. In that case, there is no distance weighting for the nearest well factor. If the nearest well factor does not meet the criteria for an observed release, it is evaluated based on potential contamination. Additionally, the population factor is evaluated for both actual (Level I and Level II) and potential contamination.

If the nearest well factor is calculated based on potential contamination, the factor value decreases the farther away from the source that the nearest well is located, up to a distance of four miles, at which point the score becomes zero. If the population factor has a value due to potential contamination, it is both distance and population weighted. The farther away from the source that the point of withdrawal is, the lower the potential contamination factor value.112 However, the greater the number of people within the target distance limit, the higher the potential contamination factor value will be.113

Surface water migration pathway:

The surface water migration pathway has two components: overland/flood and groundwater to surface water. In keeping with SARA, the surface water migration pathway is evaluated for both drinking water and human food chain threats. Additionally, it is also evaluated for an environmental threat. As previously discussed, each pathway or threat is evaluated on the same three categories, one of which is the targets category.

As with the ground water migration pathway, only the surface water migration pathway targets category is affected by weighting, in this case, dilution weighting. Within the three surface water migration pathway threats, the nearest intake and population (drinking water threat), food chain individual and population (human food chain threat), and sensitive environments (environmental threat) targets factors are dilution weighted. However, they are only dilution weighted if the particular target factor is subject to potential contamination.

Drinking water threat:

If there is no actual contamination, the drinking water threat targets factor, nearest intake, is dilution weighted based on water flow,114 assuming the surface water is a river,115 or on depth of water if the surface water is a lake or ocean.116 The population factor is dilution weighted based on stream flow or water depth and weighted based on the number of people served by the drinking water supply.117 As with the ground water migration pathway, only residents, students, and workers who regularly use the water are included in evaluating the population factor; transients, such as, travelers and customers passing through the area, are not counted.118

In essence, the greater the stream flow or water depth, the more the nearest intake factor value is reduced. Similarly, the greater the stream flow or water depth and the fewer people served by the drinking water supply, the more the population factor value is reduced. However, a potential contamination score is calculated for the population factor, even if there is actual contamination, which is not the case with the nearest intake factor.

Human food chain threat:

The human food chain threat targets category is evaluated based on two factors: food chain individual and population. If the food chain individual factor is not subject to actual contamination, its value is calculated based on potential contamination. Accordingly, that value will be diluted based on either stream flow or water depth. The greater the stream flow or deeper the water, the smaller the potential contamination value will be.

The population factor of the human food chain threat is "based on the estimated annual production (in pounds) of human food chain organisms (for example, fish, shellfish) for [a] fishery."119 The smaller the human food chain production and the greater the stream flow or water depth, the smaller the potential contamination value will be.

Environmental threat:

As mentioned, there is only one target factor in the environmental threat, i.e., sensitive environments. Each of the sensitive environments present within the target distance limit are evaluated based on both potential and actual contamination. If subject to potential contamination, the sensitive environment value is diluted based on the stream flow or water depth for that particular sensitive environment.120

Additions to the Sensitive Environments' List

The sensitive environments are one of the factors within the particular targets categories for the surface water, air, and soil exposure pathways. There is no sensitive environment factor for the groundwater pathway. The Revised HRS has greatly expanded the number of sensitive environments which are evaluated for both the surface water and air pathways. For example, under the old HRS, the only sensitive environments evaluated for either the surface water or air pathways were wetlands and critical habitats. Under the Revised HRS, both the air and surface water pathways are evaluated based on approximately thirty sensitive environments.121 Of significant importance is that while the EPA has adequate defined or described many of the sensitive environments, e.g., national parks, designated federal wilderness area, national or state wildlife refuge, etc., there are many areas which are essentially undefined.

For example, in both the surface water and air migration pathways, one of the sensitive environments subject to evaluation is a "spawning area[] critical for the maintenance of fish/shellfish species within a river, lake or coastal tidal waters."122 The EPA has defined a spawning area critical for the maintenance of fish as being "limited [to] areas [which are] used for intense or concentrated spawning by a given species."123 However, the EPA does not provide definitions for what an "intense or concentrated spawning" area is. Additionally, there are no definitions in either the Proposed or Final Rules, or the preamble preceding either, which explain what an "intense or concentrated spawning" area is.

However, given the plain meaning of the terms "intense" and "concentrated," the spawning must be at an extreme degree in one location.124 Moreover, the spawning area must be critical for the maintenance of the species within the river. By implication, this infers that if there are other areas within the river which are of greater consequence in terms of spawning than others, then the more significant spawning areas should be the areas which are considered to "intense or concentrated" spawning areas.

It is important to note that the Revised HRS provides that actual contamination occurs when a target "is associated either with a sampling location that meets the criteria for an observed release (or observed contamination) for the pathway or with an observed release based on direct observation for the pathway."125 (Emphasis added.) Thus, depending upon the target being evaluated, it may be subject to both actual and potential contamination. Even more importantly, however, is that with the target sensitive environments, it is possible for there to be actual contamination in surface water near the source, but by the time the surface water reaches one of the listed sensitive environments, the target may only be subject to potential contamination. In turn, this has a direct impact on the sensitive environments score.

Addition of Factors for Evaluating Maximally Exposed Individuals

"Maximally exposed individuals (MEIs) are those individuals in the exposed population that are expect to be exposed to the highest ambient concentration (and thus receive the highest dose) of the hazardous substance in question."126 Each of the pathways has a maximally exposed individual factor which is found in the targets category of each pathway.

In the groundwater migration pathway, the MEI factor is the "nearest well". "This [factor] was chosen because it is likely that, all other things being equal, the well closest to the site would have the highest level of contamination127." As mentioned, it includes "both the drinking water wells drawing from the aquifer being evaluated and those drawing from overlying aquifers . . . [i]nclud[ing] standby wells . . . if they are used for drinking water supply at least once every year."128

For the surface water pathway drinking water threat, "the risk to the MEI" is represented by the nearest intake factor.129 "[T]he nearest intake factor [is] based on the drinking water intakes along the . . . hazardous substance migration path for the water shed. [As with the nearest well MEI factor in the groundwater pathway, it also i]nclude[s]

[] intakes . . . if they are used for supply at least once a year."130 It is clear for both the groundwater pathway and surface water drinking water threat, that the water supply must actually be used on a regular basis by people before a value can be assigned.

Within the surface water human food chains threat category, the risk to the MEI is represented by the "food chain individual" factor. "[T]he food chain individual factor [is] based on the fisheries (or portions of fisheries) within the target distance limit for the water shed."131 The fisheries are evaluated based on whether they "are subject to actual or potential human food chain contamination."132 As with all other MEI factors, the food chain individual factor, and thus the fisheries, are evaluated based on whether they are subject to actual or potential contamination. Less clear, however, is whether the fishery has to actually be a place where people go to fish, and catch fish, on a regular basis.

However, based upon the EPA's statements in the preamble to the Proposed Rule, i.e., that "MEIs are those individuals . . . that are expected to be exposed to the . . . hazardous substance,"133 it would appear that people would actually have to use a fishery, and catch fish there, on a regular basis before an MEI value could be calculated for the food chain individual based on that particular fishery. This is especially true when viewed in the context of whether there is a "human food chain threat". If people do not fish, and catch fish, on a regular basis from a fishery, there would appear to be little risk to human health. Additionally, fisheries which are not fished on a regular basis are akin to wells and intakes which are used by transients, such as, customers and travelers passing through the area.

Under the soil exposure pathway resident population threat, the MEI factor is the resident individual.134 The resident individual "factor [] is based on whether there is a resident individual . . . who is subject to actual contamination."135 A resident individual is a person who lives or attends school or day-care on property which has observed contamination "<u>and</u> who resides, or attends school or day-care center, [] on or within 200 feet of the area of observed contamination."136 (Emphasis added.) If there is no actual contamination, the MEI factor value (resident individual) is not scored.

Similarly, under the soil exposure pathway nearby population threat, the MEI factor is the "nearest individual."137 The nearest individual factor is determined in much the same manner as the resident individual within the resident population threat.138 However, there is one significant difference. The nearby individual factor is also evaluated based on whether there are natural barriers to travel to the site.139

Under the air migration pathway, the MEI factor is the nearest individual factor.

The critical thing about evaluating all MEIs is the determination of whether the target factor is subject to actual or potential contamination. In the Final Rule, "both the population factors and the factors reflecting the hazard to the [MEIs] . . . are evaluated in relation to health-based benchmarks140 in all pathways. The sensitive environment factor in the surface water environmental threat is weighted in relation to ecological-based benchmarks; however, in the soil exposure and air migration pathways, the sensitive environment factor is weighted simply on the basis of exposure to actual contamination, and no benchmarks are used."141.

INCLUSION OF A SOIL EXPOSURE PATHWAY

The soil exposure pathway "was primarily designed to assess the potential threats posed by direct exposure to wastes and contaminated surficial materials at a site."142 The area to be addressed within the soil exposure pathway is limited to areas "within a distance limit of 200 feet [(for the resident population threat) and one mile (for the nearby population threat)] from an area of observed contamination. The 200-foot limit [in the resident population threat] accounts for those situations where the property boundary is very large, and exposure to contaminated surficial materials is unlikely or infrequent because of the distance of residences, schools, or work places from an area of observed contamination on the same property."143

As with the three migration pathways, the soil exposure pathway is evaluated based upon the likelihood of a release (called likelihood of exposure), waste characteristics, and targets categories.144 Similarly, within its targets category, a value is calculated for the maximally exposed individual. The soil exposure pathway has two threats, resident population and nearby population. The MEIs for those two threats are the resident individual and nearby individual, respectively.

In essence, the "soil exposure pathway is designed to account for exposures and health risks resulting from ingestion and contamination surficial materials."145 Although there is no potential to release factor within the likelihood of exposure category, that category is scored based upon whether there is observed contamination. Observed contamination is indicated when there is a hazardous substance present at a concentration significantly above background levels for the site and the "hazardous substance, if not present at the surface, is covered by two feet or less of cover material."146

CONCLUSION

Because of the changes and additions made to the Revised HRS, it is now possible for a potential NPL site owner or operator to influence whether or not the site is ultimately placed on the NPL. Generally, in order to influence that decision, the site owner or operator must have taken some response action to reduce the amount of hazardous waste or hazardous substances at the site. However, even if the site owner or operator does not take such action, because of other changes made in the Revised HRS, the site owner or operator can influence the score.

1 42 U.S.C. 9601 et seq.

2 A site is "Area[s] where a hazardous substance has been deposited, stored, disposed, or placed, or has otherwise come to be located. Such areas may include multiple sources and may include the area between sources." 40 C.F.R. Part 300, Appendix A, 1.1.

3 40 C.F.R. Part 300, Appendix B.

4 Pub. L. 99-499.

5 55 Fed. Reg. 51532 (December 14, 1990) (hereinafter referred to as the "Final Rule"). Since that time, based on the Revised HRS, the EPA has proposed that an additional 52 sites be placed on the NPL. See 56 Fed. Reg. 35840 (July 29, 1991) and 57 Fed. Reg. 4824 (February 7, 1992).

6 42 U.S.C. 9605(c)(1).

7 42 U.S.C. 9601 et seq.

8 "The term 'release' means any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment . . . ." 42 U.S.C. 9601(22).

9 42 U.S.C. 9601(14).

10 42 U.S.C. 9605(8)(A), now known as 42 U.S.C. 9605(a)(8)(A).

11 40 C.F.R. Part 300, Appendix A.

12 53 Fed. Reg. 51962.

13 Id., at 51963.

14 53 Fed. Reg. 51962 (December 12, 1988) (hereinafter referred to as Proposed Rule).

15 53 Fed. Reg. 51963-64, citing to H.R. Rep. No. 962, 99th Cong. 2nd. Sess. at 199-200 (1986) (emphasis added). See also, 55 Fed. Reg. 51532.

16 Supra, note 1, 9601(33).

17 Supra, note 1, 9605(c)(2).

18 Supra, note 1, 9618.

19 Supra, note 1, 9605(a)(8)(A).

20 Additionally, "each State may designate a single site as its top priority, regardless of its HRS score." 57 Fed. Reg. 4824; citing to 40 C.F.R. 300.425(c)(2). Finally, sites can be placed on the NPL if the Agency for Toxic Substances and Disease Registry has issued a health advisory about a release, the EPA has determined that the release poses a significant threat to the public health, and EPA believes that it is best to use its remedial activity to address the release. Id., citing to 40 C.F.R. 300.425(c)(3).

21 Supra, note 12, at 51963.

22 This information will include site-specific information, e.g., topography, population, and historical industrial activity. 55 Fed. Reg. 51540.

23 Supra, note 12, at 51963.

24 Id.

25 Id.

26 Id.

27 55 Fed. Reg. 51532; 40 C.F.R. Part 300, Appendix A.

28 For the purposes of this paper, the original HRS is considered to be the HRS which was in effect prior to the Final Rule, rather than the HRS as initially adopted.

29 40 C.F.R. Part 300, Appendix A, 1.1.

30 Id.

31 40 C.F.R. Part 300, Appendix A.

32 Supra, note 29, 2.3.

33 55 Fed. Reg. 51560.

34 Supra, note 29, 2.3.

35 Id., at 2.5.

36 Id., at 2.1.1.

37 Supra, note 12, at 51963-64.

38 The hazardous waste quantity factor is one of the factors which make up the waste characteristics category.

39 Because of the constraints of this paper, some of these revisions will not be addressed, e.g., toxicity and mobility factors.

40 Supra, note 33, at 51532.

41 Id. citing to H.R. Rep. No. 962, 99th Cong., 2nd Sess. at 199-200 (1986). However, Congress made no such restriction when it adopted Section 105(c)(1) of CERCLA. 42 U.S.C. 9605(c)(1). That section simply provides that the HRS "accurately assess[] the relative degree of risk to human health and the environment posed by sites and facilities subject to review." Id.

42 A source is:

> Any area where a hazardous substance has been deposited, stored, disposed, or placed, plus the soils that have become contaminated from migration of a hazardous substance. Sources do not include those volumes of air, groundwater, surface water, or surface water sediments that have become contaminated by migration, except: in the case of either a groundwater plume with no identified source or contaminated surface water sediments with no identified source, the plume or contaminated sediments may be considered a source.

40 C.F.R. Part 300, Appendix A, 1.1.

43 Supra, note 11, at 2.3.

44 Id., at 2.3.

45 Id., at 3.1.1.

46 Id., at 4.1.2.1.1.

47 Id., at 6.1.1.

48 Id., at 4.1.2.1.1.

49 Id., at 6.1.1.

50 Id., at 5.0.1.

51 Id., at 3.1.1, 4.1.2.1.1, 5.0.1, and 6.1.1. See also, id., at 4.2.2.1.1.

52 Supra, note 33, at 51546. See also, 40 C.F.R. Part 300, Appendix A, Table 2-3.

53 40 C.F.R. Part 300, Appendix A, 2.3.

54 Id., at 5.0.1.

55 Id., at 2.2.3.

56 Id.

57 Id.

58 Id., at Table 3-2. See also, id., at Table 4-2.

59 Id., at Tables 6-3 and 6-9.

60 Because of the constraints on this paper, it is beyond it s scope to discuss other potential to release factors for any of the three migration pathways.

61 Supra, note 33, at 51563.

62 Supra, note 11, at 6.1.2.

63 In the preamble to the Final Rule, the Agency states that it considers initial conditions to be those conditions which existed prior to any response action. 55 Fed. Reg. 51567.

64 See the Proposed Rule and Final Rule.

65 Supra, note 33, at 51567.

66 Id., at 51568.

67 Id., at 51568.

68 Id., at 51568.

69 Id., at 51568.

70 42 U.S.C. 6901 et seq.

71 15 U.S.C. 2601 et seq.

72 Supra, note 33, at 51568.

73 Id., at 51568.

74 Id., at 51586.

75 Other factors include toxicity in the ground water, surface water, soil exposure, and air pathways; mobility in the ground water, surface water (ground water to surface water component), and air pathways; and persistence, bioaccumulation, and ecosystem toxicity in the surface water pathway. However, even though there were significant changes to these factors, a discussion of those changes is beyond the scope of this paper.

76 *Supra*, note 33, at 51542.

77 *Supra*, note 11, at 2.4.2 et seq.

78 *Id*.

79 *Id*., at 2.4.2.1.1.

80 *Supra*, note 1, at 104(14).

81 *Supra*, note 79.

82 *Id*.

83 40 C.F.R. Part 300.

84 *Id*., at 300.5.

85 40 C.F.R. Part 257; *see* 56 Fed. Reg. 51016.

86 40 C.F.R. 257.2.

87 *Id*.

88 *Id*.

89 *Supra*, note 11, at Table 2-5.

90 *Id*.

91 Treatment "means any method, technique, or process including neutralization, designed to change the physical, chemical or biological character or composition of any hazardous waste . . . ." 40 C.F.R. 260.10.

92 Storage "means the holding of a hazardous substance for a temporary period at that end of which the hazardous waste is treated, disposed of, or stored elsewhere." 40 C.F.R. 260.10.

93 *Supra*, note 86.

94 54 F.R. 41444 (December 21, 1988).

95 55 Fed. Reg. 8760 (March 8, 1990).

96 Supra, note 11, at 2.5.

97 Id., at 2.5.

98 It it important to note that while the "media specific concentrations" for samples from the groundwater, soil exposure, and air pathways are based on samples from water, soil, or air, that the surface water samples, which can be evaluated, are substantially more detailed. In particular, media specific concentrations for the surface water pathway can be based upon surface water, benthic, or sediment samples. See 40 C.F.R. Part 300, Appendix A, 4.0 et seq.

99 Supra, note 11, at 2.5.

100 Id.

101 Supra, note 33, at 51547.

102 Supra, note 99.

103 Supra, note 11, at 3.3.1.

104 Id., at 3.3.2.

105 Id., at 3.3.3.

106 Id., at 3.3.4.

107 Supra, note 103.

108 Id.

109 The target distance limit is the "Maximum distance over which targets for the site are evaluated. The target distance limit varies by HRS pathway." 40 C.F.R. Part 300, 1.1.

110 Supra, note 104.

111 Id.

112 Id., at Table 3-11.

113 Id., at Table 3-12.

114 Id., at 4.1.2.3.1; see also, id., at Table 4-13.

115 For HRS purposes, rivers include: "Perennially flowing waters . . . and wetlands contiguous to these flowing waters. Aboveground portions of disappearing rivers. Man-made ditches only insofar as they perennially flow into other surface water. [And] Intermittently flowing waters and contiguous intermittently flowing ditches only in arid or semiarid areas with less than 20 inches of mean annual precipitation." 40 C.F.R. Part 300, Appendix A, 4.0.2.

It is important to note that intermittently flowing waters in arid or semiarid areas with more than 20 inches of mean annual precipitation are not defined as surface waters for HRS purposes. Additionally, wetlands contiguous to any intermittently flowing waters are not defined as surface waters for HRS purposes.

116 Supra, note 11, at Table 4-13.

117 Id., at Table 4-14.

118 Id., at 4.1.2.3.2 and 4.2.2.3.2.

119 Id., at 4.1.3.3.2.1.

120 Id., at 4.1.4.3.1.3.

121 Id.; see Table 4-23; see also, id., at 4.1.4.3.1 and 6.3.4. See also, id., at Table 5-5 for the sensitive environments evaluated under the soil exposure pathway.

122 Id., at Table 4-23.

123 Supra, note 33, at 51550; 40 C.F.R. Part 300, Table 4-23 n. g.

124 Intense is defined as something "existing in an extreme degree"; "having or showing a characteristic in extreme degree"; Webster's Ninth New Collegiate Dictionary, 629 (1987). Concentrated is defined to mean "to bring or direct toward a common center or objective"; "to gather into one body, mass, or force." Id., at 272.

125 Supra, note 11, at 2.5.

126 Supra, note 12, at 51978.

127 Id.

128 Supra, note 11, at 3.3.1.

129 Supra, note 126.

130 Supra, note 11, at 4.1.2.3.1 and 4.2.2.3.1.

131 Id., at 4.1.3.3.1 and 4.2.3.3.1.

132 Id., at 4.1.3.3 and 4.2.3.3.

133 Supra, note 12, at 51978.

134 Supra, note 33, at 51560; see also, note 11, at 5.1.3.1.

135 Supra, note 11, at 5.1.3.1.

136 Id., at 5.1.3.

137 Id., at 5.2.3.1.

138 Id.

139 Id.

140 Supra, note 11, at 2.5.2.

141 Supra, note 33, at 51547.

142 Id., at 51560.

143 Id.

144 Supra, note 11, at 5.1.1, and 5.2.1.

145 Supra, note 33, at 51563.

146 Supra, note 11, at 5.0.1.

RECLAMATION OF GOLD MINE SPOILS IN THE PINYON-JUNIPER ZONE OF THE GREAT BASIN[1]

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ABSTRACT

The effects of various reclamation treatments on plant establishment and community development were studied on the Borealis Mine in western Nevada. The Borealis Mine is a gold recovery venture located in the pinyon-juniper zone at an elevation of 7200 ft. (2195 m) with an average annual precipitation of about 8 in. (200 mm). Reclamation research plots were established in a block design that compared the effects of topsoil, spoil, and straw mulch on plant cover and biomass with four replications. In the fall of 1987 all the plots were 1) seeded with a mixture of grasses, forbs, and shrubs, 2) fertilized, and then 3) half of the plots were straw mulched and crimped. Results show that topsoil and mulch treatments have higher plant cover and biomass than spoil and unmulched treatments. Mulch applications trapped significantly greater amounts of snow during the first spring following seeding than unmulched treatments, and resulted in significantly higher plant cover and biomass. The primary beneficial effects of mulch appear to have been in retaining higher soil water availability and in reducing evaporation during the first growing season when seedlings were becoming established, but these diminished rapidly following the first growing season. Topsoil appears to have a more persistent effect on plant community development over time than mulch.

INTRODUCTION

The development of successful reclamation techniques that restore productivity and site stability to aridland mine sites is becoming increasingly important in the Great Basin region of the U.S. It is essential that watershed, wildlife, recreational, and other values be restored and maintained following disturbances to these lands. Awareness and concern for land use policy and management of natural resources has increased dramatically in recent decades. The nation's

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accelerating demand for minerals and other resources dictates that public land management agencies, together with resource users, be actively involved in the development of methods and techniques that protect lands from undue damage and deterioration. Research experience has shown that the most promising method of achieving this goal is the development and implementation of successful reclamation and revegetation techniques.

Some of the most difficult lands to successfully revegetate after disturbance are aridlands in the western U. S. Generally, the most widely used and better known revegetation techniques were developed for mesic and semiarid regions that receive in excess of about 15 inches of annual precipitation. In arid regions, however, where annual precipitation is less than about 10 to 12 inches, standard revegetation and reclamation procedures are generally unsuccessful. Typical climatic factors limiting successful revegetation in arid regions, in addition to low precipitation, include extended periods of high summer temperatures, low relative humidities, and variably severe desiccating winds throughout the normally long potential growing season. In addition, edaphic limitations unique to arid regions can include soils that contain high concentrations of salts, soils that are either sandy or rocky with low water holding capacities, or those high in clays with poor drainage, low permeability, and perhaps containing toxic levels of various elements and poor fertility.

An excellent example of a mined site in the Great Basin that exemplifies these conditions is the Borealis Mine in Nevada. This mine is a gold recovery venture owned and operated by Echo Bay Minerals LTD., and is located on the Toiyabe National Forest about 15 miles southwest of Hawthorne, Nevada (Figure 1). The site is in the pinyon-juniper vegetation lifezone at an elevation of approximately 7,200 ft. (2195 m), and receives about 8 in. (200 mm) of annual precipitation. The mine is an open pit operation that uses cyanide heap leaching to recover gold from the spoil material.

In 1987 the Borealis Mine was selected as a study site for the development of successful revegetation treatments for aridland mine disturbances. This mine offered an excellent opportunity for research scientists, land managers, and private mine operators to work together in developing reclamation techniques for the restoration of aridland ecosystems following disturbance. The broad general objectives of the reclamation research conducted on the Borealis Mine were to: (1) evaluate and develop various alternative revegetation techniques consistent with the native vegetation and other environmental characteristics of the site; (2) determine the long-term effects of various reclamation treatments on plant community establishment; and (3) determine the relative efficiency of the various revegetation techniques to promote plant growth and establishment and to ameliorate soil and plant water stress.

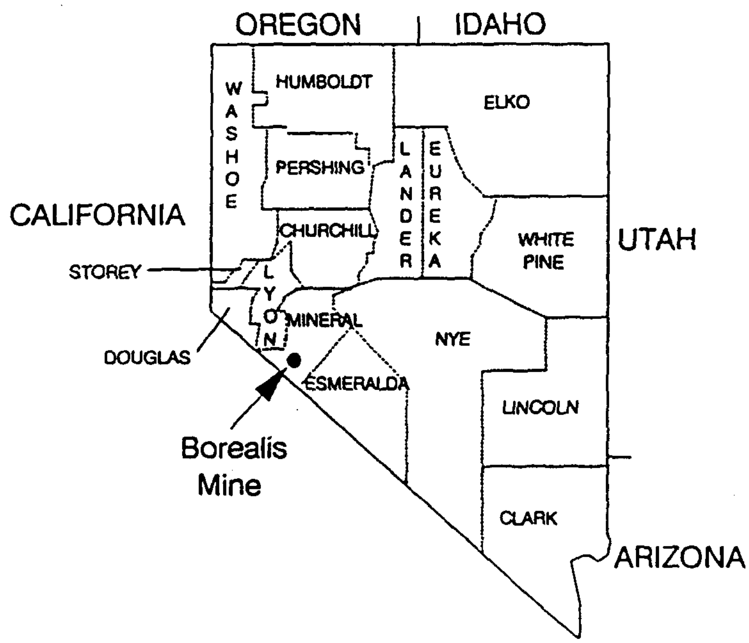

Figure 1. Map showing approximate location of the Borealis Mine, Mineral County, Nevada.

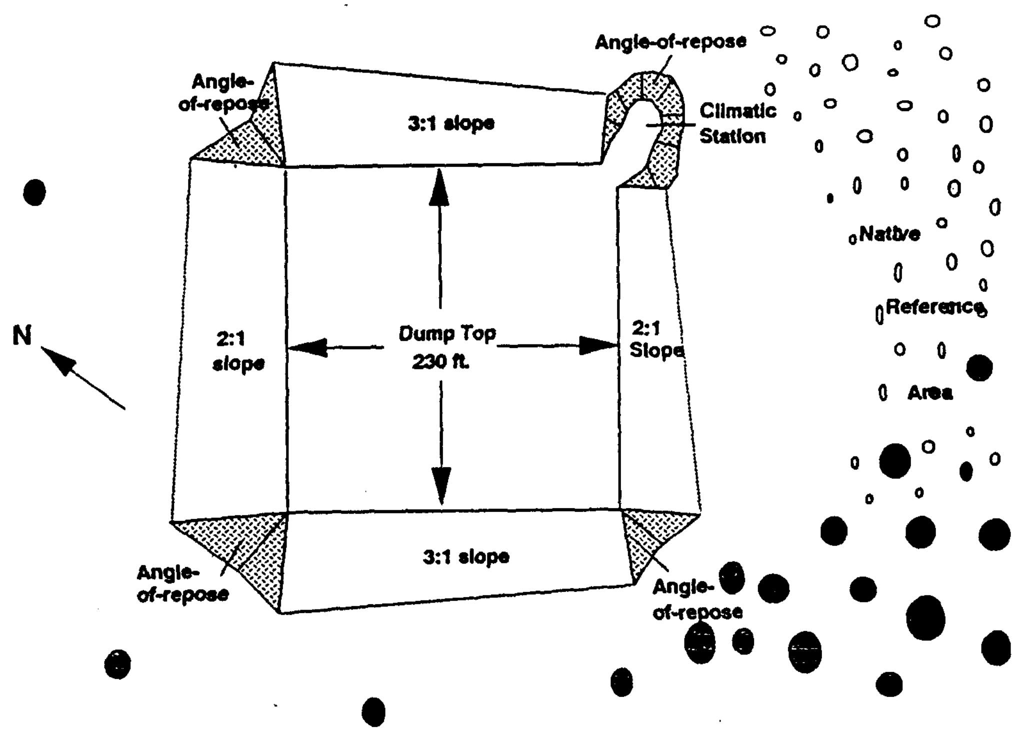

Figure 2. Drawing of the Borealis Mine dump after reshaping and contouring showing the slopes, climatic station, and native reference area.

METHODS AND PROCEDURES

Reclamation research was conducted on a small overburden dump near the south end of the mine which had been reshaped and contoured by Echo Bay Minerals, LTD. in August 1987. Reshaping provided a level flat top research area about 1.2 ac. (0.5 ha) in size with dimensions of 230 x 230 ft. (70 x 70 m). The four corners of the research area were oriented in the four cardinal directions (Figure 2), and the four slopes below the flat top were oriented to face northeast, southeast, southwest, and northwest, respectively. The northeast and southwest facing slopes were constructed with a slope angle of 3:1 (33% or 18° 26'), and the northwest and southeast slopes were 2:1 (50% or 26° 34'). The corner-slopes, located immediately below the corners and between the side-slopes, were constructed with angle-of-repose slopes. On the southeast corner a small extension of the top research area was constructed to support the installation of a weather station; all slopes below the weather station were also angle-of-repose. The entire area of disturbance after reshaping, including the dump top and slopes, was about 5.0 ac. (2.0 ha; this includes some flat areas below the slopes around the base of the dump).

Following reshaping, three strips of topsoil were applied on the level top research area (Figure 3), each 36 ft. wide by 220 ft. long (11 x 67 m) and spread to a depth of 6 to 8 in. (15-20 cm). The topsoil material consisted of native surface soil removed from adjacent areas prior to mining. The topsoil strips alternated between overburden material of the same width and length (Figure 3). No topsoil was applied to the slopes, the weather station extension, or the angle-of-repose slopes. The present discussion is limited only to the revegetation results from the plots located on the flat mine dump top.

Composite soil and spoil samples from 0-8 in. (0-20 cm) in depth were collected from 24 different locations on the dump including each slope, the research plot flat area on the dump top, and the topsoil strips. The samples were analyzed by A&L Mid West Agricultural Laboratories, Inc.[2] (13611 B Street, Omaha, Nebraska 68144-3693), and the results are shown in Table 1. Recommendations were provided for fertilizing the soil and spoil to provide the best yield of crop grasses planted in this material. Although typical crop grasses do not necessarily have the same nutrient requirements as native aridland species (Tiedemann and Lopez 1982), A&L's recommendations were used as a guide in preparing the fertilizer application rates likely to provide the best results on the site.

Plant Species Selection

Assessments of adapted plant species suited for revegetation in the area adjacent to the site were made in both 1986 and 1987. Native

[2] Use of trade names, products, or services is strictly for the information of the reader and does not imply endorsement by the USDA Forest Service.

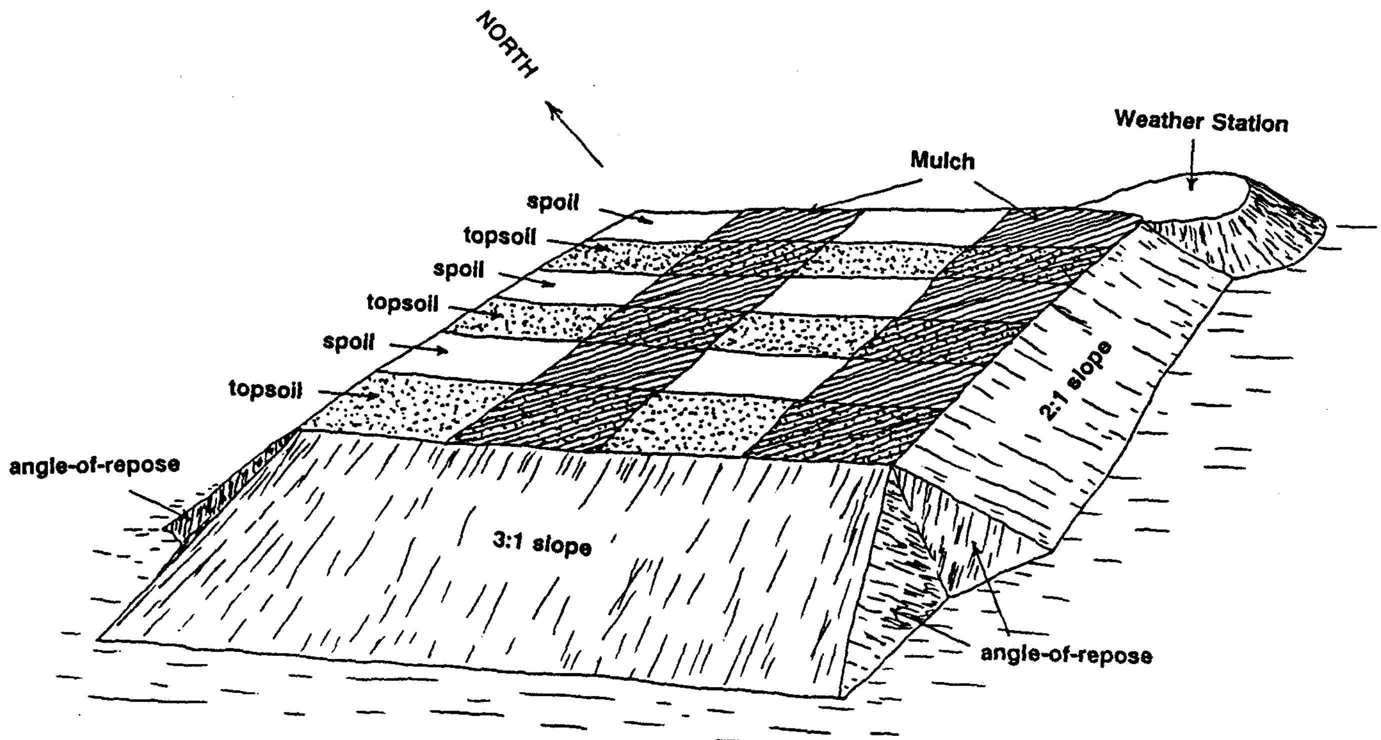

Figure 3. Drawing of the Borealis Mine dump showing locations of the topsoil and spoil strips on the revegetation research site.

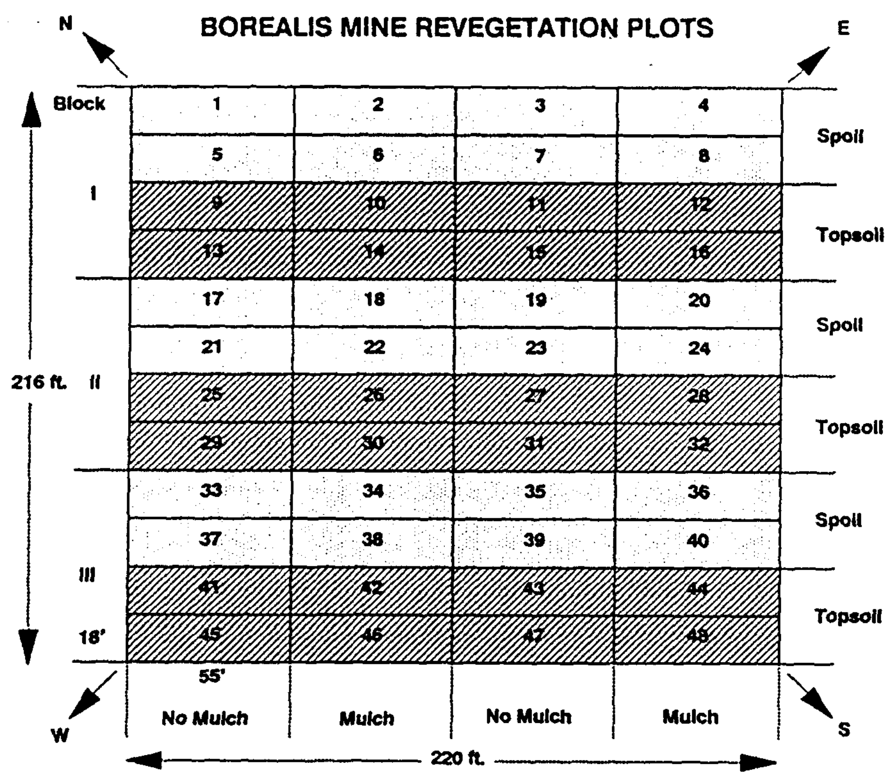

Figure 4. Drawing of the reclamation plots on the dump top showing locations of topsoil and spoil strips, straw mulched areas, blocks, and plot numbers.

Table 1. Summary of soil/spoil chemical and physical characteristics on the Borealis Mine, Nevada (from A&L Agricultural Laboratories, Omaha, Nebraska).

Soil Variable	Topsoil	Spoil
Organic Matter	1.2%	0.34%
Estimated Nitrogen Release	55.33 lbs/ac	39.65 lbs/ac
Phosphorus	8.0 ppm	6.4 ppm
Potassium	292.3 ppm	90.06 ppm
Magnesium	360.7 ppm	265.1 ppm
Calcium	1979 ppm	1898 ppm
Sodium	169.3 ppm	124.4 ppm
pH	8.03	7.25
Hydrogen	0 meq/100 g	0.182 meq/100 g
Cation Exchange Capacity	14.37 meq/100 g	12.64 meq/100 g
Soluble Salts	1.8 mmhos/cm	3.5 mmhos/cm
Percent rock (>2-mm)	34.93 %	54.45 %
Soil texture:	sandy loam	sandy clay loam
% sand	62.00	57.30
% silt	21.33	20.35
% clay	16.67	22.35
Nutrient recommendations:		
Nitrogen	70.00 lbs/ac	78.24 lbs/ac
Phosphorus (phosphate)	20.00 lbs/ac	31.18 lbs/ac
Potassium (potash)	--	50.29 lbs/ac

plant succession was observed on other, but similar and older disturbances in the area, and a list of potentially suited native and introduced species was compiled (similar to methods discussed by Brown and Johnston, 1979 and by Chambers et al., 1984). Previous experience and research data gathered at other locations (e.g., Brown et al., 1984; El-Ghonemy et al., 1980) indicated that a mixture of different species with different lifeforms and physiological traits potentially provides the best results in revegetation of severe disturbances. A total of 16 different species, including grasses, forbs, and shrubs were selected for the species mixture used on the site (Table 2). The mixture is composed of six grasses, four forbs, and 6 shrubs.

It is important that seeds of species used in revegetation be collected from sites that are similar to that being revegetated; ideally, seeds should be collected from plants growing in the immediate vicinity of the site. However, logistics of travel and great distances dictated that the seeds used in this effort would be more expensive to collect than to purchase from a reputable seed dealer. Based on data supplied by the dealers including seed germinability, place of seed origin, availability, and cost, we purchased most of the seed from Maple Leaf Industries, Inc. (480 South 50 East, Ephraim, Utah 84627; 801-283-4701), and smaller quantities from Native Plants, Inc. (400 Wakara Way, Salt Lake City, Utah 84108; 801-582-0144).

The amount of seed required of each species in the mixture was determined on the basis of seed viability, number of seeds per unit weight, and the number of viable seeds to be planted per unit surface area on the site. To equalize competition among all species in a mixture, to optimize opportunities for seedling survival, and to correctly assess the success or failure of each species, the same number of viable seeds were applied per unit area during seeding. This approach improves the chances of providing a more uniform distribution of each species when the site is seeded, and minimizes the chances of weighting the mixture in favor of lighter or heavier seeded species. The number of seeds per unit weight of each species purchased was calculated by weighing 3 lots of 100 seeds that had been randomly selected from each collection site. Seed viability was determined using standard tetrazolium tests in the laboratory (Chambers, 1989; Chambers et al., 1987; USDA Forest Service, 1948). Based on percent purity supplied by the dealer and the viability determined from the tetrazolium tests, the pure live seed factor (PLS) was calculated for each of the 16 species used. These data were then used to compute the total weight of seeds required for each species. All data and calculations for each species are shown in Table 2.

Two different seeding rates were tested on the research plots on the top of the dump to determine optimum seeding rate to be used in future revegetation efforts at the Borealis Mine (Table 2). Plots were seeded at the rate of either 2 ("light" rate) or 5 ("heavy" rate) viable seeds per species ft^{-2} (21.53 and 53.82 seeds per species m^{-2}). For the 16 species seeded in the mixture, the total seeding rates applied were 32 viable seeds ft^{-2} for the "light" rate, and 80 viable seeds ft^{-2} for the "heavy" rate (344 and 861 viable seeds m^{-2}, respectively).

Table 2. Species seed characteristics, seeds per pound, percent purity, viability, and seeding rates used in Borealis Mine seed mixture, October 1987. TZ (tetrozolium) tests for viability were conducted in the laboratory at Logan. All seeding rates are PLS (pure live seed) corrected.

Species	seeds/ pound	% purity	% TZ via-bility	PLS factor	Reclamation Research Plots: light rate no. ft^{-2}	Reclamation Research Plots: light rate lbs ac^{-1}	Reclamation Research Plots: heavy rate no. ft^{-2}	Reclamation Research Plots: heavy rate lbs ac^{-1}	Slope Reclamation no. ft^{-2}	Slope Reclamation lbs ac^{-1}
<u>Grasses</u>:										
Agropyron desertorum (desert wheatgrass)	233,812	94.0	93.3	0.877	2	0.44	5	1.11	3.5	0.77
Agropyron smithii (western wheatgrass)	102,407	92.0	88.0	0.809	2	1.05	5	2.63	3.5	1.84
Agropyron tricophorum (pubescent wheatgrass)	81,542	94.0	95.0	0.893	2	1.19	5	2.99	3.5	2.09
Oryzopsis hymenoides (Indian ricegrass)	112,686	96.0	77.3	0.742	2	1.04	5	2.61	3.5	1.83
Sitanion hystrix (squirreltail)	221,625	96.0	90.7	0.871	2	0.45	5	1.13	3.5	0.79
Stipa comata (needle-and-thread)	52,508	89.0	76.0	0.676	2	0.45	5	6.14	3.5	4.29
<u>Forbs</u>:										
Hedysarum boreale (Utah sweetvetch)	32,539	75.0	76.0	0.570	2	4.71	5	11.78	3.5	8.25
Linum lewisii (Lewis flax)	316,754	98.0	85.3	0.836	2	0.33	5	0.83	3.5	0.58
Penstemon palmeri (Palmer's penstemon)	513,113	94.0	88.0	0.827	2	0.21	5	0.52	3.5	0.36
Sphaeralcea coccinea (scarlet globemallow)	433,920	97.0	97.3	0.944	2	0.21	5	0.53	3.5	0.37
<u>Shrubs</u>:										
Artemisia nova (black sagebrush)	1,921,999	10.0	54.7	0.055	2	0.83	5	2.07	3.5	1.46
Artemisia tridentata (Wyoming big sagebrush)	1,030,891	16.0	49.3	0.079	2	1.07	5	2.68	3.5	1.88
Atriplex canescens (fourwing saltbush)	55,110	69.0	62.7	0.433	2	3.66	5	9.14	3.5	6.39
Atriplex confertifolia (shadscale)	67,808	68.0	41.3	0.281	2	4.58	5	11.44	3.5	8.01
Ceratoides lanata (winterfat)	74,052	60.0	72.0	0.432	2	2.73	5	6.82	3.5	4.77
Chrysothamnus viscidiflorus (rabbitbrush)	469.233	15.0	62.7	0.094	2	1.98	5	4.95	3.5	3.46
TOTALS:					32	26.93	80	67.37	56.00	47.14

Fertilizer Selection and Characteristics

Results of the soil analyses indicated that macronutrients normally required by vascular plants were lacking in both the spoil and topsoil materials on the dump study site (Tiedemann and Lopez, 1982; Jurinak, 1982). A granular 16-16-16 fertilizer (16% each of N, P, and K), balanced with equal amounts of the 3 major required macronutrients was applied to the entire dump at the rate recommended by A&L Agricultural Laboratories.

Two fertilizer rates were tested on the research plots; a "light" application rate of 40 lbs N equivalent per acre (44.8 kg ha^{-1}), and a "heavy" rate of 80 lbs N equivalent per acre (89.6 kg ha^{-1}). Experience has shown that fertilizer is necessary to supply plant nutrients required for growth and development, and to encourage root development that enhances survival. However, in arid environments fertilizer additions can be hazardous if applied in sufficient quantity to raise soil osmotic concentrations and thus promote severe plant water stress (Packer and Aldon, 1978). However, on the Borealis Mine soluble salts appear to be fairly low and soil pH is nearly neutral (Table 1), hence the fertilizer rates used appear to be within the ranges of tolerance of the species planted.

Revegetation Methods

A total of 48 research plots, each 18 x 55 ft (5.5 x 16.8 m) in size, were staked out on the dump top in three blocks of 16 plots each in October, 1987 (Figure 4). Half the plots (24) were positioned on the three topsoil strips, and the remaining 24 were established on the three spoil material strips that extend across the research area. Revegetation treatments applied to the research plots included 2 soil types (topsoil vs spoil) x 2 mulching rates (2 tons per acre vs 0) x 2 seeding rates (32 vs 80 viable seeds ft^{-2}) x 2 fertilizer rates (40 vs 80 lbs N per acre) for a total of 16 plots per block. Thus, a completely randomized block design was used with 4 replications of each treatment.

Plans to harrow the entire site with a Triple-K spring-toothed harrow in order to loosen the surface material before seeding and fertilizer application were abandoned when it was realized that the practice tended to pull large rocks up to the surface, thus complicating surface smoothness on the plots. The fertilizer was distributed uniformly with hand-operated distributors at the appropriate rates on the slopes and lower areas. On the research plots all applications were made by hand in order to better control the distribution near the plot borders. Pre-weighed amounts of fertilizer were prepared for each plot beforehand.

The seed had been premixed in bags at Logan, Utah prior to installing the revegetation site. The seed was distributed by hand over the entire area to avoid uneven distribution with hand-operated spreaders. Different sizes and densities of seed of the various species tended to layer in the spreaders, or in some cases jam the distribution mechanism, and resulted in uneven species distribution. This was avoided by uniformly hand spreading the seed from a bucket over small defined areas. Several crew members were experienced in this procedure and were able to distribute the seed on all slopes and revegetation plots quite easily, although spreading was confined to times of the day when the wind was calm to avoid seed loss (usually early morning).

Immediately after fertilizer and seed distribution, a small bulldozer was used to pull a Brillion seeder-packer over the site to firm the seed and fertilizer into the soil. This step tended to cover most seed to a depth of about 0.5 inch (1.3 cm), and firmed the soil/spoil surface. In particularly rocky areas some seed was left unburied, but most of the seed appeared to safely lodge between rocks and soil clods.

Straw mulch was applied with a straw-blower pulled by the dozer to half of the research plots on the dump top (see Figure 4) to test its effect on reducing both rates of evaporation and wind redistribution of seed and soil fines (Kay, 1982). Mulch was applied at the rate of 2 tons per acre (2242 kg ha^{-1}) over the surface on all mulched areas. The mulch was immediately crimped into the upper 2-4 inches (5-10 cm) of soil using a straw crimper pulled by the dozer. This treatment appeared to be highly effective because wind tended to remove excess straw outside crimped areas, whereas crimping stabilized the straw and minimized straw redistribution.

Assessment of Revegetation Plots

In June of each year the research plots were assessed for revegetation success and plant species performance (e.g., see Chambers and Brown, 1983 for detailed procedures). Percent cover of vegetation, litter, rock, cryptogams, and bare ground was determined from vertical 35 mm photographs taken of 6 separate 0.25 m^2 quadrats in each research plot. The slides were projected onto a grid and the intercepts of each variable were counted. Plant standing crop biomass was determined by species by clipping all the plants in 6 quadrats (same size as for cover) in each plot. Biomass was expressed as oven-dry (75°C) weight per unit area.

Soil Water Status

Gravimetric soil water content was assessed during April, June, and October of 1988, 1989, and 1990. Soil samples were collected in 1988, 1989, and 1990 from the 0-2.5 cm (0-1 in) and 15 cm (6 in) depths, sealed in plastic cups, and transported back to the laboratory in Logan for analysis (Sidle and Brown, 1988). These depths represent the zone of most active plant root activity and development during the first 3 years of growth after seeding. The samples were weighed, oven-dried (110°C), and reweighed for expression of water content by weight (Gardner, 1986). These data were used to assess the relative efficiency of the different revegetation techniques to ameliorate limiting soil water stress at different times during the growing season.

RESULTS

General Observations

Responses of the vegetation on the research plots were assessed during June of 1988, 1989, 1990, and 1991 for percent cover, but biomass (standing crop) was not assessed in 1990. Generally, plant biomass and percent cover decreased in order from topsoil-mulch (TM), topsoil-no mulch (TNM), spoil-mulch (SM), to spoil-no mulch (SNM) plots.

Results of plant responses to the revegetation treatments within the first year after seeding were, as expected, limited. Generally, plant establishment was good but growth and development during 1988 (the first growing season following seeding) were minimal. In April, 1988 the presence of many introduced grasses on the site brought in with the straw mulch was noted, together with numerous weedy forbs that are either native or adapted-introduced (domesticated) to the area. The seeded perennial plants were evident on the site in 1988, but the young seedlings were just beginning to emerge and were difficult to identify. By June, 1988, when the first assessment of vegetation responses was made, the seeded plants of all lifeforms were growing well on the more intensively treated areas. All the seeded species were observed on the site except the sagebrush species (Artemisia tridentata and A. nova). By October, 1988 Russian thistle (Salsola kali) had established over most of the dump and was the most obvious invader observed; other invaders observed, in approximate decreasing order of abundance, included: halogeton (Halogeton glomeratus), tansy mustard (Descurainia sophia), peppergrass (Lepidium perfoliatum), cheatgrass (Bromus tectorum), and lambsquarter (Chenopodium album). Invasion by annuals was expected and is not considered particularly unusual because similar observations are commonly made in other aridland revegetation studies (e.g., Wallace and Romney, 1980; Young, 1991). Usually Russian thistle and other annuals invade revegetated areas (Young, 1991), but their abundance normally declines within several years as the seeded species begin to dominate the site. In 1989-1991 we noted significant continuing declines in the abundances of these annual weeds on the site.

In 1989 (the second growing season) the annual weeds virtually dominated plant cover on the site, although the seeded species were becoming more evident than they had in 1988. Russian thistle, halogeton, and mustards were clearly dominant on most plots in 1989. However, in 1990 (the third growing season) a noticeable decline in annual weeds occurred while the perennial seeded species of grasses, forbs, and shrubs assumed dominance. By 1991 (the fourth growing season following seeding) annual weeds were largely absent from most plots, and the reclaimed plant community began to assume a definite shrub-dominated architecture with a scattered grass and forb understory.

Plant Biomass

Only total plant biomass (standing crop at the time of sampling of all species combined) by treatment will be discussed here due to space limitations. Later publications will discuss the relationships of lifeform and individual species with treatments. Seeding and fertilizing rates did not have significant effects on biomass in any of the years studied, hence the data were lumped and analyzed together. Biomass data discussed here is for all plants, and includes annual weeds as well as the perennial seeded grasses, forbs, and shrubs.

The data illustrated in Figure 5 compare total plant biomass by treatment and year for the Borealis Mine revegetation plots. These data show that topsoil-mulched (TM) treatments supported a much higher total plant biomass than all the other treatments in 1988 and 1989. However, by 1991 it is clear that mulched treatments of both soil types (topsoil and spoil) supported significantly higher biomass than unmulched topsoil (TNM) or spoil. Although biomass data were not collected in 1990, it appears that there was little change in biomass between 1989 and 1991 in the unmulched treatments of both soil types. However, the mulched spoil (SM) treatment resulted in a significant increase in biomass from 1989 to 1991, whereas the topsoil-mulched treatment showed a slight decline. By 1991 there was no significant difference between spoil-mulched and topsoil-mulched, and no significant difference between spoil-no mulch (SNM) and topsoil-no mulch (TNM).

The data illustrated in Figure 6 represents an attempt to sort out the effects of soil type and mulch treatments individually on total plant biomass. These data show that in any given year topsoil resulted in higher biomass than spoil, regardless of mulching. Conversely, mulching appears to have had a greater effect on biomass than soil type, resulting in significantly higher biomass than unmulched soils.

Percent Cover

The percent plant cover data collected in June 1988-1991 are summarized by treatment in Figure 7 for all plants, including annual weeds as well as perennial seeded grasses, forbs, and shrubs. Percent cover contributed by litter and rocks will be discussed in a later publication. No cryptogams (algae, fungi, mosses, liverworts, ferns, clubmosses, or horsetails) were observed on the site during the four years of assessment. Plant cover data did not differ significantly for fertilizer and seeding rate treatments, hence were lumped in the analyses.

In all years (1988-1991) plant cover was highest on the topsoil-mulch (TM) treatment, followed in order by topsoil-no mulch (TNM), spoil-mulch (SM), and spoil-no mulch (SNM) treatments. Plant cover differences between mulching treatments within soil types were never significant, but differences were significant between spoil and topsoil treatments. Plant cover was lowest in 1988 and highest in 1989, followed by a sharp decline in 1990 and 1991. The decay in plant cover in 1990-91 was primarily due to the rapid decline in the abundance of annual weeds.

The data illustrated in Figure 8 represents an assessment of the separate effects of soil type and mulch on plant cover over the period 1988-1991. Topsoil resulted in significantly higher plant cover than spoil over the entire four year period, but mulch was not significantly different than unmulched soils. As in the comparisons of treatments

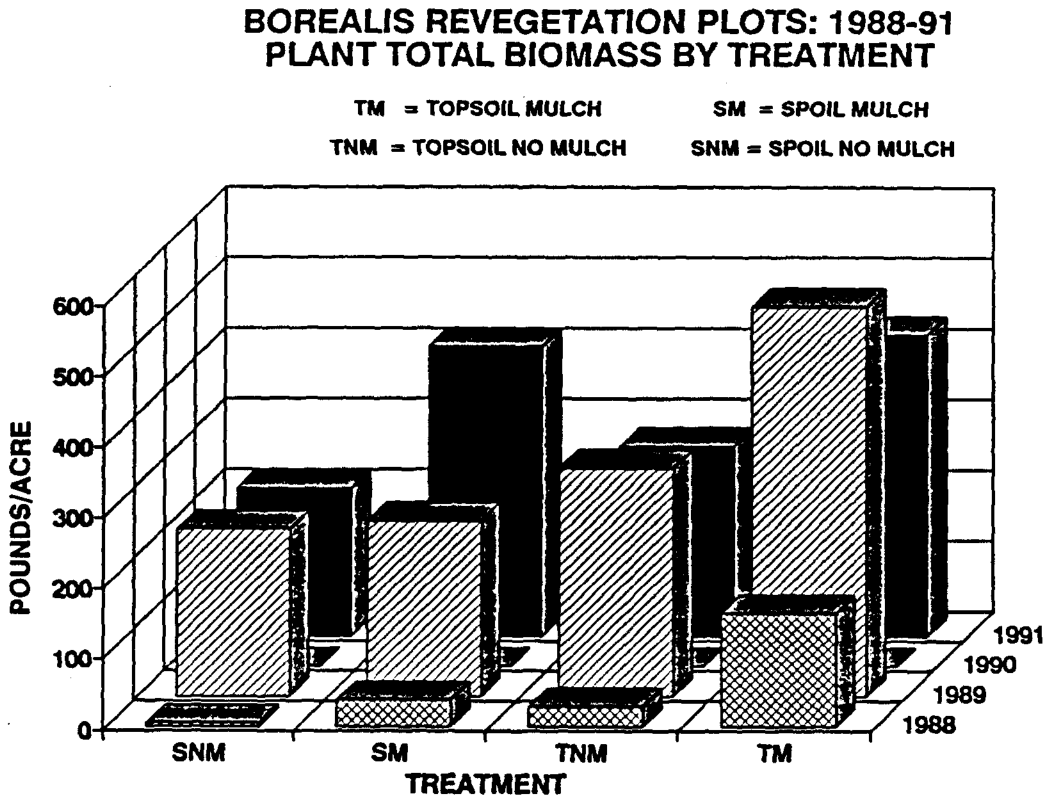

Figure 5. Total plant standing crop biomass (pounds per acre) by treatment and year on the Borealis Mine reclamation research plots, 1988-91. Note that biomass was not measured in 1990.

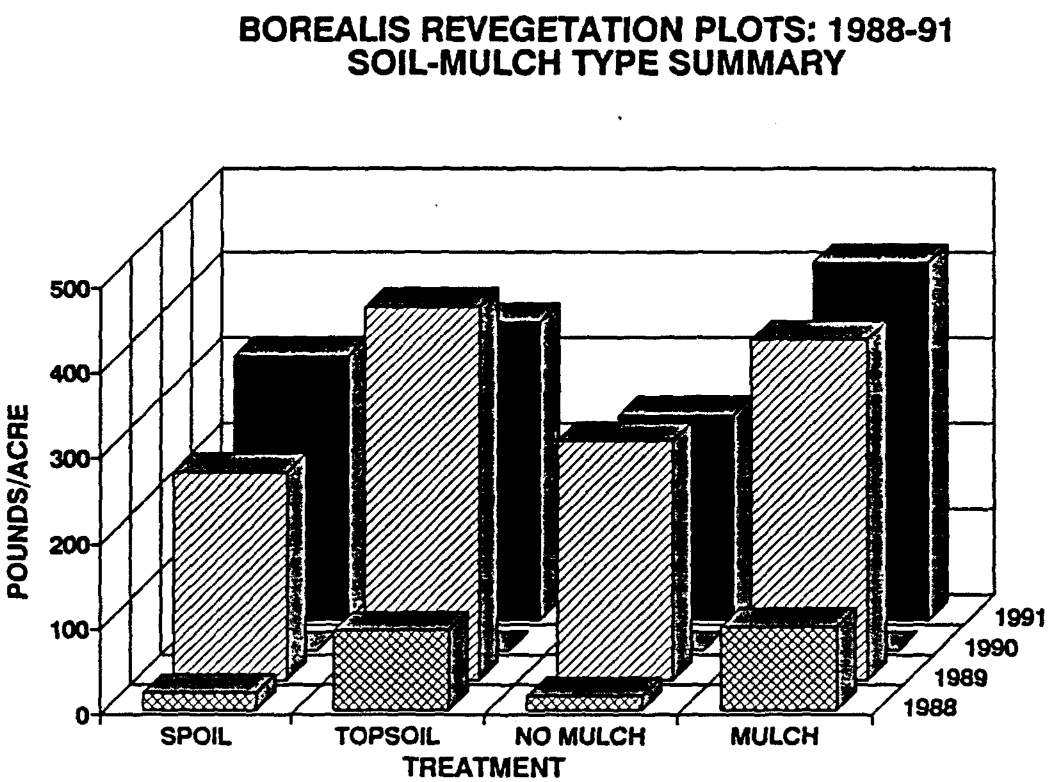

Figure 6. Total plant standing crop biomass (pounds per acre) by soil type and mulch treatment on the Borealis Mine reclamation research plots, 1988-91. Note that biomass was not measured in 1990.

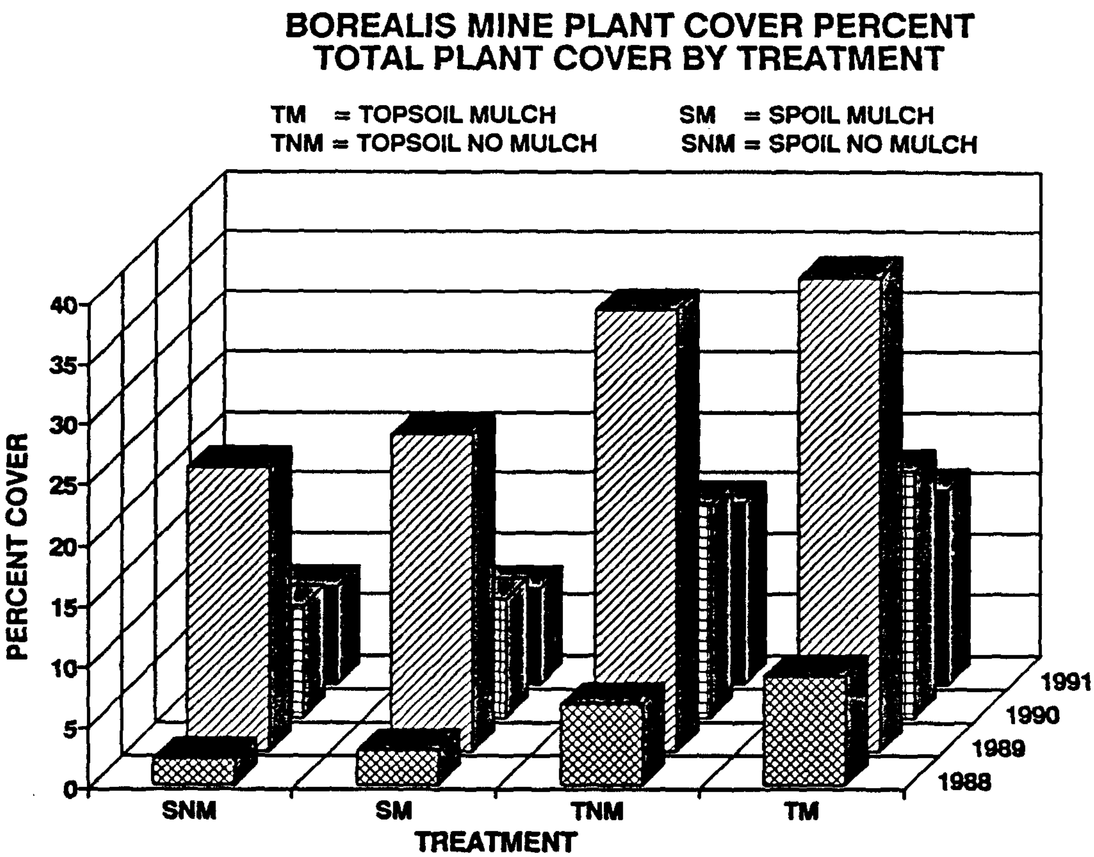

Figure 7. Percent cover of plants by treatment on the Borealis Mine reclamation research plots, 1988-91.

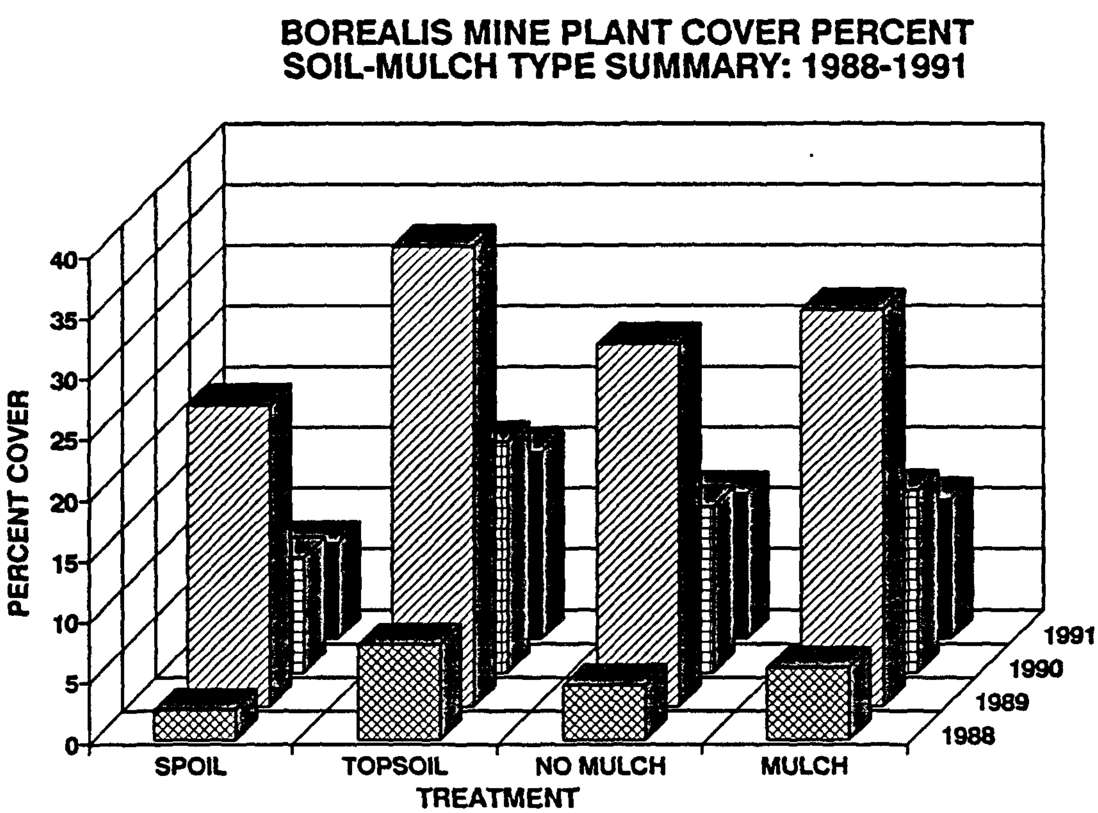

Figure 8. Percent cover of plants by spoil type and mulch treatment on the Borealis Mine reclamation research plots, 1988-91.

(Figure 7), plant cover increased sharply from 1988 to 1989 largely as the result of the establishment of annual weeds. The abrupt decline in cover from 1989 to 1990 reflects the lower abundance of annual weeds on the site.

Soil Water Status

Soil water content at the 2 and 15 cm (1 and 6 in.) depths was determined in April, June, and October 1988, 1989, and 1990 on the revegetation research plots. The data illustrated in Figure 9 compares soil water content at both depths for the different treatments, seasons, and years. In April 1988 we noted that more snow was trapped by the straw mulch than on unmulched plots, and that this resulted in higher soil water contents at 2 cm depth than on unmulched plots. Soil water content was not measured at 15 cm in April 1988. The data show that mulch was very effective for maintaining higher soil water early in 1988 (the first spring after seeding), but that this effect diminished rapidly with time. In all cases, mulched plots were significantly wetter at the surface than unmulched plots in April 1988, but differences in June and October, and at all other sampling times in 1989 and 1990, were not significant. Mulch had no significant effect on soil water status at 15 cm during any of the 9 sampling periods.

Generally, topsoil had a higher soil water content than spoil during all sampling periods regardless of mulching treatment, although differences were not always significant. Water contents at the 15 cm depth were wetter than the surface throughout the season in all years, but the effects of mulch and soil type at this depth were not significant. The higher water contents of topsoil compared with spoil were evident throughout all three sampling years, indicating that the effects of soil type on soil water status may persist longer than those of straw mulching.

This effect is illustrated in Figure 10, in which the relative differences in soil water content between mulched and unmulched plots are compared with differences between topsoil and spoil plots. These data substantiate the hypothesis that the major effect of mulching for maintaining soil water status is rather short-lived compared with that of soil type; on the Borealis Mine the effectiveness of mulch for maintaining higher soil water contents lasted only through the first spring following seeding, whereas that of soil type persisted at least through the first full three years. As shown in Figure 10 topsoil generally maintained soil water contents about 2 to 3% higher than that of spoil throughout the three years since seeding, whereas mulched plots were significantly wetter than unmulched plots only during the first spring following seeding.

DISCUSSION AND CONCLUSIONS

The comparative effects of the various reclamation treatments on the establishment of vegetation on the Borealis Mine reclamation research plots are strikingly evident after four complete growing seasons. Although there may be a potential danger in making too many

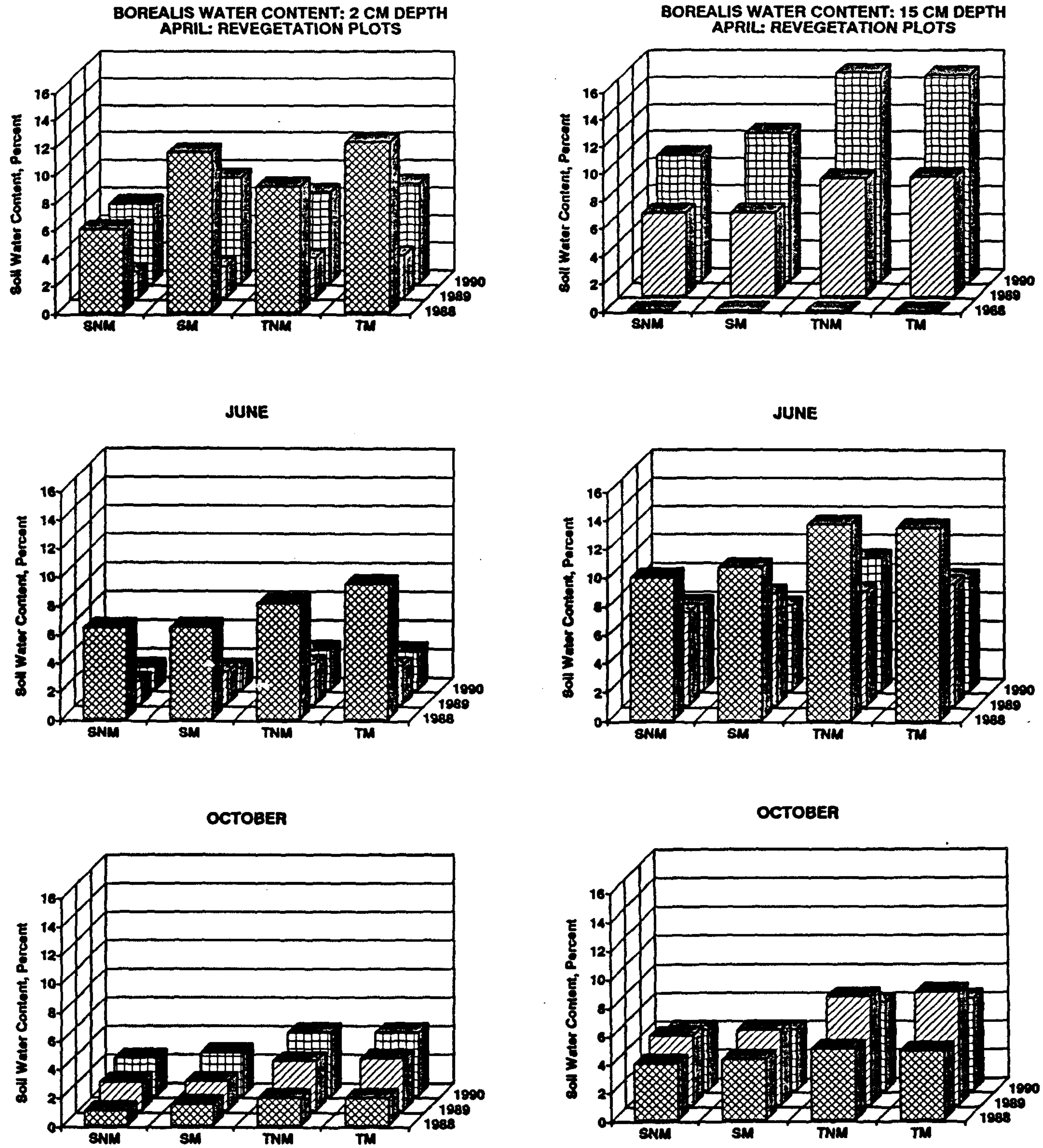

Figure 9. Soil water content (%) measured at 2 cm (left column of figures) and 15 cm (right column of figures) depth on the Borealis Mine reclamation research plots in April, June, and October, 1988-90. Symbols are: SNM spoil-no mulch, SM spoil-mulch, TNM topsoil-no mulch, and TM topsoil-mulch.

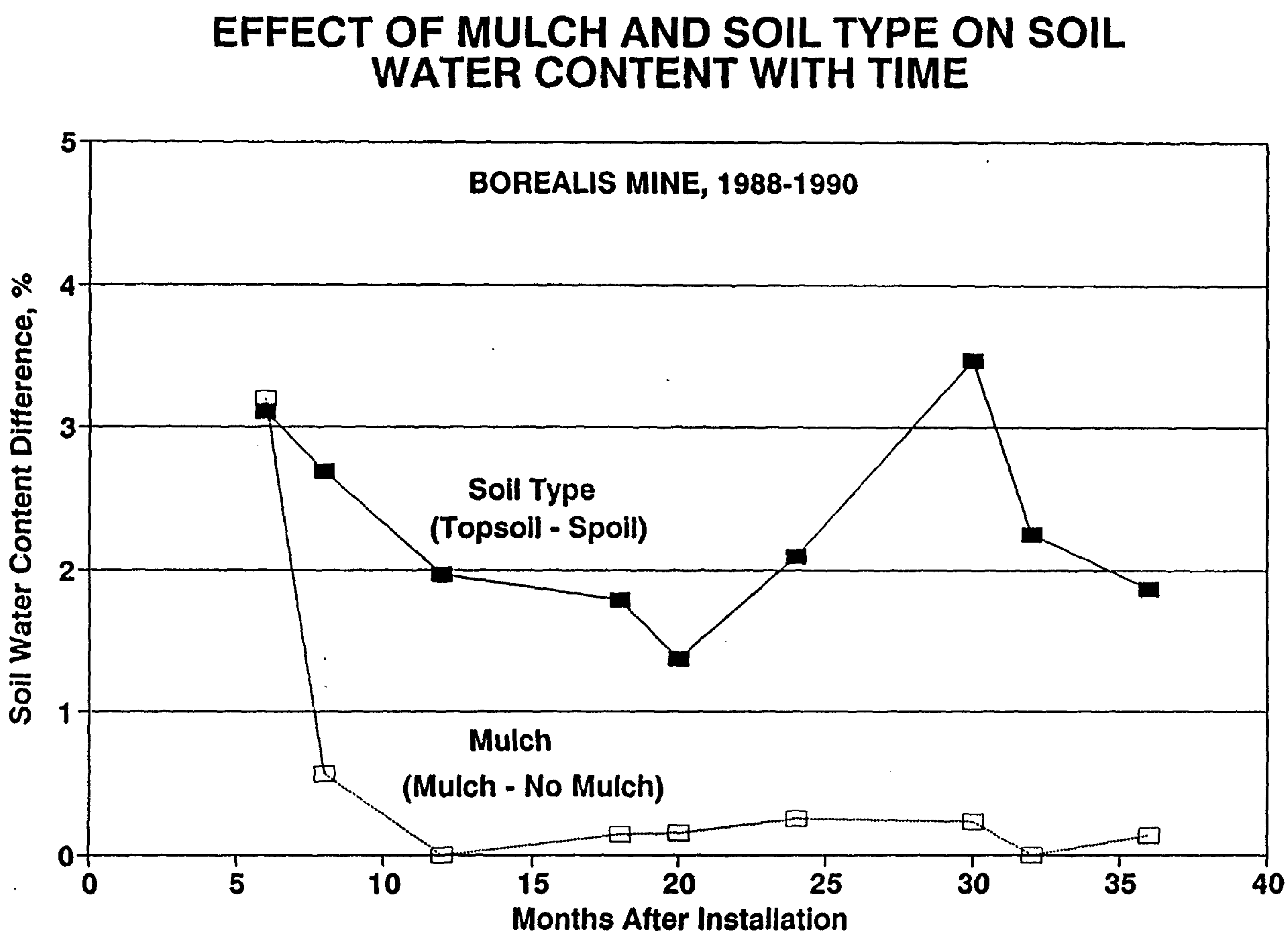

Figure 10. Effect of mulch and soil type on soil water content over time on the Borealis Mine reclamation research plots. Soil type effect (black squares) represents the difference in soil water content between topsoil and spoil plots, and mulch effect (white squares) is the difference between mulched and unmulched treatments.

long-term inferences and judgements about the development of climax plant communities in that period of time (e.g., Packer and Aldon, 1978; DePuit and Coenenberg, 1979), the relative effectiveness of the major treatments for establishing developing communities appears clear. We feel confident, based on the data collected so far, in recommending some alternative techniques and methods for reclamation on the Borealis Mine.

Topsoil and mulch treatments are significantly important reclamation treatments for the successful establishment of vegetation on mine dumps at the Borealis Mine. Of all the various treatments tested, the combination of topsoil and mulch is by far the most successful in terms of plant cover and biomass. In addition, soil water content is consistently more favorable on this treatment, which is an extremely important consideration in water-limiting environments. In addition, there is some unsubstantiated evidence from raw data collected in this study that soil physical and chemical characteristics appear to be far superior for plant growth and development on topsoil and mulch treatments over unmulched spoil. The stand of vegetation on topsoil-mulched plots is routinely more dense, taller, and has a greater diversity of age classes of plants, ranging from mature seed producing individuals to young seedlings. Not only has the topsoil-mulch treatment supported the highest plant cover and biomass over the four growing seasons studied, but it also has the highest species and lifeform richness. We have observed a greater abundance of all plant species on the site on plots treated with topsoil and mulch than on any other area except the native reference area. We strongly recommend topsoil and mulch applications during reclamation on the Borealis Mine over all other soil alternative treatments.

Mulched topsoil and spoil plots supported significantly higher plant biomass and cover than unmulched plots. Also, during the first year (1988) when the plant seedlings were first becoming established, mulch significantly increased soil water status in the soil surface. Mulch significantly enhanced snow trapping during the spring of 1988 (Sidle and Brown, 1988), and resulted in significantly increased seedling establishment. Mulch appears to improve soil bulk density and total organic matter, especially of spoil material, and perhaps improves nutrient availability as well. The positive effects of mulch on soil water status appear to be short-lived on this site, being restricted primarily to the first growing season after seeding. Other forms of mulching (e.g., straw blankets, wood chips, jute netting, etc) may have longer lasting effects on soil water, but it is not certain that this alone would be as beneficial as straw crimping. Crimping tended to provide a three-dimensional surface roughening effect that was significant in trapping snow, and perhaps also in deflecting the desiccating effects of wind. Had the first spring after seeding been unusually dry, perhaps other forms of mulching may have been more beneficial. Unfortunately, this research did not address the relative effectiveness of alternative mulching treatments. However, the data strongly suggest that mulch may be essential for seedling establishment during the first year after seeding, and that it may have significant, yet subtle, effects on other factors such as wind, microclimate near the soil surface, soil physical and chemical properties, and soil water status. Therefore, we strongly recommend the use of mulch in reclamation on the Borealis Mine.

Although mulch improved plant biomass and cover on both soil types studied, it had a much greater effect with topsoil than with spoil. Mulched spoil treatments were frequently not significantly different from unmulched spoil treatments in terms of plant biomass, cover, or soil water status. However, mulched topsoil treatments were often significantly more effective than unmulched topsoil. These data suggest that the beneficial effects of mulch are enhanced, and may only be realized, on better soil types. The spoil material on the dump is a poor medium for plant growth, and even when treated with mulch and other amendments, probably has a low potential for supporting desirable stands of vegetation in relatively short periods of time after reclamation. Without added amendments the raw spoil material is not expected to support adequate vegetation to meet minimum standards for reclamation.

Although no significant statistical differences were observed in the data comparing seeding and fertilizer rates tested on the research plots, it appears certain that the higher seeding rate (e.g., 80 seeds per sq. ft) and the higher fertilizer rate (e.g., 80 lbs N per ac) are probably preferable overall than the lower rates (e.g., 32 and 56 seeds per sq. ft. and 40 lbs N per ac). The higher rates consistently yielded higher plant biomass and cover, although variability in the data were high. Generally, higher seeding rates have been found to be more successful on harsh arid sites such as those found on the Borealis Mine than lower seeding rates, such as those normally encountered in more mesic locations (Packer and Aldon, 1978, DePuit and Coenenberg, 1979). The high bulk densities and percent coarse fragments found in the materials on the Borealis Mine limit the number of available "safe-sites" in which seeds germinate. Also, the normally high winds common on this site may result in redistribution of large quantities of planted seeds. Our data show that soil water status is highly variable temporally, and this combined with the desiccating effects of wind, may cause high mortality of germinating seedlings in most years.

The rapid and widespread establishment of Russian thistle and other annual weeds on the site during the first two growing seasons on the mine should be expected on the Borealis Mine. However, the commonly held opinion that invasion of annual weeds onto reclamation sites is somehow negative and undesirable is probably unjustified. Invasion by annual weeds plays a significant role in succession and in the development of more advanced plant communities, and represents an irrepressible natural force that probably should not (and perhaps cannot) be tampered with. These plants contribute to the development of soil from less desirable spoil materials and add organic matter and litter (or mulch) to the site. There is direct evidence that Russian thistle and halogeton both excrete oxalic acid, which when released in the soil, increases the availability of phosphorus to other plants (Dudley and Liliholm, 1989). Although annuals may be strongly competitive in some cases, the perennial seeded species used on this site appear to ultimately become established despite strong competition, and eventually achieve dominance over the annuals in the development of a reclamation plant community. We observed numerous instances during

1988 and 1989 where the annual plants appeared to aid in the establishment of perennial plants by providing protection from the desiccating effects of wind and direct solar radiation. The strongly taprooted morphology of annual plant species appears not to be totally restrictive in competition with perennials for soil water; rather, it appears that the two lifeforms may be somewhat compatible during the early stages of perennial plant development when root systems are absorbing water and nutrients from different soil regions. In succeeding years when the perennial plants are large enough to begin exploiting larger volumes of soil, they appear to compete successfully with the annuals for limiting nutrients and water, and eventually establish dominance over them.

Of the original 16 perennial species seeded on the research plots, only 10 appear to have been successfully established. These include: desert wheatgrass, pubescent wheatgrass, western wheatgrass, Indian ricegrass, squirreltail, needle-and-thread, Utah sweetvetch, Palmer's penstemon, fourwing saltbush, shadscale, and winterfat. All of the grasses seeded appear to have become successfully established, and all 4 of the forbs that were seeded have been observed on the site. However, among the forbs, scarlet globemallow and Lewis flax appear to be disappearing from the site after four years. Of the 6 shrub species seeded, fourwing saltbush, shadscale, and winterfat are by far the most abundant and dominant shrubs found on the site, and generally impart the major physiognomy to the vegetation on the dump. However, big sagebrush, rabbitbrush, and black sagebrush are either absent or make up a minor contribution to the flora on the site. Big sagebrush appears to be invading, and in 1990 we observed numerous seedlings becoming established along the contact zones between topsoil and spoil strips where accumulations of mulch lay over depressions where water appears to collect. It is certain that in time big sagebrush will become a major component of the flora on the mine dump, perhaps similar to its composition in surrounding native plant communities. Rabbitbrush, although present in small numbers, does not appear to be increasing, which is curious because it tends to be an aggressive shrub on disturbed sites adjacent to the mine dump.

The fact that the dump has not been transformed into a highly productive ecosystem after the first four years is not surprising. The low natural fertility of the spoil material and the low erratic precipitation and high winds characteristic of this area cannot be expected to develop closed solid plant communities in a short time. We feel that the vegetation on the site is very promising, and we have every expectation that it will develop into a very successful revegetation community in a relatively few years. We are encouraged by the appearance of such high densities of grasses, forbs, and shrubs, especially on topsoiled plots, but also recently on spoil areas. It is apparent that spoil areas will require many more years of vegetation development before adequate stands can become established. All of the species are increasing noticeably in size and abundance throughout each growing season, and very little mortality of established plants has been noted (although not quantified). However, persistent drought in the late 1980's and early 1990's may increase mortality in future years.

In the future we plan to continue research on the vegetation assessment on the plots and slopes on the dump, together with research on soil erosion, changes in soil properties over time, and soil and plant water relations. We feel that the Borealis Mine reclamation research plots provide a unique opportunity to study some long-term natural processes during ecosystem development that are not available at most other aridland reclamation sites. We are encouraged that public awareness of environmental quality and natural resources provides the impetus for researchers, land managers, and private mining companies to work together in learning how to reclaim disturbed lands.

RECLAMATION RECOMMENDATIONS

Based on the data collected so far, together with the experience gathered in reclamation on the Borealis Mine research plots, specific reclamation recommendations for similar sites in the pinyon-juniper vegetation zone include:

1. The site should be shaped and contoured in the late summer or early fall with slopes no steeper than 2:1, although 3:1 slopes would be preferred for use of heavy reclamation equipment and for surface stability.

2. Apply topsoil where possible to a depth of at least 6 to 8 inches (15 - 20 cm).

3. Have a soil analysis performed by a reputable soil testing laboratory of both the topsoil and spoil material, and request fertility recommendations. The following are examples of laboratories we have used successfully, although others may be equally qualified:

   Soil, Plant, and Water Analysis Laboratory (SPWL)
   Utah State University
   166/133 Agricultural Science Building
   Logan, Utah 84322-4830
   (801-750-2217)

   or:

   A&L Agricultural Laboratories
   13611 B Street
   Omaha, Nebraska 68144-3693
   (402-334-7770)

   _or_: 1010 Carver Road
   Modesto, California 95350
   (209-529-4080)

4. Select adapted plant species that represent a range of different lifeforms. For the Borealis Mine, we recommend:

Grasses:	Forbs:	Shrubs:
desert wheatgrass	Utah sweetvetch	shadscale
Indian ricegrass	Lewis flax	fourwing saltbush
needle-and-thread	Palmer's penstemon	big sagebrush
pubescent wheatgrass	scarlet globemallow	winterfat
squirreltail		
western wheatgrass		

We recommend that seed be purchased from reputable seed dealers that will insure seed origin, purity, and viability. Be sure to specify that seed origin must be from an area similar to, and preferably close by, the site to be reclaimed.

5. Broadcast the seed in the late fall of the year (when temperatures are too cool to permit germination) as a mixture of equal numbers of seeds of each species per unit area (see Table 2 for seed weights and equivalent numbers of seed). Based on the Borealis Mine reclamation data, we recommend the high seeding rate of about 80 seeds ft^{-2} (861 seeds m^{-2}). Harsh, severe sites, such as mine dumps, require much higher seeding rates than other areas.

6. Broadcast a fertilizer with quantities of nitrogen, phosphorus, and potassium that reflect the recommendations of the soil analysis report.

7. Cover the seed and fertilizer with soil to a depth of about 0.5 to 1.0 inch (1 - 2.5 cm) using a cultipacker or similar equipment.

8. Apply a surface mulch of either straw or hay at the rate of 2 tons per acre (4400 kg ha^{-1}), and either crimp it in with a straw crimper as described here, or apply netting or a tackifying agent to secure the fibers in place to minimize redistribution by wind. Alternatively, use commercial woven straw blankets or similar material in rolls, and stake it down securely.

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PANEL DISCUSSION

Regulatory and Technical Issues in Defining Successful Reclamation

Moderator: Thomas A. Colbert, IMS. Inc., Denver, CO

Panelists:
D.G. (Mickey) Steward, AMAX Coal Company, Gillette, WY
Kent Crofts, Constultant, Steamboat Springs, CO
Dan Matthews, Colorado Division of Mined Land Reclamation, Denver, CO

Revegetation Success—An "Ecoregulatory" Riddle

by
Thomas A. Colbert
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Under the Surface Mine Control and Reclamation Act of 1978 (SMCRA), the coal industry in the United States has learned to operate under a stringent, federally mandated regulatory regime. A basic tenet underlying this statute is that mined lands must be returned to beneficial use. In nearly all instances, this means the establishment of vegetation. More particularly in the western United States, most lands reclaimed under SMCRA are ordinarily reclaimed to some type of rangeland.

Language in SMCRA requires that vegetation established on reclaimed lands be diverse, permanent, effective, predominantly native, and of the same seasonality as vegetation as it existed before mining. The law also requires that statistically adequate sampling of vegetation be conducted on reclaimed land to demonstrate that these requirements have been achieved. Thus was created the need for empirical revegetation success standards.

Thus also was created technical and regulatory controversy that lingers yet today. There are those who would hold that we are little closer to achieving a workable concept for defining revegetation success than we were nearly 15 years ago. Final bond release for lands reclaimed under the permanent regulatory program of SMCRA in all of the western coal producing states is at a virtual standstill.

Despite this problem, there is an ever increasing tendency for reclamation plans and permit conditions for non-coal mining operations to include SMCRA-like empirical revegetation success standards. For these operations, and for the people who regulate them, the same sorts of problems await.

What are these problems? They fall into two basic categories. The first is mainly ecological: what set of objectively measurable characteristics adequately characterizes a desired post-mining landscape? It is important to remember that four or five measurable criteria can only begin to describe a landscape—they hardly define it. It is more like looking at a fuzzy x-ray of a vegetation community. Given set of characteristics defined in the usual terms of vegetation cover, herbaceous or total vegetation production, woody plant density, and species diversity, there are any number of potentially distinct vegetation stands which would meet the criteria. Some of these stands may not necessarily meet land use objectives. Conversely, there may be potential vegetation stands which would not meet every defined criterion which might by any other measure be considered successful reclamation. The bottom line is that *any empirical revegetation success criterion which does not tangibly contribute to describing a vegetation stand either in terms of specific requirements of the law or in terms of utility for the approved post-mining land use must be considered circumspect.* At best any such criterion may be arbitrary and therefore subject to negotiation and revision. We have also seen revegetation success criteria in approved permits which were either unachievable or just plain dumb.

There has always been an underlying bias in the coal regulatory programs in favor of establishing revegetation success criteria in terms of pre-mining baseline conditions. With reference areas, it was important to show that the proposed reference areas were statistically equivalent to the areas proposed for mining. That left more than a few mining companies with reference areas predominated by sagebrush and cheatgrass—hardly a model for successful revegetation. It is now much better understood that reference areas to be effective must resemble a desired post-mining landscape, in some instances even irrespective of the pre-mining conditions. Reference areas should not be overgrazed and should be in good or better range condition.

The second major problem with determining revegetation success is enforceability. We have seen many instances of approved permits in which revegetation success standards were ill-defined, ambiguous, or in some other way unenforceable. This can be as much a headache for the regulatory agencies as for the mine operators. Enforceability problems clearly can render the best intended revegetation success standards useless.

For any empirical success criterion, there must be clearly defined what is the variable being measured, what sampling method will be used, what statistical protocol will be employed (including sample adequacy), and what is the comparative standard (e.g., reference area or technical numerical standard). These definitions must be complete and capable of standing alone in the approved permit, such that the standards may be competently implemented and enforced by anyone later who was not involved in the original formulation of the criteria.

Some regulatory programs specify that for a given criterion revegetation is considered successful if the reclaimed area is within 90 percent of the reference area or technical standard. This can be a distinct benefit, for instance, to a mining company which may have fought hard for the approval of a woody plant density technical standard of 500 plants per acre, and which subsequently finds it can achieve revegetation success with a sample mean of only 400 plants per acre because of the 10 percent regulatory "discount" and a healthy sample standard deviation.

As the state-of-the-art in revegetation success criteria continues to evolve, questions will continue to be raised concerning such issues as the use of parametric statistics to measure populations which are not normally distributed, and the efficacy of traditional and non-traditional characteristics in describing successfully reclaimed vegetation stands. Serious questions regarding the intent and meaning of the diversity requirement in SMCRA will continue to be raised. Regarding diversity, there is an increasing trend in looking at landscape diversity (landscape 'mosaic') in addition to developing sensible ways of evaluating species diversity within vegetation types. Clearly revegetation success criteria for diversity have become the most problematic for most coal operators.

In working with our coal mining clients, we try hard to develop revegetation success criteria that are as simple and uncomplicated as possible. Further, any coal company has the right to argue for any comparative or numerical standard which will meet the minimum requirements under the regulations—and no more. In the long run, such minimum standards work in favor of the regulatory agencies as well in at least one very important regard. In approving a permit for a coal mine, a regulatory agency must make a legal finding that implementation of the approved reclamation plan will achieve the standards of performance prescribed by regulation. Approval of revegetation success criteria which ultimately prove to be unachievable constitutes a failure on the agency's part to fulfill its responsibility mandated under the law. It was not the intent of SMCRA for states to hold bond money forever.

For our hardrock clients, we generally discourage the use of empirical revegetation success criteria in permit applications. Although promises about reclamation performance far off in the future may seem cheap at permit application time, they can be a deal with the devil. Neither should such criteria be looked at as *all* bad. Properly developed in an approved permit, empirical revegetation success criteria—at least ones which are reasonable and achievable—can eliminate a lot of the uncertainty associated with bond release. The bottom line here is that if you are not absolutely sure of what you are doing, find someone who is.

The panel held at the 1992 High Altitude Revegetation Workshop on the subject of revegetation success included excellent presentations by Bill Schwarzkopf of Western Energy Company in Colstrip, Montana, D. G. (Mickey) Steward of Amax Coal Company in Gillete, Wyoming, Dan Mathews of the Colorado Division of Mined Land Reclamation, and Kent Crofts who after many years with Energy Fuels in Steamboat Springs, Colorado, now works as an independent consultant. There seemed to be an underlying concern of all the panelists that although industry's capabilities to reclaim mined lands have improved by leaps and bounds, parallel progress in achieving a satisfactory regulatory understanding of what constitutes successful reclamation has been frustratingly slow.

In summary, revegetation success is like what the old judge said about pornography: "I can't define it, but I know it when I see it."

RECLAMATION STANDARDS - CIRCA 1992

By Bill Schwarzkoph, Western Energy Company

The first surface coal mining in Colstrip began in 1923, when the Northern Pacific Railroad used coal to fuel their locomotives. Surface coal mining during this era lasted until 1957. At that time the railroad industry began using locomotives powered by diesel fuel and coal mining at Colstrip ended. Thirty-four years of surface mining left the Colstrip area with 2,100 acres of unreclaimed spoil banks. This lack of commitment in regards to the environment by the mining industry paved the way for public demand for strong reclamation standards.

When Western Energy Company (WECO), a subsidiary of Montana Power Company (MPC) began mining in 1968, strict reclamation standards were being developed. Environmentalists saw the energy shortage of the 1970's as the time to legislate Surface Mine Reclamation Standards. Montana began enforcing their standards in 1972 under the auspices of the Montana Department of State Lands (MDSL). The federal government formed the Office of Surface Mining to enforce the national standards in 1977. At that time MDSL strengthened state standards to adhere to the OSM standards (State of Montana, 1980).

When a surface mining venture begins in Montana today, the environment is protected by those standards. Before any disturbance occurs, many environmental studies are conducted. Data is gathered on wildlife, vegetation, soils, hydrology, air quality and archaeology. All these data are used to prepare a mine and reclamation plan. With these plans in hand, a mine permit is submitted to DSL and OSM. Permits average $2 million and take an average of three and a half years to obtain.

WECO's current mining and reclamation procedures, adhering to the present state and federal standards are as follows. Once a permit has been approved by MDSL and OSM, the first mining operation begins with soil salvage. During the first cut, or "boxcut", all soil is salvaged and stockpiled separately as topsoil and subsoil. Soil salvage depths average one foot of topsoil and two foot of subsoil.

Once the coal is removed, spoil banks are regraded to the approximate original contour. At this time, soil stockpiling ceases and a "direct haul" program begins. In this mode, soil is stripped and hauled directly to a regraded area. It is laid down in two separate lifts, (topsoil and subsoil). Direct hauling greatly enhances reclamation success due to the viable native seeds and mycorrhiza still alive in the soil. The soil is then ripped with a subsoiler to loosen scraper compaction. A firm seedbed for properly planting native species is then prepared by chisel plowing and/or discing and culti-packing.

The majority of WECO's reclamation consists of the establishment of native rangeland. This type of reclamation requires two different seed mixes and two different seeding methodologies. The first seed mix, made up of large seeded species, mainly cool season grasses, is drill seeded. The second seed mix is made up of small seeded species, mainly forbs, warm season grasses and shrubs. This seed mix is broadcast seeded immediately behind the drill seeding operation. Some shrubs and trees are planted at specific sites as containerized or bare root stock with the use of a tractor and three point tree planter.

Former cropland sites are reclaimed to cropland by using "Alternate Reclamation Plan" standards. Specific requirements such a cropping history, slope and soil classification must be met in order to reclaim cropland in Montana.

The reclamation is then monitored and managed for a ten year "bond release" period. During this period, management tools such as mowing, burning and grazing are used to manipulate the plant communities towards desirable bond release standards.

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To date, WECO has not received full bond release on any reclaimed land, nor has any other coal company operating in Montana. Partial bond release, however, has been obtained for about 85% of the bonds. Partial bond releases are obtained for properly regrading to a stable landform, topsoiling to proper soil depths and for the establishment of vegetation cover. Final bond release will not be obtained until the vegetation communities statistically meet pre-mine comparison standards.

Are the reclamation standards of today adequate? We believe they are, and that reclamation is working. The intent of regrading standards to have a stable landform which "approximates" the original contour is successfully being met. Steep eroding, unstable spoil banks are a thing of the past.

The salvage of soil has become routine with very successful results. Gone are the days of removing soil along with overburden by draglines. Good soil depth enough to grow grasses, shrubs, trees or crops is replaced.

Revegetation standards are being met. At the Rosebud Mine, only native species are seeded, no introduced species, fertilizer, or chemicals are used. A total of 4,000 acres have been reclaimed thus far. Presently, 3,000 acres of reclaimed rangeland are being grazed annually and 500 head of cattle graze reclamation lands from May 1 to October 1. Also, twenty head of bison graze reclamation year round. Additionally, 230 acres have been returned to croplands, with production equaling that of premine fields. A waste product, "spoil banks", has been transformed into productive land through the reclamation process.

Are the reclamation standards realistic? We believe they are when used as just described, to reclaim a waste product left over from mining into a useful productive land. Unfortunately, many standards are not enforced with reclamation in mind, but rather with restoration in mind. In this scenario, the standards are interpreted differently and are enforced to restore the land to its previous condition. Lands that have been classified as Capability Class V, VI and VII, which are unstable and, unproductive, should be "reclaimed" and not "restored" to its former unproductive, unstable condition.

In an actual case, WECO has a MDSL stipulation to a permit requiring them to restore "badland" sites, (unstable land sites analogous to old spoil ridges), on the pretense that it is important wildlife habitat. The stipulation contradicts most basic reclamation standards regarding slope, stability, soil depth, cover and productivity. Wildlife data gathered over the past 16 years by WECO does not indicate that these sites are "critical" to any wildlife species. "Badlands" are erosive and unstable with little or no soil development and have virtually no vegetation cover. This type of site can be found throughout eastern Montana. It does not seem realistic to return this type of land to its previous condition. Reclamation standards were intended to improve the land when possible.

This issue causes one to question whether the standards are realistic regarding regrading postmine topography. Restorationists are pressing for a postmine topography that "closely" resembles premine topography. Again, if the land being mined is rough, dissected country, still going through a natural erosive process, it seems unrealistic to restore it to its previous condition. Surface mining has a smoothing effect on the surface of rough, dissected land found in southeastern Montana. Most reclamation standards were written to reclaim to a stable landform, which requires stable drainages with slopes no steeper than 5:1 or 20%).

Reclamation is not a "mystery" anymore. There are still many things to learn and improve on, but the basic standards in effect today are more than adequate to return the land to a stable and productive condition. Regulators must keep in mind the original intentions of reclamation standards and remain realistic in their interpretation and enforcement.

POSTER PAPERS

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Englewood, Colorado

ECOLOGICALLY COMPATIBLE REVEGETATION ABOVE THE TIMBERLINE: A MODEL AND ITS APPLICATION IN THE FIELD

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INTRODUCTION

The present paper is an enlarged version of the poster presented at the Workshop. It is based on a long-term group research carried out within the alpine vegetation belt in Switzerland and includes both the generally valid concepts as well as the information specifically referring to machine-graded ski runs above the timberline.

THE TARGET VEGETATION

The aim of an ecologically compatible revegetation is to obtain a plant cover that is nature-like both in its species diversity as well as the age-state structure. The use of various species and the occurrence of various developmental stages within each coenopopulation should enhance the development of the plant community and promote compensation of possible individual losses. The vegetation should thus be self-supporting and maintenance-free.

MATERIAL AND METHODS

The model presented (Fig. 1) implies an exclusive use of native plants, preferably from the same type of geological substratum as the surface to be revegetated. The species selected should fulfill the principle of biological diversity, and a special attention should be payed to the growth type. A balanced proportion of "guerilla" and "phalanx" plants is recommended. The guerilla types are characterized by a loose growth and a scattered pattern of site occupation, whereas phalanx types manifest a compact growth resulting in the formation of locally dense stands (Harper 1977).

The principle of diversity was followed in our research in a twofold way: (a) plant material included various families (Table 1) or (b) numerous species belonging to only one family but charaterized by different biological features were used (Table 2).

Table 1. The diversity principle in the choice of plant material for revegetation above the timberline: (a) various plant families are included. Trial series on dolomite.

N of families	N of species (total)	Guerilla	Phalanx	Reference
7	12	6	6	Schütz 1988
5	6	3	3	Gasser unpubl.
8	11	3	8	Tschurr 1992

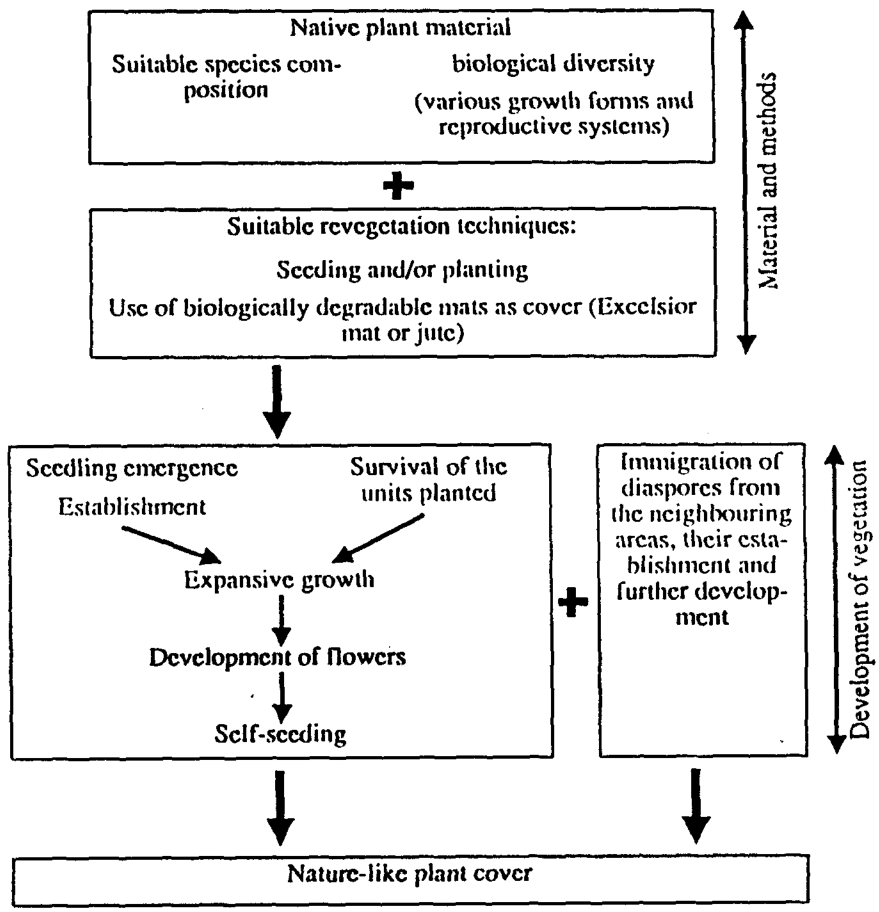

Fig. 1. The model of ecologically compatible revegetation above the timberline. After Urbanska (1989), partially modified.

Table 2. The diversity principle in the choice of plant material for revegetation above the timberline: (b) numerous species of only one family representing different biological types. Trial series on dolomite.

Family	N of species (total)	Guerilla	Phalanx	Reference
Gramineae	8	4	4	Urbanska et al. 1987
Leguminosae	11	5	6	Flüeler in press
Leguminosae	7	4	3	Hasler in prep.

SUITABLE REVEGETATION TECHNIQUES

How To Proceed?

Life condition in the alpine vegetation belt are precarious and reproduction by seed often fails, even in the intact populations. It goes without saying that the extreme conditions of machine-graded ski runs render a successful seed germination and in particular the seedling establishment uncertain, the use of native seed notwithstanding. The results obtained in our trials suggest that the revegetation by seeding **alone** may not be the technique best suited for high-alpine sites, even if some further precautions are undertaken (Schütz 1988, Flüeler in press).

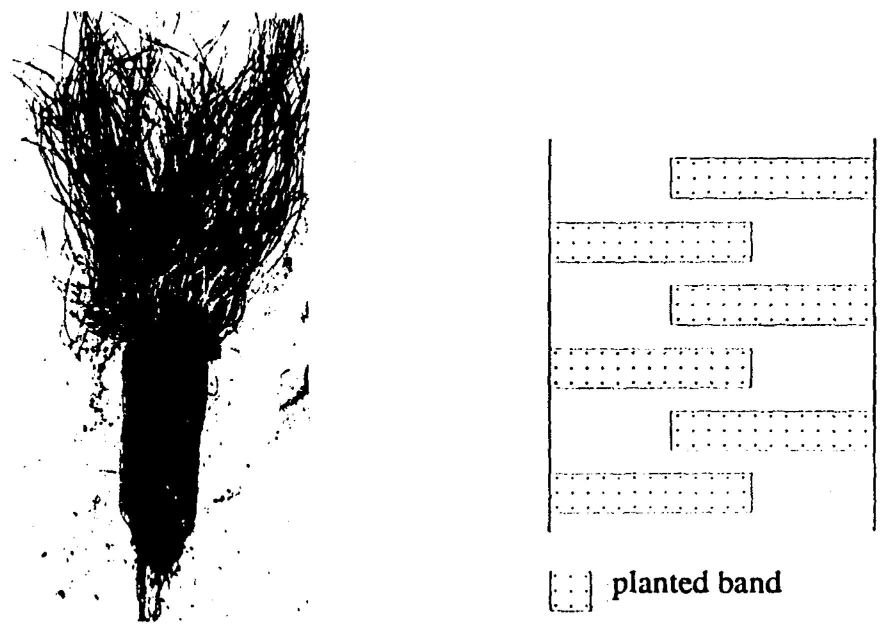

Fig. 2. Revegetation by planting. Left: a grass plug grown in Rootrainer. From Urbanska et al. (1987). Right: the "zip" pattern of planting. From Urbanska (1990).

Much more successful, on the other hand, is the revegetation done by planting, alone (Urbanska et al. 1987, Hefti-Holenstein unpubl., Hasler in prep.) or combined with seeding (Gasser 1989 and unpubl.). The plugs for planting are easily obtained from the SRC treatment (single ramet cloning, for description see Urbanska et al. 1987 or Tschurr 1990). This procedure permits to use sparingly the original native material, neither much place and sophisticated infrastructure nor highly skilled labour hands being required. To date, about 40 alpine species from Switzerland proved to be well-suited to this type of vegetative multiplication (Urbanska 1986, Urbanska et al. 1987, Gasser 1989 and unpubl., Flüeler and Hasler 1990, Tschurr 1990 and 1992, Wilhalm 1990 and unpubl.). It is interesting to note that not only some grasses and graminoids but also numerous forbs and legumes respond well to the cloning. The SRC units are grown in specially-selected Rootrainers to obtain a linear profile of the root system in the plugs (Fig. 2). This feature is very important because such plugs resist better to frost-heaving than the conically-shaped and broader units grown in standard pots.

The revegetation by planting is labour- and thus cost-intensive but strongly recommended for a local use. As far as the large machine-graded ski runs are concerned, a "zip" pattern of revegetated bands was developed (Fig. 2). Groups of 8-10 such bands, distributed at larger intervals over a ski run, would serve as centres of survival and future spreading of native plants. This technique might be combined with the seeding.

Should The Revegetated Plots Be Protected?

The answer is an unconditional yes. The protection of revegetated plots is of a particular importance as only in this way could the ecological risks be diminished. The best results in our trials were obtained in this respect with the Excelsior mats, but comparable geotextiles might possibly be used, too. The recent data of Flüeler (in press) indicate a more balanced microclimate under the covers than in the unprotected control plots. Seed germination under the Excelsior mats is less extensive than in open places, but the seedling survival and establishment is clearly better (Schütz 1988, Flüler in press). In the plots revegetated by planting the protective function of biologically-degradable mats was well-documented, too (Urbanska et al. 1987 and unpubl., Gasser 1989, Tschurr 1992, Hasler in prep.).

Apart from their protective function, the Excelsior mats apparently serve as diaspore traps and thus promote immigration of plants from neighbouring areas. This important feature will be described below in more detail.

DEVELOPMENT OF PLANT COVER IN REVEGETATED ALPINE PLOTS

The development of vegetation in the plots revegetated includes various patterns and processes. Two principal aspects may be distinguished:

- development of the plant material brought in by revegetation
- spontaneous immigration of plants from neighbouring areas.

The development of the plant material used in revegetation is obviously influenced by the technique used. In the plots seeded, the cycle begins with seed germination and proceeds through seedling establishment and the subsequent expansive growth of the plants. In the third year after the seeding the first flowers appear in the revegetated plots, and from then on the diaspore production continues, regularly or intermittently. Seedlings observed about four-five years after the revegetation are apparently issued, at least partially, from self-seeding (Schütz 1988, Urbanska unpubl.).

In the plots planted, the life cycle is greatly accelerated since no germination/establishment phase occurs initially and the main process to register is the further expansive growth of already developed plants used as plugs. Already one year after planting many biological individuals may produce flowers and seeds (Fig. 3). Seedlings, obviously issued from self-dispersed diaspores are recorded in the following years (Urbanska unpubl., Hasler in prep.).

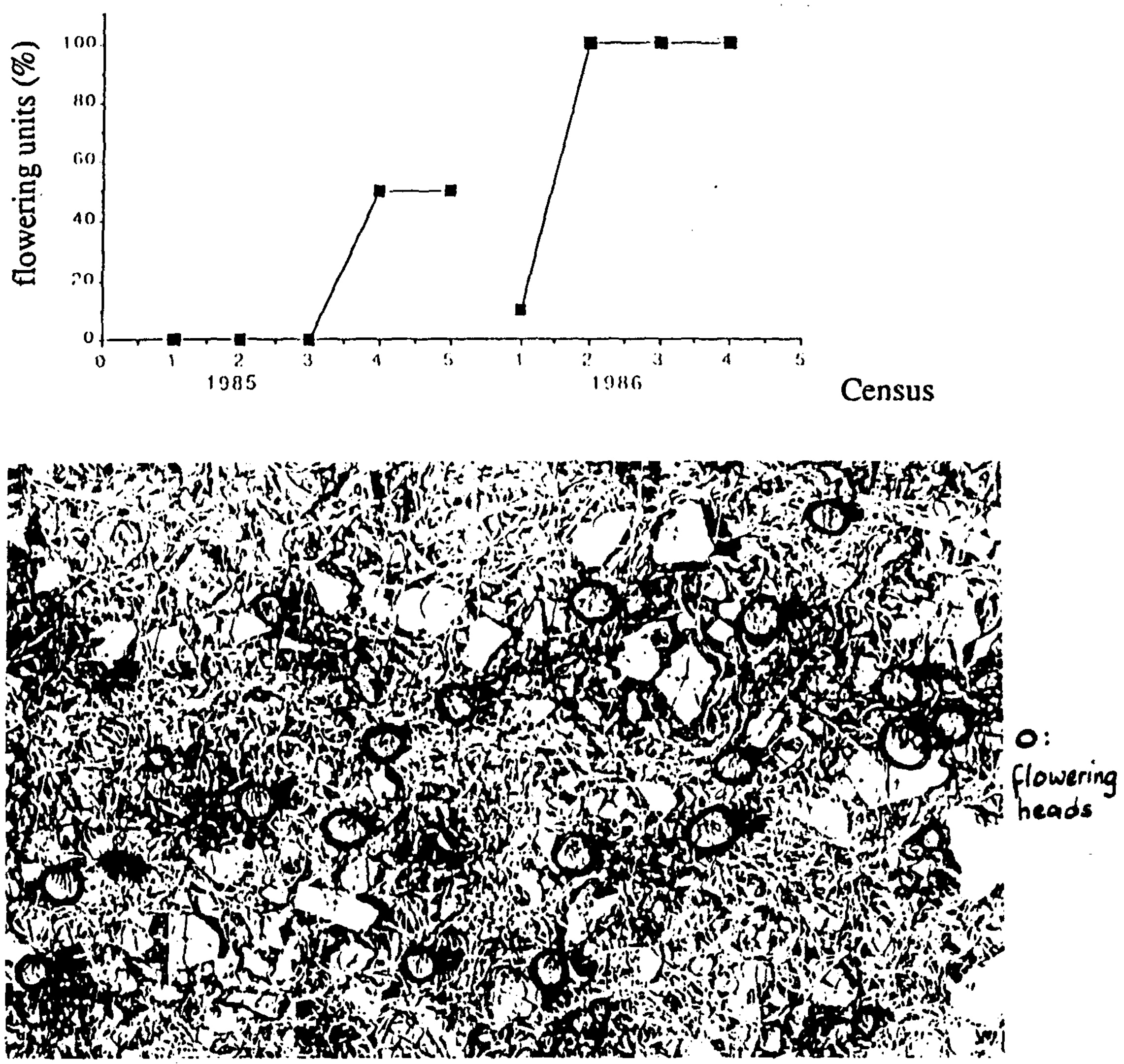

Fig. 3. Speedy flower production in the plots revegetated by planting. Above: flowering in a plot revegetated in early summer 1985 with the alpine grass Agrostis rupestris (Urbanska et al. 1987). Below: spectacular flower development in a plot planted with plugs of Trifolium nivale, the situation one year after revegetation. Hasler (in prep.).

Apart from the changes related to the development of the plant material used in the revegetation, immigration of diaspores from neighbouring areas plays an exceedingly important rôle in the development of vegetation in the revegetated alpine plots. The use of a three-dimensional cover (the Excelsior mats) apparently promote this process as suggested by the consistent appearance of immigrant species which were not included in the revegetation material (Fig. 4 and 5, Table 3). The life cycle of the immigrants obviously begins with germination and follows the usual phases of establishment, expansive growth, and eventually also the reproduction.

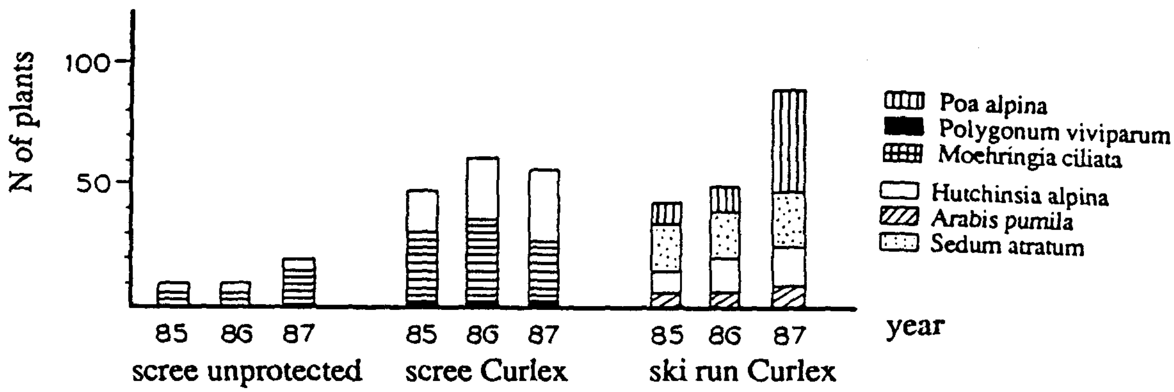

Fig. 4. Immigration in ski run plots seeded with a mixed material and protected with the Excelsior mat. The revegetation carried out in 1984. No immigration occurred in unprotected control plots (Schütz 1988).

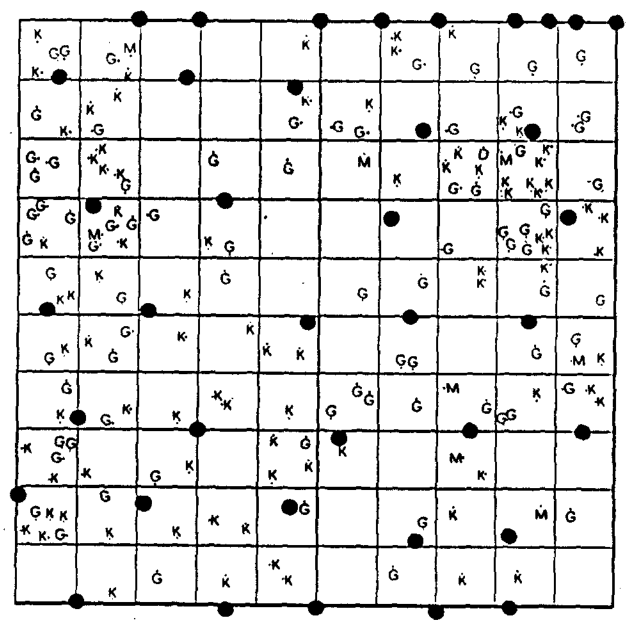

Fig. 5. Immigration in a plot planted with Achillea atrata (black points refer to single plugs) one year after revegetation. Trials on dolomite. Tschurr (1992).

Table 3. Development of the plant cover in some revegetated alpine plots: a preliminary assessment 5 years after revegetation.

K=seedlings, NR=non-reproducing plants, R=reproducing plants

Revegetation technique	N of the species used	N of the immigrant species	Approx. increase in N of individuals (%)	Age-state structure
Seeding only	12	6	80	K, NR, R
Planting only	3	5	50	K, NR, R
Planting and seeding	6	17!	150	K, NR, R

CONCLUSIONS

Ecologically compatible revegetation results in three important events:

- increase in the species diversity
- increase in the number of plants per site
- diversification of the age-state structure of the stand.

The above parameters are characterisic of the target vegetation. The development of vegetation in revegetated alpine sites may be slower or faster, depending on site conditions, but an unequivocal trend towards a nature-like plant cover may be recognized in most sites in ca. three years. Contrary to this tendency, the commercially revegetated high-alpine sites usually show an overall decline in plant vigour and stand density after three years, the reproductive phase being exceedingly rare (Meisterhans 1988).

The results of our studies are promising, but there are still problems to solve e.g., the introduction of the native plant material into the European market. The briefly outlined success of the ecologically compatible revegetation above the timberline should by no means be an alibi for further large-scale construction of machine-graded ski runs in the alpine vegetation belt.

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PENSTEMON HARRINGTONII, RARE PLANT OF CENTRAL COLORADO

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ABSTRACT

Penstemon harringtonii Penland is a plant under review for potential listing as threatened or endangered by the U.S. Fish and Wildlife Service. It is found in Eagle, Grand, and Routt Counties in Central Colorado at elevations between 6800 and 8400 feet in open stands of mountain big sagebrush (Artemisia tridentata ssp. vaseyana) on mostly alluvial and often at least somewhat calcareous substrates. It is usually found on gentle slopes. The species numbered but 1300 plants in 1990, but had increased to approximately 16,000 in 1991, presumably due to amelioration of the drought that had prevailed in western Colorado from 1987 to 1990. The largest populations are present in the Eagle River Valley where the threat from rapidly expanding recreational development is the greatest.

INTRODUCTION

Penstemon harringtonii Penland is a member of the figwort family (Scrophulariaceae) and is one of approximately 64 species, subspecies, and varieties of Penstemon occurring in Colorado (Weber and Wittmann1992). It was first collected in 1951 by H.D. Harrington in Eagle Co. and M. & C. Norton in extreme southern Routt Co. ; Penstemon specialist C.W. Penland who had made a third collection in Grand Co. in 1952 and recognized the plant as a separate species and published the new name in 1958 (Penland 1958). Until 1982, these were the only specimens and localities known. Since that time, the distribution of the plant has been filled in, but it is not known beyond those three counties in central Colorado.

IDENTIFYING CHARACTERISTICS

Penstemon harringtonii is approximately 12 to 18 inches in height with grayish-green leaves that are rather thick and arranged opposite (in pairs, as is true of all Penstemon species). Most of the leaves are basal, and, although broader than the stem leaves, these basal leaves are also grayish-green and thickish. The tube-shaped flowers are narrow at the base and flair suddenly at the top; the basal part of the flower tube is usually lavender and the flaired "face" is distinctively sky-blue. The most important feature is the presence of one pair of stamens extending out from the end of the flower tube (see Figure 1). In most Penstemon species, no stamens extend beyond the end of the flower tube.

AREAS OF KNOWN OCCURRENCE

Penstemon harringtonii is found in northern Eagle County, especially along the Eagle River Valley from Avon to Gypsum, and along small tributaries to the Colorado north of Dotsero, in extreme southern Routt County, and in extreme southwestern Grand County south and southwest of Kremmling.

HABITAT

It occurs mostly on soils derived from coarse alluvium, especially on older terrace deposits. It is usually found in the company of mountain big sagebrush, usually without abundant competition from grasses and other forbs. In heavily grazed sagebrush stands, it is typically found under the canopy of sagebrush shrubs. Perhaps because it apparently cannot tolerate heavy competition, sites of its occurrence are usually convex and well drained, although mostly on slopes less steep than 20% (5(h): 1(v)).

APPROPRIATE MANAGEMENT

Although rare, Penstemon harringtonii tolerates disturbance in the form of grazing, probably because of the effects grazing can have in reducing herbaceous competiton. It also tolerates methods of physical sagebrush removal such as "brush beating."

THREATS TO SURVIVAL

The largest populations of Penstemon harringtonii are located in the Eagle River Valley which is also the portion of its range in which the potential losses due to recreational development are highest. It is especially vulnerable because low slope sagebrush habitat is a very common location for development. Populations in Grand County are also threatened by residential development.

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Figure 1. Penstemon harringtonii. Note pair of stamens extending beyond face of flowers.

REVEGETATION PATTERNS AND RATES AT THE BODIE MINE AREA, MONO COUNTY, CALIFORNIA

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ABSTRACT

Revegetation of disturbances associated with recent and historic mining/ exploration activities as old as 100 years before present in the Bodie Mining Area in northern Mono County, California was examined using plant cover sampling. This examination was undertaken in two vegetation types common in the area: Big Sagebrush/Bitterbrush (Artemisia tridentata var. vaseyana/ Purshia tridentata) and Low Sagebrush (Artemisia arbuscula). Total plant cover and total shrub cover approached that of undisturbed areas by 50 to 100 years in both vegetation types. In the Low Sagebrush type, the total vegetation and total shrub cover exceed that of the undisturbed area by 50 to 100 years.

INTRODUCTION

In the evaluation of revegetation success in the western U.S., it has become apparent that realistic discussion of goals is often arrested for lack of an understanding of the basic successional patterns and rates in the ecosystem affected. Even though it may be argued that reclaimed or revegetated areas represent "new" ecosystems, there are often at least general expectations that revegetation will ultimately result in one or another particular local natural ecosystem.

The Bodie Mining Area is located in northern Mono County, California at an elevation of approximately 9000 feet. It is an area with a long history of development associated with gold mining for more than 100 years. The nearby ghost town of Bodie is a popular California State Park. Although mining at the site ceased in the 1950's, the interest in potential additional extractable gold has stimulated further exploration via drilling for several years. Mining/exploration at the Bodie site has disturbed two vegetation types, the Big Sagebrush/Bitterbrush (Artemisia tridentata ssp. vaseyana / Purshia tridentata) type and the Low Sagebrush (Artemisia arbuscula). Both types are heavily shrub-dominated, with very litle herbaceous plant cover.

In August, 1991, an evaluation of drill pad disturbances associated with exploration by the Bodie Consolidated Mining Company (BCMC) was undertaken to assess the condition and trend of the revegetation of such sites seeded between 1988 and 1990. While on the site, it became apparent that project personnel were intimately familiar not only with BCMC sites, but with previous drilling programs as well as previous mining disturbance as old as 100 years and more. This presented an opportunity for the examination of revegetation patterns on sites of documentable last disturbance, allowing a direct examination of revegetation patterns and rates in each of the two vegetation types.

METHODS

Formerly disturbed sites were sampled for vegetation cover using the point intercept method. A Cover-Point optical point projector was used to project 100 points along a 50 meter randomly oriented transect. Hits on a given plant species were divided by the total number of points projected (100) to determine percent foliar cover. Species composition data were collected by tallying all species present within one meter of the cover transect (2m x 50m quadrat). This allows an assessment of "species density" as number of species present per 100 square meters. One sample transect was placed at each dated disturbance; the transect was doglegged in random directions to fit within the confines of the smaller areas such as drill pads.

Despite the lack of large sample size, the results of the data collection that did occur have been graphed for purposes of discussion of apparents trends (Figures 1 through 7). In these graphs, the "undisturbed" (control) samples have been placed with an arbitrary date of last disturbance of 1800 A.D.; obviously they were probably never subject to the exact type of disturbance that have occurred in the mining areas during the last century, but for purposes of graphing, some date needed to be assigned.

RESULTS

General Revegetation Conditions

BCMC has conducted exploration and revegetation since 1988. A seed mix containing intermediate wheatgrass (Agropyron intermedium), hard fescue (Festuca ovina var. duriuscula), Indian ricegrass (Oryzopsis hymenoides), Cicer milkvetch (Astragalus cicer), and birdsfoot trefoil (Lotus corniculatus) as suggested by the U.S. Bureau of Land Management had been used in revegetation through 1991. Results of vegetation sampling showed that the seeding had led to the establishment of very little of the seeded species, and most of the reestablishing plant cover was comprised of native species of grasses, forbs, and shrubs. The poor performance of the seeded species was considered largely fortunate since, with the exception of Indian ricegrass, none of the species in the seed mix is native to North America. Although these introduced species are commonly used in revegetation and pasture improvement throughout the western U.S., their use in the Bodie Area is inappropriate.

The local ecosystems, while heavily disturbed over the past 100+ years by mining and related activities, have remarkably few adventive weed species present, contrasting starkly with the situation in much of the Great Basin area immediately to the east where such adventive plants are a continuing nuisance. While intermediate wheatgrass, hard fescue, Cicer milkvetch, and birdsfoot trefoil are not weeds under normal circumstances, adding them to ecosystems such as those in the Bodie area that are almost entirely native in composition is inappropriate, especially considering that native species are available from commercial sources or could be acquired from local collection.

Revegetation Patterns and Rates

Big Sagebrush / Bitterbrush:

Data from the sampling of disturbed and undisturbed areas within this vegetation type are presented in Table 1. Total vegetation cover in the type shows a positive trend of increase following disturbance from the initial aftermath of disturbance up to about 100 years, over which time total cover rises from about 10 to 25 percent up to about 45 percent.

The Big Sagebrush / Bitterbrush ecosystem is heavily dominated by shrubs with very little presence of herbaceous plants; native perennial grasses are the most abundant herbaceous lifeform, providing, nonetheless, an almost negligible amount of cover in undisturbed areas (see "Undist.". samples, Table 1). This state of affairs may reflect a shift in composition to woody plants providing less palatable and less available forage that was caused by overgrazing by domestic livestock beginning over a century ago, a this trend observable throughout the western U.S., and particularly in the Great Basin. During this process, the more palatable herbaceous plants were so completely and persistently removed by domestic grazing animals, that they were nearly extirpated. At the same time, the competition that the herbaceous plants posed for the shrubs was removed and that component subsequently expanded. Because of their longevity, the shrubs have continued to dominate well past the actual period of excessive grazing. Thus, reference here to "Undisturbed" conditions must be taken to mean "relatively undisturbed"; truely undisturbed vegetation, ie. in presettlement condition, is probably non-existent in this area, as in most areas of the West.

As can be seen in Figure 1, total vegetation cover in the oldest disturbed areas (approx. 100 years) somewhat exceeds that in undisturbed areas. This is reflected in both the extra abundance of shrub cover (Figure 2), as well as the extra abundance of native perennial grass cover (Figure 3), which in the undisturbed areas is nearly nil. The "opportunity" provided by the disturbance may have allowed the community to reconstitute a more balanced lifeform composition than the "undisturbed" areas, over 100 years of development. Note however, that the annual forb component is present mostly in inverse proportion to the shrub and perennial grass components, being abundant in the earliest years and fading in the 10 to 100 year period (Figure 4). The annual forb component is present in the undisturbed areas, tucked away under overarching shrub cover, and providing about 10 percent cover. Why native annual forbs are absent in the middle part of the successional sequence at this site is not known. The shrub and native perennial grass cover of these middle stages may be so vigorous and abundant (more so than undisturbed areas) that the annual forbs are out-competed.

It is important to remark on the fact that succession in all the vegetation types of this area is characterized by the absence of introduced weedy plants. In most big sagebrush ecosystems in the West, disturbance is unavoidably followed by a profuse development of mostly introduced annual plant species that sometimes delay the development of native perennial forbs and grasses, as well as shrubs. The Bodie area, perhaps due partly to fairly high elevation, is not heavily infested with such introduced weeds despite a long history of disturbance.

Low Sagebrush:

In the Low Sagebrush ecosystem, there is a similar absence of introduced weedy plants; there is also a near absence of any annual species whatsoever (Table 2). The most frequently encountered annual species was Bailey's wildbuckwheat (Eriogonum baileyi), and it occurred in only three of the eight samples in this vegetation type. Total vegetation cover in the Low Sagebrush ecosystem is lower than it is in the Big Sagebrush / Bitterbrush type. Cover in the latter type totaled about 45 percent, while in the former type it varied between about 10 and 25 percent (Figure 5). During the successional sequence total cover climbs to about 30 percent by 100 years, then declines to the aforementioned range of 10 to 25 percent. This "overshot" of vegetational cover is larger than the one observed in the Big Sagebrush / Bitterbrush vegetation type (Figure 1). It could result from the fact that the restrictive nature of the growth medium in the Low Sagebrush ecosystem , ie. shallow, very rocky soil, probably very rich in potassium (Gordon Bucknam, BCMC, personal communication), has been at least somewhat alleviated by disturbance that may have loosened the upper root zone and allowed more effective penetration of moisture and roots. In the disturbed areas sampled within the Low Sagebrush vegetation type, there were some clear instances where a restrictive feature of that environment has been relieved and the disturbed area was being reoccupied by shrubs such as basin big sagebrush that require a deeper substrate.

Since shrubs account for most of the cover in this type, it is not surprising that the pattern of shrub cover through the successional sequence closely follows the total cover pattern, "overshooting" the level found in the undisturbed areas (Figure 6). Native perennial grass cover makes a steady increase through the sequence (Figure 7), while native perennial forb cover, mainly comprised of various suffrutescent Eriogonum species is very erratic. It is not known what environmental variables account for the unpredictable presence of these wildbuckwheats in the Low Sagebrush ecosystem.

DISCUSSION

Results of the reconnaissance survey of disturbed sites within the Bodie Exploration area suggest that, in the case of the two most extensive vegetation types, Big Sagebrush / Bitterbrush and Low Sagebrush, there is a clear progression of plant establishment and growth following cessation of disturbance that leads to a plant community very close, in some cases visually indistinguishable, from areas that are not known to have sustained any disturbance over the past 100 years and longer. This progression of vegetation, or succession, on disturbed sites occurs slowly, as is typical in communities dominated by woody lifeforms. However, the area is fortunate to lack the presence of aggressive introduced plants that so often elsewhere occupy early successional stages and impede establishment of the desired native perennial herbaceous and woody plants.

SUMMARY

The overall evidence gathered during the August 1991 reconnaissance of the Bodie Exploration Area shows that the successional patterns of the area, which strongly affect the rates at which revegetation can possibly be expected to proceed, are strongly dominated by native species and are moderate in speed, requiring about 50 to 100 years to reach qualitative equality with undisturbed areas. BCMC revegetation efforts have had only three years to proceed in the successional sequence, but the procedures used appear to have allowed the establishment of shrubs and native perennial grasses that are critical to the achievement of further advances in revegetation as time continues. A few suggestions for changes in revegetation procedure, especially raking or harrowing the seed and excluding browsers and grazers, and use of an improved seed mix, will assure that the early years of revegetation accompany the establishment of the plants necessary to the recovery of natural appearance and function at the earliest possible date.

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TABLE 1. COVER DATA - BIG SAGEBRUSH / BITTERBRUSH VEGETATION TYPE, BODIE EXPLORATION AREA, MONO CO., CA - 1991

Plant Species / Site Number / Date	86 1988	193 1990	Undist. ---	166 1989	High Peak ca. 1890	near 69 ca. 1930-40	18 1974	59/62 1986	Old Road ca. 1890	121 1989	189 1990	Undist.
					PERCENT FOLIAR COVER Sample Site							
NATIVE ANNUAL & BIENNIAL FORBS												
Chenopodium berlandieri	P		P	P						P	P	P
Gayophytum nuttallii	4	10	P	2	P						6	2
Lappula redowskii		P	2 (2)*									
Phacelia humilus		2	2 (2)	2	P					P	6 (2)	6 (2)
Plagiobothrys kingii								P	P	2	P	P
Rorripa curvisiliqua			P					P		P		
TOTAL NATIVE ANN. & BIEN. FORBS	4	12	4	4	0	0	0	0	0	2	12	8
INTRODUCED ANNUAL GRASSES												
Bromus tectorum				P								
Triticum aestivum		4									6	
TOTAL INTRO. ANN. GRASSES	0	4	0	0	0	0	0	0	0	0	6	0
NATIVE PERENNIAL FORBS												
Eriogonum microthecum	P		P									
Eriogonum strictum						P						
Eriogonum umbellatum	2		P		P							2
Leptodactylon pungens				P	P							
Lupinus argenteus												
Lygodesmia spinosa				P	P							
Monardella odoratissima			P									
Phlox stansburyi		P										P
Rumex sp.							P					
TOTAL NATIVE PERENNIAL FORBS	2	0	0	0	0	0	0	0	0	0	0	2
INTRODUCED PERENNIAL FORBS												
Astragalus cicer				P								
TOTAL INTRO. PER. FORBS	0	0	0	0	0	0	0	0	0	0	0	0
NATIVE PERENNIAL GRAMINOIDS												
Carex douglasii					4		2		2	8		
Elymus cinereus				2	P		2	2	P (2)			P
Juncus balticus							P					
Oryzopsis hymenoides			P	P	P (2)		P	P	4 (2)		2	P
Poa ampla				P								
Sitanion hystrix	P		P		P (2)	P	P	P	P	P		P
Stipa comata									4			
Stipa occidentalis					P (2)				2	6		P
TOTAL NATIVE PER. GRAM.	0	0	0	2	4	0	4	2	12	14	2	0
INTRODUCED PERENNIAL GRAMINOIDS												
Agropyron intermedium				2								
Festuca ovina var. duriuscula				P		P				P	P	
TOTAL INTRO. PER. GRAM.	0	0	0	2	0	0	0	0	0	0	0	0

TABLE 1. COVER DATA - BIG SAGEBRUSH / BITTERBRUSH VEGETATION TYPE, BODIE EXPLORATION AREA, MONO CO., CA - 1991

Plant Species / Site Number / Date	86 1988	193 1990	Undist. ---	166 1989	High Peak ca. 1890	near 69 ca. 1930-40	18 1974	59/62 1986	Old Road ca. 1890	121 1989	189 1990	Undist.
	PERCENT FOLIAR COVER Sample Site											
SHRUBS												
Artemisia cana							4					
Artemisia tridentata var. tridentata	2		12	2	8	P	P	8	24	P	2	18
Artemisia tridentata var. vaseyana			2		4							4
Chrysothamnus depressus	2											
Chrysothamnus nauseosus	10	P	P			P	12	10	2	P		
Chrysothamnus viscidiflorus	12	2	P	P	P	P				P	P	2
Purshia tridentata	P	P	22	P	30	46	4	2	12	P	2	10
Ribes cereum				P			2	P				
Symphoricarpos oreophilus			2			2						
Tetradymia canescens					P							2
TOTAL SHRUBS	26	2	38	2	42	48	22	20	38	0	4	36
BARE SOIL	22	14	18	62	28	18	50	50	10	38	6	20
LITTER	32	68	40	12	20	12	10	18	34	40	56	32
ROCK	14			16	6	18	14	10	2	6	14	2
FECES						2						
CARDBOARD						2						
TRASH (Historic)									4			
TOTAL VEGETATION COVER (%)	32	18	42	10	46	48	26	22	50	18	24	46
TOTAL COVER (%)	100	100	100	100	100	.00	100	100	100	100	100	100
SPECIES DENSITY (No. per 100 sq. m.)	10	9	16	16	15	8	11	9	10	12	10	15

* Numbers in parentheses indicate hits below the shrub overstory.

TABLE 2. COVER DATA - LOW SAGEBRUSH VEGETATION TYPE, BODIE EXPLORATION AREA, MONO CO., CA - 1991

Plant Species / Site Number / Date	PERCENT FOLIAR COVER Sample Site 10 1968	170 1989	170 Undist. - - -	38&39 1977	38&39 Undist. - - -	42&54 ca. 1970	42&54 Undist. - - -	Tioga Shaft ca. 1890
NATIVE ANNUAL & BIENNIAL FORBS								
Eriogonum baileyi	P	2	P					
TOTAL NATIVE ANN. & BIEN. FORBS	0	2	0	0	0	0	0	0
INTRODUCED ANNUAL & BIENNIAL FORBS								
Halogeton glomerata		P						
TOTAL INTRO. ANN. & BIEN. FORBS	0	0	0	0	0	0	0	0
NATIVE PERENNIAL FORBS								
Chaenactis douglasii	P	P						
Eriogonum caespitosum		P	P		P		P	2
Eriogonum microthecum		P	P	P	P	2		P
Eriogonum strictum	P		P					
Eriogonum umbellatum	2				P			
Eriogonum vineum	P							
Leptodactylon pungens	4	P						P
Lygodesmia spinosa	P	2	P					
Phlox stansburyi		P						
TOTAL NATIVE PERENNIAL FORBS	6	2	0	0	0	2	0	2
INTRODUCED PERENNIAL FORBS								
Astragalus cicer		P						
TOTAL INTRO. PERENNIAL FORBS	0	0	0	0	0	0	0	0
NATIVE PERENNIAL GRAMINOIDS								
Elymus cinereus	P							
Koeleria nitida			P					2
Oryzopsis hymenoides	P			P	P	P	P	
Sitanion hystrix	P		2	2	2	2		4
Stipa comata	P			P	P			
Stipa occidentalis	2		6		2			2
Stipa thurberiana			P					
TOTAL NATIVE PERENNIAL GRAM.	2	0	8	2	4	2	0	8
INTRODUCED PERENNIAL GRAMINOIDS								
Festuca ovina								2
Festuca ovina var. duriuscula		2						
TOTAL INTRO. PERENNIAL GRAM.	0	2	0	0	0	0	0	2
SHRUBS								
Artemisia arbuscula	2		14	P	12	2	12	14
Artemisia nova								2
Artemisia tridentata var. tridentata	16					P		2
Chrysothamnus depressus			2	20	P	10	P	
Chrysothamnus nauseosus						6		
Chrysothamnus viscidiflorus	4	P	P	4				P

TABLE 2. COVER DATA - LOW SAGEBRUSH VEGETATION TYPE, BODIE EXPLORATION AREA, MONO CO., CA - 1991

	PERCENT FOLIAR COVER Sample Site							
Site Number	10	170	170 Undist.	3839	38,39 Undist.	4254	42,54 Undist.	Tioga Shaft
Plant Species / Date	1968	1989	- - -	1977	- - -	ca. 1970	- - -	ca. 1890
Eurotia lanata					P		P	
Ribes cereum				P				
Symphoricarpos oreophilus	2							
TOTAL SHRUBS	24	0	16	24	12	18	12	18
SUCCULENTS								
Opuntia erinacea							P	
TOTAL SUCCULENTS	0	0	0	0	0	0	0	0
BARE SOIL	32	58	36	54	50	30	44	42
LITTER	24	12	4	2	14	10	4	24
ROCK	8	22	36	18	20	38	40	4
FECES	4	2						
TOTAL VEGETATION COVER	32	6	24	26	16	22	12	30
TOTAL COVER	100	100	100	100	100	100	100	100
SPEICES DENSITY (No. per 100 sq. m.)	16	11	12	8	10	7	6	11

Figure 1. Vegetation Cover Development

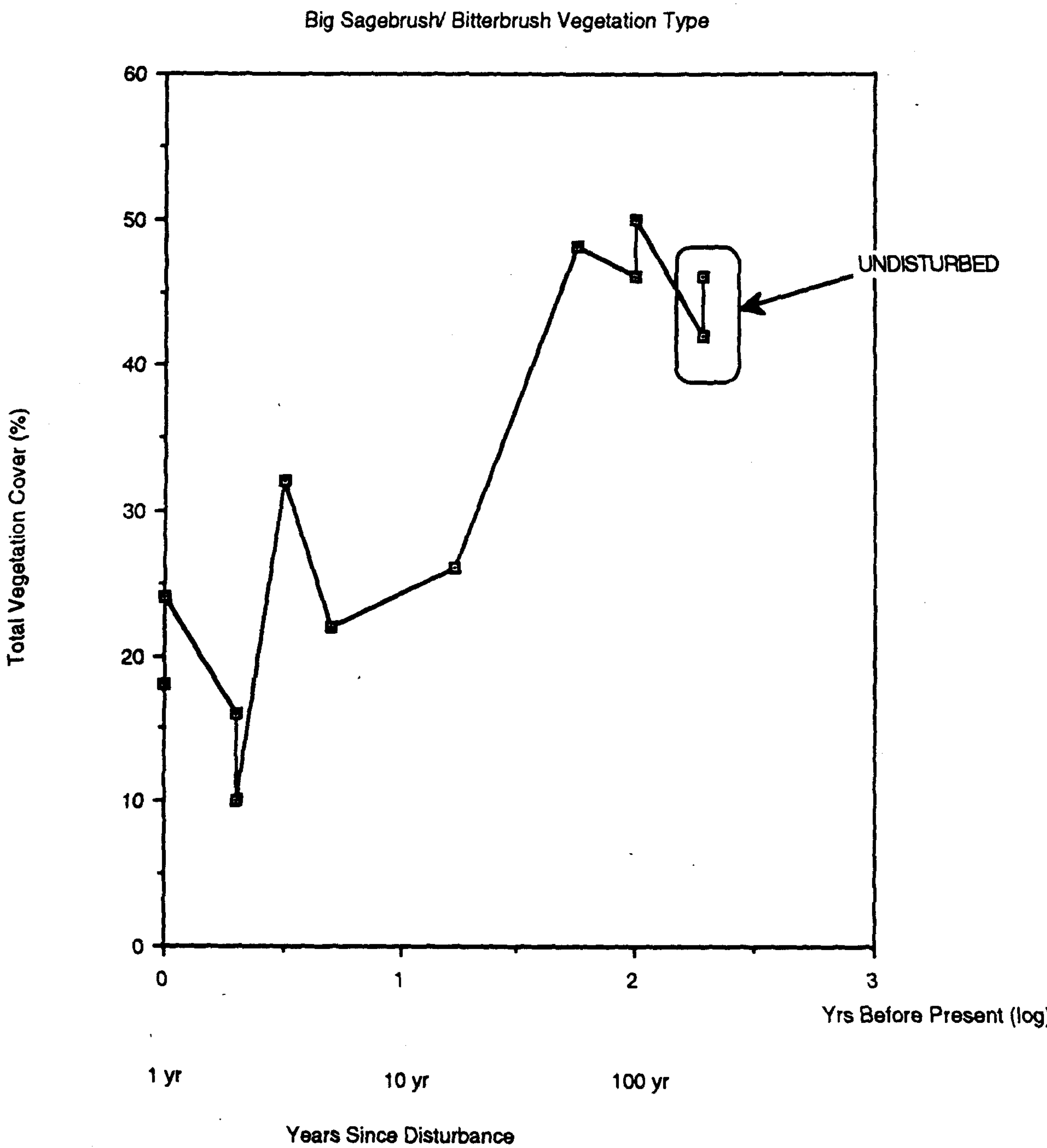


Figure 2. Shrub Cover Development

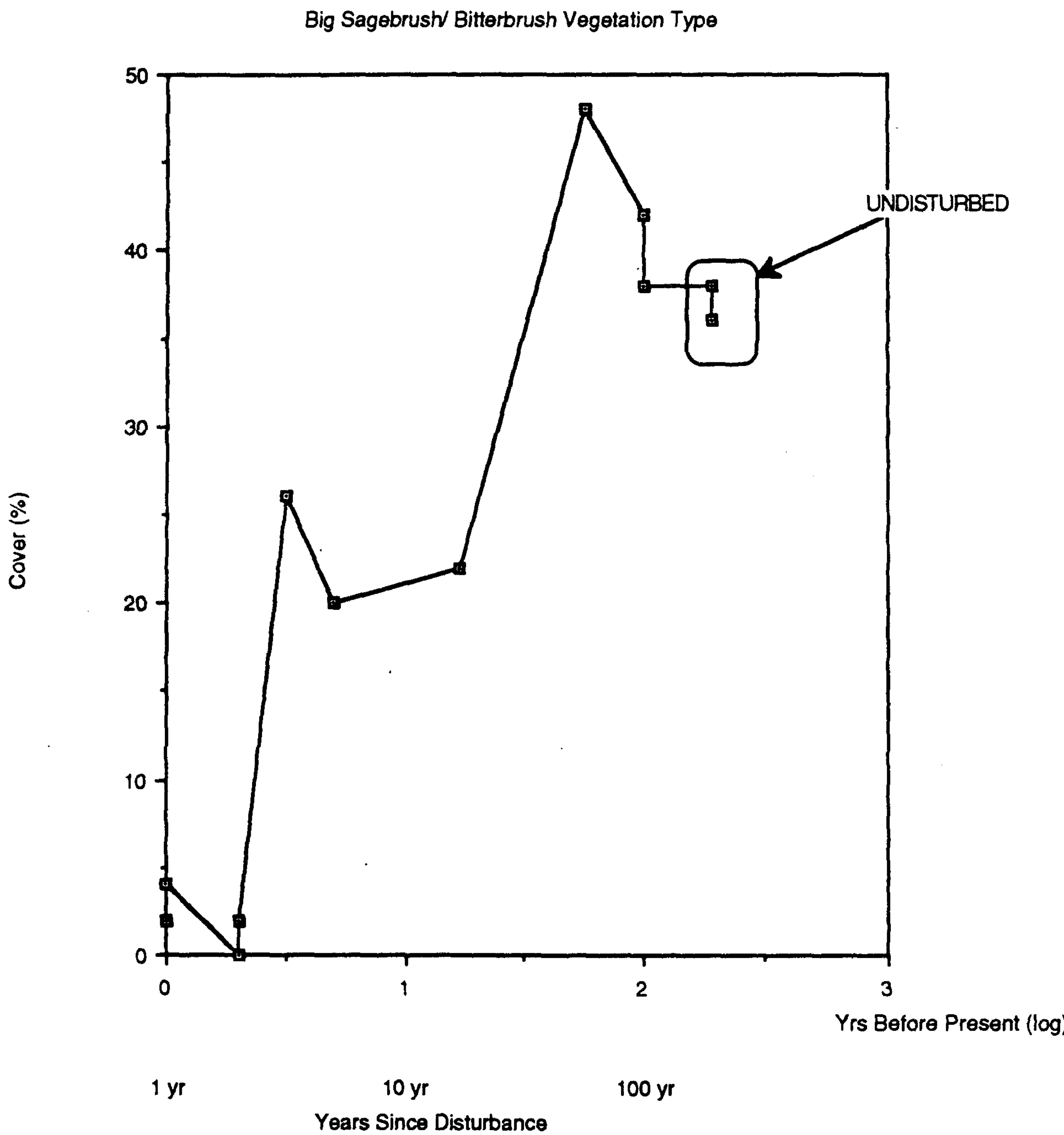


Figure 3. Native Perennial Grass Cover Development

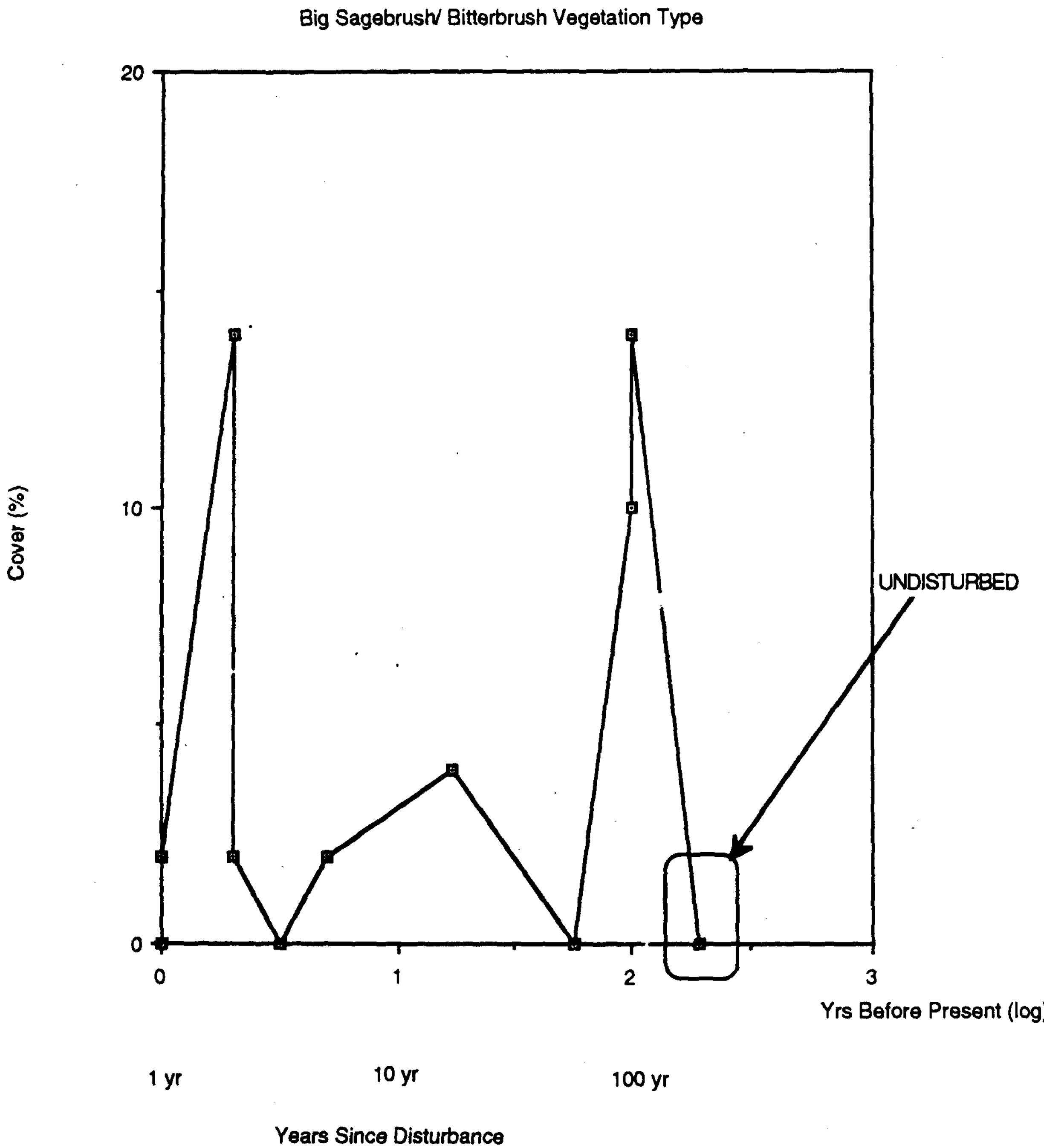


Figure 4. Native Annual Forb Cover Development

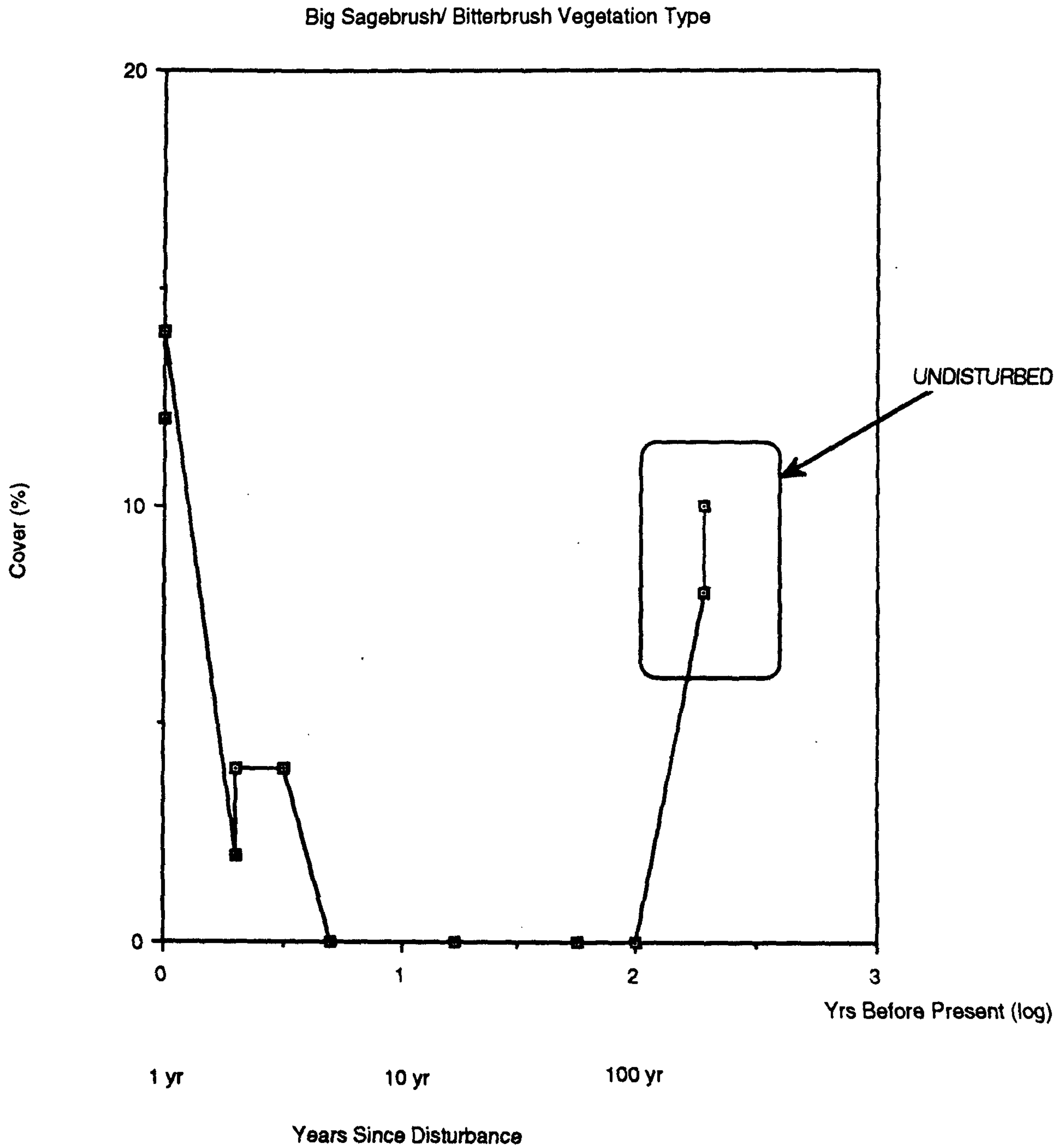


Figure 5. Total Vegetation Cover Development

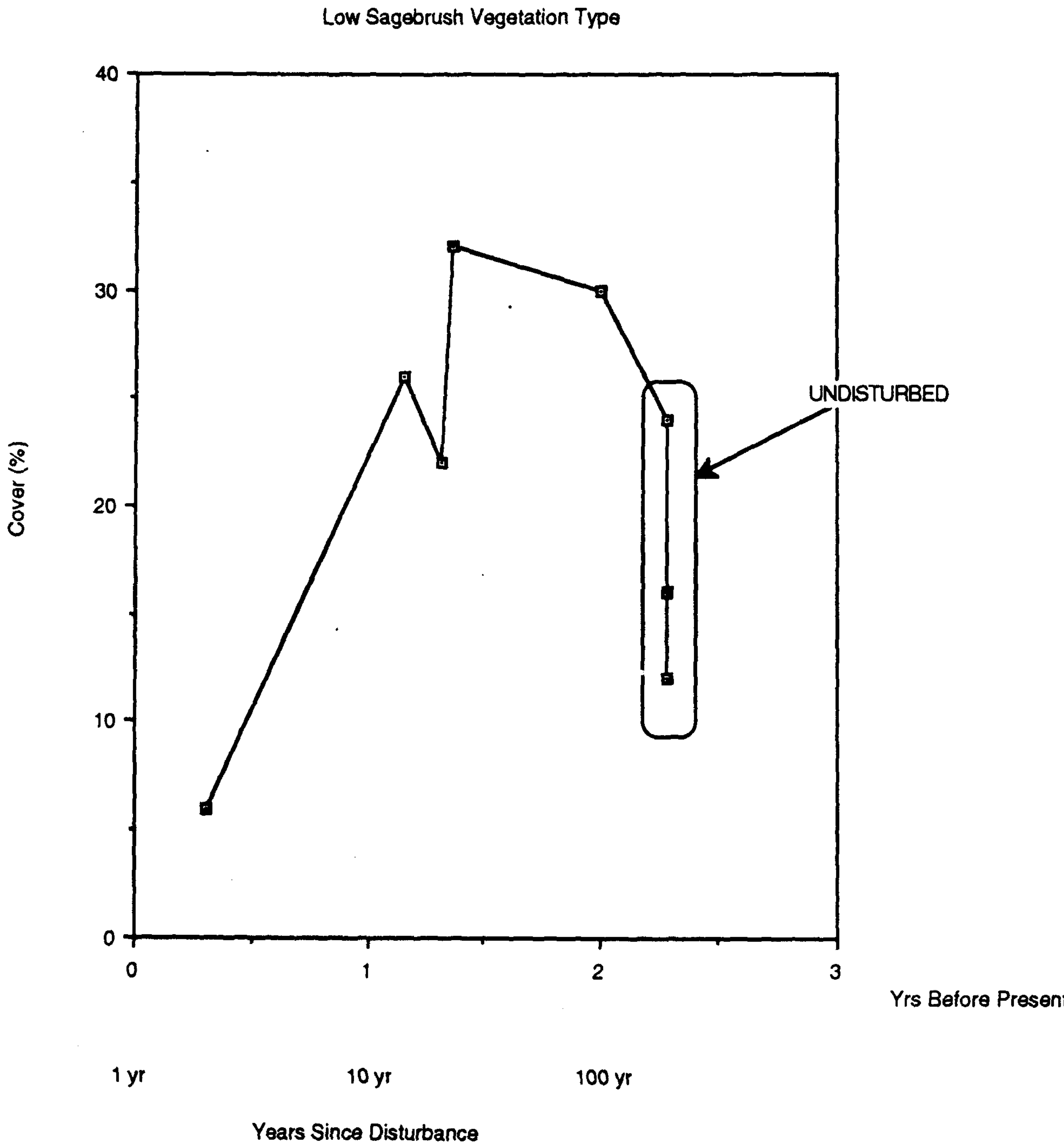


Figure 6 . Shrub Cover Development

Low Sagebrush Vegetation Type

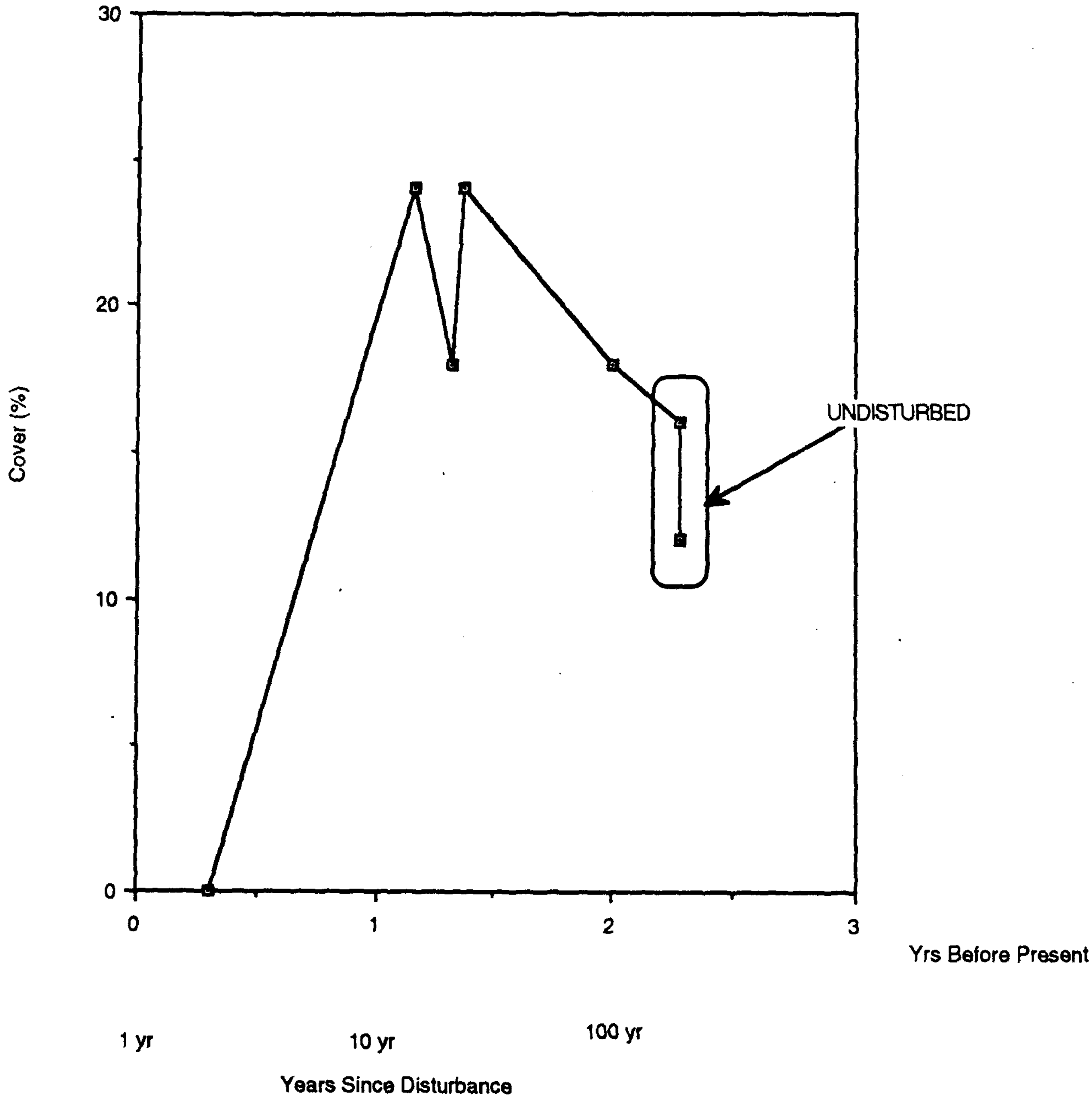


Figure 7. Native Perennial Grass Cover Development

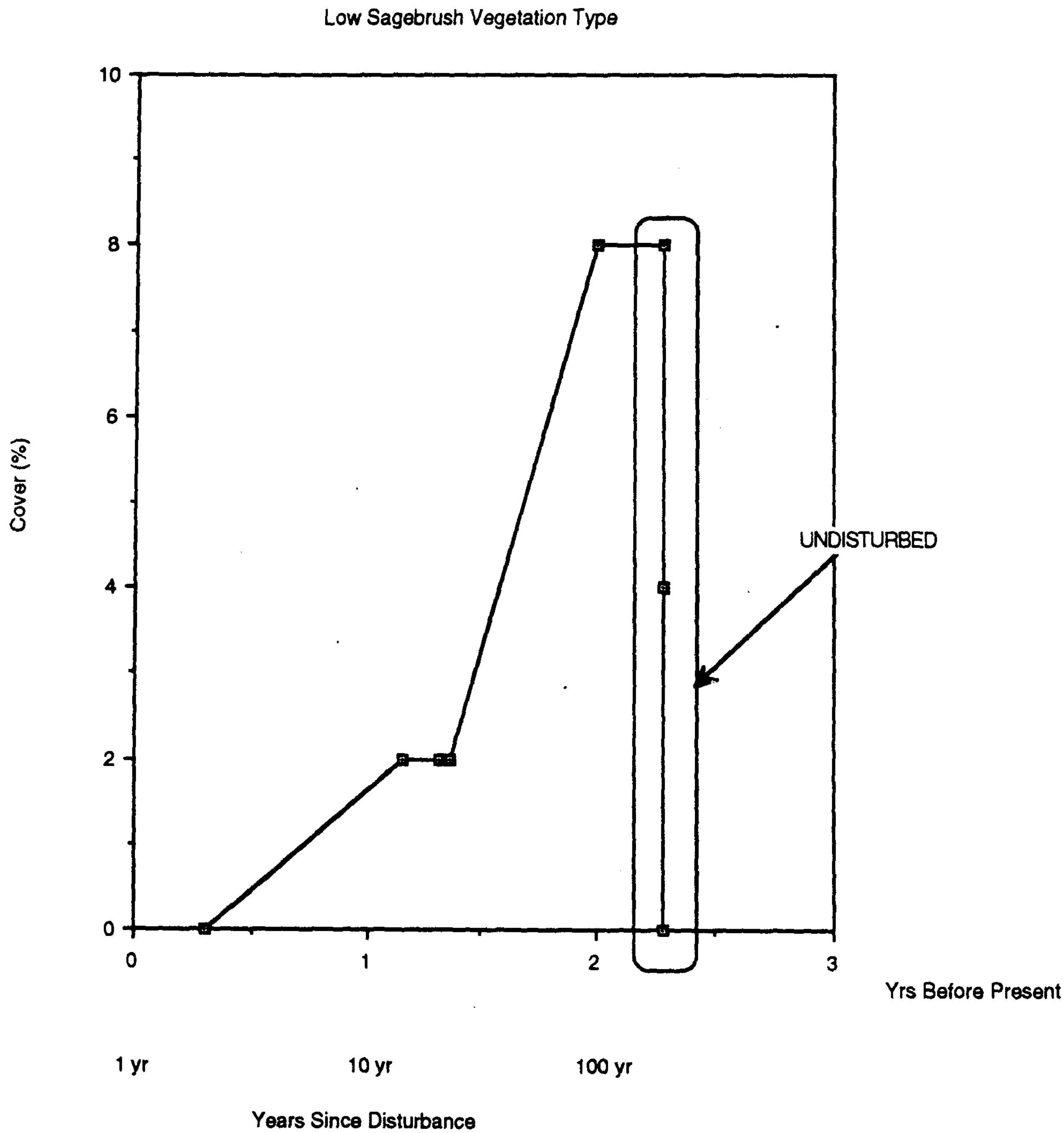
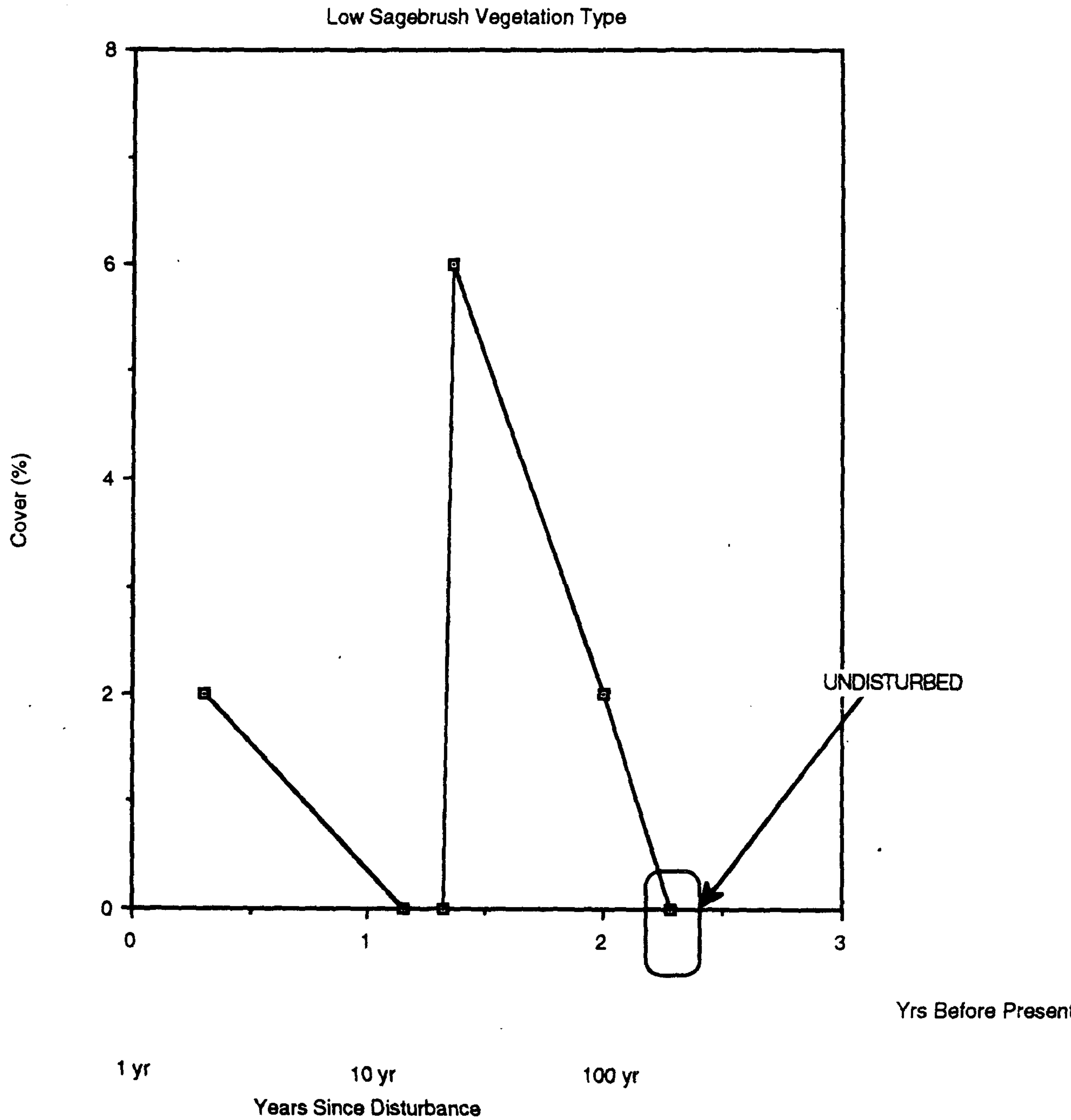


Figure 8 . Native Perennial Forb Cover Development



THE APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM TO EVALUATE ENVIRONMENTAL RESOURCE SENSITIVITY

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ABSTRACT

A geographic information system (GIS) was utilized to determine potential impacts to selected natural resources from surface gold mining in the Black Hills of South Dakota. Resource characteristics for reclamation potential, wildlife, aquatic life, visual quality, air quality, and noise levels were evaluated. The GIS was used to generate individual and composite maps according to assigned relative sensitivity ratings for each resource component.

INTRODUCTION

The Black Hills region of South Dakota has a long history of gold mining activity. Historical mining operations were primarily underground mines and placer deposits. The recent use of cyanide heap leach processing has allowed economical operation of large surface mines. Surface mines require the use of open pit excavations, with additional areas disturbed for heap leach processing, overburden and spent ore disposal, haul roads, and other facilities.

In 1989, ERO Resources was selected by the State of South Dakota as a member of a team of consultants to evaluate potential impacts from expanding surface gold mining operations. Natural resources addressed by ERO's portion of the study included: vegetation, reclamation (soils), wildlife, aquatic life, air quality, noise, and visual quality. Each of these resources were analyzed to determine the type and significance of potential impacts for various scenarios of expanded surface mining.

A geographic information system (GIS) was used to assist in compiling information on sensitive resource areas. Individual resource components that could be depicted spatially were digitized. The GIS was then used to generate a composite of all resource areas of concern and the relative sensitivity.

STUDY AREA

The study area is located in the northern Black Hills of South Dakota. The towns of Lead and Deadwood occur in approximately the center of the 80,000 acre study area. This region is the site of most historical and current gold mining. It is also considered the most likely area for gold mineralization to occur. There were 5 operating gold mines occupying approximately 2,400 acres when this study was completed in 1991.

RESOURCES EVALUATED

Not all resource attributes or concerns can be represented geographically. For this analysis, data was available for several key resources including: soils, big game wildlife habitat, aquatic life stream designations, visual resources, and areas sensitive to air and noise pollution. The discussion below outlines the attributes for each resource that were utilized in this analysis.

Soils

The Soil Conservation Service (SCS) soil survey for Lawrence County (SCS, 1979) was used to evaluate soil characteristics and map unit interpretations. The soil survey provided information for predicting soil management limitations with respect to erosion hazard, revegetation potential, and topsoil suitability. Soil survey map units were digitized into the GIS data base

Erosion Hazard/Revegetation Potential:

Many of the factors used to identify soils subject to erosion also reflect potential for revegetation success; thus, the rating for these two attributes was combined. The erosion hazard/revegetation potential rating considered factors such as slope, soil texture, structure, and permeability. Three categories were used to differentiate the relative degree of risk for erosion/revegetation. Categories ranged from high erosion/low revegetation to low erosion/high revegetation potential. Soil map units that met the criteria for the different categories were then selected from the SCS soil survey.

Topsoil Suitability:

Topsoil suitability was based on physical and chemical soil properties and on the ease of removal, storage, and handling. Three categories of topsoil suitability were used for this analysis. Some soils are classified as unsuitable for topsoil use due to high rock content, steep slopes, and shallow depth to bedrock. Those map units rated as suitable contain soils with less than 20 percent rock fragments, slopes less than 30 percent, and favorable textures. Suitable topsoils were divided into two classes: 1) those with less than 30 inches of salvageable material and 2) those with more than 30 inches of salvageable soil. Figure 1 illustrates GIS output from the selection of map units that define the criteria for each category of topsoil suitability.

Figure 1. Topsoil suitability.

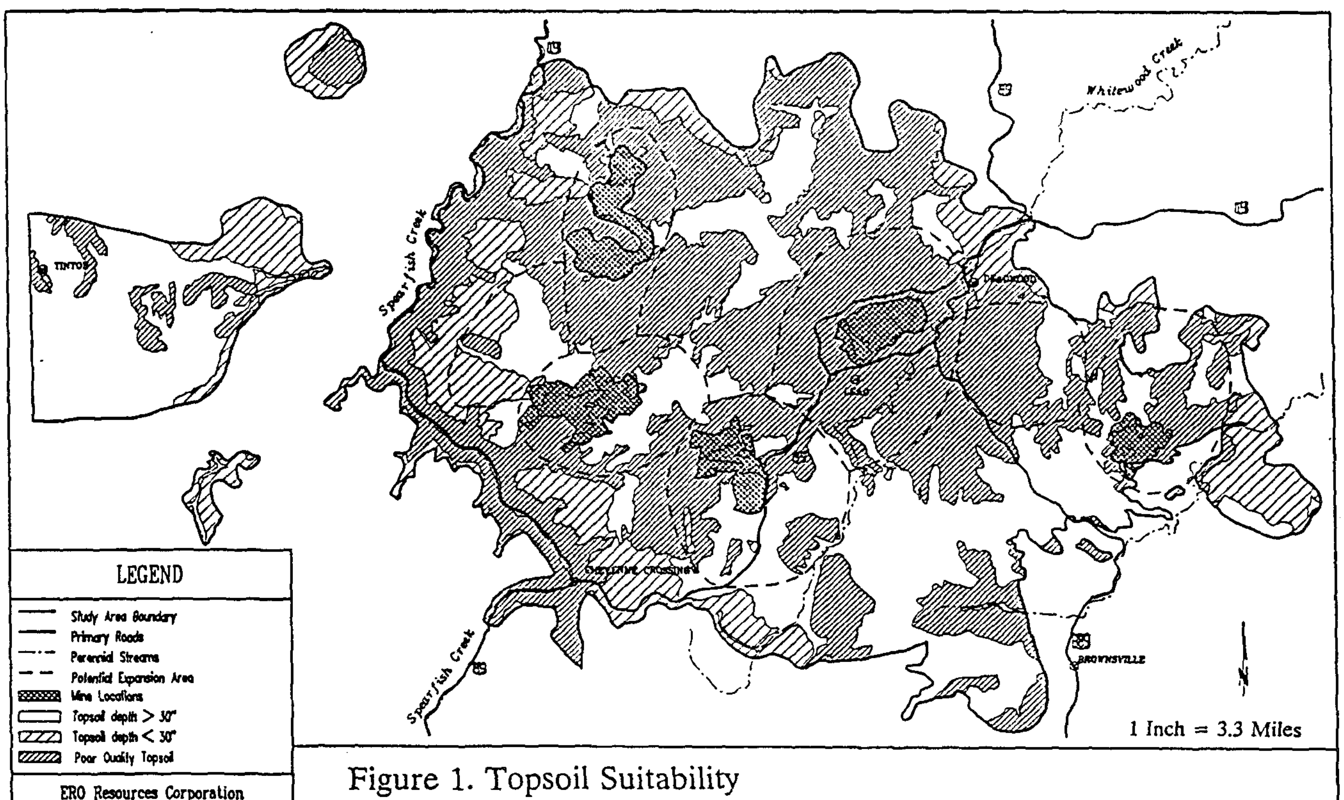

Figure 1. Topsoil Suitability

Wildlife

The Black Hills support a wide variety of wildlife with varying habitat requirements. Geographic information on wildlife habitat is available primarily for big game animals. Principle big game species include white-tailed deer, mule deer, and elk. The habitat of primary importance for deer are areas of critical winter deer range. Also of concern are areas of winter deer range, summer deer range, and year-round elk range. Each of these areas of concern were included in the GIS environmental resource data base and are shown in Figure 2.

Figure 2. Deer and elk range.

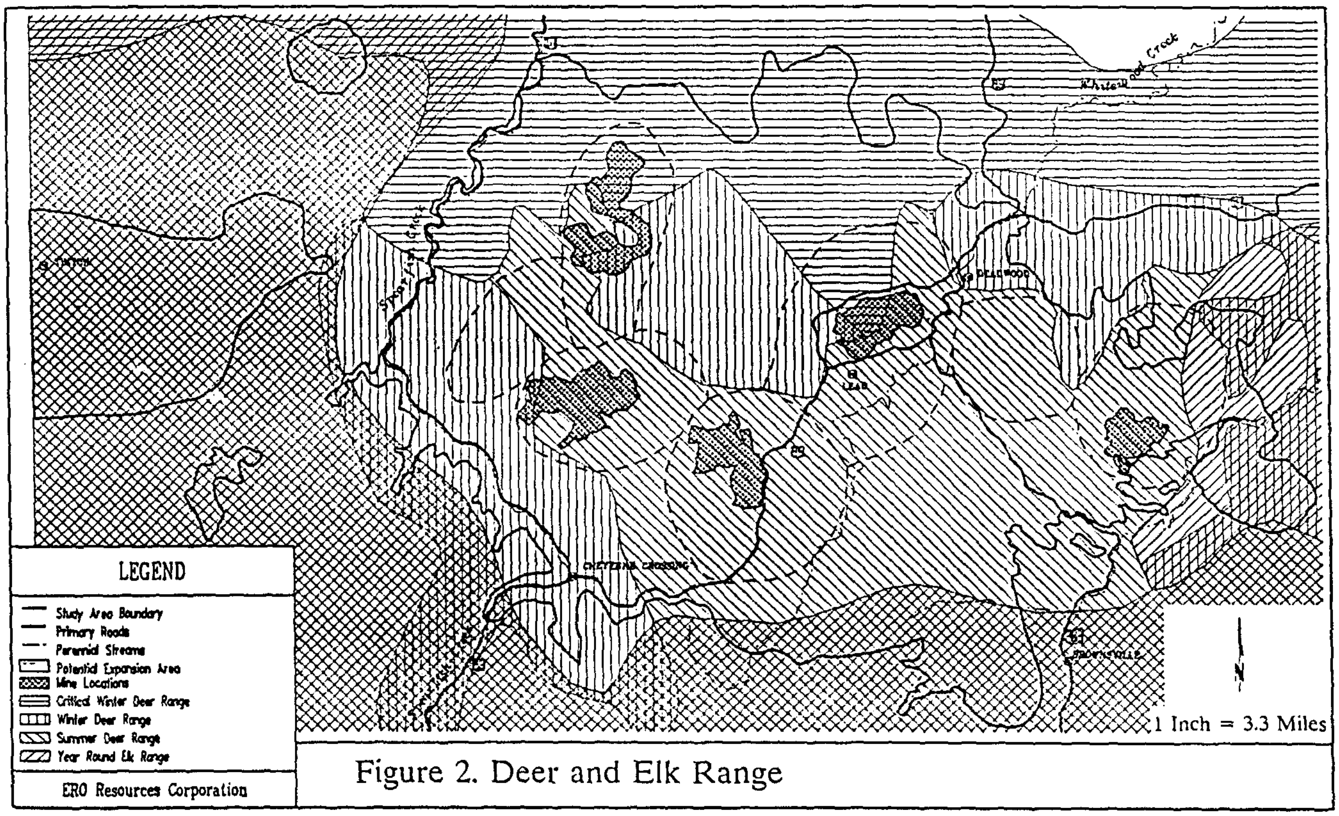

Figure 2. Deer and Elk Range

Visual Resources

The northern Black Hills region represents a diverse visual environment. The terrain is generally hilly to mountainous. Vegetation cover varies in density, diversity, and pattern and is composed primarily of complexes of ponderosa pine, aspen, white spruce, and grassland. The area has been influenced by man-made alterations including historical and current mining operations, timber harvesting, and urban development. A variety of recreation uses are common throughout the area.

The visual quality assessment relied on the Visual Management System used by the U.S. Forest Service (undated). The Visual Quality Objective (VQO) was selected as the indicator to measure potential concern for visual resources. Visual Quality Objectives describe the degree of acceptable alteration to the natural landscape based upon the public's concern for scenic quality as well as the diversity of natural features. There were three categories of VQO applicable to the study region: 1) Retention - which provides for landscape alterations that are not visually evident, 2) Partial Retention - which allows landscape alterations that remain visually subordinate to the characteristic landscape, and 3) Modification - which allows landscape alterations that visually dominate the original characteristic landscape. Each of these categories were digitized and included in the resource data base.

Air Quality/Noise Levels

Air quality degradation and increased noise levels were two concerns of residents in the study region. The Black Hills are remote from major sources of air pollution and hence the air quality is generally good. Noise levels are typical of a primarily rural community.

Mining activities can result in increased levels of particulates in the air associated with drilling, excavation, hauling, and crushing. Noise levels from each of these operations also will increase in the vicinity of mining.

Sensitive receptor zones were established in the geographic data base around urban development, rural residences, transportation routes, and recreation sites. It was assumed that degradation of air quality or increases in background noise levels would be most sensitive in these areas.

Aquatic Life

The Black Hills contain numerous streams that provide valuable habitat for aquatic life. A total of 25 fish species have been identified in the Black Hills, with brook trout, brown trout, and rainbow trout the primary salminoids (U.S. Forest Service, 1983). Several important natural resources occur in and along stream and riparian zones. Streamside zones not only protect water quality and the associated aquatic life, but support wetlands and a variety of rare plant communities as well as providing valuable wildlife habitat.

To recognize the importance of streams in the region, three categories of streams were used. These categories are based on the South Dakota Department of Natural Resources' beneficial use classification for aquatic life and fisheries. The streamlife designation of "coldwater permanent fish life propagation" was considered the highest quality waters. Second in importance were "coldwater marginal fish life propagation" waters. The remainder of streams are primarily intermitent and ephemeral and are classified by the state for wildlife and stock watering uses. For all stream reaches, a zone of 200 feet on either side of the channel was used to identify areas of concern.

INTEGRATED RESOURCE SENSITIVITY

A composite index was developed to provide a method for integrating the different resource concerns that might be affected by expanded mining activities. The criteria used in this process were subjectively determined based on the perceived level of concern for each resource. As stated previously, this analysis is not comprehensive in that data for all resource components is not available or can't be represented geographically. However, it does provide a relative ranking that allows identification of areas that are considered sensitive. Table 1 summarizes the attributes that were used in this evaluation and ratings given to each.

The GIS was then used to overlay all resource components and their associated rating. The resulting composite ratings varied with location and ranged from 0 to 28. Areas with higher values were considered more sensitive and areas with lower values less sensitive. To simplify presentation, the composite ratings were grouped into 3 classes, from least sensitive to most sensitive and plotted as shown in Figure 3.

Table 1. Ratings used for integrated resource evaluation.

ATTRIBUTE	RATING			
Erosion/ Revegetation Potential	high erosion/ low reveg. 3	mod erosion/ reveg. 2	low erosion/ high reveg. 0	
Topsoil Suitabilty	unsuitable 3	<30" 1	>30" 0	
Wildlife- Deer/Elk Range	critical winter 4	winter 3	elk 2	summer 1
Visual Resources	retention 5	partial retention 3	modification 0	
Air Quality/ Noise	near residences 6	near recreation 2		
Streamlife Designation	coldwater permanent 7	coldwater marginal 5	wildlife stockwatering 3	

Results of this analysis indicate that approximately 33% of the study area is rated as "most sensitive," 44% as "moderately sensitive," and 23% as "least sensitive." Areas rated as most sensitive may need to be avoided in future development scenarios or may require additional mitigation measures to minimize resource impacts. Alternative areas of development can be compared to determine which would disturb the smallest "most sensitive" area.

SUMMARY

The GIS is an effective tool for evaluating the potential impact on multiple resources from different development options. For this analysis, existing information provided the data necessary to generate a regional analysis of sensitive areas. Where more information is available, a detailed analysis could be prepared from site specific data. Additional types of data that could be utilized in creating a geographic resource data base include: vegetation types, wetlands, rare or endangered plant or animal habitat types, big game migration routes, groundwater recharge zones, landslide or avalanche areas, hazardous waste sites, cultural resource locations, and any other information that can be geographically located. This type of analysis is particularly effective when evaluating resource impacts associated with alternative areas of development such as road alignments or utility corridors.

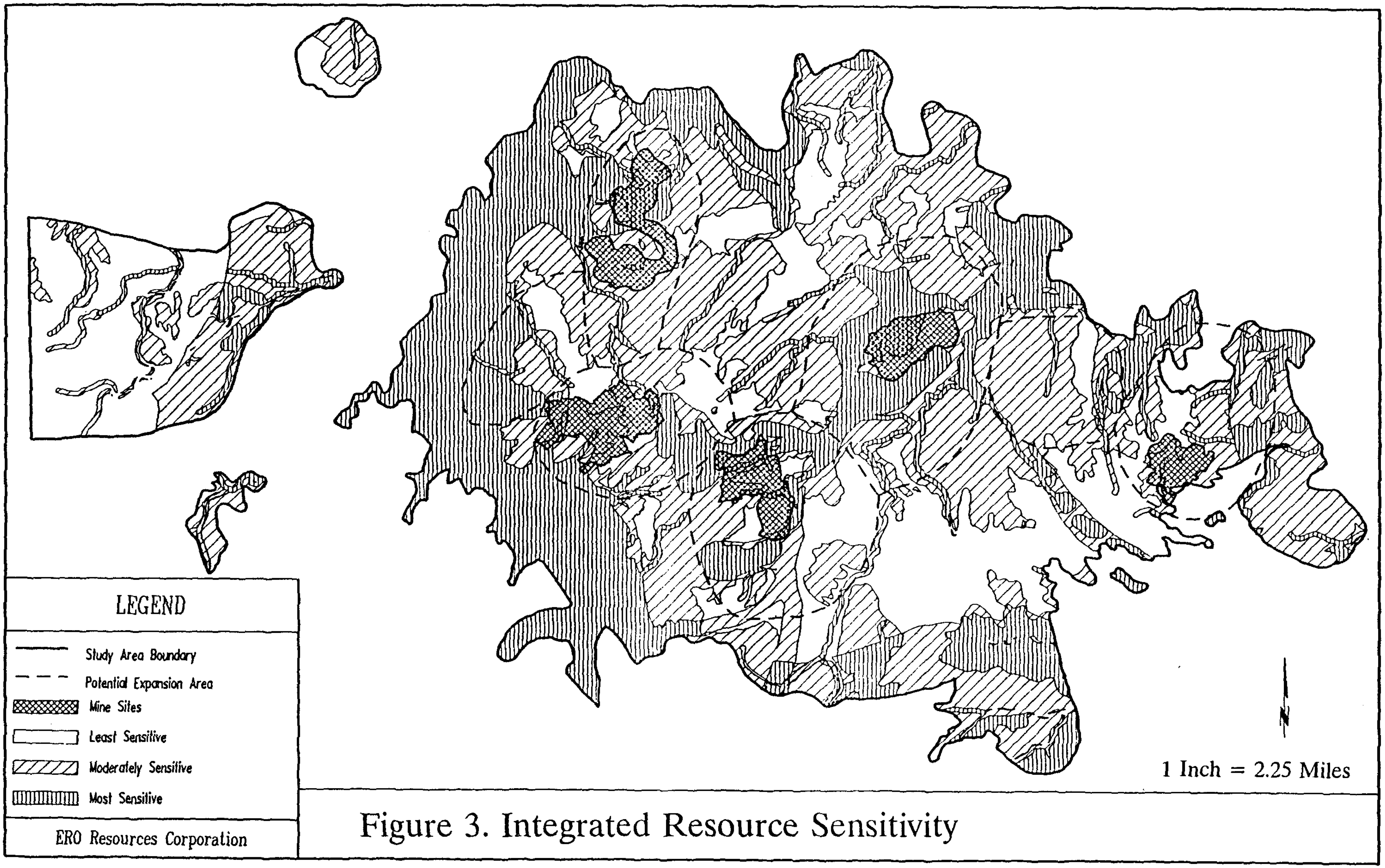

Figure 3. Integrated Resource Sensitivity

LITERATURE CITED

U.S. Forest Service. Undated. Visual Quality Objective of Black Hills National Forest, Custer, South Dakota.

U.S. Forest Service. 1983. Final EIS for the Black Hills Forest Land and Resource Management Plan. Black Hills National Forest, Custer South Dakota.

U.S. Soil Conservation Service. 1979. Soil Survey of Lawrence County. Deadwood, South Dakota.

Effectiveness of Soil-Borne Mycorrhizal Inoculum on Plant Species Growth on Mined Lands in Alaska

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University of Alaska Fairbanks, 533 E. Fireweed Ave., Palmer, Alaska 99645

Woody plant species may establish slowly on dry, nutrient-poor soils of abandoned mined lands. Mining disrupts mycorrhizae and other soil and rhizosphere microbial communities needed for nutrient cycling. Mycorrhizae are mutualistic symbioses (positive relationships) between fungi and plant roots in which the fungus assists the plant in absorbing nutrients and moisture from the soil. Mycorrhizae occur on most plant species but the degree of dependency varies with plant species and environmental conditions. Plant roots on disturbed sites generally are deficient in mycorrhizae.

Experiments were conducted in southcentral Alaska to evaluate "soil transfer" as an inexpensive source of mycorrhizal fungal propagules, which include infected plant roots, fungal hyphae, and spores. Soils from adjacent undisturbed vegetation communities were incorporated into the rooting zone of woody cuttings and seedlings on mine spoils. Poplar (*Populus balsamifera*) and alder (*Alnus crispa*) grew more when treated with soil transfer from a mature forest site than from an earlier successional site although both sites contained poplar and alder. Poplar usually colonizes sites earlier than alder. Alder is usually infected by fewer mycorrhizal fungal species than poplar.

This study was funded by the U.S. Bureau of Mines Abandoned Mined Land Program (D.L. Veith technical officer).

References

Helm, D.J., and D.E. Carling. 1990. Use of on-site mycorrhizal inoculum for plant establishment on abandoned mined lands. USDI Bureau of Mines Abandoned Mined Lands Program. A mining research contract report, April 1990. Contract J0289003. 94 pp.

Helm, D.J., and D.E. Carling. 1992. Soil transfer for reforestation of mined lands. Second International Symposium for Mining in the Arctic. A.A. Balkema Publisher. (Accepted, paper to be presented July 1992.)

REVEGETATION OF HIGHWAY IMPACTS
PROVO CANYON, UTAH
US 189 - MURDOCK WATER DIVERSION TO UPPER FALLS PARK

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Jeff Lormand.

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INTRODUCTION

This exhibit describes the revegetation design for the areas affected by highway construction along US 189 through scenic Provo Canyon, east of the Cities of Provo and Orem, Utah. The landscape design goal was to establish native plant materials on highway cut and fill slopes. Grading techniques, such as slope molding and rock cut sculpting were used to provide a more natural appearance to the impacted terrain. Wetland permitting and mitigation design for 4.5 acres of wetland was also included. A separate recreation path was designed from two miles of an abandoned railroad right-of-way.

The public involvement in this project played a critical role in bringing the design process to a successful conclusion. At the time Parson's De Leuw, Inc. became involved, the project was shut down under a court injunction. Parson's De Leuw established the Provo Canyon Design Advisory Committee (PCDAC), a group of concerned citizens to redevelop the project with a design that addressed the public's concerns.

The majority of the concerns were environmental in nature:

- Preservation of the existing gambel's oak forest.
- Lessening of impacts of vegetation through use of roadside guard rails.
- Revegetating of cut and fill slopes, and highway noise abatement.
- Wetland mitigation, mitigation of impacts to parks, recreation path design, and water quality improvements.

By bringing the various concerned groups together, along with Transportation Department Staff, City and County personnel, and Wildlife Department staff, issues were more quickly resolved and the project was kept on track and on budget.

DESIGN INFORMATION	
- Miles of Roadway	4.5 miles
- Planting Area	97.0 Acres
- Bid Construction Cost (Entire Highway Project)	$15.7 million
- Bid Construction Cost (Landscape)	$ 3.3 million

Design Team	*Parson's De Leuw, Inc. and ARIX Corporation*
Contractor	*Gilbert Western*

Design Concepts

1. Improve existing and new highway slopes by using slope molding techniques to create a more natural appearance to the landscape areas.

    a. Round tops and toes of slopes.
    b. Provide undulating slope gradients.
    c. Continue existing swales down cut slopes.
    d. Vary the distance of swales at toes of slopes.

2. Revegetate slopes using native vegetation. The plant lists should be diverse in species and sizes. Existing plant communities should be re-established over regraded slopes.

3. Reduce highway embankments by placing highway guard rail next to environmentally sensitive areas.

Planting Design Approach

1. Use four inches of topsoil and one inch of organic matter (ground turkey bedding).

2. Maintain adequate roadway visibility by placing inappropriate plant material out of site visibility.

3. Plant bundles of wattles along riverbank areas and uphill cut slopes to reduce erosion.

4. Develop individual seed mixes for each plant community.

5. Hydroseed with tackifier all areas to be seeded.

6. Plant dormant willow cuttings in wetland areas.

7. Provide temporary drip irrigation for plant establishment.

Planting Techniques

Dormant Fall Planting Method: Shrubs and trees are planted in late fall before the first killing frost. Slopes will be topsoiled and temporary drip irrigation will be provided for plant establishment. Spring snow melt and precipitation will provide water for the following growing seasons. Each plant receives a high quality backfill in its planting pit with fertilizer tablets and humectant. Trees and shrubs are planted separately from competitive grasses. An excellent quality of plant materials with well-developed root systems grown under Canyon-like nursery conditions is essential to the success of this method. One disadvantage of this method is that fall planting may be overly browsed by deer in the winter.

Spring Planting: This method provides topsoil and temporary drip irrigation for plant establishment. Trees and shrubs are planted in the late spring to early summer or in the fall with excellent backfill material, humectant, and fertilizer tables. Grasses are seeded in separate areas in the fall, if possible. Wood chip mulch is provided under shrubs and trees to preserve soil moisture and reduce competition. Deer are less likely to browse on spring and summer plantings due to the lush growth of other plants.

Wattle Planting Method: Box Elder, will, and dogwood can be established by cuttings or wattles from existing plants. Cuttings shall be planted in soil or gravel areas adjacent to the river. Soil conditions must be moist with the cut-end inserted into wet soil. Wattles were also used in upslope conditions for slope stability and erosion control.

Existing Plant Communities

Riparian Shrub and Forest: This community is found along the Provo River and in small "pockets" along existing irrigation water channels. Plant species include narrow-leaf cottonwood, box elder, red-osier dogwood, willow, elderbery, wild rose, currant, and hawthorne.

Wetland: This community is also found along the depressions within the alluvial terrace next to the river. Wetlands were of three types:

a. Forested wetland composed of cottonwood and box elder.
b. Scrub/shrub wetland composed of willow, dogwood, chokecherry, and box elder.
c. Emergent marsh composed of cattail and willow.

Oak/Maple Forest: This dominant plant community was found particularly on the north facing slopes and near the canyon bottom. Plant species include gambel's oak, big-tooth maple, snowberry, sumac, chokecherry, and box elder.

Oak Forest: This community was found upslope of the oak/maple forest and on south facing slopes. It is primarily gambel's oak with snowberry, serviceberry, and mountain mahogany.

ANDERSON , LAUREL J. and MICHAEL C. GRANT. University of Colorado, Boulder, CO 80309, USA. Reforestation of a high altitude clearcut using transplanted Engelmann spruce and subalpine fir seedlings.

The Boulder City Watershed, located in the Colorado Front Range, contains a 40 acre clearcut at 3400m that has shown little forest regeneration in 28 years. The objectives of this study were to determine factors inhibiting tree seedling survival in the site, to develop a long-term site reforestation plan, and to compare the survivorship of Engelmann spruce (*Picea engelmannii*) and subalpine fir seedlings (*Abies lasiocarpa*) transplanted into the site. 937 wild seedlings were transplanted in the summers of 1989 and 1990. Seedlings were planted behind log windbreaks .5 to 1m high, and received supplementary water zero, once or twice weekly. Seedlings were assessed for health during the growing season, measured for size, and rated according to protection received from windbreaks. Protection and watering were the most important factors influencing survivorship. Overall, the least protected seedlings had higher mortality than the most protected, and seedlings watered once per week had lower mortality than those in other treatments. Spruce and fir responded differently to both watering and protection; spruce preferred higher watering levels and was better able to withstand low protection regimes. These data are discussed in the context of enhancing reforestation efforts in high altitude clearcuts and comparing spruce and fir physiology.

RINGER SLOW-RELEASE ORGANIC FERTILIZERS IN THE ESTABLISHMENT AND GROWTH OF GRASS SPECIES FOR EROSION CONTROL.

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ABSTRACT

Important considerations when applying nutrients to promote growth in an erosion control program is the availability of the nutrients, the water solubility of the nutrients and the relative release rates interviewers environmental conditions. The nutrients need to be in a form available to the plant in ratio that is suitable to optimize plant growth. Water solubility will directly affect nutrient movement which could contribute to non-point sources of pollution. The nutrients also need to be available under conditions where the surface soil has been drastically altered and may be low in indigenous microbial activity which could affect nutrient release.

Ringer slow release fertilizers combine high protein agricultural by-product meals, bone meal and sulfate of potash with a proprietary blend of beneficial soil microorganisms to create a unique slow release fertilizer system. The Ringer products are available in a wide range of analysis to meet the nutrient requirements of various plant species.

Research carried out at universities across the countries demonstrated the Ringer products are an excellent source for slow release nitrogen in turf systems. Studies showed that 1 lb of N/1000 sq ft from Ringer products provided available nitrogen for 45 to 60 days depending on the grass species. As application rates increased the plant growth response increased. There was a significant response in plant tissue, rooting and shoot density. There was no phytotoxicity associated with the increasing application rates when tested up to 4 lbs. N/1000 sq ft. Studies carried out at Texas A&M looked at the effect of Ringer products on the rooting of grass plugs grown in different soilless media. Ringer products were shown to stimulate rooting in new sod establishment on several of the media tested.

The nitrogen in Ringer products is derived from the proteins through microbial decomposition. The relative insolubility of the proteins suggests that the material will have less potential to leach or move with water under most conditions. Work conducted at the University of Nebraska in the highly controlled conditions of the rhizotron demonstrated that the nitrogen from Ringer's products have less of a tendency to move through the soil profile with irrigation water compared to the water soluble urea or the slow release sulfur-coated urea.

Data will be presented from several university trials to support the nutrient release profile, the potential for nutrient movement from site of application and the plant growth promoting properties of Ringer products. A program demonstrating how the products can be used for erosion control management.

INTRODUCTION

The practice of establishing grass species on slopes of disturbed soil has been used as a cultural means to control the erosion of soil. Because of the sometime radical mechanical disruption of the soil profile the seed bed can range from a redistributed topsoil mix to decomposed granite. The establishment of a grass species in this type of material is quite difficult because of the overall poor condition of the soil. The soil would be depleted in most nutrients, lack a sufficient CEC and be low in microbial activity.

Fertilizer practices have included the use of highly water soluble inorganic fertilizers that were chosen because of the relative availability, low price and compatibility with application equipment. Because these material are highly soluble however they have a high potential to move with rainfall or irrigation. This movement could include surface runoff, leaching through the soil profile or volatilization. The high salt content of most water soluble nitrogen fertilizers may cause burn to the grass plant as it emerges. Soil microbial activity is important in the germination and establishment of seedlings as well as in the conversion of nutrients. The water soluble inorganic fertilizers do not contribute significantly to the microbial activity of the soil as an organic fertilizer would.

Ringer organic nitrogen fertilizers use high protein agricultural meals in combination with a soluble carbohydrate energy source and a proprietary microbial blend to produce a unique microbial driven fertilizer system. The proteins that supply organic nitrogen are derived from hydrolyzed feather meal, blood meal and soybean meal. These proteins are broken down by the microorganisms to release nitrogen that is subsequently made available to the plant (See Fig. 1). Since these material are insoluble in water they have a lower potential to move with surface runoff, downward through the soil profile or volatilize.

Since the nitrogen in Ringer fertilizers is released microbially the release is dependent on the soil temperature and moisture. This tends to parallel the growing requirements of the grass, that is as the soil temperature rises and moisture is more available the growth of the grass is accelerated as the release of nitrogen is increased.

The organic nature of the Ringer fertilizer system is important in a revegetation program since little indigenous organic matter is present. The amount of organic matter in a soil is directly related to the level of microbial activity. The addition of an organic amendment such as the Ringer system will help increase the level of soil microbial activity which is important in nutrient conversions, soil structure and other soil characteristics.

NITROGEN AVAILABILITY

Studies with Ringer fertilizer products have been conducted at universities around the country in turf culture. The initial focus was to look at the relative nitrogen availability and the nitrogen release curve of the protein-based materials.

Studies at the University of Nebraska evaluated the application of 3 and 6 lbs. N /1000 sq ft to established Kentucky Bluegrass turf for turf color and quality. The color/quality performance of the products were evaluated using the 1-9 rating scale specified by the NTEP (National Turfgrass Evaluation Procedures) protocol with 1=poorest quality/color, 5=acceptable, 9=ideal or best color/quality.
As shown in tables 1 and 2 color performance results varied among growing season, nitrogen source and rate (Table 1.3). All products, that is the Ringer, urea and ammonium nitrate, produced better color turf than the untreated control. This suggests that Ringer's products performed as we as the water soluble

urea and ammonium nitrate in color and quality.

Additional studies carried out at the University of Massachusetts looked at several nitrogen sources including a water soluble synthetic nitrogen sources, urea, and a water insoluble synthetic nitrogen source, ureaformaldehyde. Table 3 shows that the quality ratings for the Ringer treatments were statistically equal to or greater than the other fertilizer treatments and the untreated control.

The above data suggests that Ringer natural fertilizers are an excellent source of slow release nitrogen when used in a fertilizer management program.

NITROGEN MOVEMENT

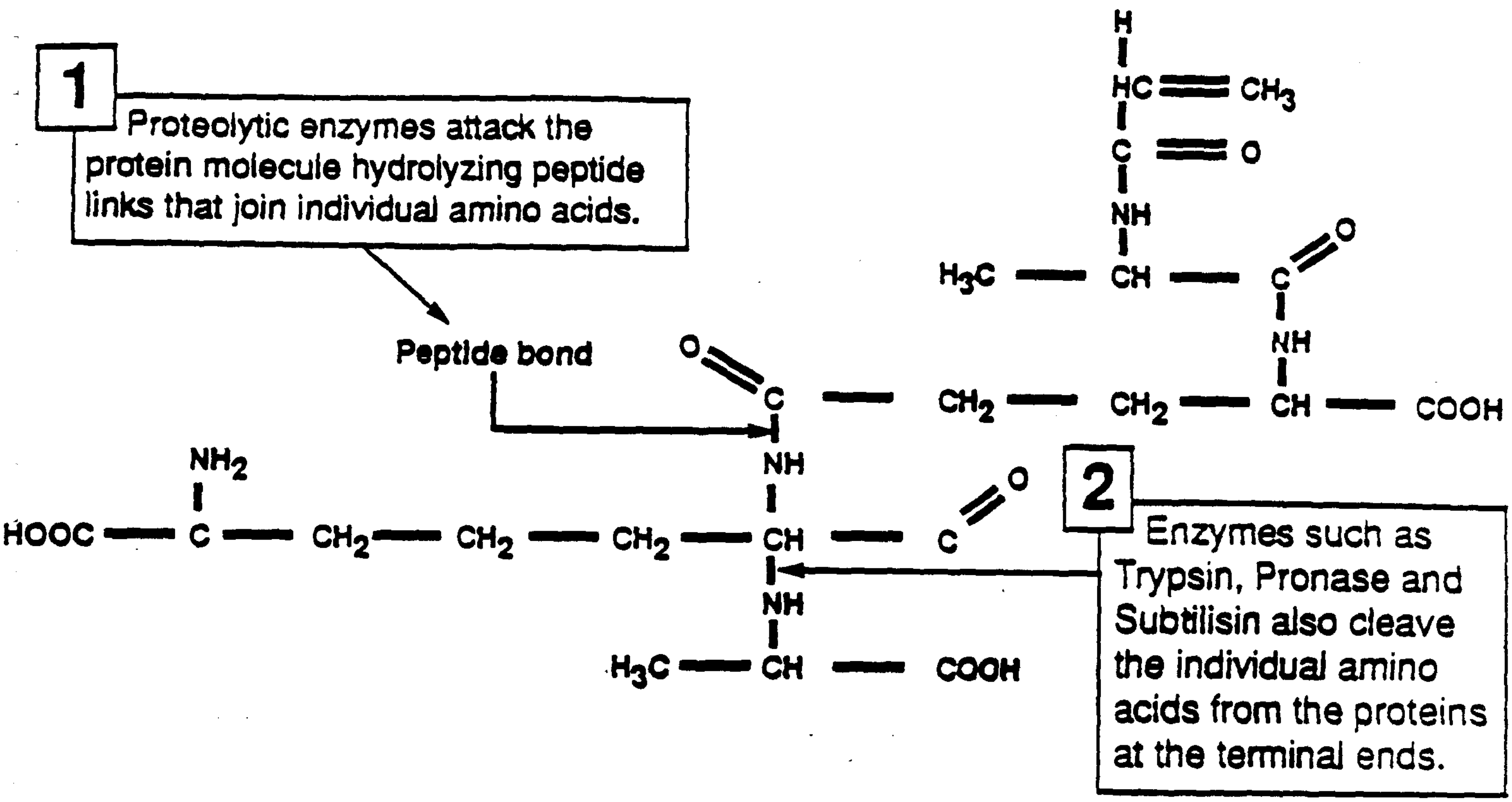
There has been a lot of work carried out at universities evaluating the fate of nitrogen when applied to soil and established turf. The results have varied and have been inconclusive as the fate is difficult to measure. In 1991, a study was established at the University of Nebraska in a rhizotron to look at the movement of nitrogen through a known, well defined soil profile.

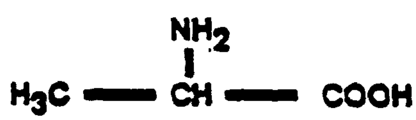
Nitrate leaching potential was measured at the University of Nebraska John Seaton Anderson Turfgrass Research Facility in a rhizotron. Release measurement was performed directly through nitrogen nitrate leachate extracted from the soil profile. Plant response to treatment application, including color development, root length and vegetative top growth was also measured. Products included in the test included Ringer® Turf 10-2-6 and Lawn Restore, sulfur coated urea, and urea. Application rates were 1.0 lbs. actual Nitrogen/1,000 ft^2 with 3 applications/season. Rhizotron cells were sodded with creeping bentgrass (*Agrostis palustris*) grown in a 100% sand media. Turf was established in June, 1990. Turf height was maintained at 0.5 inches by mowing a minimum of 2 times per week. Watering of rhizotron cells was through an automated sprinkler system calibrated to deliver 0.75 inches/day over 3 watering times.Collection of soil solution extracts was performed on time intervals consisting of 0, 1, 3, 7, 14, and 28 days following application.

Ringer natural fertilizer products Turf 10-2-6 and Lawn Restore provide an excellent source of slow release nitrogen. (Table 4) By evidence of the data received, nitrogen release rates for these products were consistent over time compared to both urea and sulfur coated urea. This was achieved while excellent color and quality was maintained. Development of root length and mass with respect to treatment could not be clearly defined from the data would require increasing the number of replication to determine what statistical differences exists.

In conclusion the Ringer slow-release natural organic fertilizers provide an excellent source of nitrogen for use in revegetation management practices because of the good release characteristics and the low potential for movement in the soil. Applications of 20-30 lbs/1000 sq. ft. of fertilizer at the time of seeding would provide adequate nutrition for the grass to establish and grow for up to 120 days.

EXAMPLE FOR DEGRADATION OF PROTEIN FOUND IN RINGER





3 Free amino acids are degraded further through deamination to release amine groups (NH_2) which are converted to NH_3.

$$NH_3 \longrightarrow NO_2^{-1} \longrightarrow NO_3^{-1}$$

4 The NH_3 is then subject to nitrification to form NO_3 which is taken up by the plant.

Table 1. Fertilizer Nitrogen Source Effects on Kentucky Bluegrass Color Response to Non-traffic Conditions.

1989

Treatment	Rate lbs. N/M	6/13	6/27	7/12	7/27	8/9	8/23	9/5	9/11	10/2	10/16	Avg.
Urea	6	8.0	8.0	7.5	7.8	7.5	8.0	7.5	8.0	7.9	8.0	7.8
L. Restore	6	7.5	7.8	7.5	7.5	7.5	8.0	7.9	8.0	7.9	8.0	7.7
NH_4NO_3	6	8.0	7.8	7.5	7.6	7.1	7.9	7.5	8.0	7.9	7.8	7.7
L. Restore	3	7.0	7.5	7.4	7.4	7.4	7.8	7.6	7.9	7.5	7.4	7.5
Urea	3	7.5	7.6	7.3	7.4	7.1	7.8	7.5	7.9	7.4	7.3	7.5
NH_4NO_3	3	7.3	7.4	7.1	7.4	7.0	7.5	7.1	7.5	7.6	7.4	7.3
Control	0	6.0	6.0	6.0	6.0	6.0	6.0	6.4	6.4	6.0	6.0	6.1
LSD (0.5)		0.3	0.3	0.3	0.3	0.2	0.3	0.4	0.2	0.3	0.3	0.2

Table 1 (con't.). Fertilizer Nitrogen Source Effects on Kentucky Bluegrass Color Response to Non-traffic Conditions.

1990

Treatment	Rate lbs. N/M	4/30	5/14	5/25	6/12	7/3	7/20	8/3	8/20	9/4	9/21	10/5	10/25	Avg.
L. Restore	3	7.5	7.6	7.6	5.0	5.5	6.0	6.0	6.5	6.8	7.3	7.5	7.0	6.7
NH_4NO_3	3	7.5	7.8	7.8	6.3	6.0	6.8	6.3	5.8	6.3	6.5	6.5	6.3	6.6
Urea	3	7.5	7.7	7.6	6.5	6.3	6.8	6.8	7.8	7.5	8.0	7.5	7.5	7.3
L. Restore	6	8.0	8.0	8.0	7.0	7.0	7.3	7.0	7.8	7.8	8.0	7.8	7.5	7.6
NH_4NO_3	6	7.8	7.9	7.8	5.8	6.5	7.5	7.0	7.0	7.0	6.8	7.0	6.3	7.0
Urea	6	7.9	7.9	7.9	6.8	7.0	7.0	7.0	7.5	7.3	7.8	8.8	8.3	7.6
Control	0	6.0	6.1	6.0	4.0	3.0	3.5	3.5	3.5	4.0	4.5	4.8	4.8	4.5
LSD(.05)		1.1	0.2	0.9	1.7	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.3

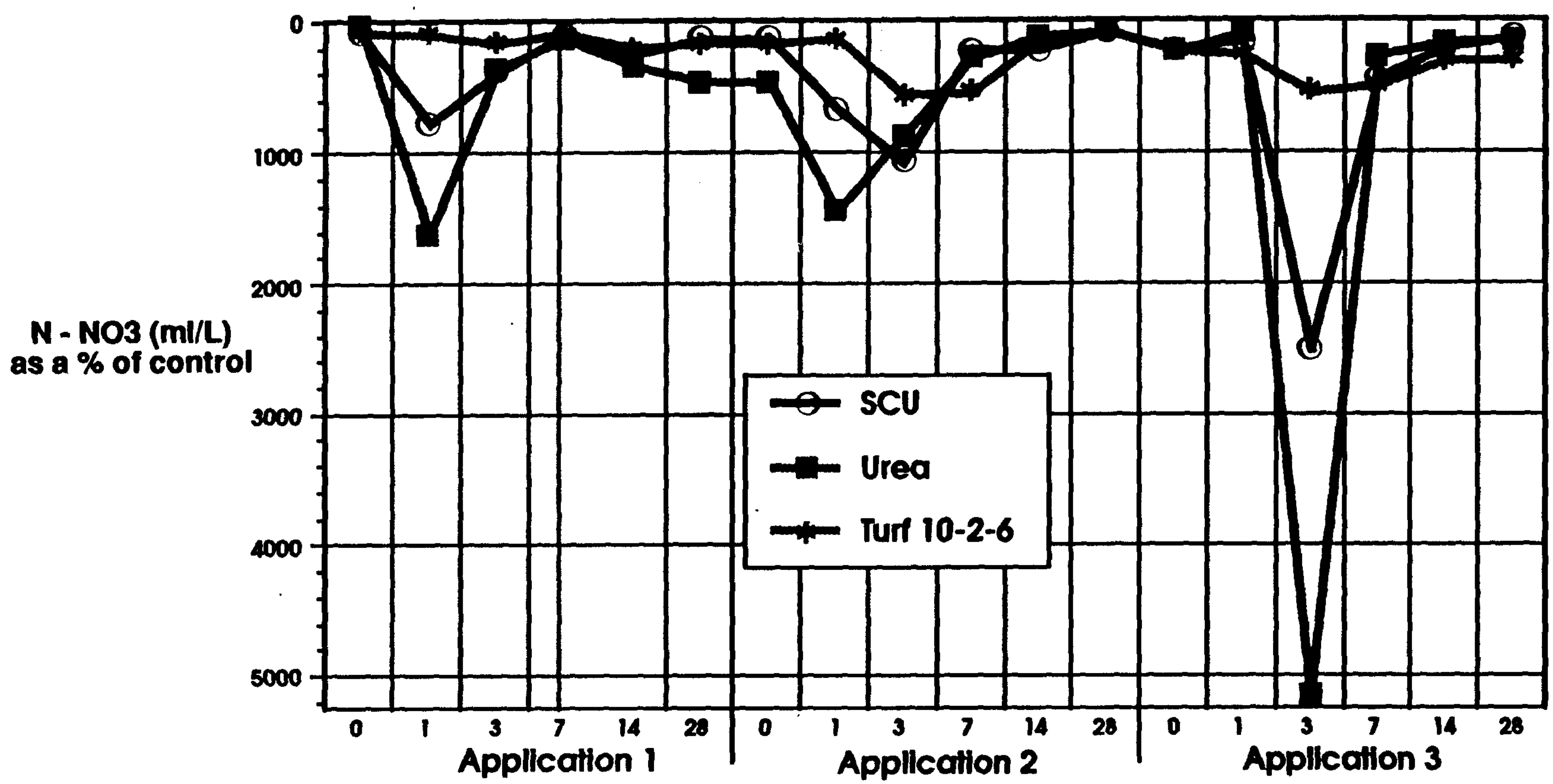
Table 2. Fertilizer Nitrogen Source Effects on Kentucky Bluegrass Quality Response Exposed To Traffic Conditions

Treatment	Rate lbs. N/M	1989 6/26	7/27	8/23	9/18	Avg.	1990 5/8	6/12	7/20	8/20	9/21	10/25	Avg.
L Restore	6	7.3	7.0	7.3	7.3	7.2	8.0	6.5	7.5	7.8	8.0	7.5	7.5
Urea	6	7.9	7.5	7.9	7.5	7.7	7.7	6.3	7.0	7.5	7.8	8.0	7.4
NH_4NO_3	6	7.8	7.5	7.6	7.5	7.6	7.3	5.3	7.0	6.8	6.8	6.3	6.6
NH_4NO_3	3	7.5	7.0	7.5	7.5	7.4	7.7	6.0	6.8	5.8	6.5	6.3	6.5
Urea	3	7.8	7.5	7.8	7.5	7.7	7.9	6.8	7.0	7.8	8.0	7.8	7.5
L Restore	3	7.5	7.4	7.5	7.4	7.5	7.7	5.3	6.3	6.0	7.0	7.0	6.5
Control	0	6.5	6.0	6.0	6.0	6.1	6.6	4.3	3.5	3.5	4.5	4.5	4.5
LSD (.05)		0.4	0.1	0.3	0.3	0.2	0.6	1.4	0.7	0.8	0.7	0.8	0.4

Table 2. Fertilizer Nitrogen Source Effects on Kentucky Bluegrass Quality Response To Non-traffic Conditions

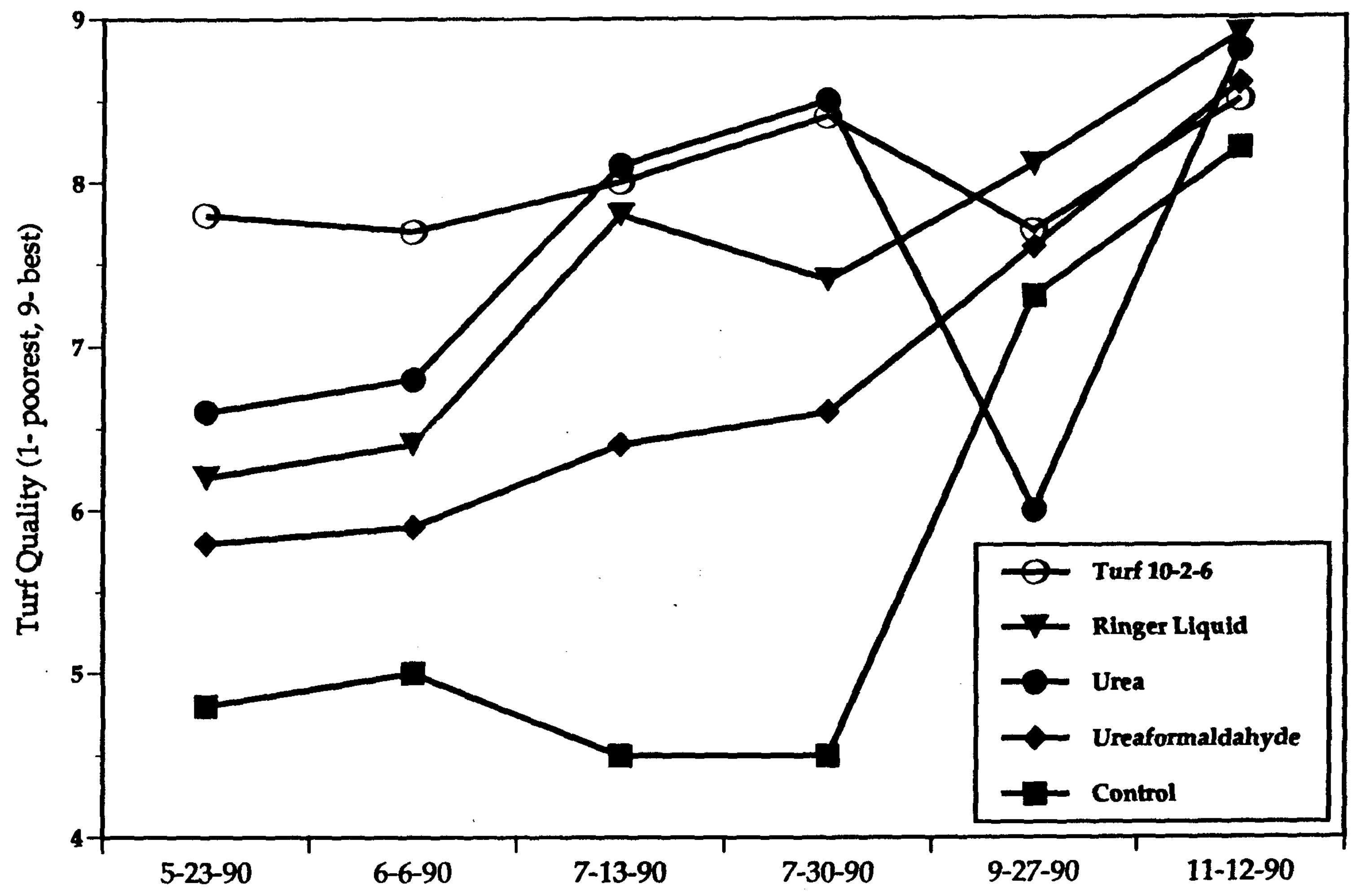
Treatment	Rate lbs. N/M	1989 6/26	7/27	8/23	9/18	Avg.	1990 5/8	6/12	7/20	8/20	9/21	10/25	Avg.
L Restore	6	7.6	7.4	8.0	7.5	7.6	8.0	5.8	6.8	7.3	7.3	7.8	7.1
Urea	6	7.9	7.5	7.8	7.4	7.6	7.8	6.3	6.8	6.3	6.8	7.5	6.9
NH_4NO_3	6	7.6	7.4	7.6	7.5	7.5	7.8	6.3	7.3	6.8	6.5	6.5	6.8
NH_4NO_3	3	7.1	7.0	7.5	7.5	7.3	7.6	5.5	6.0	5.5	5.5	6.0	6.0
Urea	3	7.3	7.1	7.5	7.4	7.3	7.9	6.0	6.8	6.5	6.8	7.0	6.8
L Restore	3	6.9	6.9	7.3	7.1	7.0	8.0	5.8	6.8	7.3	7.3	7.8	7.1
Control	0	6.3	6.0	6.0	6.0	6.1	6.1	3.3	3.8	3.5	3.8	4.5	4.2
LSD(.05)		0.3	0.2	0.3	0.3	0.2	0.2	0.9	1.1	1.4	1.4	0.3	0.8

Nitrogen Release of Various Fertilizers



University of Nebraska, Dr G. Horst

Natural Organic Fertilizer Effects on Turf Quality



University of Massachusetts, Dr. R. Cooper

Table 4. Nitrate leaching potential was measured at the University of Nebraska John Seaton Anderson Turfgrass Research Facility in a rhizotron.

Objective

The objective of the study was to determine nitrogen release and movement from applications of various nitrogen fertilizer sources grown under specific conditions.

Materials and Methods

Release measurement was performed directly through nitrogen nitrate leachate extracted from the soil profile. Plant response to treatment application, including color development, root length and vegetative top growth was also measured. Products included in the test included Ringer® Turf 10-2-6 and Lawn Restore, sulfur coated urea, and urea. Application rates were 1.0 lbs. actual Nitrogen/1,000 ft^2 with 3 applications/season. Rhizotron cells were sodded with creeping bentgrass (*Agrostis palustris*) grown in a 100% sand media. Turf was established in June, 1990. Turf height was maintained at 0.5 inches by mowing a minimum of 2 times per week. Watering of rhizotron cells was through an automated sprinkler system calibrated to deliver 0.75 inches/day over 3 watering times.Collection of soil solution extracts was performed on time intervals consisting of 0, 1, 3, 7, 14, and 28 days following application.

Conclusions

Natural fertilizer products Turf 10-2-6 and Lawn Restore provide an excellent source of slow release nitrogen. By evidence of the data received, nitrogen release rates for these products were consistent over time compared to both urea and sulfur coated urea. This was achieved while excellent color and quality was maintained. Development of root length and mass with respect to treatment could not be clearly defined from the data would require increasing the number of replication to determine what statistical differences exists.

PARTICIPANT LIST

We were pleased to have a total of 280 participants at the Tenth High Altitude Revegetation Conference. Representatives from four foreign countries as well as from seventeen 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 1994, and pass the word to your fellow workers so that the 1994 conference will be a great success.

Editors

Table 1. Geographical distribution of participants at the Tenth High Altitude Revegetation Conference.

Geographic Entity	Number of Participants	Percent of Total Participants
AUSTRALIA	1	0.4
CANADA		
Alberta	1	0.4
British Columbia	1	0.4
Yukon	1	0.4
DENMARK	1	0.4
SWITZERLAND	1	0.4
UNITED STATES		
Alabama	1	0.4
Alaska	3	1.1
Arizona	5	1.8
California	15	5.4
Colorado	191	68.2
Idaho	8	2.9
Michigan	1	0.4
Montana	15	5.4
Nevada	8	2.9
Oklahoma	1	0.4
Oregon	2	0.7
Pennsylvania	1	0.4
South Dakota	6	2.1
Tennessee	1	0.4
Utah	6	2.1
Washington	2	0.7
Wyoming	8	2.9
TOTAL	280	100.2

TENTH HIGH ALTITUDE REVEGETATION WORKSHOP

MARCH 4 - 5, 1992

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1626 COLE BLVD.
GOLDEN, CO 80401
303-231-0294

72. JULIE ETRA
TAHOE NATIVE PLANTS
BOX 13196
S. LAKE TAHOE, CA 96151
916-577-5011

73. JULIE FAIR
COLORADO STATE UNIVERSITY
RANGE SCIENCE
FT. COLLINS, CO 80523
303-491-7274

74. CHARLES FAIR
US BUREAU OF LAND MANAGEMENT
P.O. BOX 2200
CANON CITY, CO 81215-2200
719-275-0631

75. JEFF FENTON
BUREAU OF LAND MANAGEMENT
P.O. BOX 1009
GLENWOOD SPRINGS, CO 81602
303-945-2341

76. HUGO FERCHAU
WESTERN STATE COLLEGE
LIFE SCIENCE & MATH
GUNNISON, CO 81230
303-943-2015

77. JERALD S. FIFIELD
HYDRO DYNAMICS INC.
P.O. BOX 1327
PARKER, CO 80134

78. DAYLAN FIGGS
OSM-WSC-TAD-BSB-RSS
1020 15TH ST.
DENVER, CO 80202
303-844-2109

79. GARY D. FINSTAD
730 SIMMS, RM. 416
GOLDEN, CO 80401
303-236-2891

80. HARVEY FRYBERGER
SHARP BROS SEED CO.
101 E. 4TH ST. RD.
GREELEY, CO 80631
303-356-4710

81. GORDON FULLER
NORTH AMERICAN GREEN, INC.
3375 W 7800 S APT. 1228
WEST JORDAN, UT 84088
812-867-6632

82. JOHN C. FUSARO
USDA SOIL CONSERVATION SERVICE
655 PARFET ST, RM E200C
LAKEWOOD, CO 80215
303-236-2891

83. WARREN GABBERT
EG&G ENERGY MEASUREMENTS
101 CONVENTION CTR DR. #1010
LAS VEGAS, NV 89109
702-794-7463

84. BECKY GAUTHIER
WEYERHAEUSER CO.
3001 796TH SE
SNOQUALMIE, WA 98065
206-888-7501

85. JUDY GENIAC
NATIONAL PARK SERVICE, MMB
P.O. BOX 25287
DENVER, CO 80225-0287
303-969-2015

86. DANNELA GEORGE
STANISLAUS NATIONAL FOREST
19777 GREENLEY RD.
SONORA, CA 95370
209-532-3671

87. MARTIN GERTONSON
S. DAKOTA DEPT. ENR
FOSS BLDG.
PIERRE, SD 57501
605-773-4201

88. ALLAN GILL
CSU STUDENT
1500 W. PLUM #2A
FORT COLLINS, CO 80521
303-491-8924

89. ERNIE GILLINGHAM
BUREAU OF LAND MANAGEMENT
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CANON CITY, CO 81215-2200
719-275-0631

90. DONALD GOBER
U. S. FISH & WILDLIFE SERVICE
RMA, BLDG. 613
COMMERCE CITY, CO 80224
303-289-0232

91. STEVE GOLDMAN
CALIFORNIA TAHOE CONSERVANCY
P.O. BOX 7758
S. LAKE TAHOE, CA 96158
916-542-5566

92. DANNY GOODSON
UPPER COLO. ENVIR. PLANT CTR.
P.O. BOX 448
MEEKER, CO 81641
303-878-5003

93. RICK GRANARD
ENVIRONMENTAL SOIL SYSTEMS,INC
13234 WHISTLER AVE.
GRANADA HILLS, CA 91344
818-368-4115

94. JOHN GRAVES
NATIVE SEEDERS
6324 L.C.R. #1
WINDSOR, CO 80550
303-482-7332

95. CHUCK GRIMES
GRASSLANDER
RT. 1 BOX 56
HENNESSEY, OK 73742
405-853-2607

96. LAURA HAIRGROVE
U. S. FOREST SERVICE
1705 HEATHERRIDGE L105
FT. COLLINS, CO 80526
303-493-9145

97. MICHAEL HANNIGAN
GEOWEST GOLDEN, INC.
175 W. 200 S #2006
SALT LAKE CITY, UT 84101
801-359-3059

98. DALE HARBER
USFS - MANTI-LASAL NAT'L FOR.
FERRIN RANGER DISTRICT BOX 310
FERRIN, UT 84523
801-384-2372

99. WILLIAM HARDING, JR.
TRAPPER MINING, INC.
P.O. BOX 187
CRAIG, CO 81626
303-824-4401

100. WENDELL HASSELL
NATIONAL PARK SERVICE
P.O. BOX 25287
LAKEWOOD, CO 80225
303-969-2172

101. BRUCE HASTINGS
U. S. FISH & WILDLIFE SERVICE
RMA, BLDG. 613
COMMERCE CITY, CO 80224
303-289-0232

102. WILLIAM HAWKINS
COLORADO SCHOOL OF MINES
583 CERRO COURT
EVERGREEN, CO 80439
674-1874

103. MEG HEIM
GRAND CANYON NATIONAL PARK
P.O. BOX 129
GRAND CANYON, AZ 86023
602-638-7755

104. DOT HELM
UNIVERSITY OF ALASKA FAIRBANKS
533 E. FIREWEED AVE.
PALMER, AK 99645
907-745-3257

105. WALT HENES
SOUTH WEST SEED
13260 ROAD 29
DOLORES, CO 81323
303-565-8722

106. JIM HERRON
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST.
DENVER, CO 80203
303-866-3567

107. LOREN HETTINGER
DAMES & MOORE
1125 17TH STREET SUITE 1200
DENVER, CO 80202-2027
303-299-7888

108. DON HIJAR
GARRISON SEED COMPANY
P.O. BOX 1604
GREELEY, CO 80632
303-356-7002

109. RYAN HOAGLAND
P.O. BOX 1142
LEADVILLE, CO 80461
719-486-2015

110. MICHAEL HOGAN
USDA FOREST SERVICE
870 EMERALD BAY ROAD
SOUTH LAKE TAHOE, CA 96150
916-573-2600

111. MICHAEL HOULTON
GRASS-LAND SOILS & RECLAMATION
P.O. BOX 6198, 3005 AIRPORT RD
HELENA, MT 59601
406-442-0950

112. LAURIE HUCKABY
USDA FOREST SERVICE
240 W. PROSPECT RD.
FT. COLLINS, CO 80526
303-498-1147

113. TERRY HUGHES
GRAND MESA,UNCOMP,GUNN NAT FST
2250 HIGHWAY 50 S
DELTA, CO 81416
303-874-7691

114. BRUCE HUMPHRIES
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST. #215
DENVER, CO 80203
303-866-3567

115. SUSAN INGRAM
LEADVILLE CORPORATION
P.O. BOX 933
LEADVILLE, CO 80461
719-486-0722

116. CHARLES JACKSON
AMAX
1626 COLE BLVD.
GOLDEN, CO 80401
303-234-9020

117. KAY JAMES
FLATIRON COMPANIES
P.O. BOX 229
BOULDER, CO 80306
499-1441

118. BILL JEFFRESS
AMAX GOLD, INC. - SLEEPER MINE
600 SOD HOUSE RD.
WINNEMUCCA, NV 89445
702-623-1112

119. WILLIAM JENNINGS
MINING ENGINEER
P.O. BOX 952
LOUISVILLE, CO 80027
303-666-8348

120. JIM JENSEN
RINGER CORP.
2125 VINEYARD DR.
TEMPLETON, CA 93465
805-434-0735

121. WAYNE JOHANNSON
U.S. FOREST SERVICE
39696 HIGHWAY 70
QUINCY, CA 95971
916-283-0555

122. RICHARD JOHNSON
MK-ENVIRONMENTAL SERVICES
1700 LINCOLN ST. STE. 4800
DENVER, CO 80203
303-860-8621

123. WILLIAM JOHNSON
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BOX 427
CARBONDALE, CO 81623
303-963-1356

124. MATT JOHNSON
PITKIN COUNTY LAND MANAGEMENT
506 E. MAIN
ASPEN, CO 81611
303-923-6116

125. CHRISTINE JOHNSTON
COLORADO MINED LAND RECLAM DIV
1313 SHERMAN ST.
DENVER, CO 80203
303-866-3567

126. RICHARD JOLK
USMX, INC.
141 UNION BLVD. STE. 100
LAKEWOOD, CO 80228
985-4665

127. JAY JONES
HENDERSON MINE & MILL
P. O. BOX 68
EMPIRE, CO 80438
303-569-3221

128. DAMON JUDD
ESRI
1426 PEARL ST., STE. 210
BOULDER, CO 80302
303-449-7779

129. MARSHALL KAHN
ENVIRONMENTAL SOIL SYSTEMS,INC
13234 WHISTLER AVE.
GRANADA HILLS, CA 91344
818-368-4115

130. GAIL KALCO
GARRISON SEED COMPANY
P.O. BOX 1604
GREELEY, CO 80632
303-356-7002

131. DEBORAH KEAMMERER
KEAMMERER ECOLOGICAL CONS.
5858 WOODBOURNE HOLLOW RD.
BOULDER, CO 80301
303-530-1783

132. WARREN KEAMMERER
KEAMMERER ECOLOGICAL CONS.
5858 WOODBOURNE HOLLOW RD.
BOULDER, CO 80301
303-530-1783

133. W. GORDON KEARL
1518 SHIELDS STREET
LARAMIE, WY 82070
307-742-2005

134. CATHERINE E. KENNEDY
YUKON RENEWABLE RESOURCES
FISH & WILDLIFE P.O. BOX 2703
WHITEHORSE, YUKON, Y1A 2C6
CANADA
403-667-5407

135. DAVID S. KERR
EMA
1011 - 6TH AVENUE SW
CALGARY ALTA CANADA,
403-299-5600

136. BRIAN KINCAID
P.O. BOX 67
LEADVILLE, CO 80461

137. KEVIN KINSELLA
LAC MINERALS
1395 GREG ST. #107
SPARKS, NV 89431
702-356-8058

138. KEN KLOSKA
CLIMAX METALS CO.
1626 COLE BLVD.
GOLDEN, CO 80403
303-231-0283

139. DOUG KOLZ
NILEX CORP.
12503 E. EUCLID DR. #10
ENGLEWOOD, CO 80111
303-790-7222

140. PAUL KRABACHER
COLORADO MINED LAND RECL. DIV.
2882 CABOOSE
GRAND JUNCTION, CO 81503
303-248-7253

141. ANN KUENSTLING
KEAMMERER ECOLOGICAL CONSULTS.
5858 WOODBOURNE HOLLOW ROAD
BOULDER, CO 80301
303-530-1783

142. ROLLAND KUHR
LANDSCAPE ARCHITECT
P.O. BOX 3822
JACKSON, WY 83001
307-733-5564

143. CLAYTON KYTE
F.M.C. CORP.
BOX 750
KEMMERER, WY 83101
307-877-3916

144. ROB LAIRD
COOLEY GRAVEL CO.
P. O. BOX 5485
DENVER, CO 80217
303-989-0300

145. JIM LANCE
CO. DEPT. OF TRANSPORTATION
P.O. BOX 2107
GRAND JUNCTION, CO 81502
303-248-7255

146. LISA LARSEN
WESTECH
P.O. BOX 6045
HELENA, MT 59604
406-442-0950

147. JOHN LEAHY
FLORIDA CANYON MINING INC.
PEGASUS GOLD CORP. - BOX 330
IMLAY, NV 89418

148. PHILIP L. LEONHARDT
WATER, WASTE & LAND, INC.
2629 REDWING ROAD SUITE 200
FORT COLLINS, CO 80526
303-226-3535

149. LISA LESPERANCE
CHEM-NUCLEAR GEOTECH
P.O. BOX 14000
GRAND JUNCTION, CO 81502
303-248-6192

150. KIKI LEYBA
NILEX CORP.
12503 E. EUCLID DR. #10
ENGLEWOOD, CO 80111
303-790-7222

151. NANCY LOGUE
FLORIDA CANYON MINING INC.
PEGASUS GOLD CORP. - BOX 330
IMLAY, NV 89418

152. JEFFREY LORMAND
PARSONS DELEUW, INC.
1700 BROADWAY, STE .800
DENVER, CO 80290
303-863-7900

153. DANIEL LOVATO
U.S. FOREST SERVICE
11177 W. 8TH AVE.
LAKEWOOD, CO 80225
303-236-9420

154. MARK LOYE
JEFFERSON COUNTY PLANNING DEPT
700 JEFFERSON CTY PKY #220
GOLDEN, CO 80401
303-271-5806

155. ARLEI B. MACEDO
COLORADO SCHOOL OF MINES
DEPT. GEOLOGY & GEOL. ENGR.
GOLDEN, CO 80410
303-273-3108

156. CARL MACKEY
MK-ENVIRONMENTAL SERVICES
1700 LINCOLN ST.
DENVER, CO 80203
303-860-8621

157. JEFF MAGOON
LITTLE VALLEY NURSERY, INC.
13022 E. 136TH AVE.
BRIGHTON, CO 80601
303-659-6708

158. NEEL MAILE
SAN BERNARDINO NATIONAL FOREST
P.O. BOX 290
FAWNSKIN, CA 92333
714-866-3437

159. MARTHA MANDERBACH
USDA FOREST SERVICE
630 SANSOME ST., RM. 602
SAN FRANCISCO, CA 94111
415-705-2748

160. ZACH MARGOLIS
SILVERTHORNE/DILLON J.S.A.
P. O. BOX 541
DILLON, CO 80435
303-468-6152

161. DAN MATHEWS
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST. #215
DENVER, CO 80203

162. JOHN MCCARTY
CO. DEPT. OF TRANSPORTATION
P. O. BOX 1430
GLENWOOD SPRINGS, CO 81602
303-945-0493

163. JIM MCGANNON
CITY OF COLO. SPGS. PARK & REC
1401 RECREATION WAY
COLORADO SPRINGS, CO 80905
719-578-6698

164. SUSAN MCGREW
CITYSCAPE URBAN DESIGN, INC.
3030 S. COLLEGE AVE. #200
FT. COLLINS, CO 80525
303-226-4074

165. BILL MCKINNELL
WEST HAZMAT CONTRACTING INC.
76;70 S. VAUGHN CT.
ENGLEWOOD, CO 80112

166. ED MCKINNEY
USDAFS - BOULDER RANGER DIST.
2995 BASELINE RD. RM. 110
BOULDER, CO 80303
303-444-6001

167. MACK MCMULLEN, JR.
OFFICE OF SURFACE MINING
1020 15TH ST.
DENVER, CO 80202
303-844-2939

168. PETER MCRAE
DESERT BLOOM/QUATTRO RESOURCES
1625 28TH ST. #4000
SAN DIEGO, CA 92102
619-234-1444

169. DAN MCWILLIAMS
WATER, WASTE & LAND, INC.
2629 REDWING ROAD SUITE 200
FORT COLLINS, CO 80526
303-226-3535

170. CAMILLE MEYER
COLORADO MINED LAND - RECL DIV
1313 SHERMAN, RM 215
DENVER, CO 80203

171. DAN MILLER
DAMES & MOORE
1125 17TH STREET SUITE 1200
DENVER, CO 80202-2027
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172. LORRAINE MINTZMYER
MID-ATLANTIC REGIONAL DIRECTOR
N.P.S. - 143 S. THIRD ST.
PHILADELPHIA, PA 19106

173. RICK MOHR
COEURD'ALENE MINES
2417 BANK DR. #302
BOISE, ID 83705
208-385-0373

174. PETER MOLLER
BOULDER VALLEY SOIL CONS. DIST
9595 NELSON RD.
LONGMONT, CO 80501
303-772-4273

175. BOB MONTGOMERY
ARCO
307 E. PARK AVE. STE. 400
ANACONDA, MT 59711
406-503-5211

176. NAOMI MOODY
BUREAU OF LAND MANAGEMENT
WHITE RIVER RES. AREA BOX 928
MEEKER, CO 81641
303-878-3601

177. JOHN MORRONE
BUREAU OF LAND MANAGEMENT
CRAIG DISTRICT
CRAIG, CO 81625
303-824-8261

178. CHERYL MULDER
USFS - PLUMAS NATIONAL FOREST
39696 HIGHWAY 70
QUINCY, CA 95971
916-283-0555

179. PATRICK MURPHY
ESCO ASSOCIATES, INC.
P. O. BOX 18775
BOULDER, CO 80308
303-447-2999

180. STEVE MURPHY
ABR ASSOCIATES
FAIRBANKS, AK
907-455-6778

181. MARCI NEILSENGERHARDT
PAYETTE NATIONAL FOREST
P. O. BOX 1026
MCCALL, ID 83638
208-634-0620

182. FRED NICHOLS
REMOTE SENSING RESEARCH
P.O. BOX 1949
FT. COLLINS, CO 80522
303-498-8955

183. GARY NOLLER
UPPER COLO. ENVIR. PLANT CTR.
P.O. BOX 448
MEEKER, CO 81641
303-878-5003

184. BEN NORTHCUTT
INTERNAT'L EROSION CONT. ASSOC
P.O. BOX 4904
STEAMBOAT SPRINGS, CO 80477
303-879-3010

185. PETER O'BRIEN
MERISTEM NURSERY
P.O. BOX 698
REDWING, CO 81066
719-746-2290

186. LOUISE O'DEEN
USDA FOREST SERVICE
240 W. PROSPECT
FT. COLLINS, CO 80526
303-498-1147

187. KAYODE OKESANJO
JAMES P. WALSH & ASSOC.
4888 PEARL E. CIR. STE. 108
BOULDER, CO 80301
303-443-3282

188. WILLIAM ORR
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P. O. BOX 25287
LAKEWOOD, CO 80226
303-969-2568

189. DAN OWENS
PPS PACKAGING COMPANY
204 N. 7TH ST. P.O. BOX 56
FOWLER, CA 96325
209-834-1641

190. RICHARD PARACHINI
COLORADO DEPT. OF FIELDS
4210 E. 11TH AVE. RM. 351
DENVER, CO 80220
303-331-4801

191. REBECCA PARMENTER
USDA FOREST SERVICE
BOX 3307
IDAHO SPRINGS, CO 80452
303-567-2901

192. ROB PATRICK
DEPT. CONSERVATION & ENVIRONM.
P.O. BOX 303
WODONGA VICTORIA, 3690
AUSTRALIA
060-556111

193. DEE PECK
ARKANSAS VALLEY SEED CO.
4625 COLORADO BLVD.
DENVER, CO 80216
303-535-4481

194. ALISON PECK
MATRIX GARDENS
1545 REDWOOD AVE.
BOULDER, CO 80304
303-443-0284

195. JEFFREY PECKA
SYSTEMS PLANNING GROUP
5973 E. IRWIN PL.
ENGLEWOOD, CO 80112
303-770-0747

196. BARRY PERRYMAN
UNIV. OF WYOMING
RANGE DEPT, BOX 3354
LARAMIE, WY 82070
307-766-2263

197. MARK PHILLIPS
PHILLIPS SEEDING
11843 BILLINGS
LAFAYETTE, CO 80026
303-665-2618

198. MARY LOU PIERCE
BUREAU OF RECLAMATION
P.O. BOX 25007 ATTN: D-3130
DENVER, CO 80225
303-236-9095

199. LORETTA PINEDA
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST. RM. 215
DENVER, CO 80203
303-866-3567

200. PATRICK PLANTENBERG
MONTANA RECLAMATION DIVISION
CAPITAL STATION
HELENA, MT 59620
406-444-2074

201. JAMES POELL
MONTANA STATE UNIVERSITY
REC. RES. UNIT 106 LINFIELD HL
BOZEMAN, MT 59717
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202. HARRY POSEY
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DENVER, CO 80203
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203. RACHEL POTTER
GLACIER NATIONAL PARK
WEST GLACIER, MT 59936
406-888-5441

204. CONNIE PRESSON
WEYERHAEUSER CO.
522 MONTEREY LN.
TACOMA, WA 98466
206-566-8608

205. JOHN RAMSAY
SUMMITVILLE CONSOL. MINING CO.
P. O. BOX 2G
DEL NORTE, CO 81132
719-657-2741

206. LARRY RANDALL
USFS-SAWTOOTH NATIONAL FOREST
2621 S. OVERLAND AVE.
BURLEY, ID 83318
208-678-0430

207. ED REDENTE
COLORADO STATE UNIVERSITY
RANGE SCIENCE
FT. COLLINS, CO 80523
303-491-6542

208. GREGORY REED
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1020 15TH ST.
DENVER, CO 80202
303-844-2109

209. NORMAN REES
USDA AGRICULTURAL RESEARCH SVC
BIOCONTROL OF WEEDS LAB - MSU
BOZEMAN, MT 59717

210. JAMES RHETT
BLM COLORADO ST. OFF. CO-923
2850 YOUNGFIELD ST.
LAKEWOOD, CO 80215
303-239-3752

211. HAROLD ROBINSON
LAKE MICHIGAN COLLEGE
2755 E. NAPIER AVE.
BENTON HARBOR, MI 49022
616-927-3571

212. JIM ROSE
AMERICAN EXCELSIOR CO.
6475 N. FRANKLIN
DENVER, CO 80229
303-287-3261

213. LARRY ROUTTEN
COLORADO MINED LAND RECLAM DIV
1313 SHERMAN ST.
DENVER, CO 80203
303-866-3567

214. STEVEN RUSSELL
SOIL CONSERVATION SERVICE
0881 N. HIGHWAY 285
MONTE VISTA, CO 81144
719-852-5114

215. JOHN RYGH
U. S. FOREST SERVICE
P.O. BOX 396
MCCALL, ID 83638

216. SUSAN SAARINEN
LA
1900 19TH STREET
GOLDEN, CO 80401
303-278-7445

217. DENNIS M. SAKURADO
NEWMONT EXPLORATION LTD.
240 SOUTH ROCK
RENO, NV 89502
702-333-6728

218. RANDY SARGENT
RICHMOND HILL, INC.
P. O. BOX 892
LEAD, SD 57754
605-584-1210

219. PAUL SAWYER
MONTANA TECH
PARK ST
BUTTE, MT 59701
406-496-4227

220. HERB SCHAAL
EDAW, INC.
240 EAST MOUNTAIN AVE.
FT. COLLINS, CO 80524
303-484-6073

221. ANNA SCHOETTLE
USDA FOREST SERVICE
240 W. PROSPECT RD.
FT. COLLINS, CO 80526
303-498-1147

222. KIM SCHULTZ
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HC37 - BOX 811
LEAD, SD 57754
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223. MARK SCHUSTER
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910 COVE WAY
DENVER, CO 80209
303-572-7700

224. BILL SCHWARZKOPF
WESTERN ENERGY CO.
AREA C
COLSTRIP, MT 59323

225. JIM SCHWITZER
436 D ST.
SALIDA, CO 81201
719-539-2998

226. BOB SENN
ROCKY MOUNTAIN BIO-PRODUCTS
P. O. BOX 608
EDWARDS, CO 81632
303-926-1025

227. KARY SHAW
S. M. STOLLER CORP
5700 FLATIRONS PKWY.
BOULDER, CO 80301
303-449-7220

228. RICK SHERMAN
COLORADO DIVISION OF WILDLIFE
2300 SOUTH TOWNSEND
MONTROSE, CO 81401
303-249-3431

229. JOHN SHERRILL
MOUNTAIN WEST ENVIRONMENTS
P.O. BOX 2107
STEAMBOAT SPRINGS, CO 80477
879-2313

230. SLOAN SHOEMAKER
INDEPENDENCE PASS FOUNDATION
P.O. BOX 1781
ASPEN, CO 81612
303-923-4927

231. WILLIAM SIMON
ALPINE ENVIRONMENTAL
8181 COUNTY ROAD 203
DURANGO, CO 81301

232. WILLIAM SMITH
BRECKENRIDGE SANITATION
BOX 1216
BRECKENRIDGE, CO 80424
303-453-6715

233. KARRI SMITH
3485 S 1100 E.
SALT LAKE CITY, UT 84106

234. ROY SMITH
UNIVERSITY OF MI
783 S. WASHINGTON
DENVER, CO 80209
303-778-6648

235. THOMAS SNOKE
NATIONAL PARK SERVICE
P. O. BOX 185
FLORISSANT, CO 80816
719-748-3253

236. DANIEL SOKAL
BUREAU OF LAND MANAGEMENT
P.O. BOX 1009
GLENWOOD SPRINGS, CO 81602
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237. ALLEN SORENSON
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST. #215
DENVER, CO 80203
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238. STEPHEN SPAULDING
COLORADO STATE FOREST SERVICE
P. O. BOX 9024
WOODLAND PARK, CO 80866
719-687-2921

239. GREGG SQUIRE
MINED LAND RECLAMATION DIV.
1313 SHERMAN ST.
DENVER, CO 80203
303-866-3567

240. VERN STEES
AMAX COOL COMPANY
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