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High Altitude Revegetation
Workshop No. 14

Edited by
Warren R. Keammerer

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HIGH ALTITUDE REVEGETATION WORKSHOP

NO. 14

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Edited by

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PREFACE

The 14th biannual High Altitude Revegetation Conference was held at the University Park Holiday Inn, Ft. Collins, Colorado on March 8-10, 2000. The Conference was organized by the High Altitude Revegetation Committee in conjunction with the Colorado State University Department of Soil and Crop Science. The Conference was attended by 232 people from a broad spectrum of universities, government agencies and private companies. It is always encouraging to have participants from such a wide range of interests in and application needs for reclamation information and technology.

Organizing a two-day workshop and field trip is a difficult task made relatively easy by the sharing of responsibilites among the members of the HAR Committee.

In addition to the invited papers and poster papers presented on March 8-9, a field tour of the Rocky Mountain Arsenal National Wildlife Refuge was conducted on March 10, 2000. We appreciate and thank the organizers of the field tour.

We would also like to acknowledge and thank all of the people who took time to prepare invited papers and poster papers. These Proceedings are their product, and we express our gratitude to them. The Proceedings include 16 papers and 5 abstracts grouped into seven conference sessions, six poster papers and one poster paper abstract.

For current information on upcoming High Altitude Committee events, visit our website at www.highaltitudereveg.com.

Warren R. Keammerer
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REDEFINING CRITICAL HABITAT FOR ANADROMOUS FISH IN CENTRAL IDAHO

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ABSTRACT

The Endangered Species Act (ESA) is the nation's strongest and most far-reaching fish and wildlife protection law. A key component of the ESA is "critical habitat," defined as "the specific areas within the geographical area occupied by the species, at the time it is listed....on which are found those physical or biological features essential to the conservation of the species and which may require special management considerations or protections." Except when determined otherwise by the implementing agency, "critical habitat shall not include the entire geographical area which can be occupied by the threatened or endangered species."

An important issue for critical habitat designation is the treatment of "unoccupied habitat," i.e. habitat areas where no listed species are present but which may be suitable or historically used habitat. This paper describes these issues for a headwaters stream in central Idaho. The paper first surveys the statutory and policy concerns applicable to critical habitat designation, and then reviews how those factors were applied to Napias Creek on the Salmon-Challis National Forest. Next, the paper reviews the ESA petition process used to persuade the implementing agency that this stream did not satisfy the definitional criteria for critical habitat treatment. The paper concludes with some of the lessons learned and issues raised by this critical habitat revision petition experience.

INTRODUCTION

The Endangered Species Act may affect natural resource project activities, whether those activities involve reclamation, revegetation, or project development. This paper focuses on how the ESA can affect these activities through the critical habitat treatment of areas where ESA-listed species are not present, and where there is no historical record that the listed species ever were present in these areas.

The situation described in this paper addresses the Napias Creek drainage in central Idaho and how the operation of the Beartrack Project gold mine in that watershed was affected by the critical habitat designation and petition processes of the ESA. In the situation examined here, the mine's owner and operator, Meridian Gold Company, successfully petitioned for revision of the treatment of the mine area as critical habitat. This represents the first time an area was removed from critical habitat designation under the ESA as a result of a petition request to the ESA-administering agency, the National Marine Fisheries Service in this instance. The paper considers this case study example of how the agency and administrative processes work for efforts to change the critical habitat treatment for a particular area. It also addresses the significant changes such critical habitat treatment and revision can bring about for the regulatory treatment of that area and activities within that area.

BACKGROUND

ESA Statutory and Regulatory Framework

The purpose of the ESA is to conserve threatened and endangered species of fish, wildlife and plants. Application of the Endangered Species Act is triggered by the listing of a species under Section 4 (U.S. Congress 1973). The ESA protects "endangered" species (those in danger of extinction throughout all or a significant portion of their range) and "threatened" species (those likely to become endangered within the foreseeable future). The federal agencies responsible for implementing the ESA are the Fish and Wildlife Service (FWS) of the Department of Interior and the National Marine Fisheries Service (NMFS) of the Department of Commerce (FWS and NMFS 1999). In general, FWS is responsible for terrestrial and freshwater species. NMFS is responsible for marine species, including anadromous fish such as salmon and steelhead that hatch in fresh water, spend most of their adult life in the ocean, and then return to fresh water to spawn. If the Service lists a species under Section 4, the agency generally must also designate "critical habitat" for the species. Critical habitat includes those areas essential to the conservation of a listed species that require special management or protection.

ESA Section 7 requires federal agencies to consult with the appropriate Service to determine whether agency action may affect listed species or their habitat. An "action" is defined very broadly to include "all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by federal agencies in the United States or upon the high seas," including the "granting of licenses, contracts, leases, easements, rights-of-way, permits, or grants-in-aid" (FWS and NMFS 1999). Section 7 proscribes federal agencies from taking any action that is likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat. If the agency determines that its action will affect listed species or critical habitat, it must undertake formal consultation with the Service (FWS and NMFS 1999).

The product of the consultation process is generally a biological opinion issued by the Service indicating whether or not the action is likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat (a "jeopardy" opinion), or is not likely to result in such effects (a "no jeopardy" opinion). A "jeopardy" biological opinion must include reasonable and prudent alternatives, if any, that would alter the action to avoid the likelihood of jeopardizing a listed species or resulting in the destruction or adverse modification of critical habitat (FWS and NMFS 1999).

Section 9 of the ESA broadly prohibits the taking of any listed species of fish or wildlife by "any person" (U.S. Congress 1973). The statutory prohibition applies only to endangered species, but has been extended to threatened species by regulation. Both federal and nonfederal (i.e. private and state) actions are within the statutory prohibition. The statute defines "take" as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." The Supreme Court's *Sweet Home* decision upheld the Fish and Wildlife Service's regulatory interpretation of Section 9 to apply the take prohibition to significant habitat modification activities on nonfederal land (*Babbitt v. Sweet Home*, 1995).

The Service may issue a permit under ESA Section 10(a) to authorize the "incidental take" of protected species. An incidental taking is one that is "incidental to, and not the purpose of; the carrying out of an otherwise lawful activity" (U.S. Congress 1973). Similarly, for activities subject to the federal consultation requirement of Section 7, the biological opinion may include an incidental take statement authorizing such incidental take where it will not jeopardize the species' continued existence (FWS and NMFS 1999). The statement must include reasonable and prudent measures that the Service deems necessary or appropriate to minimize the impact of any incidental take on the species.

Two provisions of the Endangered Species Act are of special interest for the Act's developing application to habitat and ecosystem conservation purposes. First, Section 2(b) provides that one purpose of the Act is to "provide a means whereby the ecosystems upon which listed species depend may be conserved" (U.S. Congress 1973). The Supreme Court noted in *Sweet Home* that this ecosystem conservation purpose is one of the "central purposes" of the ESA. Second, Section 7(a)(1) directs all federal agencies to use their authorities to further the purposes of the ESA by carrying out programs for the conservation of listed species. Although conserving the ecosystems upon which endangered species depend is one of the identified purposes of the ESA, there is no specific ESA program to implement this purpose (Natl. Rsch. Coun. 1995). The critical habitat provisions of the ESA are not coterminous with an ecosystem conservation approach because critical habitat often is not designated for listed species. Also, the critical habitat designation and protections focus only on the essential elements of the habitat for the listed species and not all of the ecosystem functions of that habitat.

Critical Habitat Designation for Snake River Chinook Salmon

Under ESA Section 4, the designation of critical habitat is to be done at the time of species listing "to the maximum extent prudent and determinable." Critical habitat is defined under the ESA to include "specific areas within the geographical area occupied by the species, at the time it is listed," which includes those physical of biological features essential to the conservation of the species and which may require special management considerations. Critical habitat may include specific areas outside the geographical area occupied by the species at the time of listing only if the Service determines that such areas are essential for the conservation of the species. Critical habitat includes "only the minimum amount of habitat needed to avoid short-term jeopardy or habitat in need of immediate intervention" (*Northern Spotted Owl v. Hodel*

1991). Under the ESA, critical habitat must be specifically identified in a rulemaking notice issued by the FWS or NMFS in the Federal Register.

ESA Section 4 also provides specific petition procedures whereby any person may petition the Service to list a species, designate critical habitat, delete a species or critical habitat, revise a critical habitat boundary, or adopt or modify a special rule for a threatened species (U.S Congress 1973). When such petitions are submitted, the Service is required to acknowledge receipt of the petition within 30 days. Within 90 days after receipt of the petition, the Service must make a finding as to whether the petition presents "substantial scientific or commercial information indicating that the petition action may be warranted." If the Service issues a positive 90-day finding on a critical habitat revision petition, then within 12 months of receipt of that petition the Service must determine how it intends to proceed with the requested revision, i.e. whether it will propose to revise the critical habitat designation as requested in the petition or whether it will not take the requested action.

On December 28, 1993, NMFS designated critical habitat for listed Snake River spring/summer chinook salmon (NMFS 1993). NMFS did not designate specific stream reaches as critical habitat, but only identified the general geographic extent of the larger rivers, lakes, and streams within hydrologic units that may contain critical habitat. The textual designation excluded those areas that were not presently or historically accessible to listed salmon and reaches above impassable natural falls. NMFS acknowledged that it lacked adequate information to make an accurate and detailed characterization of stream reaches in the region that met the statutory and regulatory criteria for critical habitat.

In 1993, NMFS made no specific rulemaking findings supporting Napias Creek's treatment as critical habitat. NMFS did not assess whether Napias Falls was an "impassable natural falls," it made no determination of whether the area was presently or historically accessible to listed salmon, and it did not determine whether this stream reach was "essential for the conservation of the species" (U.S. Congress 1973; FWS and NMFS 1999). The available evidence showed that upper Napias Creek has not been occupied by listed salmon for more than a century, that salmon do not presently occur and did not at the time of species listings occur in this area, and that upper Napias Creek has historically been and is presently impassable to Snake River chinook salmon.

On January 3, 1997, Meridian filed a petition with NMFS to revise the critical habitat designation to indicate that the designated habitat excluded the upper reaches of Napias Creek above Napias Falls. On April 28, 1997, NMFS determined that Meridian's petition presented substantial scientific information indicating that the petitioned revision might be warranted. However, on January 30, 1998, NMFS published its Twelve-Month Finding indicating that Meridian's petitioned revision was not warranted. NMFS' determination overlooked key scientific information such as the effect of gravity on leaping chinook or on fish swimming in highly aerated water, the multidimensional nature of fish passage issues, launch pool conditions below Napias Creek Falls, and the horizontal distance a migrating chinook would have to leap to ascend the falls. Thus, on May 29, 1998, Meridian petitioned NMFS to reconsider its Twelve-Month Finding. Meridian's Petition for Reconsideration demonstrated NMFS' failure to adequately consider or apply the best scientific information presented to the agency. On June 2, 1999, NMFS published in the Federal Register its notice of a proposed rule to revise the critical habitat for Snake River spring/ summer chinook salmon to exclude areas above Napias Creek Falls (i.e. including upper Napias Creek) from designated critical habitat because such areas are outside the species' current and historic range.

In its final rule published October 25, 1999, NMFS determined that Napias Creek Falls constitutes a naturally impassable barrier for Snake River spring/ summer chinook salmon (NMFS 1999). Therefore, NMFS excluded areas above Napias Creek Falls from the designated critical habitat for that species. NMFS stated that the critical habitat protection measures contained in a March 1999 Biological Opinion for the gold mine project were no longer applicable. NMFS also acknowledged that its decision would lessen the mine's economic burden resulting from measures contained in the Biological Opinion.

SITE DESCRIPTION AND DESCRIPTION OF THE ISSUE

The Beartrack Mine Project is a fully permitted gold mine and processing facility in the Salmon-Challis National Forest in east central Idaho (Figure 1). The Beartrack Project is located on fee lands and on national forest land mining claims near the historic mining town of Leesburg, Idaho. The mine is situated in the Napias Creek drainage (also called the Leesburg Basin) which is located in the Panther Creek watershed, approximately 7.5 miles upstream from the confluence of Napias and Panther creeks within the Salmon River drainage (Figure 2).

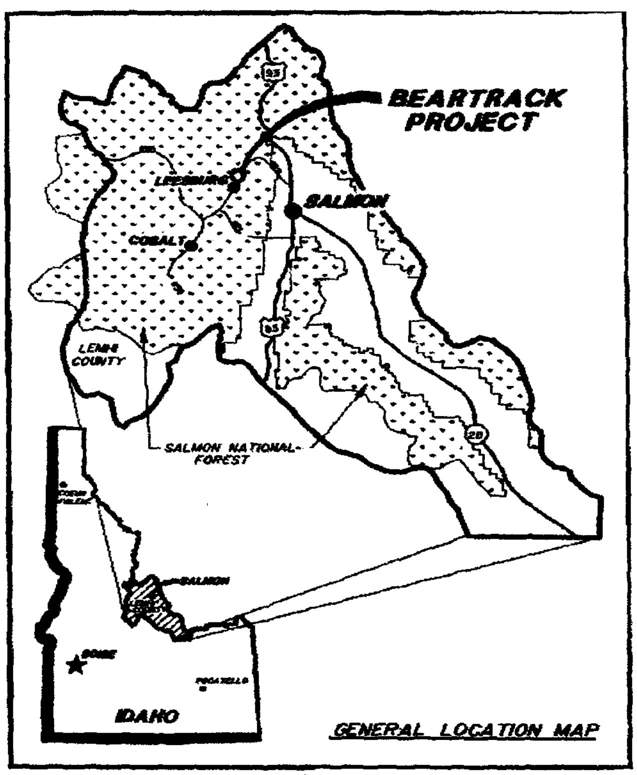

Figure 1

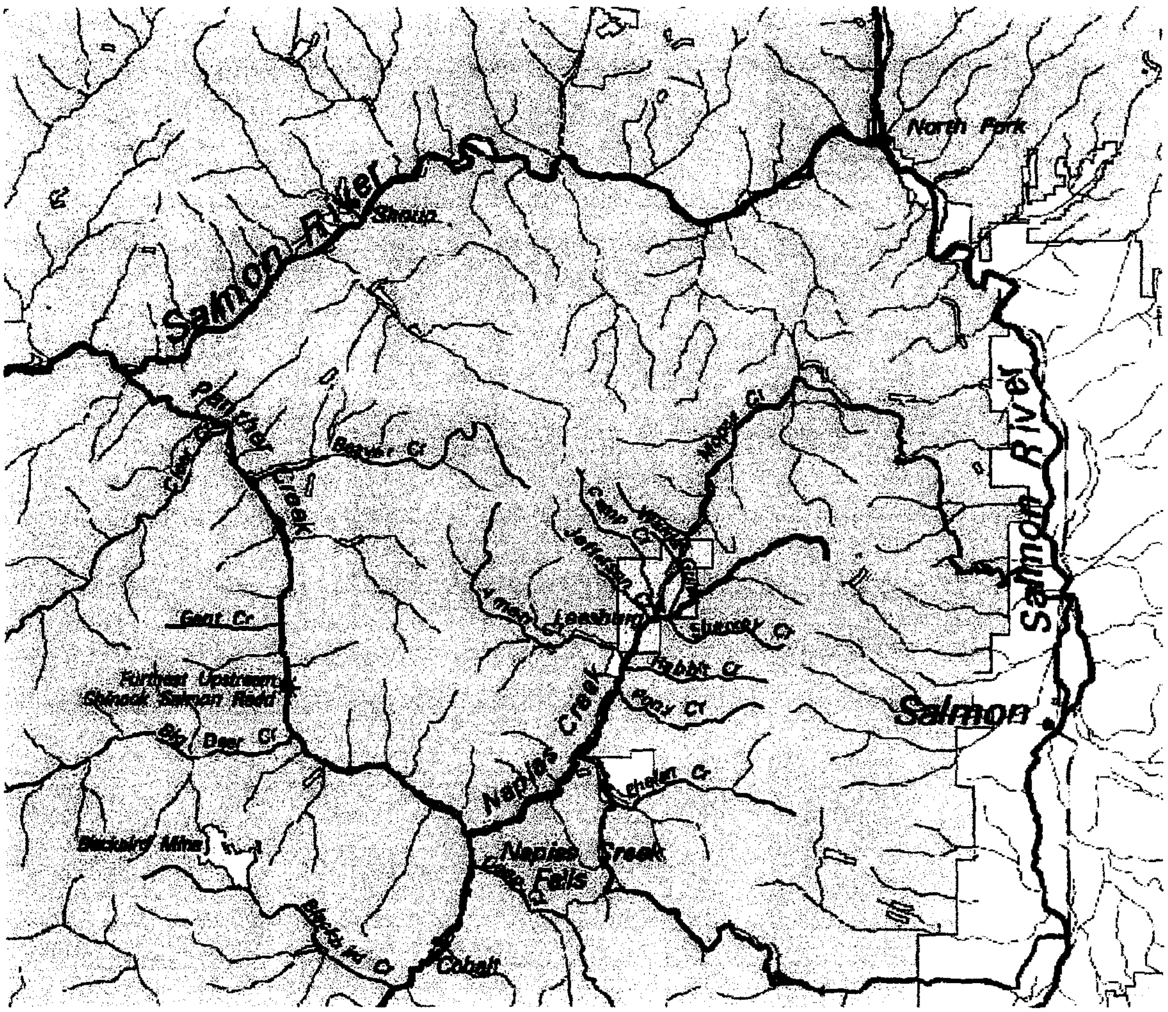

Figure 2 - Detailed Map of Napias Creek Drainage

Tributaries of Napias Creek arise at elevations of nearly 8,500 feet in the Salmon River Mountains about 12 miles due west of the town of Salmon, Idaho. Those tributaries flow into Napias Creek and ultimately into Panther Creek at an elevation of less than 6,000 feet. There are at least a dozen tributaries to Napias Creek that affect flow along the reach of the stream between the mine and the falls (Figure 2). The stream typically receives flow from these tributaries perennially, but the flows follow seasonal trends in the hydrograph which peaks in late June to mid-July. The geographical area key to this issue can be considered in two parts. One is the upper part of the watershed where the mine is located, and the other the reach below a critical set of cascades or falls. The reach of Napias Creek upstream from Napias Falls and upon which the mine is located, is referred to hereafter as "upper Napias Creek," the area it encompasses is 7 miles above the Napias Falls.

The lowest 3 miles of Napias Creek flows through a steep gradient of about 7.3% through an incised canyon. The canyon itself has gradients >10% in some portions; this is also where a series of steep cascades naturally occur (Chapman 1997). The cascades and falls are located in the last 2 miles of the Napias Creek drainage. The area critical to the passage evaluation (the cascades or falls) is especially steep and carries a gradient of 21% for about 575 feet. At numerous points in this steep section of Napias Creek there are falls in excess of 10 feet (Figure 3).

Figure 3 - Upper Napias Creek Falls

The cascades not only represent the steepest reach of the stream, but the area is littered with large boulders. Many of these boulders are in excess of 10 feet in diameter and were placed in the stream channel during a massive natural landslide flood event that happened over 200 years ago (Mussetter Engineering 1995). The boulders are naturally occurring and essentially create the cascade affect in the stream – without the boulders the falls may be more dramatic.

During high flow periods (May-July) Napias Creek may flow in excess of 200 cfs (cubic feet per second) at the mouth and at low flows (August-April) the stream may only reach a flow of 10-20 cfs. Both extremes in the hydrograph were evaluated by fisheries scientists retained by Meridian. These flows were found to be too high or too low to allow either chinook salmon or steelhead (both anadromous species) to pass Napias Falls and hence access potential habitat above the falls. Flows were identified to be potentially optimal by the NMFS during the descending leg of the hydrograph, which was typically found to be in July.

The project has undergone consultation under ESA Section 7 twice since 1994. In 1993 and 1994, NMFS and the U.S. Forest Service conducted a formal consultation on the (at that time) proposed mine. This consultation produced a biological opinion which concluded that the proposed mine: (1) would not adversely modify or destroy designated critical habitat for the listed Snake River spring/summer chinook salmon or otherwise jeopardize the species, and (2) would not result in any measurable level of "take" if operated under the terms and conditions specified in the mine permits and the opinion.

A 1994 federal district court decision remanded the initial biological opinion for further evaluation and explanation concerning its findings. In remanding the opinion, the court anticipated that this further review and discussion would not require a substantial effort. Instead, NMFS and the action agencies (U.S. Forest Service, Environmental Protection Agency, and Army Corp of Engineers) spent over two and one-half years in consultation, an effort which resulted in a broad-ranging re-visitation of potential mine impacts to listed species and designated critical habitat. Therein lies the crux of the situation from the perspective of the operator. Due to the over-riding authority of the ESA, all federal and many state controlled actions can be delayed due to the increased level of bureaucratic review required by the federal agency charged with the recovery of the listed species.

During the period the agencies were in consultation, the operation was required to submit annual work plans subject to Section 7(d) of the ESA. This requirement essentially became a permit to operate within the standard Forest Service-issued operating permit. All phases of the operation required review by the USFS and the NMFS prior to changes in the annual Section 7(d) work plan, even if they were previously anticipated in the Plan of Operations. Furthermore, no changes to the Plan of Operations or other operating permits (e.g. National Pollutant Discharge Elimination System Clean Water Act permit) would be considered until the Section 7 consultation process was complete.

The issue became more confounded when the revised Biological Opinion (BO) was finalized in 1999. The revised BO presented a drastic reversal by NMFS of its initial assessment of the impacts of mine operations. Instead of a "no adverse modification, no measurable level of take" conclusion regarding impacts to the Snake River spring/summer chinook salmon, NMFS found that the continued operation under current permit conditions of the mine would jeopardize the Snake River spring/summer chinook salmon, would adversely modify or destroy designated critical habitat for listed salmon, and would jeopardize the Snake River steelhead, another anadromous species that had subsequently been listed as threatened under the ESA.

NMFS' biological opinion contained a proposed reasonable and prudent alternative for the operation of the mine. The operator strongly disagreed with NMFS' conclusions regarding the level of impacts that the mine would have on listed species and designated critical habitat. In the course of the petition proceedings described here, the operator demonstrated that NMFS should not have treated upper Napias Creek as accessible to listed salmon and therefore the area was not properly designated as critical habitat.

ANALYSIS OF THE PROBLEM

Establishing the absence of ESA-listed anadromous fish from the Napias Creek Basin during the time of listing under the ESA was not an issue. Anadromous fish had not utilized the upper portions of Panther Creek since the 1960s due to water quality impacts from the former Blackbird Mine, located on Panther Creek tributaries upstream of Napias Creek (Riser 1986). Despite the lack of the presence of the listed species in the Panther Creek basin at the time of listing under the ESA, in the 1994 BO for the mine, the NMFS assumed that the habitat on Napias Creek should be treated as critical habitat for Snake River spring/ summer chinook salmon. The Beartrack Mine operator was then faced with the choice of: (a) living with the conditions of the BO and the increased level of operating scrutiny (bureaucratic delays) and added unnecessary environmental costs, or (b) proving that fish had not used the habitat above Napias Falls and that without significant changes to the physical nature of the creek, the salmon would not be able to access upper Napias Creek as habitat (i.e. that Napias Creek was neither "presently or historically accessible" to the listed species within terms of the agency's 1993 critical habitat designation).

Historical Analysis

Over the course of nearly four years the operator contracted with four different cultural resource firms to investigate the available historical data base regarding the presence or absence of anadromous fishes in upper Napias Creek or the Leesburg basin. The investigation involved literature searches in local, state, and regional libraries, including information located in the state Fish and Game library in Boise, Idaho, as well as the library at the University of Idaho in Moscow, Idaho, and personal libraries of consulting experts on Idaho fisheries.

One part of this study used interviews with 24 different people that had specific knowledge of local history. Of particular interest were individuals with knowledge of anadromous fish in the Leesburg Basin prior to influences from World War II-era mining impacts to Panther Creek or major dams being built on the Columbia and Snake rivers. This ethnographic research was critical for two reasons: (a) it provided a consistent verbal history with people who were linked to a time when the only variable to access to upper Napias Creek was the falls at the lower end of the reach, and (b) the federal agencies did not regard the absence of information in literature (none of the historical researchers found information that positively identified salmon in the Leesburg Basin) as conclusive evidence of the historical absence of the listed species in a particular region or designated zone of critical habitat. However, the direct experience of people who lived in the area during key times was considered valuable information.

In the final analysis, after numerous literature reviews and the ethnographic research, each historian concluded that either there was not any historical evidence of anadromous fish presence in upper Napias Creek, or if the fish were ever present (which was never found) that they were present in such small quantities that the habitat was not critical to the conservation of the species as required by the ESA.

Geomorphological Analysis

Initially the NMFS asserted that Napias Creek Falls were impacted by rocks disturbed from historic road building. This was significant because the NMFS' 1993 critical habitat rule provided that impassable falls must be natural and not man-made to comprise a migration barrier precluding upstream critical habitat designation. Consequently, the operator of the Beartrack Mine initiated a study to ascertain the origin of the falls and determine the factors associated with their genesis.

A series of field investigations by an independent geomorphologist (Mussetter 1995) involving geologic reconnaissance, immediate stream profile analysis, analysis of existing vegetative indicators (tree ages and lichen location and sizes), measurement of boulders, and an entire drainage profile analysis, concluded that:

1) the vertical elevation difference between the top and bottom of Napias Falls was due to the presence of a Pleistocene-age fault that occurred at the head of the falls,

2) the large boulders (6-10 feet in diameter) that formed the stepped longitudinal profile through the falls were primarily emplaced by a dam break flood caused by the failure of a natural landslide dam located about 2.5 miles upstream of the falls, over 200 years ago. The timing of the flood was determined by the presence of some old growth Douglas-fir trees alongside the creek. The magnitude of the flood was estimated to be 22,000 cfs which exceeded the 500 year flood event by a factor of 14 (Figure 4); and

3) Road construction in the 1880s did not affect the form of the channel within the falls and the falls are a natural feature of the landscape.

Schematic Longitudinal Section of Naplas Creek Falls Reach

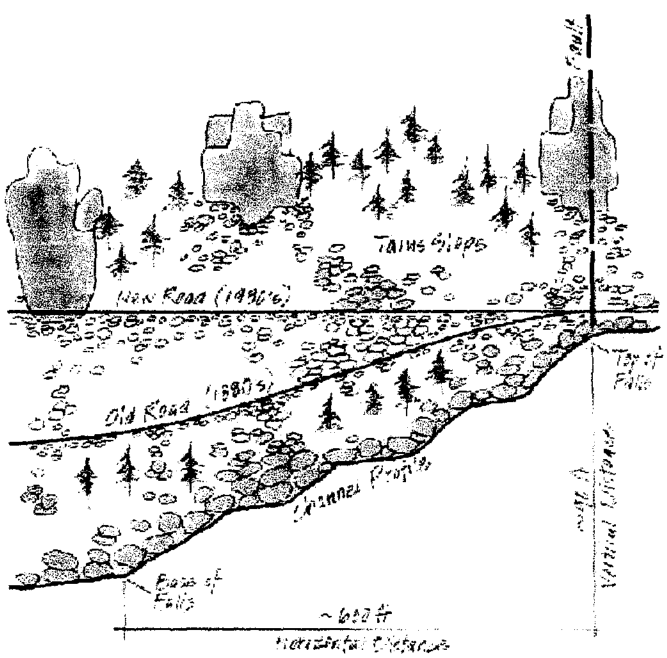

Figure 4

Engineering Analysis

Two different engineering evaluations were conducted on the falls. An initial evaluation was conducted in fall 1995 during a migration period but at low flow. This evaluation was critical to the investigation because it provided a surveyed inventory of the key falls and the boulders that impacted the ability of a migrating fish to ascend the 21% grade in Napias Falls.

The second evaluation was essential to the final argument because it developed the topographic basis to determine the hydrodynamic conditions within key segments of the falls. Survey and stream discharge measurements were made at three separate discharge rates in June (143 cfs), July (49 cfs) and August (21 cfs) 1997.

Topographic surveys were conducted using a Total Station theodolite. At the highest discharge, water surface elevations and channel bed elevations were determined by suspending a member of the survey crew above the stream in the falls with a mobile crane. A contour map was generated from over 1000 different spot elevation shots from the Total Station. Superimposition of the measured water elevations at three different survey times over the base topography enabled water depths to be established at high, medium and low flows. The survey team also tried to determine the flow rate of water over the falls in key potential fish passage locations but was unable to do so due to the extreme turbulence of the water and air entrainment in the water as it passed over the falls. Consequently, flow velocities over the large boulders that made up the falls were calculated using a pipe-flow computation. The topographic and hydraulic computations were used to provide information on the physical components of the falls for a detailed evaluation of the potential for fish to pass the falls.

Once the physical nature of the falls was assimilated into an electronic format, experts in the field of fish passage over obstacles could evaluate the potential for the listed species to negotiate and ultimately pass Napias Falls. However, in order to fully understand the magnitude of this issue it was critical to understand the biology of the anadromous fish moving in the Salmon River system prior to spawning.

Evaluation of Fish Passage

An adult salmon born in the Upper Salmon River drainage usually spends two to three years at sea, rearing in the last year in the Gulf of Alaska. There they feed in the rich waters of the North Pacific until they begin the long return to natal streams. In the spring they migrate in their last year of life to the mouth of the Columbia River; there they initiate their journey to the streams where they were born. To reach the Salmon River and its many tributaries, the salmon must ascend eight major dams on the mainstem Columbia and Snake rivers, each of which is nearly 100 feet in height. The 8-12 week trip carries the fish over 700 miles and up to 7000 feet in elevation gain (Chapman 1998) (Figure 5).

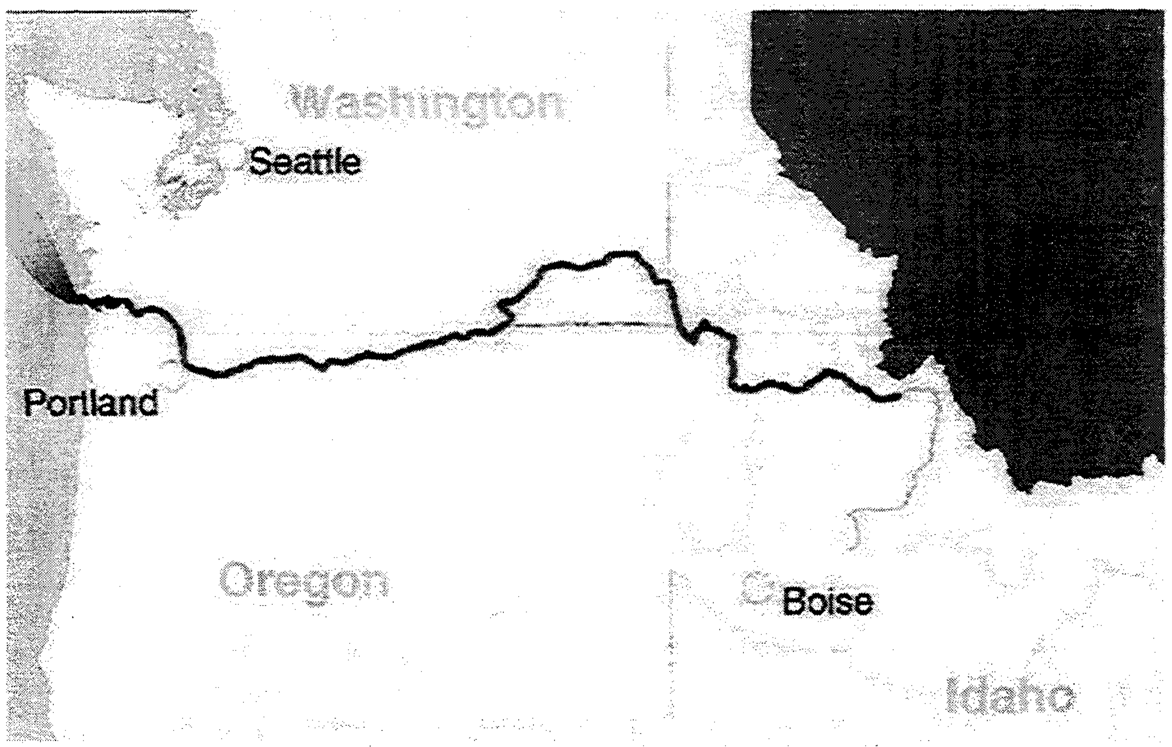

Figure 5 - Migration Path of Chinook Salmon from the Columbia River to Panther Creek

The evaluation of a particular salmon species' ability to utilize the potential habitat in upper Napias Creek required an analysis of the ability of the fish to ascend a series of falls and cascades. The analysis required knowledge of the physical ability of the fish to surmount the falls compared to the hydrologic conditions in the stream at an optimal time for passage.

When the salmon leave the ocean, the fish are essentially on their final journey; they will never return to the ocean nor will they eat again. Therefore, the energy reserves that the fish has at the time it enters the freshwater stream are all that it will have to make it to its spawning grounds in the upper elevation streams. Chapman (1998) reported that the fish use 70% of their reserves to reach their spawning grounds and 20%+ to spawn.

Once the fish arrive in the upper tributary streams they are 4-8 weeks from completion of their life cycle, consequently they are in a much-diminished physical condition and much less able to negotiate obstacles such as 10-foot falls and turbulent waters

In the analyses of the problem, the fisheries biologists and passage engineers factored in the relative condition of the salmon when they may reach their final destination. Conservatively, the biologists used a condition index of 0.75 or that the fish were at 75% of peak condition. These comparisons are not linear -- for instance the maximum vertical distance a chinook salmon could leap is about 50% less for the condition index of 0.75 than for a prime fish with an index of 1.0 (at a launch angle of 60 degrees). A condition index of 0.50 would correspond with a leap height about one-fourth that at a condition index of 1.00. The use of a condition index of 0.75 was quite a conservative estimate.

However, given differences in water years (flow rates and times of various flows) and differences in individual fish, the condition index of 0.75 seemed to be acceptable to even the most conservative agency reviewer of the submitted petition information.

The ability of salmon to leap at falls is the subject of numerous studies. Research has shown that the degree to which salmon can successfully leap over obstacles depends upon species, fish condition, conditions in the launch pool below the jump, height of the barrier, horizontal distance from launch pool to the top of the jump, and conditions within the falling water (depth, concentration of air in the water, the angle of flow over the barrier, and the velocity of the water going over the jump or falls). To fully assess the ability of the fish to successfully negotiate a series of cascades or even a single jump, the physical configuration of the various obstacles must be evaluated in three views: upstream-downstream vertical profile, from above in plan view, and in cross-section (across the stream).

Launch locations at falls often are not directly beneath the obstacle, but less optimum, lying some distance to the side or downstream. The launch location depends upon cues (stimuli) offered by the falling water jet and by conditions at the toe of the falls and within the launch pool (i.e. the physical configuration of the obstacles) (Powers and Orsborn 1985). Following the physical analysis of the falls, the trajectories of fish leaps must be analyzed. The trajectories depend upon the speed of the fish at the start of the leap (burst speed, governed by fish condition), angle of launch (critical if there is a difference between a falls and a series of cascades), and the flow conditions in the pool into which the waterfall plunges.

Through trigonometry and physics, the horizontal velocity of the leaping fish can determined. For instance, a lower launch angle lowers the maximum leap height at the trajectory apex of any particular leaping fish. All of these factors were critical in the evaluation of the ability of the ESA-listed salmon to reach habitat critical to its recovery. Armed with information regarding the biology of the listed fish and the specific conditions of the topography and stream hydraulics, the engineers and fisheries biologists developed a series of models that depicted the typical salmon attempting to ascend Napias Falls.

Following a detailed evaluation of a model that incorporated these factors pertinent to the ability of salmon to reach upper Napias Creek, the scientists and engineers determined that it was not possible for fish to ascend Napias Falls to reach the habitat that had been labeled "critical to the conservation of the species" by NMFS. While the evidence was overwhelming against the treatment of this area as critical habitat, the federal agencies moved slowly to change the formal designation of the area. It finally was concluded that the area above Napias Falls was not critical habitat because:

1. Even if salmon could pass over the falls (which was proven essentially impossible), the fish could only do so at a very specific flow that may not occur at the same time each year. That flow corresponded to the descending leg of the hydrograph.

2. The condition of the salmon or steelhead at the time of the jump would be quite diminished at Napias Falls (i.e. condition factor < 0.75).

3. The launch pool below the falls was not large enough.

4. The last falls in the cascade of falls, which appeared to present the most formidable barrier to fish passage, was the only one specifically evaluated in detail and it was too high for the fish to jump, regardless of water conditions.

5. The angle at which the water contacted the potential launch area was not conducive to fish ascending the falls by swimming.

6. There was too much air in the water for the fish to swim (i.e. the water was too turbulent and too fast).

7. The velocity of the water was too extreme except at low flows, when there was not enough water to support the fish swimming through the falls.

8. Obstacles in the way of the jump hampered access to the falls.

9. The landing site at the top of the potential jump did not have a pool to allow fish a resting spot prior to proceeding past Napias Falls.

CONCLUSIONS

As the Napias Creek critical habitat situation described here illustrates, the ESA Section 4 petition process can be an effective method for bringing detailed scientific information before the ESA-implementing agencies to revise the critical habitat designation and resulting ESA critical habitat regulation for a particular area. However, a project operator or activity proponent should not underestimate the depth of technical and scientific data that will be required to alter the agency's preconceived position as to the critical habitat status or need for special management restrictions in a particular area, even with the documented absence of ESA-listed species from the area.

In addition to the ESA Section 4 petition processes, it may also be helpful to identify additional access or pressure points for the regulatory decision making process. For instance, litigation efforts to reinforce the ESA Section 4 petition request may be necessary or helpful, as can be support from congressional representatives or other political or policy interests.

In addressing ESA regulatory and critical habitat issues such as the Napias Creek situation, one needs to be conscious of the potential hurdles posed by undefined agency objectives and hidden standards. For instance, in the case of Napias Creek, NMFS' original critical habitat rule defined critical habitat as those stream reaches "presently or historically accessible" to Snake River chinook salmon (NMFS 1993). However, neither the agency nor the rule provided a framework or method for evaluating or applying this standard to a particular stream reach or migration barrier. Thus, this situation presented a "learn as you go" scenario.

The use of undefined agency objective can discourage effective or creative input from regulated or interested parties where those parties do not know what the true standard is that is being applied. While such an agency approach is counter to the "notice and comment" rulemaking requirements under the ESA (U.S. Congress 1973), as a practical matter it does occur and needs to be considered in specific critical habitat or other ESA decision making contexts such as the Napias Creek situation.

Ultimately in the Napias Creek situation, the scientific data and the logical conclusions based on that data prevailed. The agency revised the critical habitat designation for the area to remove upper Napias Creek from treatment as critical habitat for ESA-listed Snake River spring/summer chinook salmon (NMFS 1999). NMFS also determined in subsequent rulemaking that upper Napias Creek was not critical habitat for ESA-listed Columbia River Basin steelhead.

In revising the critical habitat designation in October 1999, NMFS indicated that certain conditions previously imposed through the Beartrack Mine Biological Opinion related to critical habitat in upper Napias Creek would no longer be applicable. NMFS noted that this critical habitat revision would lessen the economic burden on the mine operator from those measures previously contained in the mine's revised Biological Opinion.

The resolution of this situation for Napias Creek demonstrates how the appropriate use of the ESA Section 4 petition process and the technical and scientific information brought to bear on the problem can result in cost savings and more flexible and efficient management options for all parties concerned, while at the same time ensuring that the continued biodiversity benefits and goals of the ESA are not compromised.

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THE MARSHALL PIT—MINED LAND RECLAMATION, PREBLE'S MOUSE HABITAT, AND WETLANDS CREATION

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ABSTRACT

Many sand and gravel sites in Colorado are uniquely suited to the creation of wildlife habitat in general and wetlands in particular through innovative mined land reclamation practices. A sand and gravel mine located in the floodplain of South Boulder Creek was successfully reclaimed as a viable self-sustaining wetland complex. Known as the Marshall Pit, today this reclaimed site supports diverse wetland flora and fauna, including Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*), which was recently listed as a threatened species under the Endangered Species Act.

INTRODUCTION

The purpose of this paper is to describe, in general details, the Marshall sand and gravel pit and the development of the site for the purpose of creating wetlands. The paper will briefly describe the site, its history and the development of the site for wetlands and Preble's Meadow Jumping Mouse habitat.

Through the reclamation of mined sand and gravel sites, aggregate producers have a unique opportunity to create viable wetlands ecosystems on large tracts of land, ultimately developing wetlands that serve a variety of functions including habitat for threatened and endangered plants and animals.

SITE DESCRIPTION

The Marshall Pit is located in the West 1/2 of the East 1/2 section 16, township one south, range 70 west of the sixth principal meridian in Boulder County, Colorado. It is a triangular parcel bounded by South Boulder Creek to the east and southeast, City of Boulder open space to the west and the "Deepe Farm" sand and gravel pit operated by Western Mobil, Inc. to the north.

The 21.5 acre site lies in the floodplain of South Boulder Creek. The adjacent properties are currently used for farming, livestock grazing and sand and gravel mining. The majority of the adjacent acreage is owned by the City of Boulder as open space. Low density residential housing exists to the southeast. The settlement of Marshall is located approximately 1/2 mile south of the site.

Historical data indicate that the Marshall Pit was homesteaded before the turn of the century and has been used for ranch and farmland until mining began in about 1965. Aerial photographs of the site were reviewed in order to identify historic land use patterns and to confirm that the site contained no wetlands prior to the beginning of mining in 1965 and 1990.

Records indicate that Horn Construction began open pit sand and gravel mining on the 21.5 acre Marshall Pit in about 1965. However, mining operations ceased shortly thereafter and the site remained unmined until 1990. In 1972 the Marshall Pit was acquired by the present owners, Loveland Ready Mix Concrete, Inc. In 1989 Loveland Ready Mix received special use approval from the Board of County Commissioners of Boulder for an open pit sand and gravel mine at the Marshall Pit. Loveland Ready Mix was also granted a mining and reclamation permit by the Colorado Mined Land Reclamation Board in 1989. Mining at the Marshall Pit began in 1990 and was completed in 1991, at which time reclamation of the pit began and was completed in 1995.

MINING PROCESS

The alluvial valley of South Boulder Creek contains extensive sand and gravel deposits. These deposits range from a few feet in thickness up to 20 feet in some areas. Underlying the sand and gravel deposits is the Pierre Shale formation, which is several thousand feet thick. The sand and gravel of the Marshall pit averages approximately 8 feet in thickness. The most recent gravel mining at the Marshall pit began in 1990 and was completed in 1991.

Mining at the Marshall pit began with the excavation of a dewatering trench around the perimeter of the pit. Following excavation of the dewatering trench the ground water captured in the trench was pumped from the site in order to dry out the gravel deposit to be mined. Once dried, the sand and gravel was excavated down to bedrock using front end loaders. The excavated gravel was then transported by conveyor from the mine site to the sand and gravel plant for processing.

Following the removal of the sand and gravel, the excavated pit was then divided into four settling ponds that were used to dispose of wash fines from the sand and gravel processing plant.

RECLAMATION CONCEPTS

The reclamation plan for the Marshall Pit involved the creation of a series of four settling ponds that were used to settle out fines from the nearby sand and gravel processing plant. The settling ponds act to decant the gravel wash water by settling out fine particles. These particles are typically less then 74 microns or 200 mesh in size. Wash water from the processing plant was pumped to the first of four settling ponds where it then flowed via culverts from one pond to the next, eventually depositing the majority of the wash water fines in the various settling ponds. After filling, the area around each pond and the dike that separates one pond from the next was graded and seeded and the surface revegetated. The last of the four settling ponds was filled in 1995.

After the ponds were filled to the desired elevation, the wash fines continued to settle over time, thereby producing a unique landscape with subtle variations in surface elevations. For the purpose of creating wetlands, these surface variations serve to establish zones of saturation that support diverse wetlands vegetation.

HYDROLOGY

There are two primary sources of water for the Marshall Pit: ground water and surface water. The Marshall Pit is located in the floodplain of South Boulder Creek, which contains ground water saturated alluvial sand and gravel found throughout the stream corridor. The elevation of the ground water fluctuates with the hydrologic cycle as evidenced by the fact that several years of ground water monitoring, adjacent to the Marshall Pit, indicated a depth to ground water ranged from one to four feet. Because the ground water is close to the surface, filled settling ponds may have open water surface areas and/or saturated soils at or near the surface.

In addition to ground water hydrology, the Marshall Pit also benefits from the availability of surface water from the irrigation of pasture land west of the pit. Flood irrigation practices supplement the prevailing hydrologic conditions by providing irrigation surface runoff to the site.

In order to establish hydrologic conditions capable of supporting diverse wetland plant species surface water control structures have been installed between each wetland basin. These passive devices were designed to maintain basin water elevations sufficient to establish various zones of saturation in each wetland basin.

Because the fall of the land is from south to north, the wetland basins are stair-stepped, which allows for the movement of water from one basin to the next. As the water level in any one basin rises to the design elevation for that basin, water overtops the batter boards and flows by culvert to the next pond where the process is repeated.

Once the desired hydrologic conditions have been established, the outfall elevation of each diversion structure will be permanently secured to prevent the water surface in each basin from being altered. This self-sustaining hydrologic regime will rely on natural ground water fluctuations associated with the alluvium of South Boulder Creek and the surface water that drains onto the site from lands to the west.

CREATED WETLANDS

Experience has shown that the wash fines deposited in the settling ponds provide an excellent growing medium for wetlands vegetation. The combination of excellent hydrologic conditions and growing medium in the form of wash fines resulted in extensive volunteer wetlands vegetation. The design and construction of the Marshall Wetlands was guided by several important factors including:

1. The ability to selectively fill each pond with wash fines to various desired elevations;

2. The hydroscopic nature of the wash fines;

3. The ability to establish various zones of saturation in each basin, and

4. The ability to fully utilize the existing hydrologic conditions.

The basic goal of the Marshall Wetlands was to create a diverse hydrologic regime capable of supporting diverse wetland plant communities.

WETLAND FUNCTIONS

To date, the results of the vegetation monitoring have shown that the dominant species in the wetlands areas are primarily wetland species that contribute to the development of hydrophytic vegetation. The abundance of these species indicates that the hydrological conditions necessary for wetland development are present at the site. In addition to the development of wetland structure, observations suggest that varieties of wetland functions are also present within the created wetland areas.

The wetland functions described below have developed over the past eight years and will continue to develop as the wetlands become more mature. Of the eight functions described below, the wetlands have the greatest potential to continue to develop as wildlife habitat, habitat for threatened species, and to provide passive recreation and scientific study opportunities.

Wildlife Habitat

The wetland areas provide a variety of different habitat types that support a diverse assemblage of wildlife species. The open water areas provide resting areas for resident and migratory waterfowl as well as providing suitable conditions for fish, amphibians, and aquatic reptile species. The shallow water provides hunting areas for large shorebirds, like Great Blue Herons. The meadow and mud flat areas provide habitats for small mammals and smaller shorebirds, and the cattail marshes provide nesting sites for Red-winged Blackbirds. Willow shrubland areas provide nesting sites for a variety of songbird species and provide shelter sites for white-tailed deer. Although there is currently much more open water habitat in the Boulder Valley than existed prior to settlement, there is only a limited amount of open water habitat in the vicinity of the Marshall wetland site. The open water and the wetland types associated with the settling basins provide important habitat features that complement the riparian vegetation associated with the adjacent floodplain areas along South Boulder Creek. The mud flats in Pond 3 represent a habitat type that is restricted in areal extent in the Boulder Valley. In pre-settlement times, this habitat type would have been present along streams following flood events. Otherwise, the type was absent. Summer resident birds such as Killdeer and American Avocets utilize this habitat throughout the summer. Other shorebirds may use this site only during migration, when it serves as an important resting-feeding area.

Groundwater Recharge

Water from irrigation return flows, precipitation, and irrigation diversions flow into the wetland areas. Some of this water evaporates, some is consumed by vegetation, some flows through the wetland areas, and some recharges the alluvial aquifer along South Boulder Creek.

Retention Basin

Although the wetland areas were not designed as retention basins, their location and configuration are such that under flood conditions along South Boulder Creek, the wetland basins would serve to retain flood water, which could be slowly discharged from the downstream outlet in Pond 4.

Nutrient Removal

This wetland function is occurring to a limited extent in the Marshall wetlands. Water from irrigation return flows and diversions from irrigation ditches often contains increased concentrations of nutrients. As the water flows through the wetland areas, some of these nutrients are being removed as a result of the growth of vegetation.

Recreation

Although the Marshall wetlands occur on private land, opportunities for passive recreation are excellent because of the proximity of adjoining public open space lands. From the open space trails, it is possible to view wildlife on the open ponds and mud flat areas.

Scientific Study

Currently, the only scientific studies that are being conducted on the site consist of wetland vegetation monitoring studies. Several public elementary and high schools are near the site, and the University of Colorado main campus is within several miles. These institutions could make use of the site for a variety of wetland studies.

Habitat for Threatened or Endangered Species

Two federally listed threatened species occur in the Boulder Valley. Ute Ladies Tresses Orchid *(Spiranthes diluvialis)* occurs within one mile of the Marshall wetlands, and Preble's Meadow Jumping Mouse has recently been observed on the site. Both of these species are dependent on wetland conditions as essential habitat components.

Visual Qualities

In addition to providing habitat for a variety of species, the overall appearance of the wetlands is aesthetically pleasing. The combination of open water, marshes, and shrublands creates a pleasant mosaic, which provides diverse photographic opportunities.

SUMMARY

- The wetlands created at the Marshall site support a wide variety of plant species, most of which are either obligate wetland, facultative wetland, or facultative species. Hydrophytic vegetation dominates most of the wetland areas in each of the four ponds.

- Cover data collected since 1996 suggest that the overall cover by hydrophytic species is increasing and the cover of less desirable species, such as birdsfoot trefoil is decreasing.

- Observations made in 1996, 1997, 1998, and 1999 suggest that the wetlands continue to support a diverse wetland flora.

- The created wetlands provide an important ecological complement to the already existing habitats on the adjacent South Boulder Creek floodplain.

- The conditions created in the wash fines disposal basins are appropriate for supporting a variety of wetland types including cattail marshes, willow shrublands, meadows/marshes dominated by rushes and sedges, and open water habitats.

- The created wetlands are providing a variety of functions.

- There is no indication that the wetlands developed at the Marshall site are likely to dry out. The proximity of the water table in combination with the fine texture of the wash fines, as well as seasonal inflow of irrigation return flows tends to keep the areas very moist or saturated at the surface.

COLORADO'S LYNX REINTRODUCTION – THE GOOD, THE BAD AND THE UGLY

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ABSTRACT

Lynx are medium sized and specialized feline carnivores native to Colorado. Lynx are highly dependent on snowshoe hares as their main prey. Lynx are still present in good numbers in the boreal coniferous forest across the core range in Canada and Alaska. In 16 of the lower 48 states, they are proposed for federal listing as threatened (this decision should be made on January 8, 2000). It appears that lynx were once quite common in Colorado but began a rapid decline around the turn of the century. The last confirmed wild lynx was taken in Colorado on the slopes of the Vail Ski area in 1973. In the spring of 1997, the Colorado Division of Wildlife (CDOW) initiated a proactive program to recover this species in Colorado. After conducting a habitat assessment involving a statewide track and pellet plot survey for snowshoe hare, the southwest corner of the state was selected as the best area. The project has been controversial and has resulted in protests from animal rights activitists, a lawsuit, and attempts to halt the capture of lynx in Alaska and Canada. Despite the opposition, the CDOW was able to release 41 lynx in the winter of 1998-1999. Fifty more lynx are planned for release in the winter of 1999-2000. An update on the status of the reintroduced lynx, what has been learned; and the possible impacts of activities such as timber management, wildland fire management, recreation (snowmobiling, ski areas), roads/trails, livestock grazing, trapping and predator control impacts to lynx will be discussed.

COAL BASIN MINE RECLAMATION CASE STUDY

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ABSTRACT

The State of Colorado, Division of Minerals and Geology is in the process of accomplishing reclamation of a previously permitted coal mining operation located in a high mountain basin. Coal Basin is a large erosional feature located on the east facing slope of the Grand Hogback in western Pitkin County, Colorado. High average annual precipitation, steep slopes and erosion prone soils combine to create the highly erosive nature of this area. Mining operations have added to the sediment load in local steam systems.

Five underground coal mine portal facilities, developed in the 1950's and 1960's along the steep flanks of Huntsman Ridge, are situated in this rugged sub-alpine environment. Coal processing facilities, including a wash plant, thermal drier and coal refuse piles are located approximately five miles east of the mine entry areas at the confluence of Coal and Dutch Creeks.

Mining operations ceased in the early 1990's. Eventually, the operating permit was revoked and the reclamation bond forfeited. Minerals and Geology assumed responsibility for accomplishing reclamation of the site in July, 1994.

Reclamation operations have focused on minimizing active and potential erosion, and resultant sedimentation, from the mining related facilities. To this end, many different erosion and sediment control techniques have been adopted, and unique revegetation procedures have been undertaken, as the reclamation process continues.

INTRODUCTION

Since 1995, the State of Colorado, Division of Minerals and Geology (DMG) has been actively accomplishing reclamation of a previously permitted underground coal mining complex in Pitkin County, Colorado (Figure 1, Coal Basin Mine). The Coal Basin Mine complex is large and diverse, with great variations in elevation, exposure, slope and topography throughout the Basin. Reclamation of the Coal Basin Mine complex has been subdivided into numerous sub-components or tasks. The public and various governmental agencies have been very involved in the reclamation process, which has contributed to the overall reclamation success at Coal Basin.

The original Coal Basin Mine began operations in the 1890's. Coal was mined from near the headwaters of Coal Creek as a part of the coal mining and steel empire of John Osgood. Operations

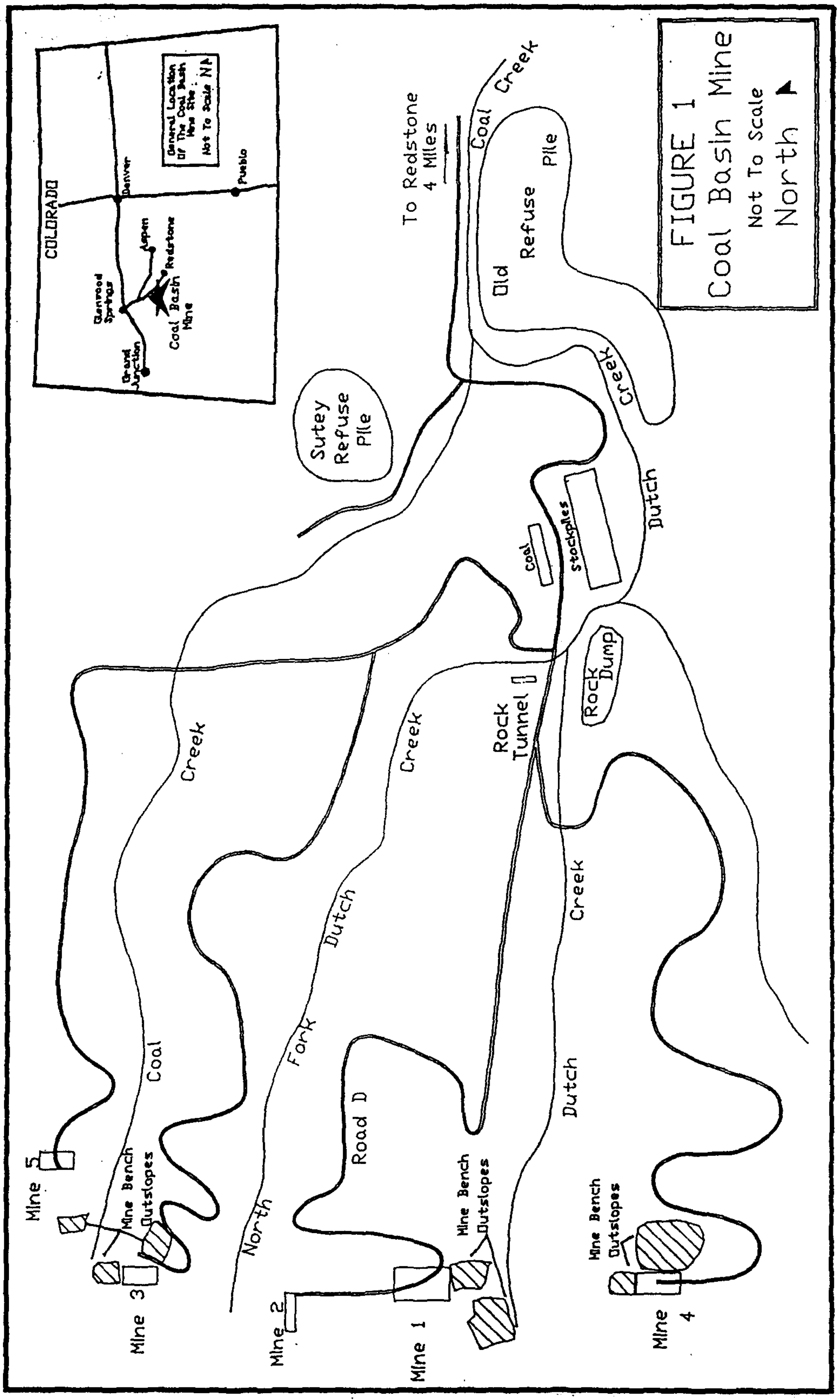

FIGURE 1
Coal Basin Mine
Not To Scale
North

ceased in the early 1900's. Mining resumed at Coal Basin in about 1953, and continued until 1991. Metallurgical quality coal was produced from five separate underground mines located in the western portion of the Basin. The mine entries are located high in the Basin at elevations of about 10,000 feet.

Following cessation of operations, the mining permit was revoked and the reclamation bond forfeited by the State of Colorado. In early 1992 the company filed for Chapter 11 bankruptcy protection. The Colorado Mined Land Reclamation Board was a secured creditor in the bankruptcy proceedings, and eventually received three million dollars in cash and services to satisfy its claims. The cash proceeds have been used to finance most of the on-going reclamation projects at the site.

ENVIRONMENTAL SETTING

The Coal Basin Mine is located within a topographic feature known as Coal Basin. Coal Basin is a large erosional feature situated on the flank of the Grand Hogback, just north of the West Elk Mountains. Coal Creek and Dutch Creek drain Coal Basin. These streams are confluent near the eastern margin of Coal Basin. Coal Creek is confluent with the Crystal River near Redstone, Colorado, four miles downstream from the mine site. The Crystal is confluent with the Roaring Fork River at Carbondale, Colorado, approximately eighteen miles downstream of Redstone.

Coal Basin is located in a sub-alpine environment. Plant communities are predominately aspen at lower elevations and Engelmann spruce at the mine entry areas. Average annual precipitation within the Basin is thirty-one inches.

Coal Basin is characterized by unique geologic conditions. Cretaceous Mancos Shale, a deep marine grey to black silty shale, predominates within the Basin up to an elevation of about 9,800 feet above mean sea level. The Mancos Shale forms steep slopes throughout the region.

Conformably overlying the Mancos Shale is the upper Cretaceous Mesaverde Formation. The Mesaverde is a thick sequence of interbedded sandstones, shales and minable coal units. The Mesaverde Formation is a steep cliff-forming unit, with sandstone members forming the vertical walls of Huntsman Ridge at the western margin of the Basin.

Due in large part to the relatively high annual average precipitation and the great exposures of the erosive Mancos Shale and Mesaverde Formation, the Basin experiences a very high degree of erosion annually. Because of the high natural erosion rates, Coal and Dutch Creeks transport large volumes of sediment annually. The mining permit application estimates that 15,225 tons of sediment per year is generated due to naturally occurring processes within Coal Basin.

RECLAMATION CHALLENGES

The challenges faced in accomplishing reclamation at Coal Basin are related to the large size of the mining operation and the physical characteristics of the Basin.

The mines are separated by about five miles from the southern most to northern-most entry area. The entries are connected by an approximately fifteen mile long road system, which joins each of the entry areas to the Wash Plant Area, located near the confluence of Coal and Dutch Creeks.

Three refuse piles are located about one mile apart from each other, while the coal preparation plant and office warehouse areas are in a relatively confined area. All told, approximately 333 acres of disturbed area are located within the 11,386 acre permit area.

The steepness of the topography, combined with the relatively high average annual precipitation results in high rates of erosion within the Basin. Erosion of the fill slopes located below the mine entry areas, and erosion from the road system have been identified as the two largest contributors of sediment from mining related facilities to adjacent water resources.

Reclamation Goals

The primary goals of the reclamation process at Coal Basin have been three fold; minimize erosion from mining related facilities, reduce sediment delivery from mining related disturbances to water resources in Coal Basin, and implementation of the post mining land uses identified in the mining permit and as described by the land owners and land management agency.

These goals are being implemented via the reclamation process, as the goal of each Project is to attain a greater degree of geomorphic stability through earth moving, runoff conveyance and revegetation techniques which are implemented during each reclamation construction phase.

Reclamation Sequencing

Funding for the reclamation projects has been primarily derived from funds made available to Minerals and Geology from the proceeds of the bankruptcy liquidation of the former operator. The assets were liquidated over a four to five year period of time. This resulted in reclamation funding being provided on a somewhat sporadic basis, because projects are bid out only as funds become available.

Because funding would be provided over the course of a few years, reclamation priorities had to be established. An inventory of the mine facilities, and a ranking of the existing or potential environmental hazard of each was established. This review indicated that the greatest environmental needs were at the mine entry areas, at portions of the road system and at one of the coal refuse piles. Given this evaluation, reclamation at Coal Basin began in 1995 at Mines 3 and 4, and at the Sutey Coal Refuse Disposal Area (Figure 1, Coal Basin Mine).

In subsequent years, reclamation proceeded at discreet locations, progressing down hill toward the coal preparation facilities area. A notable exception to this sequencing was the timing of revegetating the mine bench outslopes. This effort was accomplished in two stages, and is discussed in some detail later in this paper. Evaluations of how to best accomplish revegetation of the slopes occurred through 1997. In the mean time, it was decided to accomplish reclamation of three haul roads which provide access to some of the mine bench outslopes in 1996. This decision was made primarily to quickly reduce the sediment contribution from the road drainage systems to adjacent streams, recognizing that the mine outslope revegetation effort could be accomplished at a later date with a minimum of re-disturbance to the reclaimed road surfaces.

Reclamation progressed toward the coal preparation plant area, which was reclaimed in 1999. Sequencing of Projects in order to minimize re-disturbance and to reduce the potential of contractors' work areas from overlapping has been an important aspect of the overall reclamation plan. Completion of most reclamation is planned for the 2000 construction season, with maintenance occurring thereafter.

PROJECT OVERVIEW; INTERESTING AND CHALLENGING PROJECTS

Whenever possible, reclamation projects were designed to accomplish as many tasks at one construction area as feasible, in order to maximize the environmental benefit from the costs involved in the construction.

A good example of accomplishing multiple goals through a single reclamation task is the backfilling of the mine entry areas. In order to accommodate structural demolition during the reclamation process, all metallic materials were removed from the site, while concrete was demolished and placed at the base of the highwall. Coal materials were excavated from the bench areas, placed and compacted over the concrete rubble. Earthen materials were then excavated from the crest of the mine bench outslopes, and were transported, placed and compacted over the coal. Excavation from the crest of the mine bench outslopes served dual purposes. First, it provided a relatively coal free growth medium backfill for the final reclamation of the highwalls. Secondly, excavation of the material was accomplished in a manner which eliminated the operational drainage system, which was partially responsible for the severe gullying on the outslopes. Excavation in this manner promoted more uniform dispersal of snowmelt and rain water over the outslopes, thus helping to begin the outslope stabilization process.

Road E, F, G Reclamation Project, 1996

Approximately fifteen miles of haul roads exist at the Coal Basin Mine. The roads begin at the coal preparation facilities area at about 8,300 feet elevation, and continue on to the various mine entries at 10,000 feet. These roads traverse both Coal and Dutch Creeks, as well as a number of tributaries and small drainages. The roads vary in width from about forty five to sixty feet. During mining operations, the roads were designed to accommodate coal haulage trucks year round. The roads slope toward the inside at about two to five percent. A drainage ditch is present at the inside margin of each road. The ditch allows the road run off to drain to culverts which pass under the road. The drainage emerges from the culverts, and spills onto the fill slope at the outside margin of the road. The fill slopes are generally composed of highly erodable marine shales, and thus experienced significant erosion as a result of the addition of the road runoff.

The road reclamation plan contained in the mining permit called for narrowing the roads to about twenty feet, but contemplated retention of the ditch and culvert drainage system. Because reclamation in this manner would not significantly alleviate erosion caused by the road drainage, Minerals and Geology formulated a plan to accomplish the goal of minimizing sedimentation from the roads and fill slopes.

Reclamation entailed removing about 36 culverts from nine miles of haul roads located on the north side of the Basin. Following culvert removal, the road gradient was reversed by moving dirt from the fill, or outside, of the roadway to the cut, or inside, of the road. This gradient reversal caused the roads to slope to the fill side at a grade of two to five percent. Once the gradient was reversed, low water crossings were constructed at the creek crossings. Water bars or road dips were constructed at each larger ephemeral drainage, and at numerous other locations as well. All of these structures were designed to move water from the cut side to the fill side of the road as it would had the road system not interrupted the drainage pattern. As a final surface flow modification technique, the graded road surface remnants were deeply ripped using a light dozer. Rippers were spaced at thirty inches and sunk to a depth of about sixteen to eighteen inches. This caused the road remnant to become severely roughened, which helps promote revegetation potential and encouraged infiltration while disrupting surface flows, thus decreasing flow concentration. Finally, the reclaimed road surface was revegetated using weed free straw mulch and the Coal Basin Seed Mixture (Table 1, Coal Basin Mine Seed Mixture).

Table1. Coal Basin Seed Mixture.

SPECIES	SCIENTIFIC NAME	VARIETY	LBS/Acre PLS
Kentucky Bluegrass	*Poa pratensis*	Banff	0.25
Slender Wheatgrass	*Agropyron trachycaulum*	San luis	3.00
Mountain Brome	*Bromus marginatus*	Bromar	3.00
Tufted Hairgrass	*Deschampsia caespitosa*	Peru creek	0.20
Sheep Fescue	*Festuca ovina*	Covar	1.50
Timothy	*Phleum pratense*	Climax	0.25
Orchardgrass	*Dactylis glomerata*	Dawn	0.76
Alpine Bluegrass	*Poa alpina*	VNS	0.25
White Clover	*Trifolium repens*	Ladino	0.76
Cicer Milkvetch	*Astragalus cicer*	Monarch	0.76
Lewis Blue Flax	*Linum lewisii*	Appar	0.76
Yarrow	*Achillea millefolium*	VNS	0.10
Snowberry	*Symphoricarpos sp.*	VNS	0.38
Woods Rose	*Rosa woodsii*	VNS	0.38
Rocky Mountain Penstemon	*Penstemon strictus*	Bandera	0.38

The techniques employed were successful in meeting the goals of minimizing sediment contributions from the road system. Erosion of the reclaimed road surfaces and of the adjoining fill slopes is virtually non-existent three years following completion of reclamation.

When accomplishing reclamation of the remaining roads, it may be advantageous to increase the reversed gradient to as much as ten percent toward the fill slope. This may have some benefit in further promoting revegetation and in helping to stabilize the cut slope. However, the increased cost of placing additional fill needs to be weighed against the predicted benefit. Another technique which may be modified in the future is the road surface ripping. The 1996 ripping occurred parallel to the road. In the future, additional runoff control may be achieved during the first year following reclamation by ripping sub-parallel to the road surface, with the dozer angled toward the cut slope.

Dutch Creek Diversion Project, 1998

During mining operations, Dutch Creek, immediately above its confluence with Coal Creek, was diverted into a concrete lined channel. This twelve to fourteen feet wide by four feet tall structure was over six hundred feet long, and was bounded on the east by coal refuse and on the west by the mine facilities yard. Near the end of the life of the mine, the structure suffered from holes being punctured in its base as a result of the boulders which pass down Dutch Creek during flash floods and spring runoff. Further, the end wall foundation appeared to be near failure.

Minerals and Geology spent a considerable amount of reclamation funds to maintain the integrity of the flume during heavy runoff, and to accomplish repairs to the base of the flume. Although planned by the mining company to be a permanent structure, it became increasingly apparent that the flume would be a perpetual maintenance problem, and would certainly fail at some point in the future.

In order to address this problem, Minerals and Geology applied for a grant from the Office of Surface Mining (OSM). The grant was approved and funds were awarded for the purpose of constructing a replacement channel for the flume.

OSM personnel, assisted by Minerals and Geology staff, conducted extensive field work during the summer of 1995. These investigations, which focused upon the geomorphologic characteristics of Dutch Creek above its point of diversion into the flume, led to the development of a stream channel design by an OSM hydrologist. The design accommodated the dynamic nature of Dutch Creek, including its propensity to transport large volumes of coarse sediment on a yearly basis. The new channel is not an engineered structure, but is designed to be a geomorphically active system which mimics the natural characteristics of Dutch Creek. The approximately 1,250 feet long stream segment is actually a channel within a channel. The outer channel consists of four large meanders, while the incised inner channel has about twenty five meanders. The incised inner channel has sufficient capacity to accommodate normal annual flows, while the outer channel acts as an overflow channel to accommodate larger flows. The design allows for migration of the inner channel meanders over time.

The channel was constructed during low water conditions in the fall of 1998. The foot print of the channel was established using real time global positioning system (GPS) instruments to locate and stake the top of the channel sides on-the-ground, including cut and fill depths and the outer channel meander locations. Once the heavy equipment had roughed out the outer channel, the inner channel was similarly surveyed and staked. Construction of the inner channel was accomplished by over-excavating using a track hoe. Rip rap, salvaged from the old Dutch Creek channel, was then placed within the inner and outer channels to design specifications. The creek was diverted away from the flume and into the new channel, in November, 1998.

As expected, step pools formed during the spring 1999 runoff. The inner channel accommodated the runoff volume, but cutting at the junction of the diversion and the natural Dutch Creek channel caused some aggradation to occur within the inner channel between the first and second outer channel meanders. This deposition created a braided stream pattern within the inner channel for about a one hundred feet length of the stream.

Morphology of the reconstructed channel will be monitored over time. Permanent cross section monitoring points have been established along one bank of the channel. These cross sections are surveyed on an annual basis to document channel modifications.

Old Refuse Pile / Abandoned Mined Land Fee Funded Projects; 1998, 1999

The Old Refuse Pile is a large facility which accommodated reject from the wash plant for at least twenty years. The older, eastern portions of the pile, were constructed prior to enactment of the Surface Mining Control and Reclamation Act of 1977. Therefore, this area was eligible for reclamation funds provided to Minerals and Geology by Abandoned Mined Land Fees. Two Projects have been undertaken at the Old Refuse Pile in order to reduce the risk of large failures, and to ameliorate the steep slopes which characterize this area. The Huntsman Project was completed during the 1998 construction season, while the Bear Creek Project was completed during the 1999 construction season. These Projects reduced the 1 H : 1 V slopes of the Old Refuse Pile to 2 H : 1 V or flatter.

Huntsman Project;

The Huntsman Project is an example of Abandoned Mined Land funds being used to accomplish pre-law reclamation while enhancing overall site rehabilitation.

In order to achieve the desired 2 H : 1 V slope configuration at the Huntsman Project area, approximately 55,000 cubic yards of coal refuse had to be cut from the refuse pile. However, due to the proximity of Coal Creek at the toe of the pile, there was no room to store the majority of the excavated material near the cut area.

During completion of structural demolition at the wash plant area earlier in 1998, about 50,000 cubic yards of demolished concrete had been pushed into a flat – topped pile about one and one half acres in size. The refuse excavated during the Huntsman Project was transported about one quarter mile from the cut area, and was placed over the top of the rubbelized concrete, and compacted in place. Placement of the material in this area created an approximately two acre, slightly crowned hill at the base of a vertical cut slope. This landform compliments the post mining land use in this area, while accommodating the completion of the Huntsman Project.

Due to the length of the Huntsman cut slope, it was apparent that a slope break was desirable. The reclamation contract specified the construction of a ten feet wide, slightly inclined bench located mid-slope to address the slope break concern. However observations at other reclaimed facilities in Coal Basin indicated that snow accumulation and differential melting at bench slope breaks generally leads to their failure, resulting in large gully development, a process particularly prevalent on north facing slopes, as is the case at the Old Refuse Pile. A different method of creating the desired slope breaks needed to be implemented in order to disperse snowmelt runoff and minimize slope erosion. As a result, the concept of creating dozer dips to act as slope breaks was formulated.

Hundreds of dozer dips were constructed by placing a light dozer at the toe of the reclaimed fill slope following topsoil placement. The dozer backed up the slope about ten to fifteen feet, dropped its blade and pushed forward (downhill) until a mound of topsoil six to eight inches tall accumulated at the blade. The dozer would then lift its blade and back up and repeat the process until it reached the crest of the slope, where it would move to the side and proceed to the base of the slope to start the process all over again. This occurred until the entire slope was covered by these dips.

Observations made the spring following construction indicated that, for the most part, the dips functioned as intended. In some areas where the vertical spacing was too great, the dips had a tendency to drain at the edges, periodically forming small rills at these locations. Overall, the height and horizontal spacing of the dips appeared to be adequate to prevent gully formation.

Bear Creek Project;

Like the Huntsman Project, the Bear Creek Project was designed to ameliorate pre-law oversteepened slopes of the Old Refuse Pile. This was accomplished by cutting approximately 90,000 cubic yards of material from the upper segment of the facility, and compacting it at the toe until the target overall slope gradient was achieved. Following completion of cut and fill operations, the cut portion of the slope was ripped using a light dozer working horizontally across the slope. Eight to ten inches of topsoil were applied to the slope after ripping operations were completed.

After completion of topsoil application, weed free straw mulch was applied at a rate of two tons per acre. A light trackhoe was then used to create thousands of small hummocks on the six acre reclaimed area. The hummocks are approximately thirty inches wide, twelve to fourteen inches across and ten to sixteen inches deep. The hummocks were constructed in a random pattern, but never more than thirty inches apart from one another in any direction. These hummocks will severely disrupt the runoff pattern from the face of the pile, thereby minimizing erosion on the reclaimed surface. Construction of the hummocks also incorporates the straw mulch into the soil surface, which will help to hold soil particles in place during snow melt runoff and following rain storms. The extreme roughness of the area should also enhance revegetation potential. Following hummock construction, the area was fertilized and seeded.

Approximately 1,200 shrubs were planted at the toe of the reclaimed slope. The eastern half of the toe was planted with containerized shrubs, while the western half was planted using locally obtained willow cuttings. As these shrubs mature, it is anticipated that a natural sediment barrier will be created. To complete the reclamation process, eight hundred trees were planted in clusters throughout the cut and fill area.

Outslope Revegetation Projects; 1996, 1999

As previously discussed, development of the mine entries resulted in the creation of long, steep fill slopes, commonly referred to as mine bench outslopes. Typically, the outslopes are over 550 feet in length, and vary in size from 2.1 to 7.8 acres. The outslopes are predominately composed of dark, generally fine-grained sandstone and shale materials, with soil being essentially non-existent.

Overall slope angles vary from between 72% and 80%. The slopes are generally devoid of vegetation and are subject to significant erosion, as evidenced by well developed gullies, which are common on each outslope. Observations indicate that the mine bench outslopes are significant areas of sediment generation.

Because of the sediment contribution attributed to these areas, it was determined that outslope stabilization was a necessary component of site reclamation. The constraints of elevation, access and steepness of the mine bench outslopes, as well as the sheer volume of material contained on the slopes required that they be stabilized in place. Therefore, one or more methods of revegetating the mine bench outslopes had to be developed.

Demonstrations were conducted at Mine 1 in 1996 for the purpose of creating shelves on the outslopes which would serve the dual purpose of breaking the surficial crusting which is common on the slopes, and of providing a resting place for seed, moisture and fertilizer.

In order to accomplish these goals, a four feet diameter drum roller was fitted with steel plates welded with a twelve inch spacing (horizontal and vertical) between plates. The plates, made of one half inch steel, are twelve inches in length and six inches in height, and are welded to the drum perpendicular to the curvature of the roller in an alternating pattern. The roller is designed with a tongue so that it can be pulled up and down the outslopes by a cable attached to a heavy dozer.

The roller performs differently than an imprinter in an important way. While an imprinter creates a depression by compressing the ground surface into a depression in which seed, fertilizer and moisture can accumulate, the modified roller gouges a shelf into the slope. This distinction is important in that the full weight of the approximately four ton roller is applied to two or three thin steel plates at any one time. This pressure forces the plates into the outslope material, and digs material out of the slope as the roller moves up or down the outslope. The modified roller, because of the limited width of the plates, was observed to wedge between rocks, continuing to create the desired surface modifications even in these adverse conditions.

In the fall of 1996, the roller was applied to an approximately seventy five feet wide by one hundred twenty five feet long area of the Mine 1 outslope. Following this scarification process, seed was hand broadcast at a rate of about fifteen to twenty pounds pure live seed per acre. Commercial fertilizer (18-24-0) was applied at a rate of three hundred pounds per acre and mulch was applied to the slopes at a rate of about two tons per acre. Slope scarification and seeding in this manner were also accomplished at this time on a steep east facing fill slope located below Road D immediately north of Mine 1.

The use of mulch as a cover was intended to shade the seed from the sun on these dark colored slopes. The dark colored, generally south and southeast facing slopes get very hot at the Project Area elevation. Therefore, the use of the mulch as a shade mechanism was thought to be beneficial to the germination potential of the seed.

Initial observations of the slope in 1997 were encouraging. Visually, vegetation cover at the Mine 1 outslope was estimated to be about fifteen percent to twenty percent. In 1998, transects were evaluated for cover and species composition. The results of this analysis are presented in Table 2, Vegetation Cover Establishment.

Table 2. Vegetation Cover Estimates

	Mine 1 Outslope [1]	Road D Outslope [1]
Vegetation Cover (%)	25	20 – 25
Predominate Species	*Agropyron trachycaulum, Bromus inermis, Festuca ovina, Poa pratensis, Achillea millefolium, Penstemon strictus, Linum lewisii, Astragalus cicer*	*Bromus inermis, Agropyron trachycaulum, Phleum pratense, Festuca ovina, Achillea millefolium, Penstemon strictus, Linum lewisii, Astragalus cicer*

[1] Seeded September, 1996

During the early stages of developing a revegetation procedure for the mine bench outslopes, it was observed that a native grass species, purple reedgrass (*Calamagrostis purpurascens),* was growing on the outslopes and on adjacent, undisturbed steep slopes. Seed from the plant was harvested in the early fall of 1996. The seed was cleaned by hand, and broadcast both separately onto the scarified outslopes, and in conjunction with the commercial seed mixture used during the revegetation efforts at Mine 1. No germination was detected until the summer of 1998, when *Calamagrostis purpurascens* seedlings were observed to be establishing on the site. In the area where *Calamagrostis purpurascens* had been seeded without the commercial species, visual estimations indicate a cover of up to fifteen percent had been established.

In an effort to promulgate a seed source for this material, DMG entered into a contract with the Upper Colorado Environmental Plant Center (UCEPC), located near Meeker, Colorado. UCEPC agreed to accept some of the *Calamagrostis purpurascens* seed, clean it, conduct germination tests and attempt to cultivate it on a limited scale. Germination tests had a positive result, with a 48% to 50% of the tested seed germinating. Cultivation, however, proved to be difficult, with field plantings bearing few seedlings. Greenhouse germination was more successful. UCEPC delivered to the DMG over one thousand greenhouse grown seedlings suitable for transplanting in the summer of 1999.

Due to the success observed as a result of the demonstrations conducted at Mine 1 and at Road D, DMG decided to undertake revegetation of the remaining mine bench outslopes replicating the hill slope scarification and shelf construction accomplished in 1996. However, it was recognized that, for the most part, the slopes which needed to be treated and seeded were much more remote, and provided much greater access challenges than the relatively accessible upper reaches of the Mine 1 outslope. Therefore, an invitation for bid was issued which did not specify the mechanisms of shelf construction to be employed. Rather, the invitation specified minimum dimensions of shelves, shelf spacing and the minimum number of shelves per acre to be established.

The shelves constructed were ten inches in width and eight-inches deep, with a spacing of three feet horizontally (perpendicular to the fall of the slope) and three feet vertically (parallel to the fall of the slope). Construction in this manner would result in creation of 3,588 shelves per acre, representing 1,596 square feet of flat surface per acre on the steep mine bench outslopes.

In early September 1999, Dirt-N-Iron, the Project contractor, began work as crews were brought onto the site. Using Macleod Fire Rake / Hoes, the shelves were dug into the slopes. The Macleod Fire

Rake / Hoe is a rake-like tool that is composed of a steel plate fastened perpendicularly to the base of a four and a half-foot wood handle. One side of the steel plate is a sharpened flat blade, measuring about ten inches across. The opposite end is a four pronged rake, also measuring about ten inches across the outside of the rake. Crew members worked ten to fifteen feet distant from each other, spread horizontally across the slope. The crew worked from the top to the bottom of each slope. Observation of the construction process indicates that perhaps twenty five percent more shelves than was specified were actually created, yielding approximately 4,448 shelves per acre, representing up to 1,958 square feet of flat area per acre of mine bench outslope.

While the hand crew was creating the shelves, a second crew was collecting and cleaning *Calamagrostis purpurascens* seed. In addition, seed from a locally occurring aster (tentatively identified as *Aster glaucodes*) was collected and cleaned.

Seeding was accomplished as the crew worked down the slopes. The commercially obtained seed was distributed with a hand held seeding machine, while the seed from the two native species was distributed on the slope by hand broadcast methods. Biosol 7-2-3, a slow release fertilizer, was applied by helicopter at a rate of 1,800 pounds per acre. Certified weed free straw mulch was applied at a rate of 2,000 pounds per acre. At four of the five outslopes, the mulch was also applied by helicopter. Approximately twenty-four acres of steep mine bench outslopes were scarified, seeded fertilized and mulched during performance of this Project.

Using the *Calamagrostis purpurascens* seedlings provided by UCEPC, approximately two hundred (200) tublings were planted across each of the five mine bench outslopes at mid-slope. The mid-slope area was chosen for planting, as it is anticipated that seed produced from the plants will have an equal chance of being distributed either up- or down-slope by winds.

A variety of containerized shrubs were planted at the base of each slope. Approximately 540 shrubs were planted at each area. The purpose of this planting was to begin the establishment of vegetative sediment barriers. This planting effort will be followed up in 2000 by planting large volumes of willow cuttings at the base of some of the mine bench outslopes. The 2000 planting will establish a shrub layering affect in the target areas. It is anticipated that this follow-up planting will largely be accomplished with the help and assistance of volunteers.

Measurement of the project success will be accomplished not only in terms of vegetation cover, but also in terms of erosion control and sediment retention. In order to help assess sediment retention, staff gauges were placed in sediment traps constructed at the toe of some of the outslopes in order to measure sediment accumulation over time.

In an effort to indirectly measure the relative success of the revegetation effort as it relates to erosion and sediment delivery from the outslopes to the adjacent water resources, gully monitoring points were established within representative gullies on each of the treated slopes. Parameters such as gully width, depth, steepness, soil characteristics and relative percent vegetation cover within each gully contributing area were recorded, and will be monitored in the future.

In conjunction with the slope revegetation project, a stream monitoring network has been established on Coal and Dutch Creeks. Parameters monitored include suspended solids, settleable solids and discharge. This network is designed to isolate the mine bench outslope contributions from naturally occurring sediment so that an analysis of the relative success of the mine bench outslope revegetation effort can be made as vegetation matures.

PUBLIC PARTICIPATION AND SUPPORT

Reclamation has primarily been funded through the bankruptcy proceedings. However, these funds were earmarked only for projects contemplated by the permit reclamation plan. Site observations indicated that, in order to effectively accomplish site remediation, other tasks would need to be accommodated. Therefore, Minerals and Geology has been very active in pursuing other avenues of funding. Additional funding has been mainly developed through grants received from various State and Federal agencies. The communities near the site have been very supportive of the pursuit of additional funding in order to enhance the overall reclamation of Coal Basin.

An integral factor in being able to obtain grants, and to build consensus within the community and between interested agencies has been the creation of productive inter-governmental relationships. Minerals and Geology has been very successful in establishing effective working relationships with the Office of Surface Mining, the White River National Forest, the Army Corps of Engineers, Pitkin County, Colorado Division of Wildlife and the Colorado Department of Public Health and Environment. The importance of involving the appropriate agencies at every level of reclamation planning and implementation cannot be overstated. By maintaining productive relationships with the various agencies, coordination of Projects and implementation of reclamation plans proceeded with a minimum of delay.

One of the unique aspects of accomplishing reclamation of the Coal Basin Mine has been the general level of interest that the process has inspired in government agencies and local citizens. One success in the reclamation processes has been the involvement of many interested parties in the reclamation process. Partnerships in the community have been developed between Minerals and Geology, area citizens, local groups and organizations.

Public participation in, and support of the reclamation process has perhaps been one of the more critical elements of successfully implementing reclamation at Coal Basin. Minerals and Geology recognized the importance of gaining the trust of the community in order to achieve successful reclamation of the site. It was thought that the best way to regain public confidence in the reclamation process was by inviting the public to actively participate in the process.

In order to promote public participation, Minerals and Geology has participated in many community meetings to discuss reclamation plans, and has hosted numerous tours of the site to show and explain the reclamation process. Open and frank discussions about reclamation progress, plans and practices have been held. Volunteer tree planting activities have been hosted in the past, and volunteer shrub planting opportunities will be provided this coming season. Citizens have even helped with surveying and pre-construction project layout. The media, as well as County Commissioners, State Representatives and other Local, State and Federal officials have toured the site.

A number of area schools have been very involved at Coal Basin in the past three years (Table 3). School groups from Pitkin and Garfield Counties have participated in tree planting efforts in the past. Schools have also been using the area as an outdoor lab of sorts, in order to help teach the concepts of geomorphologic restoration, revegetation and other reclamation processes.

Table 3. Coal Basin Reclamation Facts and Figures.

Projects Completed

(3) Refuse Piles Reclaimed (51 acres)
(5) Mine entry areas and five fan entry areas reclaimed (31 acres)
(9) Miles of Haul Roads reclaimed (51 acres)
(3) Industrial areas reclaimed (wash plant, thermal drier, warehouses, shops) (22 acres)
(3) coal stockpiles reclaimed (9 acres)
(6) Mine bench outslopes reseeded (29 acres)
Stream Channel reconstructed (1,250 feet)

Grants Received

Two OSM Civil Penalty Grants (14 acres)

Non-Point Source Grant (24 acres)

Noxious Weed Control Grant (22 acres)

Two Abandoned Mined Land Fee Funded Projects (16 acres)

Public Involvement

Aspen Public Schools : Tree Planting
Colorado Rocky Mountain School : Tree Planting
Yampah Mountain High School : Reclamation and Energy Awareness Program Field Site
Carbondale High School : River Watch Program

Redstone Caucus
Redstone Community Association
Crystal Valley Environmental Protection Association
Roaring Fork Conservancy

CONCLUSION

Effective and efficient reclamation is being accomplished at the Coal Basin Mine by the Division of Minerals and Geology. This success is largely attributed to the prioritization of reclamation needs, accomplishing multiple reclamation objectives through creative construction planning, the selective use of grant monies to target areas not subject to reclamation funding by the forfeited bond, and the involvement of local citizens in the process.

The use of technology, particularly real time global positioning system, has greatly enhanced the ability of the Division to produce accurate pre- and post-reclamation topographic maps and cross sections, which provide contractors a greater degree of confidence in their ability to efficiently bid a Project. This leads to economic completion of Projects by encouraging well thought out bids, and a minimum of field modifications. The development of close working relationships with contractors has lead to the implementation of innovative reclamation solutions.

The implementation of newer techniques has helped to enhance the reclamation product. Severe surface disruption enhances revegetation potential, while alleviating erosion problems. Creation of benches on the steep mine bench outslopes, either by hand or by mechanical means, provides an economic approach to steep slope revegetation. Finally, the use of geomorphically active design parameters when approaching stream channel reconstruction problems lends itself to the creation of a naturally functioning system, which, ultimately, is the goal of reclamation.

RECLAIMING THREE QUARRIES NEAR COLORADO SPRINGS, COLORADO: A COMMUNITY PROJECT

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ABSTRACT

For nearly fifty years the Queens Canyon, Pikeview and Snyder quarries have been at the center of public controversy in Colorado Springs, Colorado and El Paso County. Many citizens believe that the highly visible quarries adversely affect the scenic quality of the Colorado Springs foothills. Over the years the quarries have provided native stone to build the Air Force Academy, the Colorado Springs airport and much of the residential and commercial development in and around the city. As the community grew, so did the quarries. In the early 1990's a remarkable community effort was initiated to develop visual objectives for the reclamation of the quarries and to recapture the scenic quality of the disturbed land. The effort involved city, county and state governments, community groups, local businesses, private citizens and Castle Concrete Company, the owner of the quarries. Funds for the project were generated from both public and private sources. The objective has been to blend the visual appearance of the quarries with the less disturbed surrounding landscape. After nearly ten years, a significant amount of this work has been completed by Castle Concrete and hundreds, if not thousands, of volunteers.

INTRODUCTION

The adverse visual affect of various types of development upon Colorado's Front Range has been an issue for many years. Quarries that have provided materials to support the development have been singled out as adversely affecting the scenic backdrops of Front Range communities. The Queens Canyon, Pikeview and Snyder quarries near Colorado Springs in El Paso County are one such group of quarries. They have been the focus of considerable controversy since the 1950s. After visiting Colorado Springs in 1966, Secretary of the Interior Stewart Udall noted that it was "the city with the scar." And at that point the controversy became known as "the mountain scars issue." The quarries are plainly visible from various locations in the Colorado Springs area, and two of them, the Queens Canyon and Pikeview quarries, are highly visible from the I-25 highway corridor that passes through the city.

This paper presents a history of the Colorado Springs mountain scars issue. It describes the development of the quarries, the evolution of the controversy, the reclamation activity that has taken place and the remarkable community effort that has moved the controversy toward a positive resolution.

THE HISTORY AND EVOLUTION OF THE MOUNTAIN SCARS ISSUE

Growth of the Colorado Springs Region and the Development of the Quarries

"The centerpiece of daily life for every resident of the Pikes Peak Region is an inspiring mountain view. For more than a century, this centerpiece has been a magnet attracting industry to the area. Tourism is a major economic force because of the centerpiece, which has attracted untold numbers of residents here as well. These are the major reasons why the three local quarry scars marring the centerpiece gain so much attention; many residents and tourists ask how it happened."

Wanda Reaves, *The Chamber Connection,* March 1995

These remarks by Wanda Reaves presented in a guest column of *The Chamber Connection* capture the essence of the mountain scars issue. To understand how the quarry scars developed and gained so much attention, one needs a brief review of the history of the region.

As the mountains of the Front Range were being uplifted about 65 million years ago, a secondary movement created the Ute Pass Fault, which pushed a layer of limestone to the surface. Limestone outcroppings appeared in the Pikes Peak region with the largest outcroppings found where the Pikeview, Queens Canyon and Snyder Quarries are now located. This unique occurrence of limestone provided a convenient, inexpensive source of building material for the people who began to settle in the area in the 1850s. The limestone was used for rock dust in the coal mines and as a reagent in the region's gold processing operations.

The City of Colorado Springs was founded on July 31, 1871. Significant quarry operations began around 1874 when the Snider brothers opened a limestone and sandstone quarry north of Manitou Springs. Over the years, the quarry was referred to as Snyder Quarry ("Snyder" now spelled with a "y"), the Black Canyon Quarry and the Manitou Quarry. Early in the 1900s the Holly Sugar Corporation obtained ownership of the quarry and used the high-grade calcium carbonate from the mine to process sugar beets.

In 1906, the first mining claim was staked on land in or near the current Pikeview Quarry. Holly Sugar Corporation and the Golden Cycle Corporation, a mining and ore processing company, later acquired ownership of the land. The Pikeview Coal Mine, which was one of about 100 coal mines operating in the Colorado Springs area between 1882 and 1965, used limestone from the quarry in its operations. The coal mine was located in the present-day community of Rockrimmon.

In 1954, William Eskeldson filed a mining claim on 160 acres of Pike National Forest Land in Queens Canyon. In 1955, Castle Concrete Company was incorporated and the company began mining operations at Queens Canyon Quarry. Thirteen years later, in 1968, Castle Concrete purchased and reopened Snyder Quarry, which had been idle for decades. Beginning in 1969 Castle Concrete leased and operated Pikeview Quarry and then in 1974 it acquired the quarry.

With the acquisition of Pikeview Quarry, Castle Concrete became the owner of all three quarries that are involved in the mountain scars controversy.

Since 1954, the material from the quarries has been used to build the Air Force Academy, the new Colorado Springs Airport, the Norwest building, NORAD and thousands of single-family homes and apartments in the Colorado Springs area. It is estimated that 70% of Colorado Springs infrastructure was built from material from the quarries.

Growth of the Controversy

"It is said that some tourists who visit this section of the country remark, after seeing the mountains, that they are pretty to look at, but that they are exceedingly hard to get over and not of very much use."

The Colorado Springs Gazette, April 20, 1902

The editors of the *Colorado Springs Gazette* went on to state with great pride that the City of Colorado Springs had found a practical use for the mountains — as an "inexhaustible" source of rock for construction. They believed that "if rock enough were removed from the summit of Pikes Peak to build three or four towns the size of Colorado Springs, an old-timer returning to the city after it had been removed would probably have to be told that the peak had been cut down."

The expansionist mindset from the early days, which relied upon the perception that natural resources were limitless, clashed with the preservationist thinking that began to emerge in the mid-1950s. The subject of controversy was the proposed Queens Canyon Quarry, and the issue was whether it was wise to allow mining to despoil the natural beauty of a highly visible area in the foothills. The National Forest Service land claimed for Queens Canyon Quarry was wild and untouched. Despite Castle Concrete Company's legal right to quarry in that location, public opposition attempted to prevent the development of the quarry. Despite the opposition, Castle Concrete was able to preserve its right to mine and the company commenced operations.

Prior to the 1950s, Snyder and Pikeview quarries were well out of sight of the population. However, as the city and suburban area grew, so did the demand for rock products from the quarries. Consequently, the size of these quarries grew. As the region expanded, subdivisions were developed within visual range of the Snyder and Pikeview quarries. These quarries, which were once in the countryside, were now in the middle of suburbia. Public opposition to Castle Concrete's mining at Queens Canyon expanded to include the Snyder and Pikeview quarries.

Beginning in the 1950s, acrimony between Castle Concrete and citizens grew as various attempts were made to thwart further development of the quarries. In 1958, Colorado Springs Mayor, Fred Simpson, called for a boycott of rock purchases from Front Range quarries, but the idea was determined to be illegal. In 1965, an anti-quarry group known as the Springs Area Beautiful Association (SPABA) blamed Castle Concrete for scarring the land made famous in Katherine Lee Bates' song, "America the Beautiful." SPABA initiated a petition drive aimed at preventing Castle Concrete from obtaining a land patent on Queens Canyon. Wasson High School administrators used the school's public address system to publicize the SPABA petition drive and distributed the petition to students to sign. In 1985, the city considered cutting off water service to Castle Concrete to force the company to shut down its quarrying operations. The mayor and city council of Manitou, Manitou residents, SPABA and the Sierra Club supported the plan. The measure failed. Then, in the late 1980s, a series of events took place that began to move Castle Concrete and the community from intractable positions toward a resolution of the controversy.

Toward the end of 1980s several quarry proposals were being considered by local authorities along the Front Range and the State of Colorado's Mined Land Reclamation Board. This was because continued growth in the state was increasing the demand for rock products. A number of citizens expressed concern about adverse visual effects that the quarries would leave upon scenic landscapes.

Two events in the late 1980s prompted political and community action in the 1990s in the City of Colorado Springs and El Paso County. The first was a proposal by Rocky Mountain Asphalt Company to develop a quarry in Waldo Canyon near Colorado Springs. This proposal met strong opposition from citizens who believed that the quarry would have an adverse impact upon visual and recreational resources in the canyon. The quarry was not developed. The other event was a request in 1989 by Castle Concrete to expand Snyder Quarry. Castle Concrete submitted an application to the Mined Land Reclamation Board to amend its Mined Land Reclamation Permit. There was strong local opposition to the permit. The opponents objected mostly to the adverse aesthetic and visual impacts from the proposed expansion. The Board determined that it did not have the authority under the Mined Land Reclamation Act to develop visual or aesthetic criteria for mining operations and it approved the Snyder Quarry amendment application because it met the requirements of the Act. The determination by the Board prompted Governor Roy Romer and political leaders from Colorado Springs to work together to examine the mountain scars issue.

Political and Community Initiatives to Move Toward Resolution of the Mountain Scars Issue

The momentum to examine and find a resolution to the mountain scars issue grew significantly when Governor Romer created the State Commission on Mountain Scarring in 1988. The Commission's charge was to examine legislative and regulatory adjustments that should be made to protect scenic backdrops, to examine the technical issues and to identify solutions to mitigate visual impacts. Although the Commission considered the visual impacts from quarries along the entire Front Range, the three quarries in Colorado Springs received most of the attention.

There were few, if any, legislative and regulatory adjustments made at the state level as a result of the Commission's review. This was largely because visual and aesthetic issues were viewed by the Colorado Legislature as a local problem to be addressed by local governments. However, regarding technical issues and solutions, the Commission generated several ideas about how to mitigate visual impacts from quarries. As the Commission completed its work, the Governor committed $75,000 from the Colorado Energy Impact Assistance Fund to be used toward the "enhanced reclamation" of the Colorado Springs quarries. Enhanced reclamation was defined as reclamation work to be performed that is over and above that which is required by the Colorado Mined Land Reclamation Act. The reclamation work required by the Act was referred to as "base reclamation." The funds committed by the Governor were restricted to the purchase of trees, wildflower seed, rock stain and supplies to do enhanced reclamation and had to be matched by funds from other sources. The money to organize and plan the reclamation also had to be raised from sources within the community. Nonetheless, the commitment from the Governor helped stimulate the community's effort.

After the Commission completed its work in 1990, continued movement toward resolving the issue did not come easily. Castle Concrete, the City of Colorado Springs, the El Paso County Commissioners and the citizens had different views regarding enhanced reclamation and how the responsibility for doing the reclamation should be allocated. At one point in 1990 the city and county governments considered boycotting Castle Concrete to force the company to do more than the legally required reclamation. The boycott did not come about and eventually representatives from the company and leaders in the community created a mechanism to manage the issue. The mechanism was the development of the joint city and county "Charter for Additional Reclamation at Castle Concrete Company Quarries" and the creation of the El Paso County/Colorado Springs Mining Reclamation Advisory Committee (MRAC).

The charter articulated the goals for enhanced reclamation and the procedures to be used to achieve them. MRAC was given the responsibility to carry out the charter. MRAC included citizens from the community appointed by the city and county and representatives from Castle Concrete. The chairman of MRAC and a representative of the Castle Concrete Company signed the charter along with the mayor of Colorado Springs and the Chairman of the El Paso County Commissioners. Although not a signatory to the charter, the Colorado Department of Natural Resources agreed to provide support and to monitor progress for the governor.

The charter directed parties to the agreement to pursue a solution to the problem by first fostering "a climate of cooperation." The charter set forth a procedure to accomplish the goal and stated that MRAC should accomplish the following:

1. Refine post reclamation land use(s) sensitive to visual compatibility concerns.
2. Develop engineering and site-specific designs for additional reclamation at the Pikeview, Queens Canyon and Snyder quarries;
3. Prepare cost estimates for all additional reclamation measures;
4. Set forth a proposed timetable for implementation;
5. Set forth the procedure for Castle Concrete Company to submit enhanced reclamation proposals as technical revisions under the Mined Land Reclamation Act; and
6. Develop a strategy for funding the additional reclamation costs from commercial, public, private and non-profit sources, and develop a process for contracting additional reclamation.

The charter included a set of enhanced reclamation concepts for each quarry. The committee was to use the Report of the Commission on Mountain Scarring, the experience of Castle Concrete, the advice of the Colorado Mined Land Reclamation Division, and the experience and expertise of the members of the committee to guide them in the development of the enhanced reclamation plans.

MRAC met regularly for two years. The meetings educated people about the history of the quarries, the role that Queens Canyon Quarry plays as Bighorn Sheep habitat, and the technical aspects of reclamation – that is, what could realistically be achieved. Members of the committee visualized what could be accomplished in the short term and what the quarries could look like twenty to thirty years later. In the spring of 1993, MRAC completed the enhanced reclamation plans. The plans described the vision of the community and identified the objectives that were to be achieved. Objectives included items such as the establishment of trees in specific areas in greater number than required under the base reclamation plans, re-contouring the mined land to improve the visual appearance of the topography of the quarries and retaining the Bighorn Sheep habitat at Queens Canyon.

At about the time that MRAC was formed, the Colorado Mountain Reclamation Foundation (CMRF) was created. While MRAC was developing the enhanced reclamation plans, the CMRF developed its structure and organization. In 1994 the CMRF hired a part-time Project Manager and Executive Director, Wanda Reaves, the foundation's only paid member. The CMRF assumed the responsibility for administering the enhanced reclamation projects for each quarry. It also became the liaison between the community and Castle Concrete. From 1991 to 1995 the CMRF created its administrative structure and developed a campaign to raise funds to match the governor's $75,000 commitment, plus the additional funds needed for the enhanced reclamation. A procedure was developed where Castle Concrete performed the necessary earthwork to prepare the quarries for the revegetation work and the CMRF recruited a large number of volunteers to plant trees, seed and maintain the reclaimed areas. The physical work of enhanced reclamation began on the quarries in 1995.

Mobilizing the Community

Through the efforts of the CMRF, the enhanced reclamation projects gained support and attracted volunteers who wanted to participate by "doing something about the scars." Funding and in-kind support have come from a variety of organizations and individuals. To date approximately $500,000 in cash has been raised, with an additional $800,000 of in-kind contributions. Numerous businesses, organizations and individuals within the region have donated cash. In-kind donations have been invaluable for acquiring goods and services that otherwise would be difficult to obtain. For example, the receipt of topsoil and organic material is treated as an in-kind donation, and logistical support for the spring planting events, such as Burger King providing breakfasts for the volunteers, is also an in-kind donation. The annual "Scale the Scar" event has attracted hundreds of people who contribute cash and participate in a hike to observe the reclamation progress. A major supporter providing cash and in-kind contributions has been Castle Concrete, which has supported the foundation's mission and the work on its quarries.

Community volunteers have been mobilized by offering numerous opportunities for individuals and groups to participate. As many as 350 volunteers have participated on Saturday mornings during April and May to plant trees. Volunteers have included soldiers from the U.S. Army at Ft. Carson who have provided transportation within Queens Canyon Quarry during the spring planting events. Maintenance crews volunteer for weekday and weekend shifts to water the seedlings and repair wind-damaged tree protectors. And volunteers prepare planting materials and occasionally provide clerical assistance throughout the year.

Individuals and companies within the community have donated organic material to supplement the soils in the quarries. Discarded lawn material has been delivered to the site, which has an added benefit of reducing the amount of space consumed by such wastes in the local landfills. (It is estimated that such waste accounts for approximately 20% of Colorado's solid waste). Discarded Christmas trees have been delivered to Rocky Top Resources, converted to mulch and the mulch delivered to Queens. Landscapers and homeowners have provided other kinds of organic materials, and the Homebuilders Association of the Pikes Peak Region has donated topsoil from building sites. Over 110,000 cubic yards of such material has been delivered to

Queens Canyon. Castle Concrete provides the labor and equipment to combine the material and spread the resulting topsoil on the sites designated for tree planting. On occasion there have been unwanted "donations" of garbage and junk that have had to be hauled to the landfill, and volunteers have been recruited to monitor deliveries to prevent such dumping.

The quarries have offered students numerous opportunities to learn geology, botany and ecology, and have provided a link to nature for those who have little access to wild places. Examples include a group of American Express Travel Division employees, most of whom were from New York, who worked as a tree maintenance crew at Queens Canyon Quarry. Their goal was to "give something back to nature" and at the same time develop team-building skills. Zachary Frank, as a sophomore high school student, won three awards for a science project on Queens Canyon titled "Mountain Reclamation: The Effects of Soil Composition on Tree Growth." His project received an award from the Horticultural Arts Society of Colorado Springs, won the U.S. Army's Best Environmental Project award, and placed third in the biology category in the Pikes Peak Region Science Fair. Seventy-five members of the Garden Club of America surveyed the progress at Queens Canyon in August 1998 as part of a meeting of the group's Conservation and National Affairs and Legislation committees.

Queens Canyon Quarry has become a popular destination for El Paso County's students, who have come by the busload to plant trees and learn from the mountain. They have come from the Air Force Academy, Colorado College, CU-Springs, District 11, District 20, Cheyenne Mountain High School and The Colorado Springs School to learn about reclamation through a hands-on experience. Sixty freshmen from CU-Springs worked as a tree maintenance crew at Queens Canyon site as part of their community orientation.

A teacher at The Colorado Springs School uses Queens Canyon as a learning tool. Her sixth grade science curriculum begins with a unit on erosion in which students experiment with models to examine, on a small scale, the causes and effects of runoff and lack of flora. The students then plant trees in the quarry, which provides them with an opportunity to apply what they have learned in class.

The significant story about the mountain scars issue in Colorado Springs and El Paso County is the transformation of the community's attitude toward the quarries during the past 10 years. The community and Castle Concrete have moved from being opponents to being partners in the restoration of the community's scenic backdrop. Castle Concrete has given up some of its mine reserve to protect the scenic quality of the foothills and is working with the community to achieve the reclamation objectives that the community wants. People in the community have gained an understanding of the role the quarries played in the development of Colorado Springs and what can be achieved with the reclamation effort. They have also learned about the benefits that the quarries provide as wildlife habitat and as a laboratory for studying biological and earth sciences and natural resources management. The enhanced reclamation process will continue for many years, and a firm foundation has been developed to continue the effort and resolve issues as they may arise.

ENHANCED RECLAMATION OF QUEENS CANYON QUARRY

History and Description of Queens Canyon Quarry

Queens Canyon Quarry began operations in 1955. Reclamation began in 1967 when the mined-out area on the upper portion of the quarry was planted with sweet clover and various grasses. At that time the post-closure land use objective was to create wildlife habitat to support the resident Rocky Mountain Bighorn Sheep herd. The lower portion of the quarry was mined until 1990, at which time Castle Concrete decided to cease mining operations. The reclamation objective approved by the Mined Land Reclamation Board for the lower portion of the quarry is also Bighorn Sheep habitat.

Overall the disturbed area is relatively steep with predominantly south and southeast facing slopes. The environment is semi-arid with sparse trees, shrubs and grasses. Tree and shrub species include Pinyon Pine, Juniper, Mountain Mahogany and Scrub Oak, typical of what one observes in the foothills along the Colorado Front Range.

Reclamation of the quarry has progressed since the initial work in 1967. The plan was updated in 1976 to meet the requirements of the Colorado Mined Land Reclamation Act and the reclamation permit was issued in 1980. The upper portion, known as Tract 1, was reclaimed and released from bond by the Mined Land Reclamation Board 1981. In 1989, Castle Concrete was given an award from the Colorado Mined Land Reclamation Board and the governor for the work performed on Queens Canyon Quarry, which included the creation of the habitat for Bighorn Sheep.

The Queens Canyon Quarry Visual Impact Issue

Queens Canyon Quarry is highly visible in the foothills landscape when viewed from downtown Colorado Springs and from the south. The quarry once stood out in stark contrast to the surrounding undisturbed landscape. It is this quarry that elicited the remark about the "scar" on the mountain from Secretary Udall.

Recommendation of the Mining Reclamation Advisory Committee

MRAC examined the base reclamation plan approved by the Mined Land Reclamation Board and became familiar with the underlying technical issues. These included the need to control erosion on the steeper dip slopes, the challenge of establishing vegetation in the arid environment, and the characteristics of Bighorn Sheep habitat, to name a few. Once the committee had an understanding of the environmental conditions at the quarry, it explored measures to improve the aesthetic results of the reclamation efforts. The MRAC report states that the "...enhanced reclamation plan seeks to maximize visual qualities consistent with a big horn sheep habitat by producing dense grass cover, a moderate shrub cover, and a scattered distribution of trees, in greater numbers than contemplated by the existing plan." The plan emphasized the use of texture to reduce the visual impact rather than attempting to change the form or topography of the site. It was realized that topographic variation for this site resulted in minor changes to the visual appearance of the quarry relative to the surrounding area. The desired texture was to be achieved by planting diverse vegetation and distributing the vegetation strategically around the site. The variation in color and size of the vegetation would create a texture that would blend more with the surrounding area as compared to a less diverse vegetation mix.

Queens Canyon Reclamation Activity and Results

Rocky Mountain Bighorn Sheep Habitat

The Rocky Mountain Bighorn Sheep is the Colorado State animal. Among the factors considered in reclaiming the Queens site are the habitat requirements of the area's resident Bighorn Sheep herd. The present-day herd, numbering between 75 and 100, grew from a group of about a dozen that came to Queens Canyon area by accident. They were being relocated from the Tarryall Mountains to Pikes Peak in 1946 when the truck carrying them broke down on Highway 24. Rather than leave the animals shut inside until repairs were made, the back of the truck was aimed at Pikes Peak and the sheep were released. Instead of heading south, they headed north and stayed. This herd is now a seed herd for establishing other Bighorn Sheep herds in Colorado

The Colorado Division of Wildlife, which maintains the herd's health, looks for a balance between tree plantings at Queens and the meadowland acreage that the Bighorns need. The Bighorn habitat requires a clear field of view to spot and flee from predators. The Bighorns' chief predator is the mountain lion, which hides in wooded areas and attacks the sheep from behind. The lion's target is the back of a Bighorn's neck. Rams have massive horns that curl back to protect their necks, then grow forward, with the tips reaching eye level when they are 7 or 8 years old. Males, thus protected, feel more comfortable in forested areas.

Ewes, on the other hand, have shorter, slimmer and less curved horns that provide far less neck protection. Except for rutting season in November, rams tend to live apart from the rest of the herd, so the ewes and their young spend most of the year living together on grassland, keeping a watchful eye for predators, including bears, coyotes and domestic dogs. When danger approaches, they need an easy escape route to safety on rocky terrain. According to the Division of Wildlife's Bob Davies, one or two of the sheep are lost each year to predators, their carcasses most often found in areas where meadow joins woodland.

The enhanced reclamation plan was developed in consultation with the Colorado Division of Wildlife, and the resulting pattern of wooded and meadowland is anticipated to meet the needs of the Bighorn Sheep herd that lives in the area.

Importing Topsoil

During the 1980s Castle Concrete recognized that the limestone waste in itself was not a suitable growth media. The company conducted studies of different methods of seeding and the use of various fertilizers and soil amendments to determine what combination of factors would improve the growth media and vegetation success. When excess soil from the Cedar Heights housing development was made available to Castle Concrete, the company deposited it on the limestone waste of the Snyder Quarry visual berm. The combination of topsoil and the moist limestone subsoil resulted in the successful establishment of vegetation. When reclamation of Queens Canyon Quarry commenced in 1990, excess soil from the Mountain Shadows development was placed in one area and produced greater success than had previously been achieved on Queens.

Based upon these experiences, Castle Concrete began to explore steps that could be taken to import soil as an amendment to use with the limestone waste.

MRAC acknowledged during its deliberations that the limestone waste material was not a suitable growth medium for achieving the objectives of the enhanced reclamation plan. MRAC supported the idea of importing topsoil and organic material to create a suitable growth media. As a result, a location was set-up for receiving donations of topsoil and organic material at Queens Canyon Quarry. More than 110,000 cubic yards of such material had been donated by the end of 1999.

A study compared vegetation development rates and patterns on topsoil with the development rates and pattern on mine spoil. It was determined that the topsoil accelerated the rate of development three to five times over what occurs on mine spoil. However, the topsoil tends to reduce the rate of successful invasion by native species and creates lower diversity of vegetation and a much higher number of annual species, especially weeds (Heifner, 1998).

Revegetation of the Disturbed Areas

Revegetation objectives targeted four types of plants to be strategically located on the site. To achieve the objective of Bighorn Sheep habitat, the upper portion of the quarry is to be planted with mostly grasses and a few shrubs to provide for the meadowland acreage. To achieve the texture objectives, the lower portion of the quarry is planted with trees, wildflowers and grasses. It is expected that shrubs will eventually invade the lower part of the quarry. As of September of 1998, 122 plant species have been identified on the site. This is probably no more than 80% of the species that occur on the site. Only about 15 of the species on the list were planted. The rest have invaded from surrounding lands, from the imported topsoil or from long-distance wind or animal dispersal. The planting objectives are discussed below.

The "forest" that is being created is not an attempt to replicate the condition of the land before mining, because although the dry, thin soils on the slope's original surface supported shrubs, few trees were established. With the addition of the topsoil and the re-contouring of the surface, the land and the materials being worked today are not the same as those prior to mining. The tree planting plan has been designed to soften the appearance of the scar and blend the mined area with the surrounding area, where patches and lines of trees are mixed with grassland.

Trees were first planted at Queens in the late 1960s. Nursery-grown Juniper and Ponderosa Pine seedlings and Pinyon Pines transplanted from a road construction site were planted in quarry spoils, with varying degrees of success. There also were test plantings of non-native Russian olive, shrubs and yucca, much of which did not survive.

When the CMRF began planting trees in 1995, much more was known about the conditions that would be needed to promote tree survival to meet the enhanced reclamation objectives. Topsoil, as discussed above, was needed to provide a better growing medium; improved water retention around the seedlings was necessary; the seedlings needed to be protected from the dry winter winds to prevent desiccation; and competition from other plants needed to be reduced. These requirements led to the creation of a method used by the volunteers to plant the seedlings during the annual tree planting. The method is as follows:

1. A round hole is dug at least 1 foot in diameter and 9 inches deep.

2. A handful of polyacrylamides is placed in the hole. The polyacrylamides are used to store water in the rooting zone.
3. The seedling is gently removed from its container, holding as much soil together around the roots as possible, and placed in the hole.
4. Loose soil is placed back over the roots, filling the hole halfway. The soil is lightly tamped and then the rest of the hole is filled. The soil is tamped again unless it is very wet. Tamping wet soil reduces the oxygen available to the roots.
5. A small dam is built around the seedling to retain water.
6. Weed-barrier fabric is placed around the base of the seedling and secured with metal pins and rocks.
7. Bamboo stakes are threaded through two sides of a mesh tree guard and gently lowered over the seedling. The stakes are pushed into the soil. The tree guard protects the seedlings from browsing.
8. A wind barrier is positioned next to the seedling to protect it from wind desiccation. (Reaves, 1999)

A mix of Pinyon Pine and Rocky Mountain Juniper has been planted at Queens, for a total of 4,260 trees since 1995. Larger trees have been more difficult to establish than seedlings. Dry-land species such as Pinyon and Juniper tend to have broad, fairly shallow root systems, and when the trees are collected for transplant, the feeder roots are lost. This isn't a problem with seedlings, because they come out of the container with their entire root system intact. When the Queens enhanced reclamation plan was developed, the estimates of potential tree survival varied from 10% to 80%. After the first five years, the seedling survival rate is about 80% overall, with some sites as low as 30% and others as high as 95%. The growth pattern of Pinyon Pines and Junipers is outward rather than upward, and given the high percentage of survival so far, it is anticipated that some of the trees will yield to competition from their neighbors. There is also some evidence that damage to the trees by the sheep may reduce the overall survival rate. Others may eventually need to be thinned to promote the overall health of the new forest. The ultimate measure of success, however, is the number of trees that survive to reproductive age, in about 15 years.

In 1997 an attempt was made to plant 45 larger Ponderosa Pines, but all the trees died. These trees were replaced with two to three foot Ponderosa Pines. Approximately half of these trees have survived. The trees are regularly watered through a drip irrigation system.

When a vegetation survey was conducted in 1998, it was noted that tree plantings of Pinyon Pine and Juniper have been mostly on the dip slope of the quarry. The final areas to be planted toward the bottom of the quarry have less slope and greater water availability. Consideration is being given to planting broad-leaved species in the wetter areas, such as Narrow-leaf Cottonwood and Chokecherry. This would add variety to the visual scene, fall color and new habitat.

Part of the reclamation has included the planting of wildflower seeds. Wildflowers were introduced into the enhanced reclamation plan to provide greater plant diversity, as well as to provide visual enhancement. The seeding has been concentrated on 12 acres on the lower third of the quarry where the soil is the richest. The basic concept is that if wildflowers are established in one area of the quarry, they will then spread to other areas with suitable conditions. Funding for wildflower seed planting has come from the Broadmoor Garden Club. Among the species planted are Blue Flax, Rocky Mountain Penstemon, Palmer Penstemon, Blue Lupine, Gaillardia, and Fleabane.

The first wildflower seeding in 1995 used a wide variety of species. Seeds were distributed in a range of microenvironments that included planting in established grass communities as well as on freshly distributed soil. A dry spell during the two prime months for germination resulted in drought kill of a number of seedlings. Nonetheless, observations from the first wildflower seeding that could be made included the following:

1. Planting into established grass results in sparse success with regard to creating showy patches of wildflower growth, but is successful enough to establish a significant gain in species diversity.
2. Planting in freshly spread soil works far better, but only on sites where grass growth is not expected to be extremely favorable, e.g. north facing slopes.
3. Many of the species thought to be capable of growing on the site do not do well in any of the wide variety of environments encountered. This is probably due to the specific habitat requirements for those species. (Heifner, 1998)

Two different planting methods were used in 1998. For the first method, wildflower seeds were hand planted in hundreds of small "gardens" where there were openings in the grass cover. The soil was raked, the seeds planted on slopes with aspects other than north facing and then raked again.

The other method was to distribute seeds onto freshly spread topsoil. Blue Flax was distributed over the entire area to be seeded, and Gaillardia and Rocky Mountain and Palmer Penstemon were distributed in large patches. Immediately after the wildflower seed was distributed, the grass seed, primarily Blue Grama and various wheatgrasses, was distributed in a separate operation. The seeding rate for the grass was about 50% of the normal rate to reduce competition for the wildflowers.

As of this writing it is too early to determine what the long term results will be for the two seeding methods. A vegetation survey was conducted in the fall of 1998 and, generally, the early results are what one would expect. Where the wildflower seeding rate was high, the wildflowers were more abundant relative to the grass. Where the wildflower seeding rate was lower, the grass is more abundant. In 1998 it was reported that Rocky Mountain Penstemon and Blue Flax were doing the best. It was also noted that where tall weeds dominate (Ragweed and Lambsquarters), there was not much wildflower growth, even where wildflowers were heavily planted. Grass growth in these areas was more evident. This suggests that wildflowers are not able to compete with the vigorous growth of the weeds. A recommendation from the 1998 vegetation survey is that the wildflower plantings should be on freshly distributed soils. The planting should be done first in marked zones followed by grasses at a rate of about 50% of the normal rates.

Weed invasion in disturbed areas is always a concern. In the case of Queens Canyon the problem was compounded because of the importing of soil and other organic material from a variety of locations within the county. In particular, Canada Thistle, Spotted Knapweed and Diffuse Knapweed have become a problem. Based on the distribution of the Spotted Knapweed and the Diffuse Knapweed, it appears the Spotted Knapweed was introduced in topsoil and the Diffuse Knapweed via long-distance dispersal, most likely from vehicles. Canada Thistle appears to be well controlled. Weed control is being accomplished through manual clearing and cutting and the use of herbicides under the guidance of the weed control agent for El Paso County.

Water

The enhanced reclamation plans recognized that water needed to be provided to the site if the tree planting efforts were to be successful. Initially, a water tank placed on-site by Castle Concrete was supplied with water by the City of Colorado Springs. Milk jugs were filled from the tank and hand carried to water the seedlings. This process was very inefficient. Eventually two volunteers built a water tank trailer with hoses that extend to the planting area to water each tree seedling. This has been a much more successful watering system. As noted earlier, there is a stationary drip system that goes to some Ponderosa trees. The water is brought to the site regularly during the spring and summer. This effort, along with the extensive preparation of the soil to enhance water retention, has contributed significantly to the high survival rate of the trees.

Rock Staining

A small amount of rock was stained with Permeon to determine if the stain would provide any visual benefits. The stain did successfully darken the rock, but it has been determined that because most of the enhanced reclamation relies on establishing vegetation to create the desired visual result, that staining the exposed rock, of which little remains, would not contribute much visual benefit, if any.

ENHANCED RECLAMATION OF PIKEVIEW QUARRY

History and Description of Pikeview Quarry

The Pikeview Quarry is located near Rockrimmon in northwest Colorado Springs. No clear record exists as to when mining first occurred on this site, but it is believed to be around the turn of the century. The mining that exposed the most significant amount of underlying rock was conducted by contractor Peter Kiewit & Sons between 1955 and 1959 when approximately 3.5 million tons of rock was mined to provide material for the construction of the Air Force Academy. Soon after the Academy was completed the mine was idled, and at that time it had the appearance of steeply sloping, stripped limestone. Castle Concrete gained access to the quarry in 1969 through a lease with the Golden Cycle Corporation and purchased it in 1974. To mine the steeply dipping limestone deposit, Castle Concrete developed benches to create safe working conditions. The benches created the linear feature that extends across the face of the quarry today. Castle Concrete is currently mining the quarry.

The quarry has steep post-mining slopes with the predominant aspect being eastern with some northeastern exposure. Due to this aspect, the quarry is cooler and has more moisture available for vegetation than is found at Queens Canyon Quarry. The vegetation of most of the surrounding forested area is predominately Douglas Fir and Ponderosa Pine with Mountain Mahogany and Gamble Oak. Drier areas have Pinyon Pine and Juniper.

The Pikeview Quarry Visual Impact Issue

Pikeview Quarry is visible from the I-25 corridor north of Colorado Springs and to the homeowners in the Rockrimmon development. The linear appearance of the benched slopes and the exposed light colored rock standout in contrast to the surrounding natural landscape.

Recommendation of the Mining Reclamation Advisory Committee

MRAC recommended that the mining should continue, as it was the best way to achieve an overall acceptable final topography as material is moved. The MRAC report recognized that the previously mined areas would be difficult to address because of the unstable slope. The committee recommended that rock staining be attempted to reduce the color contrast between the previously mined area and the surrounding area. The initial application was to be experimental to see if the desired effect was achieved. The MRAC report also recognized that the inaccessibility of the benches would make it difficult to directly apply topsoil and seed. The report acknowledged that distributing topsoil on the benches could not be practically achieved and as an alternative recommended that the benches be seeded using aerial or hydroseeding methods.

For the areas that are yet to be mined, the MRAC report recommended that the benches be constructed to provide for continued accessibility so that topsoil and vegetation can be placed on the surface. The report also recommended that the planting on the benches be in a pattern that mimics the existing vegetation patterns on the undisturbed slopes above the quarry.

Pikeview Reclamation Activity and Results

After the MRAC plan was developed, Castle Concrete re-evaluated its mine plan and determined that a significant amount of the area at the south end of the quarry that was to be exposed by mining could be removed from the mine plan. If mined, this area would have been highly visible because of its high elevation within the quarry. In lieu of mining the area, Castle Concrete wanted to mine deeper into the pit, which is below the line of sight. The concept received support from the community, and subsequently 25 acres that were to be mined were removed from the permit area. In addition, this modification enabled the community and Castle Concrete to accelerate the enhanced reclamation on a portion of the quarry to the south. The south end of Pikeview Quarry was sculpted and reclaimed with topsoil, trees and wildflowers. Under the current plan, the north end will be left as benched rock. The benches are to be sprayed with Permeon, a rock stain that creates the look of weathered rock. An alternative to this plan, known as the "layback" plan, is currently being considered and is discussed below.

South End Reclamation

In 1996 and 1997 Castle Concrete finished grading the south end of the quarry so it could be reclaimed. Between 1996 and 1998, donated topsoil was hauled to the site and placed on the regraded slopes. Approximately 100 Air Force Academy cadets planted more than 700 Douglas Fir seedlings on the south end in 1997. Additional plantings by volunteers in 1998 brought the total number of seedlings to 1,200. Weed control became necessary in two areas of the plantings in 1998. Weeds were cut and the noxious weeds sprayed with herbicides to reduce competition for the seedlings.

In 1999, a slump caused by harsh spring rain and snowstorms dislocated approximately 350 of the Douglas Fir seedlings in the south end reclaimed area. The area will be reworked in 2000 to stabilize the slope and replant seedlings where necessary.

Rock staining

Early in the project there were high expectations that staining the exposed limestone would contribute significantly to a reduction in contrast between the light-colored limestone and the darker rock in the surrounding area. Rock staining along portions of Colorado's scenic highways has had very positive results, notably Vail Pass and Glenwood Canyon, and some mines have used rock staining with favorable results. However, because the Pikeview benches are covered with unstable rock, it is predicted that stained rock would eventually slough and expose the light-colored, unweathered layer. For this reason, rock staining was suspended until the stability problems could be addressed. The layback plan addresses the stability problem.

The Layback Plan

Since the initial enhanced reclamation plan was developed, Castle Concrete and the community have continued to consider alternatives to achieve the best possible reclamation for Pikeview. The better-than-expected results at Queens Canyon Quarry and concerns over the stability and unsightly appearance of the benched rock have led to the development of a plan to create a gentler slope on the mined north face and remove the crumbly limestone veneer. This would leave a foundation of stable granite. The granite base would be backfilled with quarry waste, covered with topsoil and revegetated. Remaining granite outcroppings would be stained to enhance the natural look of the slope. This plan would include filling the pit to achieve the overall desired final slope. The layback plan would take several years to achieve because the area would be re-mined, but the end result would be a more stable slope and a greatly improved visual appearance.

One reason the layback plan was not part of the original plan and not addressed by MRAC is because the layback will affect the land managed by the U.S. Forest Service to the west of the quarry. Historically, Castle Concrete has not had access to this land, which has limited its mining and its ability to resolve some of the stability and visual impact problems. Within the past few years the layback concept has been discussed with U.S. Forest Service representatives and presentations have been made to the Colorado Springs City Council and the El Paso County Commissioners, with favorable response from all to date. The concept is currently being presented to groups within the community.

RECLAMATION OF SNYDER QUARRY

History and Description of Snyder Quarry

The Snyder Quarry, first mined in 1871, is located south of Queens Canyon and north of Manitou Springs. It had been mined periodically during the 1900s. Castle Concrete acquired the property in December 1969 and commenced mining in 1970. Initially most of the mining was conducted by underground methods, so the surface disturbance was not extensive. By 1980, when Castle Concrete obtained a Mined Land Reclamation Permit, all but a small amount of the mining was conducted by surface methods. Between 1980 and 1989 Castle Concrete expanded the permitted area from 30 acres to 80 acres. Approximately 30 acres remains disturbed today. The quarry currently is not being mined, but Castle Concrete plans to mine it in the future. The efforts of the MRAC process prompted Castle Concrete to make further modifications to its reclamation plan in 1994 to achieve the enhanced reclamation objectives once it recommences operations.

The site is located at the head of a side canyon to Black Canyon. The site faces southeast and is high on the valley wall. The vegetation on the site is generally forest with scattered areas of shrub and grasses. The site tends to have more moisture than Pikeview and Queens Canyon as evidenced by the domination of cool season plant species and the overall success of the vegetation.

Because Snyder Quarry is not being mined and future mining is anticipated, there has been limited work performed at the site. Castle Concrete constructed a visual berm in 1984 and between 1996 and 1998 additional trees and wildflowers were planted on the berm by CMRF volunteers.. This included approximately 850 trees planted on the berm, a back wall and the road.

The Snyder Quarry Visual Impact Issue

Snyder Quarry is not nearly as visible as are the Queens Canyon and Pikeview quarries. A portion of the quarry is potentially visible from the city and valley to the southeast and it is visible from some of the homes that have been built in the area. Before Castle Concrete modified its reclamation plans for Snyder Quarry, as discussed below, there was concern that portions of the quarry would become more visible as the operation expanded.

Recommendation of the Mining Reclamation Advisory Committee

The visual berm was recognized by MRAC as a successful effort to hide the quarry disturbance as viewed from Highway 24, from the road leading to the quarry and from some locations in the valley. The MRAC plan encouraged continued management of the berm and planting additional vegetation to improve the results on some areas of the berm.

The principle recommendation of the MRAC enhanced reclamation plan for the areas to be mined in the future is to adopt an intense revegetation plan that will create greater density and diversity on the reclaimed areas than approved in the reclamation permit. The enhanced reclamation plan describes in detail how the soils are to be managed and how trees and shrubs are to be placed on the mine benches.

Snyder Reclamation Activity and Results

Mine Plan Modifications

After the MRAC report was completed, Castle Concrete voluntarily removed approximately 10 acres from its mine plan and re-sequenced the order in which the remaining land will be mined. The modification increased the depth of the mine, which will be less visible and will offset the loss of reserve from the removal of the 10 acres. The result is that a highly visible area will not be mined and the re-sequencing will allow for more concurrent reclamation. This will enable reclamation to occur on the more visible portions of the quarry before the mining operation is completed.

MRAC's emphasis on the reclamation of the benches prompted Castle Concrete to develop a mathematical model that improved its planning of bench configurations. It is anticipated that the use of this model will enable reclaimed slopes to be created with greater accuracy and consistency than was previously possible. This will improve bench construction and provide a stable foundation upon which to place topsoil and grow vegetation.

Visual Berm Reclamation

Between 1996 and 1998 approximately 600 Pinyon Pine and Juniper seedlings were planted on the berm. As of 1999, most of the seedlings had suffered storm damage, but the survival rate is still about 80%. In addition, 50 two-to-three foot tall trees were planted on the berm in 1996. About half of the 50 trees survived. Replanting of some of the areas that were damaged is under consideration. Vegetation growth on the berm from plant material remaining in the salvaged soil has been very successful, particularly the establishment of Mountain Mahogany.

Other Activity

One of the visible features at Snyder Quarry was a large waste pile that was a remnant of past mining activity. Castle Concrete has reduced the size of the waste pile by pushing most of the material into the pit. This has removed what some considered an unsightly feature at the quarry.

SUMMARY AND CONCLUSIONS

The 50-year mountain scars controversy has produced a remarkable story. For many years the citizens in the community and Castle Concrete were unable to resolve the controversy because of their competing interests: the desire to preserve the scenic beauty of the foothills versus the need to supply rock products to support economic growth in the region. In the late 1980s a series of events created an atmosphere that mobilized state and community leaders, Castle Concrete Company and citizens to begin to look for ways to resolve the controversy. The governor's commitment of $75,000 in seed money for enhanced reclamation helped spur the community's progress toward a resolution. The next critical step was the creation of MRAC by the city and county governments and the development of a process that encouraged communication among the parties and the exploration of reclamation ideas. The process enabled the parties to educate each other and to learn how to work together. Once MRAC and Castle Concrete agreed upon the enhanced reclamation plans, the elements were in place to develop community support and citizen participation in the reclamation projects. This was accomplished through the efforts of the CMRF. After five years of working together on the quarries, a cooperative relationship has been developed between Castle Concrete and the community that will enable them to solve problems as they arise and to complete the enhanced reclamation.

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CLOSURE OF A TAILING IMPOUNDMENT AND CREATION OF EAGLE PARK RESERVOIR

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ABSTRACT

Colorado's Climax Molybdenum Mine provides a unique and storied history of mineral development and high altitude land stewardship spanning 80 years. A component of ongoing site reclamation activities includes the development of water resources in areas impacted by mining operations. This paper presents a case study on project development, water quality assessment, and the regulatory framework that contributed to the success of a project that began at the Climax Mine in 1993 to reclaim a tailing impoundment storing oxide tailing. The Oxide Pond was constructed in the 1960's during the extraction of molybdenum from oxide ore located adjacent to the Climax molybdenite deposit. The fine–grained tailing material from the complex extraction process was impounded behind an earthen–core dam. This impoundment, located at high elevation on privately held land, presented an opportunity for reclamation and water resource development beginning with the establishment of cooperative regional water alliances. Tailing materials were removed from the reservoir between 1995 and 1996 and the reservoir was evaluated for the effect residual substrate and lake dynamics would have on in-stream water quality. Water from Eagle Park Reservoir was delivered to the Eagle River in late 1998 and stands as a model for future reclamation efforts that involve water delivery to highly sensitive receiving waters.

INTRODUCTION

This paper describes a tailing removal project that occurred between 1993 and 1996 at the Climax Mine, Climax, Colorado that was designed to obtain a post-mining beneficial land use of developed water resources in the Eagle River Valley. Conversion of the Oxide Pond into the freshwater Eagle Park Reservoir was accomplished through the cooperative effort between Climax and the Eagle Valley Consortium. The Consortium, a group of water users, municipalities, and ski industry interests in the Eagle Valley, supported development of the project for upstream replenishment of water withdrawals during low flow periods. Discussed in this paper are the removal of tailings from the tailing pond, employment of pollution prevention from upstream mine process water sources, water quality assessment, and reclamation of the 25 ha water body.

BACKGROUND

The Climax Mine, located at the Continental Divide (elevation 3450 m) on Fremont Pass in central Colorado (Figure 1), is the largest identified molybdenite orebody in the world. The first processing of molybdenite from Bartlett Mountain occurred in 1918. Climax has since led research and development of molybdenum use in numerous products and applications.

The location of the Climax Mine is unique in that the facilities straddle the Divide and encompass the headwaters of three drainages: Tenmile Creek, draining north to Lake Dillon and the headwaters of the Blue River, the Eagle Rivêr draining to the Colorado River through the central portion of the Upper Colorado River Basin, and the Arkansas River, flowing south then east to the Mississippi River. The mine receives approximately 63 cm of precipitation annually, 75 percent of which is snow. Average annual snowfall at the site is 6.9 m. Major activities at the site currently include water treatment and water management for a multitude of downstream water uses.

Climax developed an infrastructure of water delivery conveyances to support consumptive water use in the processing of molybdenite. Today the system serves as an extremely flexible water delivery and trans-basin conveyance network that serves both future molybdenum processing and the management of water allocations in three major Colorado drainages.

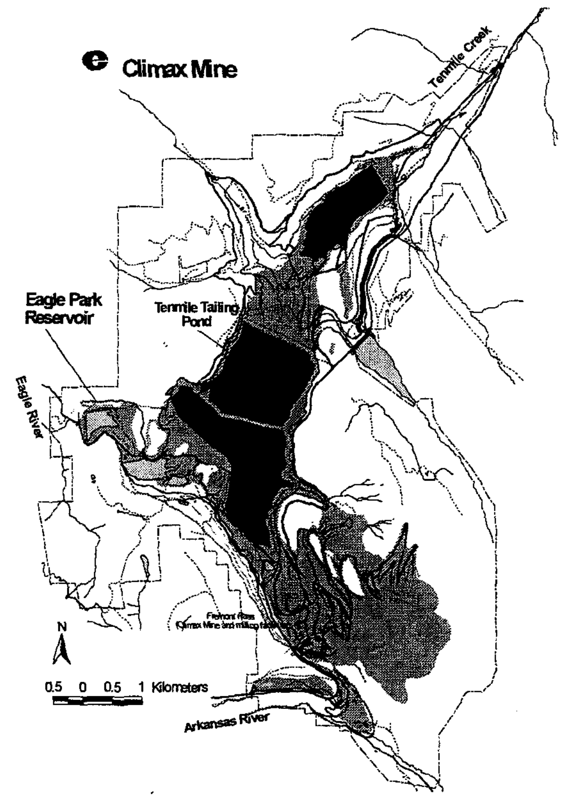

Figure 1. Diagram of the Climax Mine showing locations of the three drainages and the location of Eagle Park Reservoir

THE OXIDE PROCESS

In 1961, the Climax Molybdenum Company explored potential molybdenum extraction techniques from an ore zone containing oxide molybdenum (ilsemannite; $Mo_3O_8 \cdot nH_2O$) that surrounded the central molybdenite orebody. Recognizing that molybdenum could be extracted from this mineralized source, Climax embarked on processing of the oxide ore. The process consisted of a complex treatment of selected mixed ores fed to a 5,100 metric ton per day processing plant capable of recovering 0.7 kg of molybdenum per ton of plant feed. The process began with preconcentration following basic classification for tailing that had passed through the sulfide flotation circuit. Fines were separated in the preconcentration step and pumped as a pulp to the oxide plant where the pulp was agitated with sulfur dioxide and sulfuric acid. Desorption tanks were then used to drive off sulfur dioxide. Air was injected into the system to reoxidize the dissolved molybdenum allowing it to adsorb onto carbon filters. The carbon filters containing molybdenum were then subjected to stripping columns using a gaseous stream of ammonia (Amax, inc., 1966).

This process produced a solution of ammonium molybdate that was purified and heated to a crystallized form. Finally, this ammonium molybdate was roasted and converted to commercial grade molybdic oxide. The entire Molyoxide process was complex and sensitive to rather precise control of temperatures, pressures, and volumes.

Production at the Molyoxide plant ran from July of 1966 to September of 1968. Curtailment of production occurred largely due to the plant's interruption of efficiencies in the sulfide milling circuit that were then processing 40M tons of sulfide ore daily. Obvious additional expenditure was also foreseen as federal environmental legislation of the late 1960's came into play (Voynick, 1996).

Wastes generated from the Molyoxide process required special handling. The silt size fraction of the tailing material prevented their incorporation with the slurried and cycloned sulfide tailings deposited on the Tenmile Tailing Pond (Figure 1). The separate circuits also required separate water handling to prevent poisoning of one circuit in the management of another. At the time, Climax was producing tin, tungsten, and pyrite as well as molybdenum. The development of the oxide ore processing circuit also required tailing management in a manner that did not disrupt the handling of other ores and extraction processes at the Climax Mine and Mill. To accomplish this, Climax constructed an earthen core dam at the head of the East Fork of the Eagle River west of the primary tailings disposal facilities in the Tenmile drainage. In the two years of operation of the Molyoxide plant, 917M m^3 of tailing were deposited in this facility known as the "Oxide Pond".

PROJECT DEVELOPMENT

In 1989 a clear understanding of the water asset value of the property and a desire to reduce care and maintenance costs led to the assessment of alternatives for site footprint reduction and reclamation. Review of the Oxide Pond, from which over 370M m^3 (300 acre-feet) of water had been annually pumped to the Tenmile water treatment facilities for the 30 years following curtailment of the Molyoxide processing, determined that removal of the tailing in the reservoir was feasible (Woodward-Clyde Consultants, 1998).

The Climax Mine Reclamation Permit, held with the Colorado Division of Minerals and Geology, calls for reclamation of the Oxide Pond to a post-mining beneficial land use of *Developed Water Resources*. The methods by which Climax would obtain this designated post-mining land use were not specifically outlined in the permit. Climax evaluated long-term management of tailing in the pond and considered tailing removal using dredge and pump systems, truck and shovel removal, or capping and fix-in-place alternatives to retire the facility. Both physical and chemical characteristics of the materials were reviewed in the pre-feasibility evaluation.

The study found that cost effectiveness, long-term maintenance cost management, and the most favorable environmental protections were best obtained through tailing removal (Woodward-Clyde Consultants, 1998). The driver for this project ultimately became the regional recognition of the potential beneficial use of stored water at the headwaters of the Eagle River.

The Eagle Valley of Colorado is host to recreation and residential development activities in support of a thriving ski industry. Water use in the Eagle Valley increases during winter months for snowmaking and municipal water treatment during the winter tourist season. Stream depletions in the Eagle Valley are not replenished until the Eagle River and the Colorado River converge well downstream of water use. Upstream replenishment of in-stream depletions was therefore a desire of Eagle Valley water users, the Colorado Water Conservation Board, and other stakeholders for water use in the valley. The location of the Oxide Pond, on private land at the headwaters of the Eagle River, coupled with the presence of an earthen core impoundment capable of storing fresh water rather than tailing, provided the site for in-basin water storage. Capacity of the new facility would be 3.9MM m^3 (3,148 acre-feet) with a live yield of 2.5MM m^3 (2,016 acre-feet) (W.W. Wheeler &

Assoc., 1994). In 1993, Climax and Vail Associates entered a cooperative agreement to initiate tailing removal and tailing pond reclamation using the preferred removal options outlined in the pre-feasibility process.

PROJECT CONSTRUCTION

The preferred option using removal by hydraulic monitoring and pumping began in 1993. This initial method proved untenable due high plasticity of the material and inadequate tailing density in the slurry being pumped under high head. A truck and shovel operation was initiated in early 1995 to haul the tailing from the Eagle River basin to the Tenmile Creek basin, a distance of approximately 4.8 km. Truck and shovel operations continued through the summer of 1996.

Management of the tailing and dewatering proved to be the largest challenges during the construction project. The initial assessment of the tailing revealed that the material was predominantly composed of silt-sized particles with liquid limits ranging between 32 and 40 and plasticity indices ranging from 1 to 6. Moisture content of the material ranged from 35 to 49 percent indicating that the moisture content of the oxide tailing was above the liquid limit. Materials were considered to be of very low strength, and large settlements were anticipated under small loads (Woodward-Clyde Consultants, 1998). During excavation, the material did behave as a heavy liquid, requiring short loading of trucks and the installation of special tailgates to hold liquefied tailing during the haul.

An equally important aspect of the removal operation was the management of water during the period of excavation and hauling. Water management was an important task in allowing equipment access and egress. In addition, thirty years of tailing storage in the impoundment had contaminated dam foundation materials as water seeped through the dam to a seepage return system at the dam's toe. This seepage and all water in the reservoir throughout the removal project required pumping to the Climax Water Treatment System in the Tenmile Creek basin. Climax treats all mine water under a National Pollution Discharge Elimination System (NPDES) permit in an active lime neutralization process to a discharge point in Tenmile Creek.

Additional pollution protections and infrastructure construction occurred through 1998. A concrete cutoff wall was constructed to a bedrock foundation in the drainage between upgradient process water facilities and the reservoir. Climax managed seepwater at the toe of the dam through pump upgrades and pipeline improvements. Because the Oxide Pond was designed to prevent the release of water down the Eagle Valley, outlet works in the Class 1 (high hazard) dam, reconstruction of the emergency spillway, and installation of conveyance and flow measurement devices were required. These dam improvements were subject to review by the Colorado Office of the State Engineer.

Since reservoir capacity was to be maximized, additional excavation occurred after Climax identified growth media (topsoil) residing beneath the tailing. During the fall of 1996, 41M m^3 (33 acre-feet) of growth media were hauled 6 km to temporary stockpiles for reclamation of overburden wastes near the Climax milling complex. This activity provided needed materials for successful high-altitude reclamation at other site locations while increasing the total yield of the reservoir.

RESERVOIR SEDIMENT AND WATER QUALITY ASSESSMENT

Reservoir Sediments

Early review of the project had determined that residual materials and impacted soils beneath the oxide tailing could pose a concern to water quality of the reservoir following tailing removal. Eagle Park Reservoir, once source tailing material was removed, would not be subject to NPDES permit requirements. Criteria upon which water delivery would be predicated, however, had not been determined. The concern for ultimate deliverability of impounded freshwater from the reservoir culminated in a Sampling and Analysis Plan (SAP) to define and measure the chemistry of soils and waters during and following tailing removal.

Sampling of the reservoir tailing in the prefeasibility stage of the project showed the tailing chemistry to be characteristic of geochemical profiles from the Climax orebody. The tailing were non-toxic but acidic due to the nature of the extraction process that used sulfuric acid. Parameters measured in the pond water and tailing reflected parameters assigned to Eagle River standards under Aquatic Life Class 1 Cold, Recreation Class 1, and Water Supply use classifications (Table 1). Initial testing revealed that manganese, iron, zinc, and to a lesser degree aluminum and copper, were the primary constituents found in the tailings and Oxide Pond waters.

Table 1. Water Quality Standards for Segment 3 of the Eagle River

Physical/Biological	Inorganic (mg/l)		Metals (ug/l)		
D.O.=6.0 mg/l	NH_3(ac/ch)=TVS	S=0.002	As(ac)=50(Trec)	Fe(ch)=300(dis)	Ni (ac/ch)=949.2/988.4 TVS
D.O.(sp)=7.0 mg/l	Cl_2(ac)=0.019	B=0.75	Cd (ac)=10.3 TVS(tr)	Fe(ch)=1000(Trec)	Se(ac)=135 TVS
pH=6.5-9.0	Cl_2(ch)=0.011	NO_2=0.05	Cd (ch)=1.17TVS	Pb (ac/ch)=101.9/4.1 TVS	Ag (ac)=2.2 TVS
F.Coli=200/100ml		CN^-=0.005	CrIII (ac)=50(Trec)	Mn (ch)=1000(Trec)	Ag (ch)= 0.3 TVS
		Cl=250	CrVI (ac/ch)=18.4 TVS	Mn (ch)=50(dis)	Zn (ac/ch)=120.8/109.5 TVS
		SO_4=250	Cu(ac/ch)=18.4/12.2 TVS	Hg(ch)=0.1	

TVS = Table Value Standards based on hardness of 103.8 mg/l as $CaCO_3$ ch = Chronic ac = Acute
Trec = Total recoverable dis = Dissolved

The Sampling and Analysis Plan (SAP) was designed to demonstrate source removal and prove limited interaction of residual material with the large volume of water storage (Titan Environmental Corp., 1996). The SAP consisted of a reservoir bottom material sampling event utilizing composite samples taken at a depth of 0 to 15 cm on thirty 0.8 ha sample plots. QA/QC followed EPA's CLP standards to ensure data quality for soil and water samples. Soil samples were subjected total metals analysis and to a modified Meteoric Water Mobility Procedure of the Nevada Division of Environmental Protection (Nevada Division of Environmental Protection, 1990). This test used lixiviant adjusted to a pH of 7.5 to 8.0 to reflect background water pH ranges measured in the diversion canals used to fill the reservoir. Further analyses were made for total organic carbon and soil texture. Results of these soil and sediment analyses are provided in Table 2.

Several factors led to the conclusion that residual materials would not pose a threat to ultimate water quality in the reservoir. First, there was a clear distinction between the tailing material and the underlying soils and rock overlain by tailing deposition. Second, any waters introduced to the reservoir that would be in contact with residual materials would be small when compared to the overall volume of the reservoir. Third, following thirty years of tailing storage, more soluble components of the tailing had already dissolved. Mineral components of the remaining tailing were considered to be much less soluble than those in the material originally deposited (Titan Environmental Corp., 1996). Other factors that aided in the understanding of low potential soil and sediment impacts to water quality included the presence of bedrock over much of the reservoir floor, and the removal of growth media as described above. Reservoir configuration and depth (35 m) were considered favorable because lake turning and stratification (10 m) would limit the suspension of lake sediments.

Reservoir Water

Using results of the reservoir sediment analyses, a straight dilution model assuming 100 percent mobility of metals revealed that primary standards for the East Fork of the Eagle River could be obtained following reservoir fill. However, this conservative modeling for secondary drinking water standards for Mn (50 µg/l) showed reservoir levels slightly above the standard. Freshwater delivery of water into Eagle Park Reservoir began in the spring of 1997 through two diversion canals that bracket the Climax water treatment and process water circuit upgradient of mine facilities. These freshwater sources had previously been used to divert freshwater around the reservoir to the Eagle River. The 50 ha basin below the diversion canals provided additional water to fill the reservoir. Figures 2 and 3 show water quality in the reservoir for selected parameters through the filling period and SAP sampling conducted in 1997. Post-project sampling in the reservoir demonstrates that water quality has stabilized, with most parameters measured at or below detection limits. Water quality is also being monitored during winter delivery periods to further demonstrate the success of closure and reclamation of the Oxide Pond.

CONCLUSIONS

Reclamation of the Eagle Park reservoir demonstrates the public benefits that can accrue through cooperative initiatives between industry and regulatory agencies. Water delivery to the East Fork of the Eagle marks the first time in thirty years that water within the Eagle Park Reservoir basin will be routed to the original drainage.

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Table 2. Reservoir Sediment Total and Leachable Metal Concentrations

	As		Cr		Cu		Fe		Pb		Mn		Ni		Zn		Ag	
	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)
Min	0.55 U	0.0025 U	5.6 U	0.004 B	5.6 U	0.005 U	27 B	0.01 U	9	0.001 U	2.8	0.11	5.6 U	0.01 U	17	0.01 U	1.4 U	0.05 U
Mean	2	0.0025	13	0.01	24	0.05	16,741	0.01	48	0.001	180	4.93	12	0.02	45	0.02	2.3	0.05
Max	4 B	0.0025 U	20	0.018 B	51	0.07 B	22,400	0.03 B	84	0.001 U	444	16.7	20	0.05 B	89	0.07 B	2.8	0.05 U

U = Analyte was not detected at the Method Detection Limit (MDL).
B = Analyte concentration detected between the MDL and the Practical Quantitation Limit (PQL)

Note: boron, cadmium, selenium, mercury, chloride, and nitrate were removed from the parameters analyzed in preliminary screening analysis.*

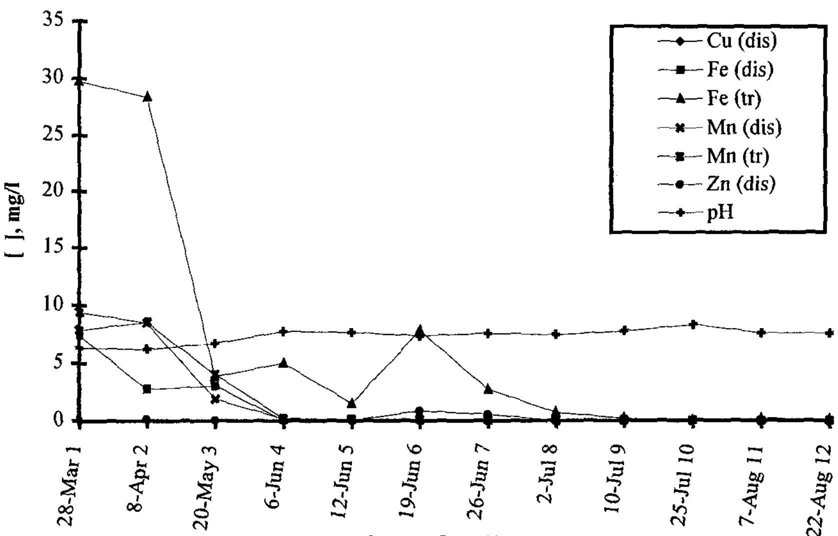

Figure 2. Eagle Park Reservoir Water Quality Trend 1997

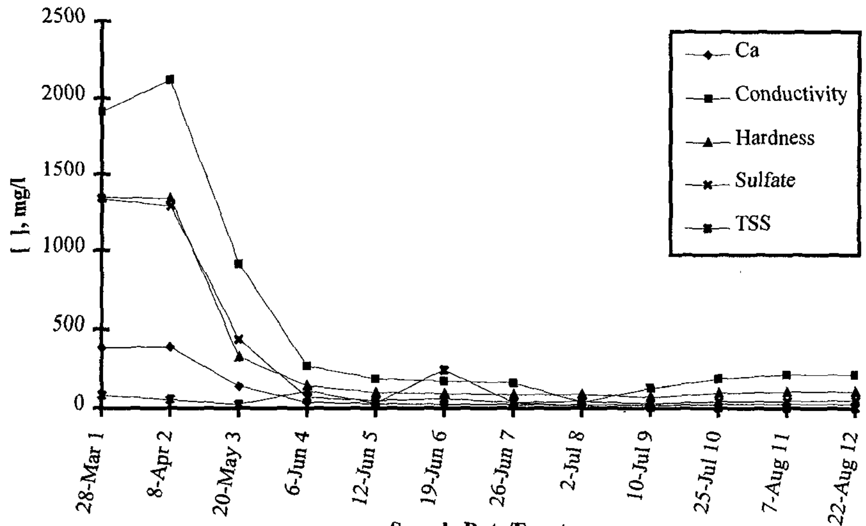

Figure 3. Eagle Park Reservoir Water Quality Trend 1997

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ROADSIDE RECLAMATION ALONG HIGHWAY 82: ASPEN TO BASALT, COLORADO

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ABSTRACT

Colorado highway 82 from Basalt to west of Aspen is under construction to widen the highway from two lanes to four lanes to alleviate traffic congestion. Reclamation of roadside slopes is challenging as terrain is steep with less than 1:1 slopes adjacent to sections of the highway and the Roaring Fork River. Roadside construction and reclamation along the fifteen-mile corridor is divided into six projects. Elevations range from 6640' to 7740', with annual precipitation of approximately 18". Plant inventories and topsoil investigations are made prior to site disturbance. Topsoil is stripped on site, stockpiled for re-application and soil amendments are added based on soil test results. Seed mixes and plant lists are developed from vegetation inventories. Planting amendments vary by project, including fertilizer, porous ceramic, mycorrhizae, and wood mulch. Drip irrigation is installed for shrub and tree establishment. All disturbed slopes are seeded, mulched and tacked. Erosion control is critical necessitating use of a variety of treatments from excelsior logs, willow cuttings and riprap to silt dikes, temporary pipe, blankets and reinforced silt fence. Projects are evaluated for reclamation success in terms of vegetation establishment/erosion control, visual quality and costs.

INTRODUCTION

The reclamation objective for highway 82 is to replace vegetation removed during construction, control erosion and create a visually acceptable environment. This requires seeding, planting and installation of drip irrigation to provide water for plant establishment for five years.

While it is an objective to minimize use of walls and to maximize use of native vegetation, steep terrain has made vertical walls essential. The amount of site disturbance resulting from wall construction is effected by the types of walls used and methods of construction. In some locations steep 1:1 slopes dictate use of walls that don't require site disturbance above the walls as the slopes cannot be adequately reclaimed.

Revegetation with introduced species versus native grasses and forbs is an important consideration. The approach for these projects is use of quick germinating annual grains and short lived native grasses with slower establishing native species. Less aggressive and low growing grasses have been used to favor establishment of forbs.

METHODS AND PROCEDURES

Where terrain and narrow right of way make it necessary to build walls, mechanically stabilized earth walls (MSE) are commonly used due to lower costs. Construction of MSE walls on cut slopes has required excavation of a 25 foot wide work area behind wall locations to install reinforcing material and replace backfill. This creates long backfill slopes above walls that require reclamation. Where existing corridor slopes exceed 1½: 1, more costly soil nail walls with a fascia panel are used, leaving uphill slopes and vegetation intact.

Before construction activity begins, erosion control products are installed at the toe of existing slopes and around inlets. Topsoil depths are then verified with the equipment operator prior to stripping topsoil. Once stripping has begun, frequent inspection is required to ensure quality topsoil. Compaction of topsoil by scrapers and bulldozers is inevitable but where possible, long low stockpiles are constructed to minimize additional compaction.

On the first corridor project, undulating slopes were constructed with 1 ½:1 and 2:1 slopes. Topsoil was mixed with compost at a ratio of 9:1 and applied 6 inches deep over all disturbed areas.

In preparation for seeding, slopes flatter than 2:1 were harrowed and steeper slopes were hand raked to break up the surface crust. Seed was mixed with a polyacrylamide humectant, 1 pound humectant per 100 pounds of seed, and seeded with broadcast seeders. A tractor mounted seeder was used to seed slopes flatter than 2:1, steeper slopes were seeded with hand held seeders. Seed was raked or harrowed into the soil to establish good seed soil contact. Seeding was done after September 1 and prior to ground freeze.

Three seed mixes were used with varying amounts and species of forbs and shrubs. Mixes were designed for planted, nonplanted and riverside slopes. The following mix was used on nonplanted slopes:

Common Name	Scientific Name	PLS Pounds
Grasses		
Idaho Fescue 'Joseph'	*Festuca idahoensis*	4.0
Arizona Fescue 'Redondo'	*Festuca arizonica*	2.0
Mountain Brome 'Bromar'	*Bromus marginatus*	5.0
Slender Wheatgrass 'Primar'	*Elymus trachycaulus*	3.0
Approximately 90 seeds per square foot.		
Forbs		
Lupine	*Lupinus perennis*	2.0
Palmer Penstemon	*Penstemon palmerii*	2.0
Fireweed	*Epilobium angustifolium*	.25
Lewis Flax	*Linum lewisii*	1.0
Blanket Flower	*Gaillardia aristata*	1.0
Rocky Mountain Penstemon	*Penstemon strictus*	2.0
Prairie Sage	*Artemisia ludoviciana*	0.5
Shrubs		
Wax Currant	*Ribes cereum*	1.0
Woods Rose	*Rosa woodsii*	1.0
Mountain Snowberry	*Symphoricarpos oreophilus*	1.0

Weed free straw mulch was blown on seeded areas at a rate of two tons per acre, so soil was barely visible through the straw. Tackifier made from Plantago insularis was mixed at 100 pounds per acre with 150 pounds of wood fiber and 700 gallons of water. The mixture was sprayed over the straw to hold it in place until seed germinated the next spring.

Plumeless thistle was abundant on adjacent fields and became a problem along the highway right of way. A backpack sprayer was used to spot spray thistle with Telar and Banvel at manufacturers' recommended rates.

A simple gravity drip irrigation system was installed on the two major cut and fill slopes. Half and one gallon per hour pressure regulating emitters were installed to irrigate one and five gallon native plants. During planting, holes were backfilled with soil and a porous ceramic product at a rate of one pound per one gallon plant and 5 pounds per 5 gallon plant.

Mycorrhizae was applied to plants in an attempt to reestablish mycorrhizal populations destroyed by moving and stockpiling topsoil. AgBio Development applied endomycorrhizae to random containerized plants at the nursery. After planting, these plants were measured for two years for comparison with a control population. Recent jobs have included mycorrhizae application to plant roots during planting.

Four inches of wood mulch was applied to entire plant beds to reduce competition with grasses during shrub establishment. Fertilizer was added to the beds to improve the high C: N ratio anticipated from the wood mulch. Sulfur coated urea 23-0-0 was applied 5#/1000 square feet and mixed with soil in planting beds prior to mulching.

Plants were irrigated for one hour two to three times per week based on temperatures and soil moisture in the root zones.

A variety of products were used to control erosion. A temporary creek channel was protected using nearby rock, gravel and erosion control blanket. The permanent channel was then established with a combination of riprap, excelsior logs, coconut blanket and willow cuttings. A problem was encountered where the creek began to undermine several excelsior logs and riprap had to be placed below the log to prevent additional erosion. After two years the willow cuttings are well established along the creek.

Pipe was used successfully for temporary channels and it can be quickly installed and removed. Where ditch erosion was anticipated, silt dikes and silt fence checks have been installed at 100'+ intervals to catch sediment. Inlets are protected with silt dikes, hay bales, silt fence and excelsior logs. Fencing has been used to reinforce silt fence that is to remain in place for several years. Sediment removal is paid by equipment hours or lump sum payment depending on the contract.

DISCUSSION

After 2 1/2 years of growth on the first project, vegetative cover ranges from 40 to 60 percent on most of the site and approximately 30 percent in previously compacted areas and on 1 ½:1 slopes. Slender Wheatgrass, Mountain Brome and Wheat provided early spring cover while Fescues and forbs are still slowly getting established. Showy Goldeneye and Flax began blooming during the first year of growth. Scarlet Gilia, Blanket Flower, Penstemons, Globemallow, Wallflower and

Asters bloomed during the second year. Shrub seedlings are scarce; it appears there has been little germination. An additional year of growth will provide a better indication of the success of the seeding.

Late spring and early summer seedings were required on two later jobs due to accelerated job deadlines. Germination was exceptional due to a wet summer but 3 months of drought followed. Slender Wheatgrass and Fescues shrivelled and when snow cover finally arrived the newly germinated grasses were dead. Low survival is anticipated. Biosol (1800 pounds per acre) was hydraulically applied during the spring seeding contributing to a flush of annual weed growth. The weeds were not noxious and if there hadn't been drought conditions with extreme competition for water, the weeds might have acted as a nurse crop. Instead, it is anticipated that the weeds may be the only survivors. An objective was to compare seeding on slopes with: 4" of topsoil and 1800 pounds of Biosol versus 4" and 6" of topsoil and compost. Due to fall versus summer seeding times there may not be a good comparison site yet.

Seeding costs for several jobs ranged from $1600 per acre to $3600 per acre. Costs included seed, site preparation, seeding and incorporation by harrowing or hand raking. Topsoil stripped, stockpiled, mixed with compost and reapplied cost an average of $16 per cubic yard or $8518 per acre, 4" deep.

The application of two tons per acre of straw mulch has been successful and tackifier applied at 100 pounds per acre is adequate in flatter areas protected from wind. Along the edge of roadways and on slopes subject to strong winds, 100 pounds per acre was not adequate to hold straw in place for six to eight months and it appears this rate should be doubled in these conditions. Weed free mulch applied at 2 tons per acre was $194 to $480 per acre, with an additional $150 to $300 per acre for tackifier.

Survival of one and five gallon shrubs was greater than 90 percent after the first growing season. Irrigation was infrequent during the second year and loss was greater. Elk and deer pruned and removed shrubs during the winters making our data for mycorrhizae inoculated plants versus control plants inconclusive.

Surviving plants are well established. Roses, Rosa woodsii, are spreading rapidly by rhizomes creating thickets. Junipers, Juniperus scopulorum, are surviving but foliage has scorched on the side facing the highway and hot dessicating winds. Sagebrush, Snowberry, Rabbitbrush, Oak and Serviceberry are producing seed.

Additional time is needed to evaluate pros and cons of fully mulched shrub beds but after 2 ½ years of growth, the shrubs look good and survival is high. The mulch held down competition without erosion, and helped retain moisture through prolonged dry spells.

Irrigation frequency will be cut back to one to two times per week to encourage adaptation of the shrubs. Water will be reduced each year until the plants are well established, approximately five years total.

The project is visually successful with a variety of shrubs, grasses and wildflowers established to replace what was removed during construction. As plantings mature and wildflowers become more established along the right of way the visual quality will be enhanced.

MOUNT HUMBOLDT CLIMBING ROUTE IMPROVEMENT AND RESTORATION PROJECT: A CASE STUDY IN ADDRESSING RECREATIONAL IMPACTS ON COLORADO'S WILDERNESS PEAKS

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ABSTRACT

A primary focus of the Rocky Mountain Field Institute is to develop strategies and techniques for mitigating climbing impacts in wilderness environments and restoring and/or reclaiming disturbed sites. RMFI has been working since 1992 to address the issue of climbing impacts on Colorado's alpine peaks and basins. RMFI has conducted hiking and climbing impact studies on all of the peaks over 14,000 feet and completed extensive trail construction and restoration work on three peaks: Mt. Belford, La Plata Peak, and Mount Humboldt. RMFI has also completed considerable work in South Colony Lakes Basin where Mt. Humboldt is located. The majority of this work has, to date, been conducted under the auspices of the Colorado Fourteeners Initiative, a partnership between several nonprofit organizations and the US Forest Service that was founded under RMFI's leadership. RMFI is presently completing trail construction and restoration work on Mount Humboldt and Handies Peak, and conducting research in South Colony Lake Basin to assess visitor impacts, and to identify effective restoration strategies and techniques.

During the period 1997-1998, the Rocky Mountain Field Institute completed an extensive erosion control and restoration project on Mount Humboldt (14,064 ft.) in the heart of the Sangre de Cristo Wilderness. The project involved the stabilization and revegetation of a climber created erosion gully between 12,000 and 13,000 feet, and the construction of a new summit trail.

This paper summarizes why the project was developed, the methodology that the project is based upon and the accomplishments to date.

INTRODUCTION

Accurate statistics on the numbers of persons currently climbing Fourteeners (peaks over 14,000 ft. in elevation) and the rate of increase in the popularity of this recreational activity are lacking. However, reviews of trailhead and summit registers and field observations indicate that roughly 75,000 persons ascend the Fourteeners in Colorado annually. This represents an increase of as much as 300 percent over the past 10 years on some peaks. Visitation varies dramatically from mountain range to mountain range and from peak to peak. For instance, isolated or more technically difficult peaks in the Sangre de Cristo and San Juan Ranges receive as few as 500 ascents per season, whereas peaks located in the Front Range receive this many ascents on a busy weekend.

Alpine ecosystems are vulnerable to low levels of human disturbance. The impact recovery rates for some alpine flora communities in the Southern Rockies, once damaged or compromised, are long: in the order of ten to a thousand times that of lower elevation ecosystems (Zwinger and Willard 1972). This is due to several factors that include alpine climatic characteristics including short growing seasons, low seasonal increase in biomass and unpredictable diaspore production (Chambers et al. 1990). Alpine mountains are by nature unstable environments. Boulder, scree and fell-fields constantly move and shift. The estimated time for the revegetation of a kobresia meadow, at a minimum is 500 years (Zwinger and Willard 1972). Recovery is based on the assumption that a disturbed area is stabilized and that disturbance is controlled or eliminated. On steeper slopes, seasonal run-off, or snow melt, and high winds radically accelerate soil and vegetation loss in disturbed sites. These factors create a positive feedback system that effectively prevents recovery to pre-disturbance conditions.

The current levels of use are having a significant impact on the peaks. Major soil erosion and vegetation loss has occurred on many of the popular hiking and climbing routes. Inventories completed by the Colorado Natural Heritage have indicated that on many peaks, hiking and climbing are posing risks to rare plant species.

These impacts and disturbances present a special concern in wilderness and wilderness study areas where preservation standards are high. Thirty-eight of the fifty-four peaks over 14,000 feet in elevation in Colorado are located in wilderness areas. It is fair to say that many of the popular climbing route corridors have already reached and, in many cases, surpassed acceptable or desirable levels of disturbance. The continued growth in the popularity of climbing Fourteeners and the potential for even greater levels of disturbance in the future have made this an important land management issue.

If Colorado's wilderness peaks are to be preserved, it is important that steps be taken to mitigate the impacts that are presently taking place. Furthermore, climbers have already heavily impacted many of the peaks. It is important as well that damaged areas be stabilized and restored to the greatest degree possible.

PROGRAM METHODOLOGY

It is RMFI's position that climbing route improvements in wilderness should be undertaken for the purpose of achieving preservation and restoration goals and not to make routes less tame or safe. Leaving climbing routes as undeveloped as possible is consistent with wilderness designation and protects the nature and challenge of the wilderness climbing experience. On the other hand, it is unrealistic to expect that heavily visited peaks and alpine areas remain totally unimproved. Route improvements serve to focus use and impacts, reduce the level of impact from climbers, and direct visitors away from sites of critical or special concern. Also, in cases where multiple "social trails" (visitor created trails worn into the landscape) or trail braiding is occurring, the establishment of a single path creates opportunities for restoration, thus improving wilderness conditions.

Route improvements on alpine mountains or peaks within wilderness should be viewed, first and foremost, as restoration actions, the goal of which is to achieve a meaningful and quantifiable reduction in present levels of disturbance. In the alpine zone, additional stabilization, revegetation or habitat improvement or protection actions are often required. In fact, for routes where impacts are significant, these actions may require far more resources and constitute a larger portion of the project than route improvements.

RMFI has developed the following program to provide a structure for mitigating climbing impacts. It includes the following components:

I. Mitigation and Restoration
   - Phase 1 – Impact Assessment
   - Phase 2 – Development of mitigation and restoration plans
   - Phase 3 – Completion of impact mitigation and restoration actions

- Phase 4 – Continued monitoring of impacts and assessment of mitigation and restoration actions taken.

II. User Education and Stewardship
- Development and implementation of site specific visitor information program
- Provide programs and opportunities for public participation in mitigation and restoration work.

Again, the fundamental premise of the program is that climbing route improvements must be completed within the context of a thorough and comprehensive plan to restore the route corridor.

RMFI has proposed a classification system to provide guidance and direction for making improvements on climbing routes in wilderness (Table 1). This classification system ties improvements directly to disturbance levels and the physical and biological characteristics of the areas or terrain through which the climbing route passes. In cases where existing disturbance levels or threats are minimal, little if any action is required. However, in cases where disturbance levels or threats are high, more aggressive or substantial improvements are needed.

Table 1. Classification System for Wilderness Climbing Route Improvements.

CLASS	ENVIRONMENTAL CONDITIONS	ROUTE MANAGEMENT	MITIGATION OR RESTORATION ACTIONS
I. Open Route Corridor	Corridor in pristine condition and few if any human disturbances. Minimal threats to sensitive cultural and/or biological resources exist.	Disperse use along the route corridor	None Required
II. Identified/Defined Route	Human disturbance along the corridor route is overall minimal and within acceptable limits; however, trail braiding, soil erosion and/or slope destabilization and/or damage to sensitive cultural or biological resources is likely to occur at select locations along the route corridor.	Direct hiking/climbing along an identified/defined route	Mark preferred route with cairns
III. Developed Route	Human disturbance is evident. Trail braiding, soil erosion and/or slope destabilization has occurred and there is a serious threat for continued degradation.	Travel along a developed route located on the most stable terrain and away from sensitive sites.	Make select improvements to reduce soil erosion and vegetation loss, and construct necessary soil retention and water drainage structures. Make the route easily identifiable. Restore social trails and/or disturbed sites.

Additional Actions:

The following actions apply to each class of climbing routes:
- Provide information at trailhead or beginning of route on Leave No Trace protocols for hiking and camping in pristine terrain with attention given to minimum impact hiking in alpine terrain. Work with guidebook authors to include this information in publications.
- Monitor environmental conditions in areas of concern and maintain all improvements.

It is important to note that, in theory, a climbing route may have unimproved sections as well as improved sections. In particularly sensitive locations, a fully developed trail or path may be needed. However, in locations where the climbing route passes through areas where climbing or hiking does not pose a significant threat, like alpine boulder fields, climbers can be left to choose their own way or can be directed with cairns which keep them on route. Again, the intent of the classification system is to address resource threats while maintaining the pristine and undeveloped character of the climbing route. The following route improvement guidelines are recommended:

- Develop and complete route improvements within the context of a protection/restoration plan for the route corridor and/or mountain.
- Keep the level of improvement to a minimum. Do only what is necessary to achieve resource protection goals.
- Work within existing disturbances and do not disturb new ground unless there is a compelling reason to do so, and only as a matter of last resort.
- Utilize all material removed during construction (rocks, soil and vegetation) to restore or reclaim disturbed sites.
- Monitor environmental conditions along the route corridor and maintain all improvements or structures.

There are a number of factors that need to be considered when aligning or improving a climbing route. These include:

- Unique or special characteristics or features of the route.
- Existing use patterns or trends.
- Areas with sensitive biological and/or cultural resources.
- Fragile ecosystems, i.e. fell-field, snow-bed and wet meadow communities.
- Unstable terrain prone to soil displacement or erosion.
- Areas of high objective hazard, i.e. rock fall and avalanche zones.

MOUNT HUMBOLDT PROJECT

Project Description

Mount Humboldt is located in the heart of Southern Colorado's Sangre de Cristo Wilderness southwest of Westcliffe, Colorado. The mountain is one of the famed Crestone group peaks. Mount Humboldt is a popular climbing objective. Estimates are that approximately 2,000 to 3,000 climbers ascend the peak each year. The overwhelming majority of climbers access the peak via the South Colony Lakes basin, a relatively narrow alpine cirque valley with two main lakes. The basin is surrounded on three sides by rugged and spectacular alpine peaks: Broken Hand Peak, Crestone Needle, Crestone Peak and Mount Humboldt. These peaks tower over 2000 feet above the basin floor forming an area of outstanding natural beauty. From the basin, the standard ascent route climbs up to a col or saddle at 13,000 feet, and then follows the west ridge of the peak to the summit.

An impact assessment program completed by RMFI in 1992 and 1993 revealed that many sections of the Mount Humboldt west ridge route had become heavily eroded. The likelihood of even greater degradation was also deemed to be very high. The Mount Humboldt project was initiated by the Rocky Mountain Field Institute and the USDA Forest Service to mitigate the damage.

Project History

A site analysis, resource inventory and environmental assessment for the proposed project were completed by the Forest Service with the assistance of RMFI in 1995. This was followed by a planning study of South Colony Lakes Basin in 1996. This study was completed so that the Mount Humboldt project could be developed within the context of overall resource protection and restoration needs in the basin. The study reviewed ecological resources and recreational use in the basin; queried visitors about environmental condition; and identified management needs for the area at large.

The erosion gully between 12,000 and 13,000 feet was identified as the highest priority for the project. This gully was located on a 40-50 percent south facing slope. The slope supports a mesic alpine meadow dominated by *Acomastylis rossii, Potentilla subjuga* and *Carex elynoides* (Conlin 1998). A plan was devised to improve as much of the gully as possible for climbing use and to stabilize and reclaim those sections that were judged to be too steep or unstable for climbing. For the latter sections, the plan called for the construction of an alternate route. One of the challenges of the project was harvesting rock on site to accomplish both the stabilization and improvement of existing sections and the reclamation of the remaining sections. During 1996, RMFI designed, built and tested a rock transport system or tram that could safely and efficiently deliver rock from nearby boulder or rock fields. The system was also designed to reduce the impact of the project on the surrounding vegetation.

With respect to restoring and reclaiming the section from 12,000 to 13,000 feet the following strategies were identified:

- Where possible, fill the gully with rock to replicate naturally occurring rock streams.
- Construct terraces in the most deeply eroded sections of the gully into which vegetation from the new alternate route could be transplanted.
- Stabilize and revegetate all other remaining impact areas.

For the section of the route from 13,000 feet to the summit, a plan was developed to mark or identify a route up the ridge with cairns (Class II), to make selective improvements as needed (Class III) and to monitor impacts.

During the summers of 1997 and 1998, RMFI spent a total of 24 weeks reclaiming the section of the route between 12,000 and 13,000 feet. Approximately 200 tons of rock were moved from adjacent boulder fields to reclaim the gully and construct the new alternate route. RMFI also marked the route up the west ridge from the saddle to the summit with cairns. In total, approximately 3,000 feet of the existing route were improved and 2,000 feet of the gully and social trails were reclaimed. Approximately 1,000 feet of new trail were built. The west ridge was defined with cairns located 150 feet apart.

The work was completed by seasonal crews hired and trained by RMFI with the assistance of over 300 volunteers. These volunteers devoted nearly 1,000 volunteer days to the project. The volunteers included individuals recruited by the Colorado Fourteeners Initiative as well as persons involved with the CFI partner organizations which included the Colorado Outward Bound School, America's Adventures, The Colorado Mountain Club, Mountain Trails Youth Ranch, The Rocky Mountain Youth Corps, and Volunteers for Outdoor Colorado.

The work in 1998 and 1999 was funded through contributions and grants from a number of sources including CFI and its partner organizations: Great Outdoors Colorado, the National Forest Foundation, the US Forest Service, the Conservation Alliance and numerous companies within the outdoor industry.

The effectiveness of the restoration work on Mount Humboldt is of key concern to RMFI and the US Forest Service. During the summer of 1998, a study was begun by Colorado College to examine the success of the sod transplantation that was completed. After one year of study, it appears that turf-transplantation is an effective method for reclaiming disturbed sites in the particular alpine vegetation community (Conlin 1998). However, further study is needed to evaluate the full effectiveness of this technique. The success of the two other revegetation techniques that were used to reclaim this section of the route (transplantation of individual tillers and seeding) are presently being studied.

CLOSING COMMENTS

The work completed on Mount Humboldt to date has succeeded in mitigating a great deal of the climbing impacts on this alpine peak. There is little question that this type of work is greatly needed on other similarly impacted peaks, and that it has obvious benefits. However, considerable restoration work remains to be done on Mount Humboldt and additional improvements are still needed on the upper sections of the peak. Furthermore, RMFI does not claim to have fully "restored" the areas of the peak where work has been conducted. Full restoration implies a return to pre-disturbance conditions. While this is an important standard to have in wilderness, the Mount Humboldt project is proving the monumental difficulty of achieving this in alpine environments. There is little question that the most important lesson that the Mount Humboldt Project has taught, and continues to teach, is the significance of preventing disturbance of the type and magnitude that have taken place on the peak from occurring in the first place.

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HIGH ELEVATION TRAILWORK IN UNITED STATES NATIONAL PARKS, PERU AND NEPAL

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ABSTRACT

With the increase in high-elevation tourism worldwide, impacts on the vegetation of these most-sensitive areas has increased tremendously. Trails that once could sustainably withstand the impacts of use have now become multiply rutted, eroded, braided, and de-vegetated. Land management agencies struggle with appropriate solutions to these impacts.

In United States National Parks where I have worked, high-elevation trails in sensitive meadow and riparian environments have been rerouted and relocated (Kings Canyon National Park, CA), reconstructed on old alignments with a hardened trail surface and improved drainage (Yosemite National Park, CA), or a combination of the two (Rocky Mountain National Park, CO).

In protected areas in Perú and Nepal, similar visitor use problems exist. The ancient Incas of Perú constructed remarkable hardened trail surfaces (Cordillera Vilcabamba, Perú), and in Nepal, the local villagers have constructed impressive sections of stone steps on ancient trade routes (Anapurna, Nepal).

All of these trail solutions protect high-elevation vegetation by minimizing and controlling the erosive effects of moving water and high use. In the United States National Park solutions in particular, aggressive revegetation is always part of the project, attempting to naturalize and restore the landscape to its pre-impact condition. The solutions that I have been involved with have been very successful. Slides will illustrate the various solutions and project locations referred to in parenthesis.

INTRODUCTION

Over the last part of the 20th century high-elevation tourism worldwide has increased dramatically, and correspondingly, non-sustainable impacts have also increased on the vegetation of these most-sensitive areas. Trails that once could sustainably withstand the impacts of routine use have now become multiply rutted, eroded, braided, and de-vegetated. Properly designed and constructed trails can mitigate these impacts by consolidating use on an improved alignment and hardened tread. Present United States land managers and agencies are not the only ones to have struggled with appropriate solutions to these impacts; worldwide some past and present trailwork provides excellent examples of sustainable trails in very difficult terrain.

I have been a part of the planning and implementation of major high-elevation projects designed to protect and restore sensitive vegetation to a natural condition in several United States National Parks. I have also traveled internationally to popular high altitude recreation destinations and observed and studied solutions to similar problems implemented in other countries. In 1997 I traveled to the Nepal Himalaya, and most recently, I participated in a fact-finding trip to the Cordillera Vilcabamba in Perú to investigate 600 year-old Inca trailwork.

UNITED STATES NATIONAL PARKS

In United States National Parks where I have worked, high-elevation trails in sensitive meadow, riparian, and tundra environments have been both relocated out of the sensitive vegetation, and also reconstructed on old alignments with a hardened trail surface and improved drainage. In Kings Canyon National Park (CA), high elevation trail segments on the John Muir trail in the Evolution Basin area had become badly eroded and multiply rutted by the end of the recreation boom of the 1970's, and similar problems existed in Yosemite National Park (CA) in Rafferty Meadow. As an answer to these two similar high-altitude problems of impact, two very different solutions were implemented. In Yosemite, the existing alignment through the meadow was reconstructed, and in Kings Canyon, the trail was rerouted to higher, less sensitive ground. In 1998 and 1999 in Rocky Mountain National Park (CO) a combination of both approaches was incorporated into reconstructing and realigning one and one-half miles of the Continental Divide Trail above timberline. Rocky Mountain crews also have reconstructed segments of other high elevation trails. The following projects are presented both in chronological order and in the order of their cost and complexity, with the most complex first.

Yosemite National Park

In Yosemite National Park, Rafferty Meadow is a popular high-elevation trail for both hikers and stock. The area is located approximately 6 miles south of the Tuolumne Meadows trailhead and is the main route into Vogelsang High Sierra camp - a seasonal overnight camp run by the park concessionaire. During the 50's and 60's, the heavy use and lack of construction on the trail through the 9600-foot elevation meadow combined to create an alignment of multiple eroded and braided ruts (Snyder, 1978). As is common in high elevation areas throughout the world, as an individual rut became deeper and carried more water, hikers and stock created adjacent paths to avoid walking in the mud and trench of the existing alignment, and these paths in turn become additional ruts. Multiple ruts followed. In Rafferty Meadow, after a reroute attempt in the seventies to circumnavigate the meadow failed because it was not a desirable route, the entire alignment was reconstructed as a rock causeway during three short early-fall seasons in 1983 through 1985. The multi-year project was the culmination of the trailwork season for Yosemite's trail crews, including two 18-person California Conservation Crews. The total number of persons involved with the project each season was approximately 60, including several full-time packers moving supplies in and trash out of the backcountry camp. The project involved establishing a preferred alignment, usually the original one through the meadow, and constructing 4 to 5 foot wide stepped rock causeways on that alignment, and thoroughly revegetating the adjacent abandoned ruts. Fundamental to the success of the project was the re-establishment of an effective natural drainage system to facilitate water movement across the trail alignment. Overall, over 2500 feet of rock causeway was constructed, providing both hikers and stock a high and dry trailtread.

Rock quarries were established and large stones were moved to the project site using stoneboats and teams of pulling mules. Impact to the meadow was minimized by performing the work in the dry early fall of the High Sierra. Tread material was obtained from nearby natural drainages and streambeds and transported to the project sites using strings of mules equipped with hinged dirtboxes. (Techniques to construct rock causeways are described in Birkby, 1996; and Griswold, 1998).

When I most recently visited the project several years ago, the revegetation efforts have been very successful, and only a few problem areas on the lengthy causeways were observed where stock and hikers have stepped off-trail to avoid close passing. This was a very costly, yet successful project. The budget was approximately $100,000 annually for the three years.

Kings Canyon National Park

In the Sierra Nevada south of Yosemite, a similar problem in Evolution Basin in Kings Canyon National Park had developed. The Evolution Basin is a more remote area than Yosemite's Rafferty Meadow and consists of a series of large stepped lakes on the upper reaches of the North Fork of the San Joaquin River. The John Muir trail winds its way up the basin, linking the lakeshores of several of the major lakes as it approaches Muir Pass at more than 12,000 feet in elevation. Similar to Rafferty, the route included many areas of severe erosion and multiple rutting in the fragile meadow and riparian grasses of the lakeshores. During four seasons from 1989 to 1993, National Park Service trail crews were joined by a California Conservation Corps backcountry crew for a total of approximately 22 persons each season. For 3 months each year they methodically rerouted the lakeshore trails to higher terrain above the lakes, while thoroughly revegetating the damaged lakeshores.

Rock was quarried from the numerous talus slopes, and was moved into position by hand. Meadow ruts were filled with soil, drainage established to prevent further erosion, and grasses were transplanted into the scarified soils. Tread material for the new trail alignment was both transported by strings of pack mules from adjacent drainages, and obtained by quarrying soil from the existing rutted trail.

The work in the Evolution Basin has held up well and succeeded in rerouting through hiker and stock traffic to a new alignment above the sensitive vegetation. The damaged lakeshores are well on their way to recovery. This project was more primitive (and remote) than the Yosemite project. The budget for the Kings Canyon crews was approximately $50,000 per season for 4 seasons.

Rocky Mountain National Park

In Rocky Mountain National Park, both reconstruction approaches - reconstruction on the original alignment and rerouting of the trail – are being used beginning in 1998 to reconstruct a portion of the Continental Divide Trail on Bighorn Flats above timberline. The recently designated Continental Divide Trail in Rocky Mountain National Park climbs from the deep forested canyons of the west side of the Continental Divide and crosses between drainages on the high-elevation tundra of Bighorn Flats and Flattop Mountain. The trail, little more than a route, evolved from use with no attention being paid to a proper sustainable alignment or constructed drainage. As use increased, the trail eroded and in many sections the trail was little more than a boggy rut for most of the hiking season. Multiple ruts soon began to evolve. Using both the approaches employed in the California parks, the Rocky Mountain National Park trail crews have both constructed an improved trail and tread on the existing alignment, and rerouted the most problematic wet sections to higher ground within approximately 100 feet of the present route.

A packable steel tripod system was used to transport rocks without damaging the fragile tundra. Tread material was quarried whenever possible from the existing trail, and also flown to the site using a high-elevation heavy-lift helicopter in the fall of 1998. Project budget was $60,000 for the crew in 1998 and $100,000 for the helicopter time.

This project continues and is scheduled to conclude this 2000 trail season. In 1999, a small crew continued with the final phases of the reroute for several weeks in early September, and in 2000 a crew will do the same. The elevated sections of trail have been very successful at providing hikers with a desirable surface upon which to walk, eliminating impacts from the wet, sensitive tundra adjacent. Cost for the crew in 1999 and 2000 is approximately $12,000 per season.

Crews in Rocky Mountain National Park have also reconstructed high elevation portions of the extremely popular Longs Peak trail (up to 1500 persons per day) and the lightly used Stormy Peaks trail by restoring and reconstructing the trails on their original alignments.

The Challenge

The challenge of either reconstruction approach is to provide a trail surface that can withstand the affects of seasonal water movement, and the impacts of recreational hiking and stock use, as well as be the route of choice for hikers and stock. An appropriately constructed trail will consolidate the recreational use within a corridor that can sustain it, and protect the surrounding or nearby vegetation from the potential impacts of that use, if it is an alignment that effectively takes users where they want to go.

INTERNATIONAL EXAMPLES

In protected areas in Perú and Nepal, similar problems of impact exist in high elevation areas. The ancient Incas of Perú constructed remarkable hardened trail surfaces that were part of an ancient road network of over 10,000 miles. In particular, the riprap trailtread in the Cordillera Vilcabamba, as it approaches the spectacular ruins of Machu Picchu, is an outstanding example of a sustainable trailtread that protects the adjacent landscape and vegetation. In the Anapurna and Khumbu regions of Nepal, the local villagers have constructed lengthy sections of stone steps to harden the trailtread on ancient trade routes and to protect the landscape from the effects of erosion.

Cordillera Vilcabamba, Perú

In the fall of 1999, I had the privilege of participating in a fact-finding trip to the Cordillera Vilcabamba of Perú to investigate the rockwork of the Incas. The Incas constructed a network of rock highways throughout the central Andes that connected the empire to the high-elevation capitals of Quito, Ecuador and Cusco, Perú (McIntyre, 1975). Many of these routes are still in use, and on the famous Inca trail to Machu Picchu the number of hikers is certainly far greater today than could have been anticipated by the Inca engineers 600 years ago. The Perúvian Park Service, the Instituto Nacional de Cultura (INC), actively maintains this trail and estimates that more than 800 persons will pass from the trail to its terminus at Machu Picchu daily during the peak hiking/tourist season. The Inca trail includes more than 40 kilometers (25 miles) of continuous rock riprap which has survived with little more than routine maintenance for well over 500 years. (Trail riprap is discussed in Griswold, 1996)

The Incas are well recognized as masters of drystone masonry (Protzen, 1997). Their temples at places like Machu Picchu, Sacsayhuaman, and Ollantaytambo are world-renowned (Frost, 1999), and their high elevation trails are also masterfully constructed. The Inca trail crosses three high elevation passes, and protects high-altitude vegetation by strongly meeting the challenge discussed above: the trail both provides a sustainable corridor to endure the impacts of use, and takes hikers where they want to go. The Incas incorporated many trail rockwork structural techniques into their trail: including riprap tread, walls, and drainage structures. Most noteworthy is the extreme attention paid by Inca engineers to drainage. Every section of Inca trail rockwork is protected by a thorough drainage system. Nearly the entire uphill edge of the riprap trail tread is lined by a trail edge-wall that provides a drainage to move water down the inside of the trail and then across or through the trail at one of a number of cross-trail drainage structures. The Incas teach us that a sustainable trail consists of not only quality high-standard work, but also must be protected by a thorough drainage system.

Khumbu and Anapurna, Nepal

In Nepal, ancient trade routes wind their way up and down steep mountain ranges. These trails have been in use for many hundreds, even thousands of years, and are still relied upon today as major trade routes and essential to maintaining the lives of the local peoples in the heavily populated the foothill regions. With the addition of tourist traffic on popular trekking routes, and the added requirements of supplying the tourist trade, these ancient trails have had to withstand impacts unforeseen in their long histories of use. In very remote areas, erosion and severe impacts may be found, but in many local areas, villagers have protected the trail alignment by hardening the trail tread using rock steps. I observed constructed trails in both the Khumbu and Anapurna regions, and in the Anapurna foothills, the most heavily populated of the two regions, lengthy sections of rock steps have been constructed utilizing rock slabs. These slabs are laid to form gently sloping steps that shed water off the trail onto the downslope side, filling formerly eroding ruts with a sustainable trail surface.

HIGH-ELEVATION TRAIL RECONSTRUCTION

As I participated and observed these projects over the last 15 years, I have learned many things. Several of the most significant are discussed below: the importance of aggressive revegetation, a method to obtain trail tread material where it is scarce, and a simple structure to facilitate the easy movement of large rocks.

Revegetation

Aggressive revegetation is an essential part of any high-elevation trail reconstruction project. The process of revegetation attempts to naturalize and restore the landscape to its pre-impact condition and stabilize the area from further deterioration. Less-successful projects in the past have failed in part because of faulty assumptions regarding the capacity of the landscape to restore itself. Abandoned, eroded ruts do not refill themselves, and slow-growing naturally-restoring vegetation alone will not check continued erosion of the old alignment. Soil must be restored to the ruts, and this soil must be secured in place by frequent log or rock checks in order to prevent further erosion. Each section must be consciously protected by a drainage solution, guiding moving water through and across the segment (Griswold, 1998).

Tread Material

In locations such as Kings Canyon and Rocky Mountain National Parks where soil for trail tread is very difficult to obtain, crews have successfully quarried soil from the existing rutted trail alignment. Soil is stockpiled adjacent to the trail on tarps or plastic (to protect the underlying vegetation) by first digging up and removing as much soil as possible from the damaged trail, essentially making the trail rut deeper. Reconstruction of the trail then follows by laying rock steps, drainage structures etc. over a bed of crushed rock and backfilling the old rut with crushed rock to within approximately 4 to 6 inches of the final tread elevation. The stockpiled soil is then placed on the reconstructed trail bed and crowned or outsloped to facilitate proper drainage. The final step is to compact the soil as much as possible. This soil quarrying method eliminates the impact of borrow pits to the surrounding landscape. The crushed rock fill below the trailtread also facilitates the movement of water through and off the project.

Moving Rocks

In Rocky Mountain National Park, a packable steel tripod system was used to transport rocks to the project site without damaging the fragile tundra. This system was first introduced to the crew by Lester Kenway of Baxter State Park in Maine. The easy-to-construct and easy-to-use system facilitates the movement of large rocks and large quantities of rock quickly across the frequently wet tundra, protecting the vegetation from the impacts of construction, and saving the workers some of the backbreaking labor of rolling and lifting rocks. The tripod consists of 10-foot long adjustable legs made of square steel tubing, and linked together at the top with an all-thread rod. The legs may be cut into several sections and joined together at the project site to facilitate packing on livestock. Two tripods are used and two large snatch blocks are hung from each of the two all-thread rods. The tripods are separated the necessary distance to move rock from the quarry site to the project and a grip-hoist cable is hung from the two snatch blocks. The separation of the tripods is limited by the length of the cable - a two hundred foot cable is recommended. Rocks are contained in either a chain-basket or large slings made of webbing. The baskets and webbing should be adequately rated to hold the weight of the rocks to be transported. Once the rocks are safely placed in the basket, the basket is hooked to a pulley or snatch block attached to the main overhead line and raised off the ground by taking up the slack in the main cable. This is accomplished by pulling the cable through the grip-hoist, a very strong come-along like device. The basket containing the rocks is then easily pulled or pushed, depending on grade, to the second tripod, nearer the project site. The cable is lowered and the rocks are unloaded. If the source site is far away, additional set-ups may be required. The entire system is easily and rapidly relocated (Kenway, 1997 and Demrow, 1998, illustrated on the cover).

CONCLUSIONS

These trail solutions protect high-elevation vegetation from the effects of trail use by minimizing and controlling the erosive effects of moving water as well as the direct effects of the high use. Well-laid rock surfaces are the most sustainable of trail treads. Quality riprap work is extremely resistant to erosion, even to water flowing right on the alignment. Less labor intensive, but equally durable, soil tread surfaces can be constructed by skilled crews and have proven successful in several high-elevation environments.

In the United States National Park solutions, both improving the trail on the existing alignment and rerouting the trail to less sensitive habitats have been successfully implemented. As in Perú and Nepal, high quality trailwork is essential to success, particularly after damage has already occurred to the alignment as use and erosive impacts increase. The ancient engineers of Perú and Nepal demonstrated hundreds of years ago that a sustainable trail, one that protects the landscape and vegetation, consists of appropriate high quality trail construction, including a hardened trail tread if required, and meticulous attention to drainage.

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RECLAMATION OF URAD MOLYBDENUM TAILING: 20 YEARS OF MONITORING CHANGES

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ABSTRACT

Reclamation of the tailing from Urad Mine was completed in the late 1970's. The surfaces of the two tailing ponds were covered with about three feet of waste rock. The waste rock was amended with up to 30 tons/acre of biosolids, 20 tons/acre of woodchips and 300 lbs/acre of triple superphosphate. This addition of organic matter, nitrogen, and other nutrients needed to sustain plant growth has resulted in a more balanced growth medium.

Although there are a number of potentially toxic elements present in the waste rock growth medium, there is no visible evidence of plant toxicity problems after 20 years. However, concentrations of molybdenum and fluoride are high in legume species.

Seeded grasses are well established and cover and production of the revegetated areas all exceed that of the control, a nearby burned-over spruce-fir community. Reclaimed areas are dominated by a few species of grasses, and forbs occur infrequently. Species diversity has increased significantly with time since the areas were seeded in 1975-1978. The number of naturally occurring and seeded species on most reclaimed areas is similar to or greater than that of the control community.

INTRODUCTION

Background

Urad Mine tailing is located at an elevation of about 10,200 feet in the mountains west of Denver. Climax Molybdenum Company, then AMAX, completed reclamation of the Urad Mine site in the late 1970's. The surfaces of the Urad molybdenum tailing ponds were covered with about three feet of Henderson Mine waste rock. The waste rock material covered the tailing, effectively eliminating wind and water erosion of the tailing and provided a more stable growth medium for vegetation establishment (Brown, 1976).

About 30 tons/acre of biosolids and 20 tons/acre of wood chips were added to the waste rock surface (in 1975 and 1976 only 20 tons/acre of biosolids was used) and the wood chips and super phosphate were ripped into the surface. These additions were made yearly to different portions of the tailing ponds over a period of five years (1975-1979). The tailing was amended and revegetated as the waste rock cover and amendments were applied. A history of amendment additions is shown in Table 1. Use of biosolids added organic matter and plant essential growth nutrients to the medium. The Climax seed mixture that contains both grasses and forbs was then broadcast onto newly prepared areas. An inorganic nitrate nitrogen fertilizer was broadcast (200 lbs/acre) over all previously seeded areas in 1979. In addition, seedlings of shrubs and trees were hand planted in some of the reclaimed areas.

Monitoring of reclaimed areas has been done to follow changes on the site through time. Species composition has been estimated through the years at 4 - 6 year intervals. Diversity and production on various reclaimed areas as related to length of time since seeding have also been determined. These data were collected to determine if seeded species were increasing, decreasing, or simply maintaining themselves on the reclaimed tailing. It was hypothesized that introduced species would be replaced through time by invading or planted native species, causing a reduction in some introduced species within the stands.

Rock waste growth medium placed on tailing ponds has been subjected to various physical and chemical analysis since 1976. These analyses showed levels of soil development, fertility and potential toxic elements. Concentrations of certain toxic compounds, elements, and heavy metals have been measured in vegetation established on the waste rock growth medium covering the Urad tailing. These concentrations have been monitored through time. An additional objective has been to determine the long-term impact of biosolid addition on soil and vegetation development.

Table 1. Amendment additions to Urad tailing reclamation areas.

Year of seeding	Amendments	Additional treatments
1975	20 tons/ac of biosolids and wood chips	300 lbs/ac P_2O_5
1976	20 tons/ac of biosolids and wood chips	300 lbs/ac P_2O_5
1977	30 tons/ac of biosolids and 20 tons/ac wood chips	300 lbs/ac P_2O_5
1978	30 tons/ac of biosolids and 20 tons/ac wood chips	300 lbs/ac P_2O_5
1979	30 tons/ac of biosolids and 20 tons/ac wood chips	No fertilizer added
1992		100 lbs/ac NH_4NO_3

Biosolids

The agricultural use of biosolids provides environmental and economical benefits through reuse of essential nutrients and organic matter contained in these materials (Krebs et al., 1998). However, the use of biosolids as fertilizers have raised numerous environmental and health issues because of the concentrations of toxic metals, organic compounds, and pathogens commonly found in these waste materials (McBride et al., 1997). Despite these risks, utilization of biosolids has increased through the years and it is predicted that it's beneficial use will continue (Goldstein, 1998).

Biosolids contain considerable amounts of nitrogen (N) and phosphorous (P), which make it a good fertilizer, but the input can also result in excesses (Hooda et al., 1997; Krebs et al., 1998). Biosolids application affect soil properties in many ways; it increases pH, organic matter content, electrical conductivity and available phosphorus (Tsadilas et al., 1995; Moreno et al., 1999). Some of these changes are short term while others are long term. For example, acidification of the soil is a potential long term effect that may seriously alter the mobility and uptake of metals (Tack et al., 1998).

The application of biosolids can be problematic because of harmful components that are potentially toxic elements, particularly heavy metals (e.g. Cd, Cu, Ni, Pb, Zn, Mn) (Tsadilas et al., 1995; Krebs et al., 1998). These metals are considered to be mainly associated with organic matter in the biosolids, which mineralizes with time, but the heavy metals remain in the soil with very low mobility in the soil profile (Sloan et al., 1997; Singh and Pandeya, 1998). The half-life of organic decomposition has been estimated to be about 10 years (McBride, 1995). However, the persistence of metals in the soils and their uptake by plants still exists many years after biosolid organics have decomposed. This can be a problem and these heavy metals can be toxic to animals and humans when consumed (Tsadilas et al.; 1995 Krebs et al., 1998). Plant uptake is one of the major pathways by which biosolid-borne toxic elements enter the food chain, but problems can also arise where these elements go into surface and groundwater and pollute water supply (Chaney, 1990; Harris-Pierce et al., 1995; Krebs et al., 1998). Research has shown that availability of biosolid-borne metals to plants is generally the greatest immediately following application of biosolids to soil but diminishes thereafter (McBride, 1995). After biosolids application, the soil will gradually establish new biochemical equilibria with decomposition of biosolids-added organic matter, and in many cases, acidification of the soil (Hooda et al., 1997).

Soil and Vegetation Interaction

Plants vary widely in their uptake and requirements for various macro- and micro-nutrients (Swaine, 1955). At least 16 elements are known to be essential for plant growth. Of these, nitrogen, phosphorus and potassium are most often deficient in soils. Secondary or micronutrient deficiencies are found in some soils, with sulfur, zinc and boron being the most common.

Whether an element or compound is limiting or toxic in many cases depends on its availability and concentration (Lindsay, 1979b; Mailman, 1980; Baker and Walker, 1989). Nitrogen (N) is an essential component of protein but excesses in soils can affect human and animal health and can degrade the quality of the environment (Brady and Weil, 1999). Nitrogen-deficient plants often have a low shoot-to-root ratio and they mature more quickly than healthy plants, whereas excess nitrogen can result in weak stems, delay maturity and cause susceptibility to disease and insect pests. Nitrogen is usually the most limiting nutrient and phosphorus (P) commonly the second most limiting (Lindsay, 1979; Mailman, 1980; Baker and Walker, 1989). Phosphorus is often deficient in highly weathered soils, calcareous 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 (K) is the third most likely element to limit plant productivity in natural communities. However, plants are capable of substituting sodium (Na) 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. For example, excess potassium may reduce the uptake of magnesium, manganese, zinc, and iron.

Zinc (Zn) content in forage normally ranges from 20 to 10,000 ppm (μg/g) (Holmes, 1944). Therefore, plant leaves with less than 20 ppm zinc may be deficient in this micronutrient. Ample, but not excessive, levels commonly range from 25 to 150 ppm (Chapman, 1966; Kabata-Pendias and Pendias, 1992). Zinc concentrations greater than 400 ppm may indicate zinc excess. Acidification of soils may bring about zinc toxicity in substrates that are high in zinc.

Iron (Fe) was shown to be an essential element for plant life over a century ago and is required by plants in quantities larger than manganese (Mn), zinc, copper (Cu), and molybdenum (Mo) (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 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 in plants results from low availability of iron in the soil for plant uptake.

Plants vary widely in their requirements for molybdenum (Mo) and in their ability to extract this element from the soil (Reisenauer, Walsh and Hoeft, 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 matter content, as does that of most other nutrient elements. Additions of biosolids may also result in increased molybdenum uptake by plants (Soon and Bates, 1985; Pierzynski and Jacobs, 1986; Kabata-Pendias and Pendias, 1992). 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, minerals and colloids below pH 6.0. Therefore, availability of molybdenum in acidic soils may be limiting plant growth (Robinson and Alexander, 1953; Gupta and Kunelius, 1980; Kabata-Pendias, and Pendias, 1992). Under alkaline conditions, plants take molybdenum up much more readily. Reductions in plant growth from excess levels of molybdenum can be expected when tissue concentrations exceed 200 ppm (Reisenauer, Walsh and Hoeft, 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 in 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-sulfur 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 (As) 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 accumulation resulting from herbicide applications, however, has reduced productivity of some 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 vary from 1.0 - 1.7 ppm (Kabata-Pendias and Pendias, 1992).

Presence of abnormally high concentrations of fluoride (F) in aboveground parts of plants, with low concentrations in the roots, usually indicates that the atmosphere is the principle source of fluoride (Brewer, 1966). However, high fluoride soil level can occur through contamination by the application of biosolids (Kabata-Pendias and Pendias, 1992). The usual fluoride content in foliage of plants grown in areas removed from possible sources of air pollution ranges from 5 to 30 ppm. High fluoride concentration in roots usually indicates absorption of fluoride from the soil (Brewer, 1966). Animals may be detrimentally affected by eating forage containing less than 50 ppm 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.

Cadmium (Cd) is one of the most toxic metals found in biosolids and can enter the food chain through plants and result in a significant health concern (Singh and Pandeya 1998; Moreno et al., 1999). Cadmium is a non-essential element for plants and its concentration in normal plants ranges from 0.1 - 2.4 ppm, but it can become excessive or toxic at 5-30 ppm (Kabata-Pendias and Pendias, 1992; Ramachandra and D'Souza, 1998). Soil pH is an important factor regulating the solubility of Cd and its rate of uptake by plants (Eriksson, 1989). Acidic soils result in cadmium being more available for plant uptake (Kabata-Pendias and Pendias, 1992).

Most of the soil chromium (Cr) occurs as Cr^{3+} and it is considered to be very stable in soils and its availability to plants is low (Kabata-Pendias and Pendias, 1992). However in acid media, it becomes more mobile. Yet there is no evidence of an essential role of chromium in plant metabolism and its concentration in normal plants ranges from 0.1 - 0.5 ppm.

The content of aluminum (Al) in plants varies greatly, depending on soil and plant factors (Kabata-Pendias and Pendias, 1992). The mobility of Al increases sharply in acidic soils with pH below 5.5 and it can be taken up rapidly by plants leading to plant injury or toxicity. Aluminum toxicity may occur as interactions with other elements and is frequently associated with increased levels of iron and manganese.

The natural lead (Pb) content of most soil is usually derived from parent rock (Kabata-Pendias and Pendias, 1992; Brady and Weil, 1999). However, with widespread lead pollution from automobiles before the use of unleaded fuels, contamination of soils with lead had come primarily from airborne lead. Lead is in general relatively immobile in soils and is tied up as insoluble carbonates, sulfides and oxides and is largely unavailable to plants (Koeppe, 1981; Kabata-Pendias and Pendias, 1992). Normal concentration in plants range from 5 - 10 ppm lead and it can be become toxic when above 30 ppm.

Selenium (Se) is readily absorbed by plants when present in soluble forms (Kabata-Pendias and Pendias, 1992). The uptake is also dependent on temperature and rainfall, with low temperature and high rainfall resulting in low uptake. There is a positive linear correlation between selenium in plant tissue and Se content of soils. Its concentration in normal plants ranges from 0.01 - 2 ppm and becomes toxic above 5 ppm.

Boron (B) is important in plants metabolically and its concentration in normal plants ranges from 10 - 100 ppm (Kabata-Pendias and Pendias, 1992). Boron is sorbed more strongly by soils than are other anions and organic matter exercises a powerful influence on its mobility and availability, particularly in acid soils.

Nickel (Ni) concentration in surface soils can reflect soil-forming processes, pollution or biosolid application (Kabata-Pendias and Pendias, 1992). Nickel appears to occur mainly in organically bound forms, which are unavailable to plants, and its concentration decreases with increasing acidity. The concentration range of nickel in normal plants is from 0.1 - 5 ppm and it can become toxic above 10 ppm.

Some essential elements can be taken up in excess and may become toxic to the plant (Lindsay, 1979; Tsadilas et al., 1995). Even if an element does not become toxic to the plant, it might become toxic to grazing herbivores that utilize the forage (Gupta and Lipsett, 1981). In addition, plants can take up some toxic elements or compounds 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. Soil testing is sometimes useful in determining whether nutrients are either deficient or excessive. To have significant predictive value, these tests should measure the amount of nutrient made available to plants from a wide range of soils under a variety of conditions. Testing soil for micronutrient anions is difficult because plant requirements for these nutrients are quite low and availability of most of them is dependent on climatic factors and several chemical, physical, and biological processes (Reisenauer, Walsh and Hoeft, 1973).

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 concentrations, yield, and nutrient supply are obtained at a specific location in a year. However, year-to-year and location-to-location variations in these relationships are often quite widespread 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 that affect the ability of soil to supply the nutrients and by factors, which affect the plant's ability to utilize the supplied nutrients (Corey and Schulte, 1973). Available nutrients dissolved in the soil solution might be derived from a number of sources such as weathering of minerals, decomposition of organic matter, atmospheric deposition and application of fertilizers or biosolids. 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 plants or microorganisms absorb it or it is leached, denitrified, or otherwise disposed of (Corey and Schulte, 1973). Sulfate anions act in a similar manner in neutral or alkaline soils but tend to be absorbed in acidic soils. Most other nutrient elements form some type of relatively insoluble compound, which tends to maintain an equilibrium concentration in the soil 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; and phosphorus forms iron, aluminum and calcium phosphates.

Soil pH and temperature are important factors in determining solubility of elements that tend to equilibrate with a solid phase. Soil pH is a common limitation to plant growth and there is usually a great increase in plant uptake of micronutrient cations as soil pH declines (Melsted and Peck, 1973; Baker and Walker, 1989; Larcher, 1995).

Solubility 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 solubility 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 activity of all exchangeable cations to some extent. Solubility of iron, aluminum, and calcium phosphates are markedly pH-dependent, as are solubility of molybdate (MoO_4) and SO_4 anions.

Another factor important in determining the concentration of nutrients in the soil solution is the redox potential (Corey and Schulte, 1973). The redox potential is related to soil aeration, which in turn is dependent on rates of microbial and root respiration and oxygen diffusion. It affects solubility of nutrient elements that can exist in more than one oxidation state. These elements include C, H, O, N, S, Fe, Mn, and Cu.

OBJECTIVES AND PURPOSE

There were several purposes for these studies. First, they were conducted to determine what changes occurred in the growth medium through time. Secondly, it was important 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, and how these concentrations changed through time and how they affected the vegetation. A third objective was to document vegetation dynamics through time, that is what were the proportions of native vs. introduced species and planted species vs. invading species on the reclaimed tailing through time. It is possible that introduced species might be replaced by invading or planted native species through time, causing a reduction in some introduced species within the stands. Finally, it was important to determine the long-term impacts of biosolid application and to determine if some toxic heavy metals as well as nutrient elements remained in the soil and how concentrated they were in vegetation as a result of biosolid decomposition.

METHODS AND PROCEDURES

Chemical Analysis of Waste Rock

Samples of mine waste rock material were collected in 1975 prior to addition of sewage (biosolids) and wood chip amendments. Samples were also collected from 1978 through 1999 (1979, 1985, 1992, 1997 and 1999) after additions of biosolids, wood chips, fertilizer and seed. Various portions of the tailing reclamation area were seeded with a mixture of grasses and legumes beginning in 1975 and continuing through 1979. Therefore, samples of the growth medium could be related to the year of seeding (1975 through 1979).

All sampling of the growth media (waste rock) on the Urad reclamation area was done to a depth of 30 cm during the growing season. Research has shown that heavy metals accumulate mostly in the upper soil and little movement occurs below 30 cm depth (McBride, 1995). Two plant growth medium samples were taken from each year of seeding (1975, 1976, and 1977). In 1999, three samples were taken from each community; reclaimed tailing, roadcut, controlled burned area, and a small meadow at the base of an avalanche run. The native community in the 1879 burned-over area above lower Urad Lake, a grassy community at the base of an avalanche run nearby, and a reclaimed roadcut near the Henderson mine were sampled as no biosolids had been added to these sites.

All samples of growth medium were submitted to the Soil, Water, and Plant Testing Laboratory at Colorado State University for analysis. Analyses of this material were for pH, conductivity, saturation, lime, organic matter (OM), SAR, phosphorus (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), lead (Pb), cadmium (Cd), arsenic (As), molybdenum (Mo), selenium (Se), fluoride (F), nitrate (NO_3-N), calcium (Ca), magnesium (Mg), and sodium (Na). In addition, the 1979 samples were analyzed for the first time for arsenic (As), cyanide (CN) and fluoride (F). The Front Range Lab conducted cyanide analysis, whereas fluoride was analyzed in the Range Science Laboratory at Colorado State University. In 1999 additional analyses were made for chromium (Cr) and nickel (Ni).

Samples of waste rock growth medium were air dried, ground to pass through a 2-mm sieve, and subsamples submitted for chemical analyses. Spark source mass spectrometric analysis was utilized to determine elemental concentrations of many trace elements. This service was provided by CDM/ACCU Labs in Wheat Ridge, Colorado. Two samples collected in 1979 were submitted: a composite soil sample taken from a native spruce-fir stand above Lower Urad Reservoir and waste rock material from which the plant growth medium had been derived. Not enough samples were taken to make statistical comparisons of data derived from these analyses. Actual data obtained from the two samples are given in Table 2.

Data for analyses conducted by the Soil, Water, and Plant Testing Laboratory were subjected to analysis of variance and correlation analyses (Steel and Torrie, 1980) where appropriate to determine whether nutrient regime on heavy metals in the growth medium had changed through time and as a result of cultural treatments. When significant ($P < 0.05$) F-values were found, Newman-Keul's Range Test was utilized to separate significant ($P < 0.05$) mean differences. These analyses were also informative for evaluating relationships among variables and for assessing fertilizer requirements.

Plant Species Cover, Diversity and Production

Data collected for this study 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 species 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 10-20% 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 10 x 10-m plots on tailing ponds reclamation areas, whereas paced transects covered more total area of these stands. Urad tailing areas seeded in 1975, 1976, and 1977 were all 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 lower Urad Lake was also sampled as a control site to compare vegetation of a native community with that on reclaimed sites.

The 0.1-m^2 frames were placed at 1-m intervals along transects in each of two replications within a stand. The starting point for a transect was determined using a restricted random start method. Five individual transect lines in each plot were sampled (50 quadrats) in 1979 in both a fertilized and unfertilized plot on the tailing ponds reclamation area. Fertilized plots had received 200 lbs/acre of ammonium nitrate fertilizer, split between two applications during the 1979 growing season. Unfertilized plots were marked with metal corner stakes and were located adjacent to fertilized plots. No additional fertilizers had been applied since 1979 until June 1992. However, previous analyses (Trlica, 1989) indicated no significant difference between fertilized and unfertilized areas. Therefore, these two sampling blocks were considered as replications in latter years.

Two 50-m transects were established on the road cut reclaimed area and native burned-over community. Quadrats (0.1 m^2) were sampled at 1-m intervals along each transect (replications) in these stands. Data similar to that collected for the tailing ponds reclaimed areas were taken for these stands.

Most data were analyzed using analysis of variance procedures and simple linear correlations (Steel and Torrie, 1980). Significant differences were accepted at $P<0.05$. A repeated measure test for treatment effects was made. If treatments were different, then an LSD test was run to separate significant means ($P < 0.05$). If significant interactions were found, then a Bonferroni test was used to separate interaction means. Some data were not appropriate for statistical analyses (frequency and diversity), but were summarized. These data and analyses should aid in future determinations of successional rates on reclaimed areas.

Heavy Metal Uptake by Vegetation

Seedings made from 1975 through 1977 on Urad tailing ponds were sampled in August 1979, 1985, 1992, 1997 and 1999. Plants were at about peak production at this time. A native community in the 1879 burned-over area above lower Urad Lake was also sampled as a control site to compare vegetation of a native community with that on reclaimed sites. From 1979 to 1997 an important grass, smooth bromegrass (*Bromus inermis*) and a legume, white clover (*Trifolium repens*), growing on reclaimed tailing were clipped at ground level and placed in paper bags. In addition, cicer milkvetch (*Astragalus cicer*) was sampled in 1992 to correlate concentration of elements within this forage with that in white clover, as white clover had become infrequent on reclaimed areas. In 1999 hard fescue (*Festuca ovina*) was sampled at three sites within the tailing reclamation area where biosolids addition had been made. Hard fescue samples were also collected from three sites without biosolids addition; the roadcut area, burned area and native grassland at the base of an avalanche run. Hard fescue was sampled instead of smooth bromegrass and white clover, since their cover had decreased and hard fescue was present in all four communities. Individual plants were sampled along transects over much of the areas to be sampled. Foliage that was collected was bagged by species and site, and kept separately. Three samples (replications) of each species along separate transects and for each year of sampling were taken.

All samples were returned to the laboratory where they were washed in tap water and blotted dry. Samples were then dried at 60°C, ground to pass through a 20-mesh screen, and stored in ziplock bags until analyzed. All samples were submitted to the Soil, Water, and Plant 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. In addition the following elements were analyzed in 1999; calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P), titanium (Ti), cadmium (Cd), chromium (Cr), strontium (Sr), boron (B), barium (Ba), silicon (Si), vanadium (V), sodium (Na), nickel (Ni) and selenium (Se). In 1999, analysis of samples of hard fescue for carbon (C), nitrogen (N) and crude protein were done at CSU Rangeland Ecosystem Science Laboratory.

Data for the chemical constituents of the species foliage were analyzed using standard analysis of variance techniques (Steel and Torrie, 1980). When significant differences ($p < 0.05$) were detected among years of seeding, Newman-Keul's Range Test was used to separate these differences. When data were below detection limits of instruments, they were not analyzed statistically. Simple linear correlations and multiple regression analyses among soil chemical constituents and concentrations of elements in plant foliage were also made to determine whether soil chemistry was related to plant uptake of chemical constituents.

RESULTS AND DISCUSSION

Waste Rock Growth Medium

Elemental analysis of native soil and waste rock:

A comparison of elemental concentrations in a native soil from a spruce-fir community near the Urad tailing ponds with that of waste rock used as the plant growth medium in reclaiming the tailing ponds indicated that several elements were considerably more concentrated in waste rock than in soil (Table 2). Beryllium, bismuth, molybdenum, sulfur, and tungsten were more than 10 times more concentrated in waste rock material than in soil. The beryllium cation is considered very toxic, whereas oxygenated anions of molybdenum and tungsten, and the cation of bismuth, are considered moderately toxic to plant life (Bowen, 1966). Very toxic was defined by Bowen (1966) as toxic effects may be seen at concentrations below 1 ppm (µg/ml) in nutrient solution. Moderately toxic effects are noted at concentrations between 1 and 100 ppm in nutrient solutions. The toxicity of elementary sulfur is unique since the element is insoluble in water. Sulfur is toxic to most bacteria and fungi, but is almost without toxicity to higher plants. Thus, high levels of sulfur in waste rock might be detrimental to microbial populations in the growth medium, which in turn could affect decomposition of organic matter, nutrient cycling, and plant growth.

Twenty other elements were also more than twice as concentrated in waste rock as in soil (Table 2). However, just because an element is more concentrated in waste rock material does not necessarily mean that it is in an available state or readily taken up by plants. Availability is dependent not only on concentration, but also on pH, soil chemistry, soil water, microbial activity, solubility, environment, etc. (Lindsay, 1979).

Seven elements were more than twice as concentrated in soil as in waste rock material (Table 2). However, only one of these elements, boron, is essential for plant growth and development. Boron deficiencies for plants may not exist as only about 0.1 to 1.0 □g/ml (ppm) are needed in solution and waste rock had a concentration of 6.7 ppm. Just how much of the boron is actually available from the waste rock is not known at the present time.

Changes in waste rock growth medium through time:

There were large changes during the period from 1976 to 1979 in the nutrient regime of the waste rock growth medium with additions of wood chips and biosolids. Dramatic increases in organic matter (0.7 to 2.4%), nitrate-nitrogen (NO_3-N) (54 to 137 □g/g), phosphorus (P) (3 to 179 □g/g), and zinc (Zn) (14 to 100 □g/g) were found soon after addition of the amendments in 1976. Two to three years after the addition of biosolids, wood chips, and seed (1978 and 1979), some decline in conductivity (salts), nitrate-nitrogen (NO_3), phosphorus (P) and zinc (Zn) were noted. Leaching and plant uptake were probably responsible for most of these changes and similar results have been noted by other researchers after addition of biosolids (McBride et al., 1997).

These results were not unexpected. One would suspect that additions of large amounts of biosolids and wood chips would cause an increase in organic matter, nitrate-nitrogen, phosphorus and zinc in the growth medium as these were probably quite high in the biosolids. 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. Experimental evidence from other research suggests that there is relatively little movement of biosolids-applied metals below the surface soil, even over periods of several decades (McBride, 1995). The pH remained slightly basic the first nine years, but was slightly acidic by 1992, which agrees with other studies (Krebs et al., 1998) (Table 3).

Iron (Fe) concentrations and pH remained relatively constant between 1976 and 1979. Biosolid additions on degraded semiarid grassland in New Mexico resulted in increased soil N, P and K compared with untreated soil, but organic matter and pH were not significantly higher in amended areas (Fresques et al., 1990). Micronutrients of Cu, Fe, Mn and Zn increased in soil when biosolids had been applied as compared with untreated soil. A recent study of biosolids application to a sagebrush community in western Colorado showed that forage quality of perennial grass species was improved with increased tissue nitrogen concentration (Pierce et al., 1998).

The plant growth medium (waste rock) data were then statistically analyzed to determine whether significant changes occurred after amendments had been incorporated with waste rock. Samples collected in 1978, 1979, 1985, 1992, and 1997 from areas that were seeded from 1976 through 1978 were analyzed. These data indicated that pH, nitrates, and potassium decreased through the first nine-years (1976-1985) after application of amendments (Table 3). However, nitrates increased again in 1992 as the reclamation area was fertilized with ammonium nitrate at 100 lbs/acre in June. Nitrates were again low (2 µg/g) by 1997. Phosphorus, manganese (Mn) and copper remained relatively constant. Salts (conductivity), organic matter, zinc, and molybdenum (Mo) showed increases between 1978 and 1992. Molybdenum and fluoride concentrations were even greater in 1997 (36.3 and 3.8 µg/g, respectively). Weathering of waste rock and plant uptake of elements for growth and development on these reclaimed areas probably account for most of the changes observed in soil chemistry. As long as the growth medium remains neutral or only slightly acidic, Mo availability for plant uptake should remain fairly low. Leaching may have also removed some of the ions from the 0- to 30-cm surface layer.

Table 2. Elemental concentrations (% or ppm wt.) of Urad soil and waste rock in 1979 as determined by spark source mass spectrometry.

Element	Soil	Waste rock
Aluminum (Al)	> 1%	> 1%
Antimony (Sb)	0.58	0.69
Arsenic (As)	1.4	4.7*
Barium (Ba)	4200	4600
Beryllium (Be)	<0.33	7.0**
Bismuth (Bi)	0.35	8.2**
Boron (B)	29+	6.7
Bromine (Br)	1.2	6.0*
Cadmium (Cd)	0.68	1.4*
Calcium (Ca)	4700	> 1%**
Cerium (Ce)	340	190
Cesium (Cs)	4.9	8.6
Chlorine (Cl)	15	15
Chromium (Cr)	130	280*
Cobalt (Co)	2.2	5.1*
Copper (Cu)	24	24
Dysprosium (Dy)	4.0	2.7
Erbium (Er)	2.3	1.9
Europium (Eu)	0.66	0.66
Fluorine (F)	450	1900*
Gadolinium (Gd)	1.7	4.0*
Gallium (Ga)	8.4	15
Germanium (Ge)	0.70	1.4*
Hafnium (Hf)	18+	7.9
Holmium (Ho)	1.1	0.65
Iodine (I)	0.29+	0.10
Iron (Fe)	> 1%	> 1%
Lanthanum (La)	100	68
Lead (Pb)	35	120*
Lithium (Li)	43	43
Lutetium (Lu)	0.44+	0.22
Magnesium (Mg)	>0.5%	> 1%
Manganese (Mn)	18	66*
Molybdenum (Mo)	1.5	69**
Neodymium (Nd)	51	51
Nickel (Ni)	10	56*

Table 2. (Cont.).

Element	Soil	Waste rock
Niobium (Nb)	43	
Phosphorus (P)	1600	2400
Potassium (K)	> 1%	> 1%
Praseodymium (Pr)	4.9	9.9*
Rubidium (Rb)	560	420
Samarium (Sm)	6.2	12
Scandium (Sc)	5.4+	2.7
Selenium (Se)	0.16	0.94*
Silicon (Si)	> 1%	> 1%
Silver (Ag)	0.2	0.43*
Sodium (Na)	>0.5%	0.43*
Strontium (Sr)	230	240
Sulfur (S)	51	2400**
Tantalum (Ta)	3.6+	1.5
Terbium (Tb)	0.41	0.81
Thallium (Tl)	0.60	4.0*
Thorium (Th)	24	24
Thulium (Tm)	0.26	0.43
Tin (Sn)	3.1	13*
Titanium (Ti)	4200	4200
Tungsten (W)	0.46	4.6**
Uranium (U)	2.7	5.4*
Vanadium (V)	50	50
Ytterbium (Yb)	1.8	0.92
Yttrium (Y)	29	43
Zinc (Zn)	38	160*
Zirconium (Zr)	600+	230

+ Indicates concentration of element in soil exceeds that in waste rock by at least 2x.

* Indicates concentration of element in waste rock exceeds that in soil by at least 2x.

** Indicates concentration of element in waste rock exceeds that in soil by at least 10x.

Table 3. Average characteristics for the plant growth medium from 1978 through 1997 on the Urad tailing reclamation area.

Year of sampling	**1978**	**1979**	**1985**	**1992**	**1997**
No. of samples	6	6	6	6	6
pH	8.1a[1]	7.2b	7.1b	6.1b	6.6b
Conductivity (mmhos/cm)	0.5b	1.4a	1.4a	1.5a	1.3a
SAT (%)	--[2]	--	34b	43a	46a
Organic matter (%)	2.0b	2.9ab	2.5ab	4.3a	2.5ab
NO_3-N (□g/g)	12a	5bc	2c	10ab	2c
P (□g/g)	62a	72a	34a	30a	35a
K (□g/g)	112a	101a	71b	68b	53b
Zn (□g/g)	22b	39ab	25b	54a	52a
Fe (□g/g)	78a	93a	41a	108a	111a
Mn (□g/g)	17a	23a	34a	72a	80a
Cu (□g/g)	7b	22a	7b	18a	14a
Mo (□g/g)	1.5c	1.8c	9.4bc	14.2b	36.3a
As (□g/g)	--	<0.03	--	--	
F (□g/g)	--	0.61	--	--	
CN (□g/g)	--	<1.00	--	--	
Pb (□g/g)	--	--	13a	23a	12a
Cd (□g/g)	--	--	0.2b	0.6a	0.5a
F (□g/g)	--	--	1.7ab	0.8b	3.8a

[1] Means in the same row followed by a similar letter are not significantly different at $p > 0.05$.
[2] No data collected.

Changes in the growth medium as affected by year of seeding and year of sampling:

Plant growth medium samples collected in 1978, 1979, 1985, 1992, and 1997 were stratified according to when the tailing was seeded. This arrangement of the data showed few differences existed in chemical constituents among areas seeded in different years (Table 4). However, the small sample size (N = 2) had a large effect on detecting significant differences. Molybdenum concentrations appeared to be increasing in the growth medium of all seeded areas from 1978 (0.9-1.8 □g/g) to 1997 (8.9-52.0 □g/g). The pH also declined from about 8.2 in 1978 to 6.5 in 1997. With a decrease in pH, we might expect molybdenum to be less available for plant uptake, but other metals should be more available (Larcher, 1995).

It appears that growth and development of plants on the amended waste rock material has had only minor effects on characteristics of the growth medium. Major changes to the growth medium occurred when biosolids and wood chips were added. Additions of inorganic nitrate-nitrogen in fertilizer application in 1979 and 1992 had little influence on concentrations of nitrates in the surface layer (0-30 cm) of the plant growth medium during later years. This nitrate source was probably

Table 4. Average chemical characteristics for the plant growth medium of reclaimed Urad tailing areas that were seeded in 1975, 1976, or 1977. All samples were collected in August of 1978, 1979, 1985, 1992, and 1997 from the top 30 cm of growth medium.

	Year of collection														
	1978			1979			1985			1992			1997		
Year seeded	1975	1976	1977	1975	1976	1977	1975	1976	1977	1975	1976	1977	1975	1975	1977
No. Samples	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
PH	8.1a[1]	8.3a	8.2a	7.3a[1]	7.2a	7.2a	7.0a[1]	7.2a	6.9a	6.6a[1]	6.4a	5.4a	7.4a	6.0a	6.6a
Conductivity (mmhos/cm)	0.4a	0.6a	0.6a	1.3a	1.0a	2.0a	1.6a	1.0a	1.8a	1.7a	1.6a	1.2a	1.1a	1.2a	1.7a
SAT (%)	---	---	---	---	---	---	31a	43a	28a	43a	45a	42a	38a	50a	49a
OM (%)	3.2a	1.6a	1.3a	2.6a	3.4a	2.8a	2.2a	3.3a	2.0a	3.8a	4.6a	4.4a	2.0b	3.8a	1.7b
NO_3 (□g/g)	18a	10a	7a	2b	1b	11a	2a	2a	2a	26a	2b	2b	2.5a	2.5a	2.0a
P (□g/g)	72a	28a	85a	60a	52a	102a	27a	32a	44a	22a	14a	54a	30a	41a	34a
K (□g/g)	105a	107a	125a	80b	104ab	120a	72a	71a	70a	94a	73a	67a	61a	51a	49a
Zn (□g/g)	14a	20a	32a	35a	32a	49a	18a	20a	36a	49a	58a	55a	33a	69a	56a
Fe (□g/g)	59a	79a	97a	70a	85a	124a	37a	39a	47a	84a	167a	73a	37b	195a	100ab
Mn (□g/g)	12a	20a	19a	24a	22a	23a	30a	9a	64a	55a	150a	11a	15b	122a	102a
Cu (□g/g)	5a	6a	10a	23a	16a	27a	6a	6a	10a	14a	10a	30a	6b	24a	12ab
Mo (□g/g)	0 .9b	1.8ab	1.8a	3.9a	0.6a	0.8a	8.2a	7.5a	12.4a	10.0a	18.6a	13.8a	8.9b	52a	48.2a
Pb (□g/g)	---	---	---	---	---	---	10a	11a	18a	28a	7a	34a	10a	17a	9a
Cd (□g/g)	---	---	---	---	---	---	0.2a	0.2a	0.3a	0.6a	0.5a	0.8a	0.3a	0.8a	0.4a
As (□g/g)	---	---	---	<0.03a	<0.03a	<0.03a	---	---	---	---	---	---	---	---	---
F (□g/g)	---	---	---	0.7a	0.5a	0.6a	1.9a	1.2a	2.0a	0.7a	1.5a	0.2a	4.8a	2.2a	4.4a
CN (□g/g)	---	---	---	<1.0a	<1.0a	<1.0a	---	---	---	---	---	---	---	---	---

[1] Means in the same row within any one year of sample collection that are followed by a similar letter are not significantly different at $p > 0.05$.

rapidly taken up by plants and microbes, or was lost to leaching and volatilization. Areas that were fertilized had plants that were a darker green in color than plants on unfertilized areas, but plant production on fertilized and unfertilized areas was similar (Trlica, 1989). Addition of nitrate fertilizer in 1992 caused a significant increase in nitrate availability on the area seeded in 1975, but not in other areas. This was probably caused by poor distribution of fertilizer that was applied by helicopter across the tailing reclamation area.

Effect of biosolids on growth medium characteristics:

Soil characteristics were compared among treatment, where biosolids had been added in reclamation of Urad tailing but was not added to the burned area, avalanche run, and roadcut (Table 5). Conductivity and pH were significantly higher in Urad tailing where biosolids were used as compared with the other treatments. Soil organic matter was highest for the avalanche run, but no differences were found among the other three sites. Soil SAT was then higher in the grass community at the base of the avalanche run and in the old burned-over area than in the two reclaimed sites.

Few differences were found among sites for most plant nutrients, however copper was significantly higher in Urad tailing. Copper is known to form strong complexes with organic matter (Sloan et al., 1997). Speciation studies that extracted the organic fraction from biosolid-amended soils before the oxide fraction, found that most of the Cu was in the organic fraction.

No significant differences were found in the amount of lead among treatments, but it was somewhat higher in the roadcut where biosolids were not used, but near a road. Results of this study show that significant amounts of biosolids-derived lead can be applied to soil with no long-term increase (15+ years) in easily extracted forms of soil pH (Sloan et al., 1970).

Table 5. Average chemical characteristics for the plant growth medium in 1999 for Urad tailing waste rock reclamation with biosolids addition as compared with a roadcut, control burn, and avalanche run sites where biosolids where not applied.

	Treatment			
	Urad tailing	Roadcut	Control burn	Avalanche run
No. samples	3	3	3	3
PH	7.2a	6.2b	5.7c	5.7c[1]
Conductivity (mmhos/cm)	1.0a	0.3b	0.2b	0.3b
SAT (%)	35.3ab	28.5b	44.3a	48.5a
SAR	0.4b	0.7a	0.5ab	0.4b
OM (%)	2.8b	2.2b	4.5ab	6.5a
NO_3-N (□g/g)	3a	3a	6a	4a
P (□g/g)	29a	4b	4b	9b
K (□g/g)	50b	58b	129a	180a
Zn (□g/g)	23a	24a	1a	20a
Fe (□g/g)	61b	43b	94ab	131a
Mn (□g/g)	15ab	21a	5b	19a
Cu (□g/g)	5.4a	2.0b	0.4b	1.7b
Mo (□g/g)	12.1a	0.1b	0.1b	0.1b
Pb (□g/g)	9a	32a	2a	4a
Cd (□g/g)	0.2a	0.4a	0.1a	0.4a
As (□g/g)	0.050a	0.006b	0.003b	0.004b
F (□g/g)	3.0a	2.1ab	2.8a	1.6b
Cr (□g/g)	0.07a	0.07a	0.05a	0.06a
Ni (□g/g)	0.4ab	0.2b	0.2b	0.6a
Ca (meq/L)	11a	2b	2b	2b
Mg (meq/L)	0.6a	0.4a	0.7a	0.6a
Na (meq/L)	1.1a	0.7b	0.5b	0.5b
K (%)	0.6b	0.5b	1.1a	0.9a
Se (□g/g)	0.04a	0.02c	0.02c	0.03b

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

Cadmium is one of the most toxic elements in biosolids. No differences were found in its concentration in soil among sites and there appears to be no simple relation among plant uptake and amounts present in the soil (Pandeya et al., 1998). Cadmium solubility is influenced by pH, due to negatively charged particle surfaces in the mineral soil that cadmium binds to (Eriksson, 1989). High levels of cadmium have negative effects on soil microbial biomass C, but they can recover as microorganisms become adapted to high cadmium concentrations (Moreno et al., 1999). High levels of cadmium in organic amendments can inhibit mineralization of the water soluble C fraction.

Phosphorus, selenium, arsenic, sodium, calcium and fluorides were all higher in the Urad waste rock growth medium than in soils from the other three sites. Some of these increases may have resulted from the additions supplied in the biosolids amendment taken from the Denver Metropolitan area.

There were good correlations of calcium, arsenic and selenium with pH (Table 6). Calcium, sodium, phosphorus, copper and molybdenum were correlated with EC. Saturation was correlated with organic matter and negatively correlated with iron.

Data collected for chemical characteristics of soil from the four communities sampled in 1999 showed that Ca, Na, P, Cu, Mo, As, and Se were all highly correlated ($R > .60$) with both pH and EC of the soil (Table 6). This would indicate that as pH and EC increased, these elements were more abundant in the soil. Correlations among elemental concentrations and soil organic matter (OM) and saturation (SAT) were not as high ($R < .60$).

Correlations among chemical characteristics of the plant growth medium:

There were good correlations of phosphorus with potassium, potassium with molybdenum, zinc with copper, iron with copper, and manganese with molybdenum that yielded r values greater than 0.6 (Table 7). Molybdenum concentration was positively correlated with Mn concentration ($R = .66$) and negatively associated with pH ($R = -.48$), as expected. This may indicate a relatively close association among these growth medium parameters. Unfortunately, molybdenum was not highly correlated with any other metal, OM, or nitrate concentration. The generally weak correlations among constituents would essentially prohibit monitoring of some components to predict the level of others in the plant growth medium. Hooda et al. (1997) found that in soils from 13 different sites where there had been additions of biosolids that pH was more important than clay content in regulating the plant availability of Cd, Cu, Ni, Pb and Zn. The effect of organic matter, cation exchange capacity CEC, free Fe oxides and hydrous Mn oxides on metal accumulation in the plants was less clear.

Table 6. Correlation coefficients (R values) for various chemical characteristics of the plant growth media with elemental concentrations in the media. Plant growth medium samples were collected in 1999 from Urad tailing reclamation, a roadcut, control burn and avalanche run sites and data were combined.

	pH	EC	OM	SAT
Ca	.86	.99	-.28	-.19
Mg	-.12	.20	.47	.50
Na	.77	.86	-.49	-.42
NO_3-N	-.34	-.25	.56	.61
P	.64	.78	-.01	.10
K	.22	.46	.27	.20
Fe	-.56	-.26	.92	-.87
Mn	.09	.14	.15	-.05
Cu	.77	.83	-.28	-.26
Zn	.33	.29	.06	.03
Mo	.64	.88	-.22	-.20
Cd	-.06	-.09	.33	.25
Cr	.56	.39	-.25	-.32
Pb	.21	-.04	-.52	-.59
As	.86	.79	-.36	-.25
Se	.74	.85	-.13	-.06
pH		.86	-.52	-.41
EC		-.26	-.27	-.18
OM				.94

Table 7. Correlation coefficients (R values) for various chemical characteristics of the plant growth media with elemental concentrations in the media. Samples were taken from reclaimed areas on Urad tailings from 1979 through 1997 (four years of data combined).

	P	K	Zn	Fe	Mn	Cu	Mo	NO_3	pH	EC
K	.70									
Zn	.16	-.25								
Fe	.10	-.13	.63							
Mn	-.27	-.54	.56	.79						
Cu	.54	.21	.74	.63	.11					
Mo	-.24	-.63	.58	.52	.66	.17				
NO_3	-.04	.26	-.05	.03	-.09	-.03	-.24			
pH	.10	.39	-.71	-.37	-.40	-.59	-.48	.20		
EC	-.09	-.33	.46	.20	.42	.31	.31	-.01	-.40	
OM	.15	-.10	.52	.40	.30	.50	.12	.04	-.63	.13

Vegetation Dynamics

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 as a control) was the most diverse community (Tables 8 and 9). Twenty-six species occurred along transects through this community in 1979, 30 species were recorded in 1985, 32 were found in 1992, and 45 were present in 1997 (Table 9). The Urad tailing reclamation areas seeded in 1975, 1976 and 1977 had fewer invading species and were thus slightly less diverse than the burned-over area (Tables 8 and 9). Species numbered from 23 to 39 in 1997, with those areas reclaimed earlier having more species present (Table 9). However, frequency of occurrence of some species was low on reclaimed areas. Species diversity of a road cut reclamation area was quite similar to the tailing reclamation area. Species diversity has increased through the years on all sampled areas as a result of succession and favorable weather conditions during the past 19 years.

These data indicated that invasion was fairly rapid within five years of seeding, and that additional increases in species continued more slowly through 1997. Also, invasion was directly related to length of time since seeding of the reclaimed tailing ponds (Table 9). However, not all of the invading species were considered desirable, as some are weedy species. If one considers total species number, that includes all planted species as well as invading species, then the reclaimed tailing is as diverse as is the control community for total species number. It will be interesting to determine whether invading species increase in cover and production in the future, as their importance and abundance in reclaimed areas was still fairly low in 1997.

Table 8. Species invading seeded areas of Urad reclamation sites, Henderson Mine road cut, and a burned-over spruce-fir community that served as a control.

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
1975 SEEDING - URAD TAILING				
GRASSES AND SEDGES				
Agropyron trachycaulum (slender wheatgrass)	x			x
Bromus marginatus (mountain brome)	x	x		x
Bromus tectorum (cheatgrass)	x			
Carex sp. (sedge)			x	x
Hordeum jubatum (foxtail)	x			
Luzula sp. (wood rush)			x	x
FORBS AND SHRUBS				
Achillea lanulosa (western yarrow)	x	x	x	x
Agoseris sp. (bent grass)				x
Antennaria rosea (rose pussytoes)		x	x	x
Arctostaphylos uva-ursi (bearberry manzanita)	x			
Aster bigelovii (bigelow tansy aster)	x	x	x	x
Boechera drummondii (arabis)				x
Campanula parryi (Parry bellflower)	x		x	x
Castilleja sp. (red paintbrush)			x	
Cerastium sp. (chickweed)				x
Chaenactis alpina (alpine dusty maiden)	x			
Chrysopsis villosa (hairy goldenaster)			x	x
Claytonia sp. (spring beauty)				x
Descurainia richardsonii (Richardson tansy mustard)	x		x	x
Epilobium angustifolium (fireweed willowherb)	x	x	x	x
Eriogonum sp. (buckwheat)			x	x
Erigeron compositus (fernleaf fleabane)				x
Fragaria americana (strawberry)		x	x	x
Geranium viscosissimum (pink geranium)	x	x		x
Hirculus serpyllifolius (golden saxifrage)				x
Juniperus communis (common juniper)				x
Lilly sp.				x
Medicago sativa (alfalfa)		x		
Penstemon whippleanus (whipple penstemon)	x	x	x	x
Phacelia sericea (purple fringe)	x	x	x	x
Polemonium viscosum (sticky polemonium)				x
Potentilla fruticosa (shrubby cinquefoil)		x	x	
Potentilla glandulosa (gland cinquefoil)		x	x	x
Ranunculus sp. (buttercup)				x
Rosa woodsii (wood rose)		x	x	
Rumex acetosella (sheep sorrel)	x	x	x	x
Rumex crispus (curly dock)	x		x	
Salix sp. (willow)	x	x	x	x

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation			
	1979	1985	1992	1997
1975 SEEDING - URAD TAILING				
Sambucus cerulea (elderberry)		x	x	
Sedum lanceolatum (stonecrop)	x	x	x	x
Senecio ambrosioides (butterweed)		x	x	x
Senecio hydrophilus (blackheaded groundsel)				x
Senecio soldanella (butterweed)		x	x	x
Shepherdia canadensis (buffaloberry)				x
Taraxacum officinale (dandelion)		x	x	x
Trifolium pratense (red clover)	x			x
TREES				
Abies lasiocarpa (subalpine fir)			x	x
Picea engelmannii (Engelmann spruce)			x	x
Populus tremuloides (quaking aspen)		x	x	x
TOTAL SPECIES	**19**	**21**	**28**	**39**

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
1976 SEEDING - URAD TAILING				
GRASSES AND SEDGES				
Bromus marginatus (mountain brome)			x	
FORBS AND SHRUBS				
Achillea lanulosa (western yarrow)	x	x	x	x
Agoseris sp. (false dandelion)				x
Androsace septentrionalis (rock jasmine)				x
Antennaria rosea (rose pussytoes)			x	x
Arctostaphylos uva-ursi (bearberry manzanita)	x			x
Aster bigelovii (bigelow tansy aster)	x	x	x	x
Astragalus sp. (loco weed)				x
Campanula parryi (Parry bellflower)			x	
Chrysopsis villosa (hairy goldenaster)			x	x
Descurainia richardsonii (Richardson tansy mustard)			x	x
Epilobium angustifolium (fireweed willowherb)	x	x	x	x
Fragaria americana (strawberry)	x	x	x	x
Geranium viscosissimum (pink geranium)			x	
Juniperus communis (common juniper)				x
Lonicera involucrata (bush honeysuckle)				x
Machaeranthera coloradoensis (Colorado aster)				x
Medicago sativa (alfalfa)		x		
Penstemon whippleanus (whipple penstemon)			x	x
Phlox sp.				x
Polemonium viscosum (Jacobs ladder)				x
Potentilla fruticosa (shrubby cinquefoil)				x
Potentilla glandulosa (gland cinquefoil)	x	x	x	x
Rubus sp.			x	x
Rumex crispus (curly dock)	x			
Salix sp. (willow)		x	x	x
Sambucus cerulea (elderberry)		x	x	
Sedum lanceolatum (stonecrop)			x	x
Senecio atratus (black groundsel)				x
Senecio ambrosioides (butterweed)			x	x
Senecio crassulus (thickleaf groundsel)				x
Senecio soldanella (butterweed)			x	x
Solidago sp. (goldenrod)				x
Taraxacum officinale (dandelion)			x	x
TREES				
Abies lasiocarpa (subalpine fir)	x	x	x	x
Populus tremuloides (quaking aspen)	x	x	x	x
TOTAL SPECIES	**8**	**9**	**21**	**30**

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
1977 SEEDING - URAD TAILING				
GRASSES AND SEDGES				
Agropyron cristatum (crested wheatgrass)		x		
Agrostis sp. (bentgrass)			x	x
Luzula sp. (wood rush)		x	x	x
Poa ampla (big bluegrass)				x
Trisetum wolfii (wolf trisetum)				x
FORBS AND SHRUBS				
Achillea lanulosa (western yarrow)		x	x	x
Alnus sp. (alder)		x		
Antennaria umbrinella (umber pussytoes)				x
Aster bigelovii (bigelow tansy aster)		x	x	x
Astragalus sp. (loco weed)				x
Chaenactis alpina (alpine dusty maiden)				x
Chrysopsis villosa (hairy goldenaster)				x
Campanula parryi (Parry bellflower)				x
Epilobium angustifolium (fireweed willowherb)			x	x
Fragaria americana (strawberry)				x
Hymenoxys odorata (bitterweed actinea)		x		
Lepidium sp. (pepper grass)		x		x
Oxytropis sericeus (white pointloco)				x
Penstemon confertus (little flower penstemon)			x	x
Penstemon sp.			x	
Phacelia sericea (purple fringe)		x		
Potentilla fruticosa (shrubby cinquefoil)				x
Potentilla glandulosa (gland cinquefoil)			x	
Rumex sp. (dock)		x		
Salix exigua (willow)		x	x	x
Salix lutea (yellow willow)				x
Sedum lanceolatum (stonecrop)		x	x	x
Senecio ambrosioides (butterweed)			x	x
Solidago sp. (goldenrod)		x		
Taraxacum officinale (dandelion)		x	x	x
Trifolium pratense (red clover)		x		
TREES				
Populus tremuloides (quaking aspen)			x	x
TOTAL SPECIES	**0**	**14**	**13**	**23**

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation			
	1979	1985	1992	1997
1972 SEEDING - HENDERSON ROAD CUT				
GRASSES AND SEDGES				
Agrostis sp. (bent grass)				x
Bromus sp. (bromegrass)	x	x		
Carex sp. (sedge)			x	
Carex aquatilis (water sedge)	x	x	x	x
Deschampsia caespitosa (tufted hairgrass)	x			
Festuca thurberi (Thurber fescue)	x			
Hordeum jubatum (foxtail barley)			x	
Juncus drummondii (Drummond rush)		x	x	x
Luzula parviflora (millet woodrush)	x	x	x	x
Muhlenbergia sp. (muhly)			x	
Phleum alpinum (alpine timothy)			x	x
Phleum pratense (timothy)				x
Poa sp. (bluegrass)				x
Trisetum wolfii (wolf trisetum)				x
FORBS AND SHRUBS				
Achillea lanulosa (western yarrow)		x	x	x
Agoseris sp. (false dandelion)			x	
Antennaria rosea (rose pussytoes)			x	x
Arnica cordifolia (heartleaf arnica)		x		
Aster bigelovii (bigelow tansy aster)	x		x	x
Boechera divaricarpa (false arabis)				x
Campanula uniflora (alpine harebell)		x		
Cerastium sp. (chickweed)				x
Chrysopsis villosa (hairy goldenaster)			x	x
Cirsium arvense (Canada thistle)				x
Clementsia rhodantha (rose crown)		x		x
Coeloglossum viride (greenbog orchid)				x
Conioselinum scopulorum (Rocky Mtn. hemlock parsley)				x
Crucifer sp.		x		x
Epilobium angustifolium (fireweed willowherb)	x	x	x	x
Equisetum sp. (horsetail)	x		x	x
Fragaria americana (strawberry)		x	x	x
Gentianoides algida (Arctic gentian)				x
Geranium richardsonii (Richardson geranium)				x
Langria vulgaris				x
Leucanthemum vulgare (oxeye daisy)				x

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
1972 SEEDING - HENDERSON ROAD CUT				
Melilotus officinalis (yellow sweetclover)	x			
Penstemon whippleanus (whipple penstemon)		x	x	x
Potentilla glandulosa (gland cinquefoil)		x	x	x
Salix sp. (willow)				x
Saxifraga sp. (saxifrage)				x
Senecio sp. (groundsel)		x	x	x
Solidago sp. (goldenrod)				x
Taraxacum officinale (dandelion)	x	x	x	x
Trifolium pratense (red clover)			x	x
Vaccinium sp. (huckleberry)				x
TREES				
Abies lasiocarpa (subalpine fir)				x
Picea engelmannii (Englemann spruce)				x
Populus tremuloides (quaking aspen)				x
TOTAL SPECIES	**10**	**16**	**20**	**38**

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
CONTROL - SPRUCE-FIR BURN AREA				
GRASSES AND SEDGES				
Agrostis humilis (snow bent)	x	x	x	x
Bromus marginatus (mountain brome)		x		x
Calamagrostis rubescens (pine reedgrass)	x	x	x	x
Carex sp. (sedge)	x	x	x	x
Deschampsia caespitosa (tufted hairgrass)		x	x	
Festuca ovina (sheep fescue)	x	x	x	x
Poa sp. (bluegrass)				x
Poa interior (inland bluegrass)	x	x	x	x
Sitanion hystrix (bottlebrush squirreltail)			x	x
Trisetum spicatum (spike trisetum)				x
FORBS AND SHRUBS				
Achillea lanulosa (western yarrow)	x	x	x	x
Antennaria rosea (rose pussytoes)	x	x	x	x
Aquilegia micrantha (columbine)			x	x
Arctostaphylos uva-ursi (bearberry manzanita)	x	x	x	
Arnica cordifolia (heartleaf arnica)	x	x	x	x
Aster sp. (aster)	x	x	x	x
Astragalus sp. (loco weed)			x	x
Boechera divarricarpa (rockcress)				x
Castilleja miniata (scarlet paintbrush)	x	x	x	x
Castilleja sulphurea (yellow paintbrush)	x	x	x	x
Cerastium sp. (chickweed)	x	x	x	x
Chaenactis alpina (alpine dusty maiden)				x
Cirsium sp. (thistle)		x	x	x
Chrysopsis villosa (hairy goldenaster)			x	x
Clementsia rhodantha (rose crown)	x	x	x	x
Epilobium angustifolium (fireweed willowherb)	x	x	x	x
Eriogonum sp. (buckwheat)			x	x
Fragaria americana (strawberry)	x	x	x	
Hirculus chrysanthus				x
Juniperus communis (common juniper)	x	x	x	x
Mertensia sp. (bluebells)				x
Microseris gracilis (microseris)				x
Phacelia hastata (scorpion weed)				x
Polemonium palcherrimum				x
Potentilla fruticosa (shrubby cinquefoil)	x	x		
Potentilla glandulosa (gland cinquefoil)	x	x	x	x

Table 8. (cont.)

SCIENTIFIC NAME (Common name)	Year of observation 1979	1985	1992	1997
CONTROL - SPRUCE-FIR BURN AREA				
Pseudocymopterus montanus (false spring parsley)	x	x		
Rosa woodsii (woods rose)	x	x	x	x
Rubus sp.				x
Sambucus sp. (elderberry)	x	x	x	x
Saxifraga bronchialis (spotted saxifrage)	x	x		
Sedum sp. (stonecrop)		x	x	x
Senecio sp. (groundsel)				x
Shepherdia canadensis (buffaloberry)	x	x	x	x
Solidago sp. (goldenrod)			x	x
Taraxacum officinale (dandelion)				x
Thalictrum sp. (meadow rue)				x
Trifolium sp. (clover)				x
Vaccinium myrtillus (myrtle blueberry)	x	x	x	x
Viola sp. (violet)				x
TREES				
Populus tremuloides (quaking aspen)	x	x	x	x
TOTAL SPECIES	**26**	**30**	**32**	**44**

Table 9. Number of naturally occurring (not seeded) species found in 1979, 1985, 1992, and 1997 on reclaimed tailing areas, a roadcut in the Henderson-Urad mining area, and a burned-over spruce-fir community.

	Number of species															
	Grasses & Sedges				Forbs & Shrubs				Trees				Total			
Study area	1979	1985	1992	1997	1979	1985	1992	1997	1979	1985	1992	1997	1979	1985	1992	1997
1975 Seeding - tailing	4	1	2	4	15	20	23	32	0	0	3	3	19	21	28	39
1976 Seeding - tailing	0	0	1	0	7	8	18	28	1	1	2	2	8	9	21	30
1977 Seeding - tailing	0	2	2	4	0	12	10	18	0	0	1	1	0	14	13	23
1972 Seeding - roadcut	5	4	7	8	4	11	13	27	0	0	0	3	9	15	20	38
Control - 1879 burn area	5	7	7	9	20	22	24	35	1	1	1	1	26	30	32	45

Table 10. Frequency of occurrence of soil surface characteristics for stands on reclaimed Urad tailing, Henderson Mine road cut, and a native burned-over spruce-fir stand.

	Percentage of hits							
	Bare soil				Rocks			
Study area	1979	1985	1992	1997	1979	1985	1992	1997
Urad tailing ponds	0d[1]	2cd	1d	1d	26a[1]	12bc	16bc	14bc
Henderson roadcut	12a	5bc	10a	6b	6c	15bc	19ab	20ab
1879 burned area	3bcd	2cd	10a	5bc	21ab	13bc	13bc	17abc
	Moss				Litter			
Urad tailing ponds	0b[1]	2b	15a	14a	39a[1]	17b	17b	21b
Henderson roadcut	2b	10a	12a	14a	41a	8c	8c	7cd
1879 burned area	1b	2b	0b	0b	12bc	11bc	9c	4d

[1] Means for each characteristic followed by a similar letter are not significantly different at $p > 0.05$.

Table 11. Frequency of occurrence (%) of vascular plants on reclaimed Urad tailing ponds, a Henderson Mine road cut, and a native burned-over native spruce-fir stand.

Year	**1979**	**1985**	**1992**	**1997**
Percentage	34c[1]	58a	42bc	46b

Treatment	**Tailing ponds**	**Road cut**	**Burned area**
Percentage	43a[1]	39a	54a

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

Canopy cover:

Canopy cover for grasses and forbs on each stand was sampled utilizing a slight modification of the Daubenmire (1959) technique. Cover of plants was estimated to the nearest one percent. The cover for all vegetation for reclaimed areas and the burned-over spruce-fir community showed that total cover was greatest in 1979 (48%) and declined significantly by 1985 (26%), with some improvement again by 1997 (35%). Grass cover made up most of this cover and is illustrated in Figure 1. Cover of the tall introduced grass, smooth bromegrass (*Bromus inermis)*, declined on all tailing pond reclaimed areas from 1979 to 1985 and has continued to have low cover values around 5% through 1997. However, the shorter stature species, hard fescue (*Festuca ovina)*, increased on most of these reclaimed areas during the same 19-year period (Fig. 2). This is what had been predicted (Trlica, 1989), as available soil nitrogen became more limited on reclaimed tailing pond areas. This is not an undesirable reaction in grass species succession, as hard fescue is a native plant in the area whereas smooth bromegrass is an introduced pasture grass from Europe. However, one might expect aboveground biomass production to decline with an increase in the shorter stature species.

Total grass cover actually declined on most reclaimed areas and the burned-over community between 1979 and 1985 and has remained at about 20-25% through 1997 (Fig. 1). Again, this response may have been caused by lower nitrogen availability in the growth medium as application of N fertilizer only occurred in 1979 and 1992. However, grass cover in the burned-over spruce-fir community also declined during this same period. This may then indicate that natural variations in weather patterns were primarily responsible for the overall decline in grass cover.

Grass cover on all reclaimed areas was significantly greater than on the native spruce-fir community that had been burned in 1879 (Fig. 3). Reclaimed areas on the Urad tailing also had greater grass coverage than was found on a roadcut reclamation area near the Henderson Mine, which indicates the desirability of using the amendments of biosolids and wood chips in reclamation. This may also have resulted from steeper slopes on the roadcut, one of which was a south-facing slope. Thus, the steep reclaimed roadcut had less vegetation cover than reclaimed tailing ponds.

There was very little cover by forbs on any of the tailing or roadcut reclamation areas throughout the 19-year period (Fig. 4). Forb cover on the old burned area was much greater than on reclaimed areas. This was anticipated as the spruce-fir community has had more than 100 years of secondary succession to allow for more forb recovery. Species diversity is greater within this natural community and the number of forb species is high. The only forbs seeded onto reclaimed areas were white Dutch clover (*Trifolium repens)* and cicer milkvetch (*Astragalus cicer)*. All other forb seed must reach these reclaimed sites by natural means (i.e., wind or animal carriers).

Total cover for all vegetation has been greater through most of the 19-year period on reclaimed areas compared with the burned-over spruce-fir community. This has been effective in reducing wind and water erosion on reclaimed areas. By 1997 forb cover on the reclaimed tailing ponds was significantly greater than in previous years (Fig. 5). This indicates that forbs are moving into the reclaimed areas through natural processes. However, cover of white clover has declined, and a reintroduction of white clover or some other legume on reclaimed sites might improve both forb cover and available nitrogen, as they may fix atmospheric nitrogen.

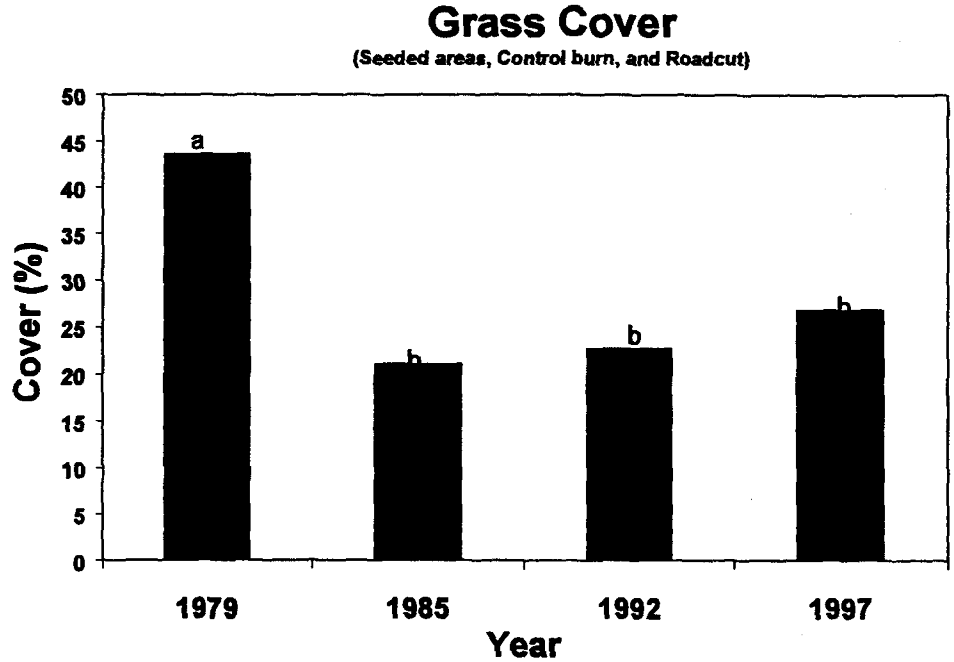

Figure 1. Average grass cover for all treatments at the Urad-Henderson reclamation area from 1979 through 1997. Different letters above a bar indicate significant differences (P < 0.05).

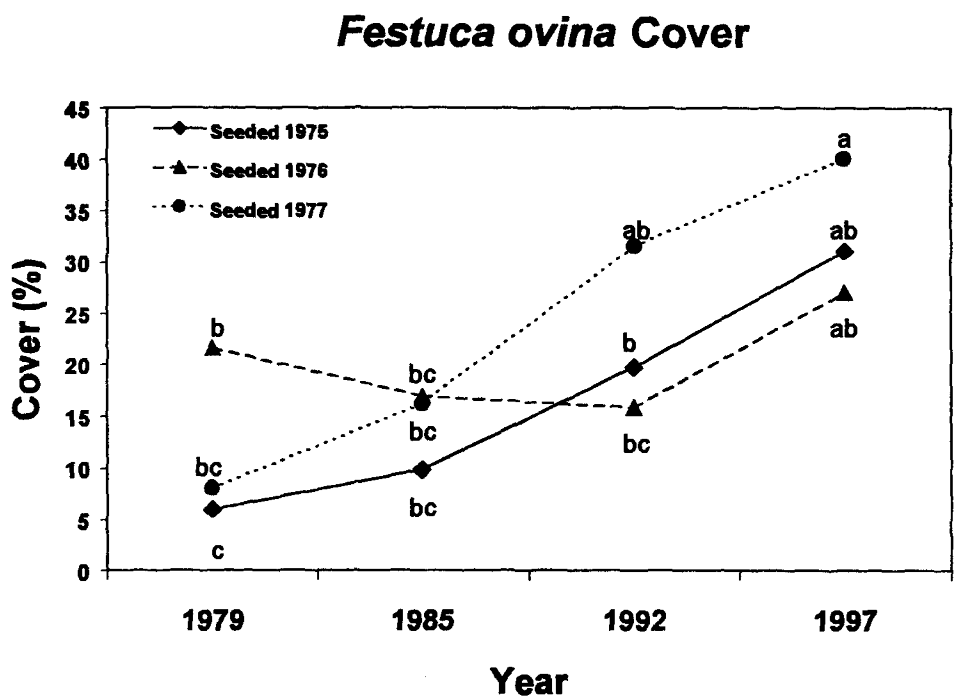

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Figure 2. Aerial cover of hard fescue (*Festuca ovina*) from 1979 through 1997 on Urad tailing reclamation areas seeded in 1975, 1976, and 1977. Means with different letters are significantly different (P < 0.05).

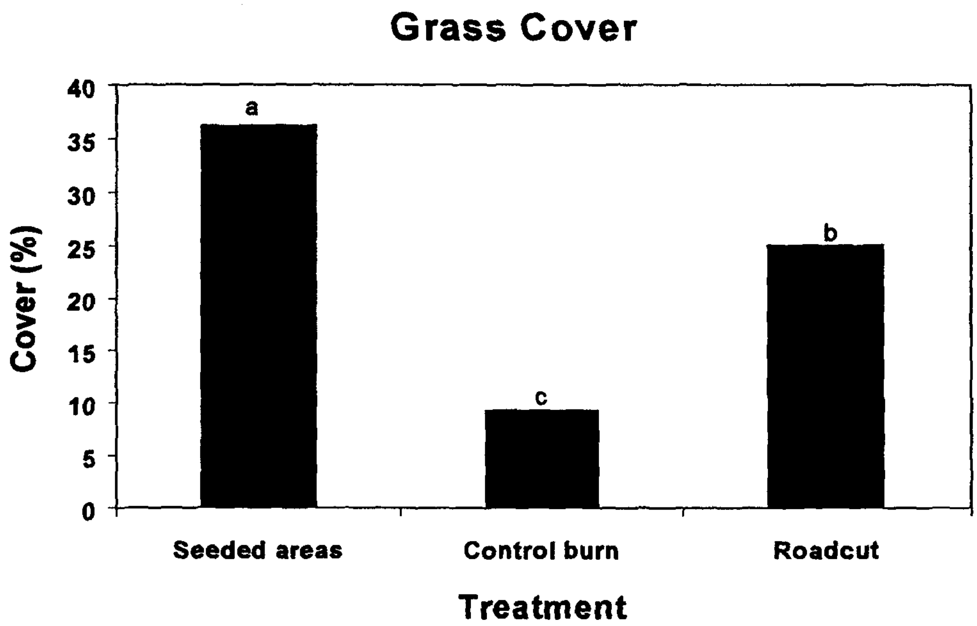

Figure 3. Average grass cover from 1979 through 1997 on seeded areas of the Urad reclaimed tailing, control burned area, and a road cut near the Henderson Mine. Different letters bove a bar indicate significant differences (P < 0.05)

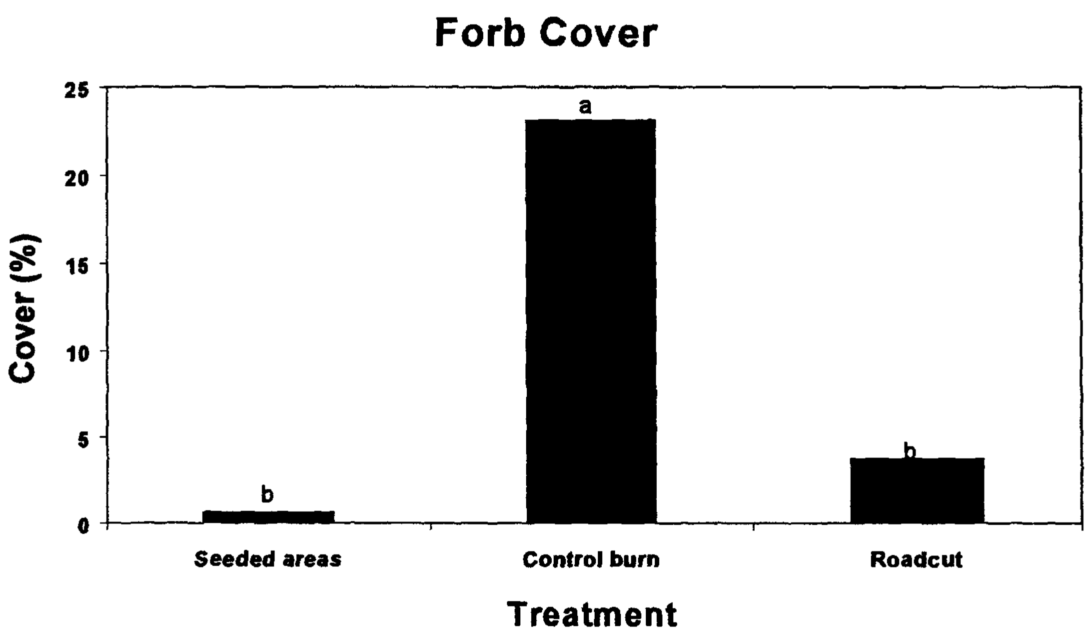

Figure 4. Average forb cover from 1979 through 1997 on seeded areas of the Urad reclaimed tailing, control burned area, and a road cut near the Henderson Mine. Different letters above a bar indicate significant differences (P < 0.05).

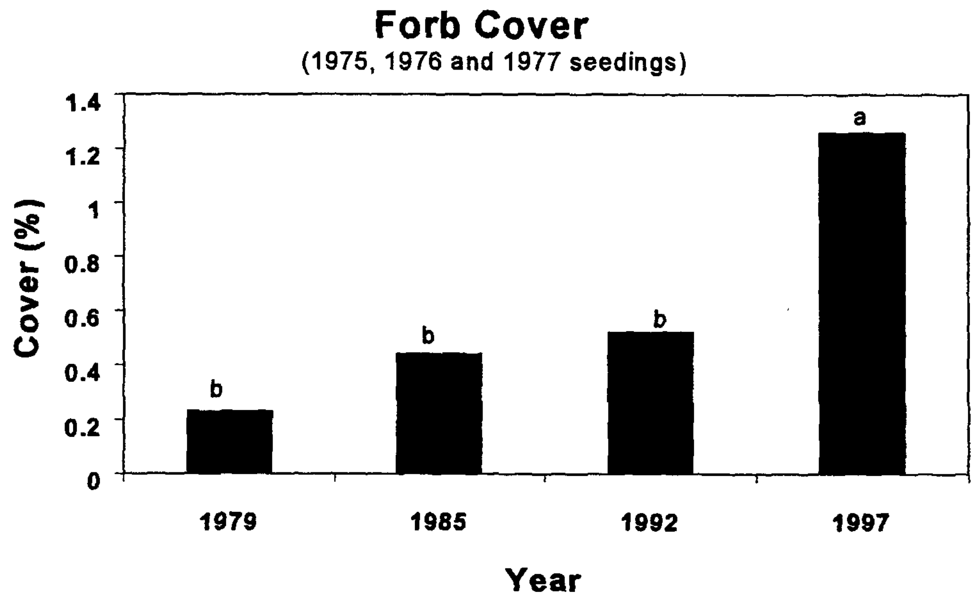

Figure 5. Average forb cover from 1979 through 1997 for areas seeded from 1975 through 1977 on the Urad tailing reclamation area. Different letters above a bar indicate significant differences ($P < 0.05$).

Production:

Aboveground standing crop of current year's growth was estimated using 0.1-m^2 quadrats for which cover had been sampled. Ten or 20 percent of the quadrats were randomly sampled to determine actual standing crop of oven-dried (60°C) biomass. A linear regression analysis was used to correct all estimated weights based on actual clipped quadrat weights. The Urad reclamation areas produced significantly more aboveground biomass during the four years of sampling than did either the roadcut area or the burned-over spruce-fir community (control) (Fig. 6). Production on reseeded tailing ponds was somewhat greater in 1985 than in other years of sampling (Fig. 7). The area seeded in 1977 produced more biomass than the area seeded in 1975 in two of the four years of sampling. In general, there was an increase in production between 1979 and 1985, even though vegetation cover declined somewhat (Fig. 8). This probably resulted from a very wet spring and above average precipitation for 1985. Precipitation in 1985, 1992, and 1997 exceeded the 20-year average according to weather records from Winter Park, Colorado, that is not too distant from the study area.

Production on the tailing ponds and roadcut areas was similar to that of shortgrass prairie; whereas, production on the control area was more like that of a desert grassland or sagebrush-grassland type (Sims et al., 1978).

Applying 200 lbs/acre of inorganic fertilizer to the tailing ponds seeded areas during the 1979 growing season did not significantly increase the aboveground standing crop in 1979, but production was greater in 1985. Vegetation that received the added nitrate fertilizer had a dark green color and appeared more vigorous in 1979 even though production was not increased. Dead grass crowns were noted between 1985 and 1992 and nitrogen deficiency was suspected. No additional fertilizers had been applied until June 1992, when 100 lbs/acre of ammonium nitrate was applied by helicopter. This application was not evenly distributed across tailing reclamation areas and resulted in increased production in some areas, but not on others. There was no indication in 1997 that additional fertilizer was needed at this time.

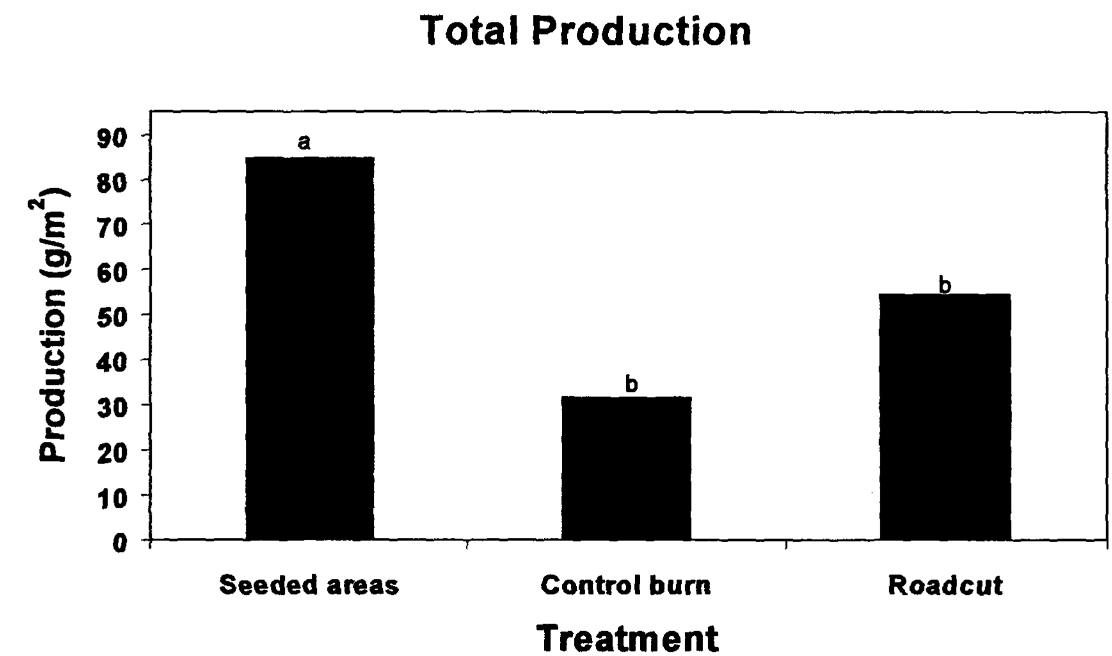

Figure 6. Total aboveground biomass production for seeded areas on the Urad reclaimed tailing, control burned area, and a roadcut near the Henderson Mine. Production values are averages for the years 1979, 1985, 1992, and 1997. Different letters above a bar indicate significant differences among areas ($P < 0.05$).

Heavy Metal Uptake by Vegetation

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 12). Arsenic, copper, and fluoride concentrations in the waste rock growth medium were lower than that reported for soil. Lead and molybdenum were sometimes higher in the Urad growth medium than in soil. This was expected, as these two elements were concentrated in waste rock taken from the molybdenum ore body.

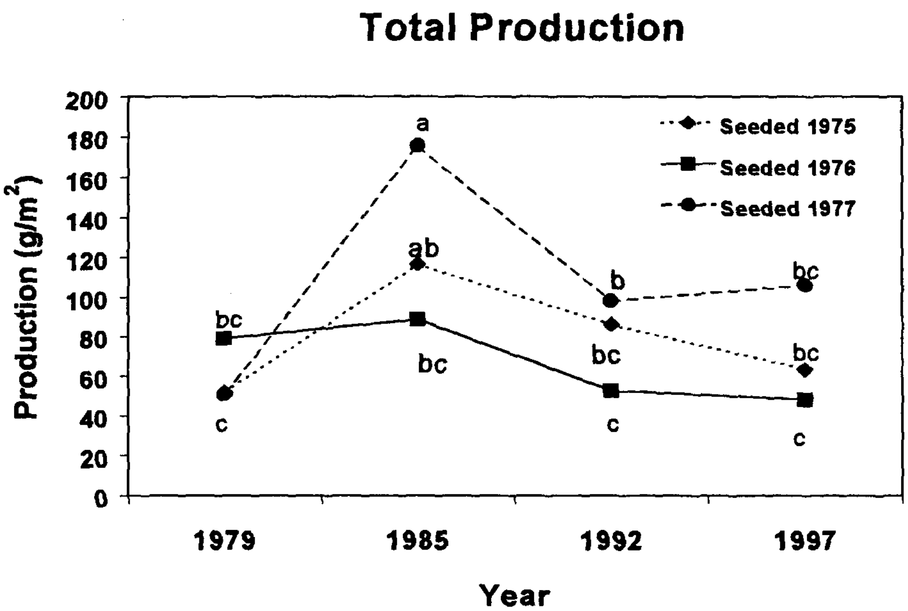

Figure 7. Total aboveground biomass production from 1979 through 1997 on Urad tailing reclamation areas seeded in 1975, 1976, and 1977. Means with different letters are significantly different ($P < 0.05$).

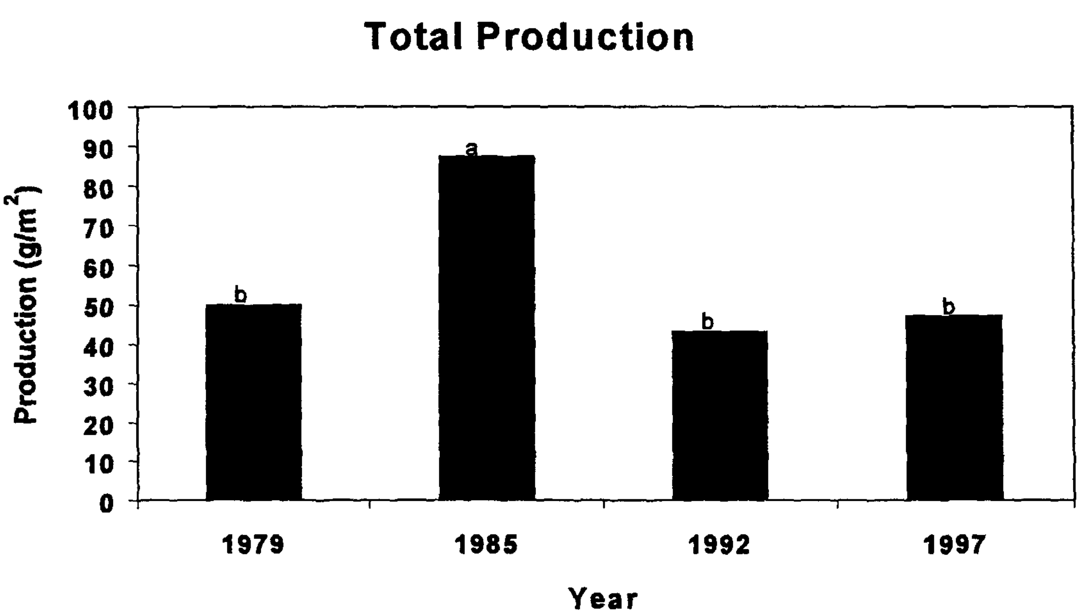

Figure 8. Total aboveground biomass production on Urad tailing reclamation from 1979 through 1997. Different letters above a bar indicate significant difference ($P < 0.05$).

Table 12. Average concentration (μg/g) of elements in soil as compared with 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)	0.6	0.4-0.7	190	20-500	NAS, 1971
Lead (Pb)	27	11-44	16	2-200	Swaine, 1955
Manganese (Mn)	207	5-655	600	200-3000	Swaine, 1955
Molybdenum (Mo)	188	0.1-440	2.5	0.6-3.5	Robinson & Alexander, 1953
Zinc (Zn)	30	5-64	5-175	10-300	Swaine, 1955

Comparison of year of seeding:

Data for both smooth bromegrass and white clover were utilized in analysis of variances to determine whether differences existed in either species or for both species in the areas seeded over a three-year time period (1975 through 1977). These analyses revealed that vegetation growing on the newer seeding (1977) had higher concentrations of molybdenum than did plants from the 1975 or 1976 seedings (Table 13). Plants that were growing on the area seeded in 1975 had higher concentrations of aluminum, iron, and copper:molybdenum ratios than did plants growing on the area seeded in 1976 or 1977. This might indicate that the pH of the 1975 seeded area, that was slightly more acidic by the time it was sampled in 1979, had allowed for slightly greater uptake of metal cations.

Comparison of year of sampling:

Few differences existed in elemental concentrations among plants in the three or four years of sampling, except for iron and copper (Table 13). Both of these metals have decreased in plant tissue from the early years of study until 1997. This has resulted in a decrease in the Cu:Mo ratio through time as well. The Cu:Mo ratio has always been below the 2:1 ratio recommended for cattle consumption of forages. Molybdenum levels averaged 40 μg/g in smooth bromegrass and 354 μg/g in white clover (Table 13). These levels were exceedingly high and surpassed most levels previously reported in plants (Kubota, 1976; Gupta and Lipsett, 1981).

Comparison among species:

The legume, white clover, had significantly higher concentrations of arsenic, aluminum, zinc, iron, manganese, copper, molybdenum, and fluoride in foliage than did smooth bromegrass (Table 13). This was expected as legumes are known to concentrate several elements more than do grasses. The exceedingly high average concentrations of molybdenum (354 μg/g) and somewhat high concentration of fluoride (19 μg/g) in white clover would certainly not make this

Table 13. Average elemental concentration in forage samples of smooth bromegrass and white clover collected from Urad tailings seeded in 1975, 1976 and 1977. All samples were collected in August, 1979, 1985, 1992 and 1997.

	Chemical constituent (μg/g)								
Variable	As	Al	Zn	Fe	Mn	Cu	Mo	Cu/Mo	F
Year sampled									
1979	-	-	-	-	203a	11a	172a	0.17a	25a
1985	0.08a[1]	72a	76a	143a	186a	7c	213a	0.15a	4b
1992	0.09a	79a	86a	98b	235a	8b	179a	0.16a	-
1997	0.10a	88a	99a	82b	210a	7c	224a	0.07b	-
Year seeded									
1975	0.12m[1]	119m	78m	161m	228m	8m	162n	0.18m	14m
1976	0.07n	68n	86m	90m	202m	8m	179n	0.12n	17m
1977	.09mn	51n	97m	73n	194m	8m	249m	0.11n	12m
Species									
Smooth bromegrass	0.07y[1]	32y	67y	48y	177y	7y	40y	0.25x	10y
White clover	0.11x	127x	107x	168x	240x	9x	354x	0.03y	19x

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

species desirable forage for ruminants. Fluoride concentration in plant foliage normally ranges from 2 to 20 μg/g (ppm) (NAS, 1971). The concentration of molybdenum (40 μg/g) in smooth bromegrass across all four years of sampling would also limit its utility for use by livestock (Table 13). With the high concentration of molybdenum and the low but normal concentration of copper in both species, the copper:molybdenum ratio was dangerously low for ruminants. Copper: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.

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 14). This was anticipated as there usually is not a linear relationship between soil variables and the uptake and concentration of elements in plants. The concentration of molybdenum in the growth medium and in both plant species was not highly correlated ($R = .10$ and $.43$) (Table 14). This indicated that prediction of plant uptake of molybdenum from molybdenum concentrations in the growth medium could not be done accurately. The pH of the growth medium was also not well correlated with uptake of metals by smooth bromegrass and white clover. Analyses of data for accumulation of heavy metals in several crops grown on soils previously amended with biosolids for many years shows on the other hand that soil total metal concentration was found to be the principal factor controlling metal contents in the plants, along with pH and clay content (Hooda et al., 1997).

Table 14. Simple linear correlation coefficients (R values) of growth medium parameters with chemical constituents in foliage of plants. Samples were collected on the Urad tailing reclamation area in early August, 1979, 1985, 1992 and 1997 (data sets combined).

Parameter	Plant Zn	Plant Fe	Plant Mn	Plant Cu	Plant Mo
			Smooth bromegrass		
Medium Zn	.10	-	-	-	-
Medium Fe	-	-.38	-	-	-
Medium Mn	-	-	.04	-	-
Medium Cu	-	-	-	.35	-
Medium Mo	-	-	-	-	.10
Medium pH	-.09	.28	-.05	.26	-.09
			White clover		
Medium Zn	.16	-	-	-	-
Medium Fe	-	-.10	-	-	-
Medium Mn	-	-	.48	-	-
Medium Cu	-	-	-	.03	-
Medium Mo	-	-	-	-	.43
Medium pH	.08	.21	.01	.09	.04

Comparisons among foliage concentration of metals in white clover and cicer milkvetch:

Cicer milkvetch was sampled in 1992, as white clover had almost disappeared from the reclaimed tailing ponds. Samples from both species were compared to determine whether uptake of metals was similar and highly correlated between the two species. We wished to be able to only sample cicer milkvetch in the future, as it had become much more prevalent on reclaimed tailings through time.

Results of these comparisons revealed that cicer milkvetch behaved more like smooth bromegrass than white clover, or that it was intermediate between the grass and the clover in uptake of metals (Table. 15). Correlations of similar metals concentrations in white clover with those in cicer milkvetch were not high. This indicated that cicer milkvetch could not be used as a good indicator of metal concentrations that might be found in white clover. Therefore, the milkvetch was not sampled in 1997 to try to predict elemental concentrations in white clover. We continued to sample white clover as in the past, even though it was found only infrequently on reclaimed tailing. Hard fescue (*Festuca ovina*) was sampled in 1999 to determine metals uptake by vegetation on all four areas as this species occurred on all four sites.

Table 15. Average elemental concentration in forage samples of smooth bromegrass and white clover collected from Urad tailings seeded in 1975, 1976 and 1977. All samples were collected in August, 1992.

Year seeded	Species	Chemical constituent (μg/g)								
		As	Al	Zn	Fe	Pb[1]	Mn	Cu	Mo	Cu/ Mo
1975	Both[2]	.08a[3]	73b	62b	102a	<5	179a	9a	169ab	.23a
1976	Both	.09a	100a	100a	110a	<5	300a	8ab	142b	.08b
1977	Both	.08a	40c	66b	65b	<5	140a	7b	240a	.05b
1975-77	Smooth brome	.08y[2]	22z	60y	41z	<5	166x	7y	46z	.29x
1975-77	White clover	.10x	137x	111x	156x	5	303x	10x	310x	.04y
1975-77	Cicer milkvetch	.08y	54y	57y	81y	<5	150x	7yx	195y	.04y

[1]Data often below detection limits (< 2.5).

[2]Both indicates that data for smooth bromegrass and white clover were summed and averaged together.

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

Effect of biosolids on concentration of elements in vegetation

Concentration of metals in hard fescue (*Festuca ovina*) showed little difference between the Urad tailing where biosolids had been added and those sites were biosolids were not used (Table 16). Chang et al. (1984) came to the conclusion that vegetation removes an insignificant amount of the heavy metals introduced into the soil through land application of biosolids, while Hooda et al. (1997) recommended that the surest way to control the accumulation of metals in vegetation was by controlling their concentrations in the soils. Other factors that control concentration of metals in vegetation are metal and plant species, clay type in the soil, and pH (Hooda et al., 1997).

Iron was significantly higher in hard fescue from the avalanche run area and control burn than from reclaimed areas. Vegetation on Urad tailing was significantly higher in the concentration of molybdenum than from other sites. The availability of molybdenum causes a large increase in its uptake when plants are grown on contaminated sites (Kabata-Pendias and Pendias, 1992). No differences in cadmium uptake of plants among sites was noted, and its concentration was well within normal range reported (Ramachandra and D'Souza, 1998; Brady and Weil, 1999). Research has shown that cadmium and zinc content in aerial plant parts generally decreases as the pH level increases, but physiological differences among species may also be an important factor (Eriksson, 1989; Ramachandran and D'Souza, 1998). Simple correlations between growth medium characteristics and elemental concentrations of various plant constituents were usually quite low (R < .60) (Table 17). The growth medium pH and EC were usually better correlated with elemental concentrations in vegetation than were organic matter and saturation of the growth medium. Plant Zn and Mo concentrations were most highly correlated (R > .60) with the pH and EC of the growth medium.

Table 16. Average elemental concentration in forage samples of hard fescue in 1999. Samples were collected from Urad tailing reclamation areas where there had been biosolids addition and from three other sites (roadcut, avalanche run, and control burn) where biosolids had not been added.

	Treatment			
	Urad Tailing	Roadcut	Control Burn	Avalanche run
No. samples	3	3	3	3
P (%)	0.17ab	0.19a	0.14bc	0.10c
K (%)	0.58ab	0.72a	0.53ab	0.27b
Zn (μg/g)	100a	46bc	82ab	28c
Fe (μg/g)	74b	72b	193a	268a
Mn (μg/g)	180a	194a	106a	112a
Cu (μg/g)	7.0ab	5.2c	5.9bc	7.6a
Mo (μg/g)	18a	8b	4b	4b
Pb (μg/g)	3.6a	6.7a	4.6a	8.8a
Cd (μg/g)	0.7a	0.5a	0.6a	0.4a
As (μg/g)	0.7a	0.6a	0.7a	0.6a
F (μg/g)	29.3a	2.0b	0.1b	0.1b
Cr (μg/g)	2.0a	2.2a	2.2a	2.4a
Ca (%)	0.4a	0.4a	0.4a	0.3a[1]
Mg (%)	0.3a	0.1a	0.1a	.1a
Na (%)	0.001a	0.001a	0.001a	0.000a
Se (μg/g)	0.26a	0.35a	0.30a	0.27a
Al (μg/g)	54bc	43c	153ab	220a
Ti (μg/g)	1.6b	1.7b	3.5a	4.9a
Ni (μg/g)	4.0a	1.8a	1.5a	5.5a
Sr (μg/g)	15a	12a	10a	13a
B (μg/g)	5.7b	6.2b	5.9b	8.3a
Ba (μg/g)	10a	17a	14a	17a
Si (μg/g)	32a	84a	72a	17a
V (μg/g)	0.9a	1.2a	1.0a	1.4a
Carbon (%)	43a	44a	43a	44a
N (%)	1.0b	1.3a	0.9b	1.4a
P (%)	6.0b	5.7b	8.6a	7.8a

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

Table 17. Simple linear correlation coefficients (R values) of chemical characteristics in the plant growth medium with elemental concentrations in hard fescue (soil samples from Urad tailing, roadcut, avalanche run, and control burn all utilized).

	Growth medium			
	pH	EC	O	SAT
Al	-.46	-.49	-.0	-.05
As	.09	.26	.1	-.06
B	-.56	-.43	.3	.46
Ba	-.65	-.51	.5	.41
C	-.29	-.05	.5	.52
Ca	.12	.11	-.0	-.01
Cd	.44	.40	-.4	-.35
Cr	-.39	-.35	.3	.25
Cu	.10	.20	-.1	.01
Fe	-.49	-.53	-.1	-.08
K	.15	.29	.1	.05
Mg	.40	.65	-.1	-.16
Mn	.11	.34	.2	.22
Mo	.67	.77	-.0	.07
N	-.68	-.48	.7	.79
Na	-.28	-.23	.0	.09
Ni	-.09	.07	-.2	-.12
P	.16	.28	.4	.35
Pb	-.50	-.39	.1	.17
Se	-.37	-.22	-.0	-.10
Si	-.23	-.20	.1	-.16
Sr	.12	.42	.2	.31
Ti	.48	-.55	-.1	-.00
V	-.52	-.52	.3	.34
Zn	.72	.62	-.5	-.48

Table 18. Simple linear correlation coefficients (R values) of elemental concentrations in foliage of smooth bromegrass and white clover in 1979, 1985, 1992 and 1997 with some important growth parameters in the Urad tailing reclamation growth medium.

Growth medium	Fe	Zn	Mn	Cu	Mo	Cu/Mo
(Independent variables)	Smooth bromegrass					
pH	.28	-.09	.05	.26	-.09	.15
EC	.29	.27	.23	.21	-.08	.11
OM	-.42	-.34	.16	.02	-.06	.19
NO_3	-.10	-.07	.40	.20	-.34	.68
P	.12	.36	.01	.61	-.14	.19
K	-.16	-.32	-.22	.02	.64	-.20
	White clover					
pH	.21	.08	.01	.09	.04	.07
EC	.22	-.06	.08	-.14	.10	-.10
OM	-.11	-.15	.14	.19	-.32	.30
NO_3	.06	-.17	-.06	.20	-.14	.23
P	-.40	-.37	-.22	-.03	.09	.01
K	.01	.36	.48	.25	-.20	.32

Foliar concentrations of some metals compared with some important growth parameters of the tailing growth medium:

Comparisons were made between the concentration of iron, zinc, manganese, copper, and molybdenum in foliage of smooth bromegrass and white clover collected in 1979, 1985, 1992 and 1997 with some important characteristics of the growth medium during the same period. These characteristics of the reclaimed tailing growth medium were pH, electrical conductivity (EC), organic matter (OM), nitrate (NO_3), phosphorus (P), and potassium (K) levels that may all affect plant growth. A simple linear correlation between each of the growth medium parameters with elemental concentrations within the foliage indicated that few significant correlations existed (Tables 14, 17 and 18). Good correlations were only found for phosphorus concentrations in the medium with copper concentrations in foliage and potassium concentration in the medium with molybdenum concentrations in foliage of smooth bromegrass. Growth medium pH and EC were more important in affecting plant foliar concentration of metals than was soil organic matter and saturation (Table 17). The lack of few significant simple correlations between growth medium characteristics and uptake of metals by plants indicated that more complex relationships existed between plant uptake of metals and growth medium characteristics.

Multiple linear regression analysis was then run to determine whether combination of growth medium characteristics might account for more of the variability found in concentration of some metals in foliage of two species growing on the reclaimed tailing. These analyses indicated that pH and electrical conductivity (EC) of the growth medium accounted for very little of the variation of iron, zinc, manganese, copper, and molybdenum concentration in foliage of either smooth bromegrass or white clover (Table 19). Most of the growth medium parameters only accounted for small changes in variability of metals within the foliage of smooth bromegrass or white clover. Most of the metal concentration in foliage could not be accounted for by various measures made of the growth media. Only 53 to 61% of the variation in copper or molybdenum concentrations in foliage of smooth bromegrass, respectively, could be accounted for by the combination of all six growth medium parameters (Table 19). However, only 18 to 19% of the variation in concentrations of molybdenum or copper in foliage of white clover could be accounted for by measuring these same six characteristics of the growth medium. Therefore, some of the important soil and plant characteristics that affect plant uptake of metals were not being measured in this monitoring effort.

Table 19. Relationships among growth medium characteristics of the reclaimed tailing and foliar concentrations of some metals as determined by multiple regression analysis. Numbers reported in the table are sequential R^2 values.

Growth medium	Fe	Zn	Mn	Cu	Mo	Cu/Mo
(Independent variables)			Smooth bromegrass (dependent variable)			
pH	.08	.01	.01	.07	.01	.02
EC	.16	.08	.06	.11	.02	.04
OM	.24	.33	.14	.18	.05	.18
NO_3	.25	.34	.20	.19	.14	.53
P	.30	.39	.21	.52	.15	.55
K	.30	.40	.28	.53	.61	.60
			White clover (dependent variable)			
pH	.04	.01	.00	.01	.00	.00
EC	.09	.01	.01	.03	.01	.01
OM	.10	.03	.04	.13	.15	.21
NO_3	.10	.04	.08	.16	.15	.23
P	.19	.30	.15	.16	.17	.23
K	.20	.38	.31	.19	.18	.28

SUMMARY AND CONCLUSION

Only five nutrients have been found sufficiently deficient to limit agronomic crop production in Colorado (Soltanpour et al., 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 was still limiting on much of the reclamation area (Table 3). Phosphate levels are presently very high and potassium levels are moderately high in the growth medium. Therefore, additions of phosphate and potassium fertilizers cannot be justified; whereas periodic nitrogen fertilizer additions may be needed.

Concentrations of the micronutrients zinc, iron, copper, and manganese were all considered very high in the waste rock medium (Soltanpour et al., 1979) (Table 3). Certainly no additions of these elements are recommended. Soil organic matter is moderate and pH is neutral to slightly acidic. Therefore, the plant growth medium should readily supply elements for plant uptake. Salts are 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 appear to be marginally low in the growth medium (Table 20). However, both elements have high concentrations in waste rock material (Table 3). Therefore, we might expect availability of these two elements to increase with time, so fertilization is not recommended at the present time unless an inexpensive source of $CaCO_3$ is available. Additions of $CaCO_3$ could be made to small test plots to determine whether plants will respond to the addition. The $CaCO_3$ might also help alleviate some of the acidification that is underway as well, as pH has declined from 8.1 in 1978 to 6.7 in 1997.

Table 20. Suggested ranges of optimum concentrations (Φg/ml) of elements in nutrient solutions for plant growth as compared with concentrations in the plant growth medium from Urad tailing 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 - 180*
Mo	0.01 - 0.1	0.1 - 18*
N	70 - 250	90 - 180
Na	0.06 - 350	4 - 19
P	30 - 150	1 - 305
S	50 - 270	---
Se	<1	0.26
Si	<0.09	32
V	0.01 (-10)	0.9
Zn	0.02 - 0.2	5 - 175*

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

Of the 25 elements in Table 2 that were more than twice as concentrated in waste rock material as in native soil, five (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 waste rock growth medium. If growth medium pH should become more acidic in the future, more of these toxic elements may become available for plant uptake (Baker and Walker, 1989). However, some of these elements may also be leached from the rooting zone or tied up in the organic fraction.
Microorganism populations may also be affected by these toxic elements. Bacteria, fungi and algae are often more sensitive to toxic elements than are higher plants. Therefore, if microorganisms are less effective in decomposition of dead material, nutrient cycling and humus production may be slowed. Dead organic matter may then accumulate on the surface and interfere with or retard plant growth and succession.

Vegetation on the reclaimed waste rock material still persists under these difficult circumstances; it has withstood the very severe climate of this high elevation and the poor plant growth characteristics of the growth media. The vegetation has withstood this tough test of time and is still doing well 22 to 25 years after the reclamation efforts. There is currently no indication that it will not continue to thrive indefinitely.

Plant Species Cover, Diversity and Production

The waste rock material placed on Urad tailing and as amended with biosolids and wood chips has made an effective plant growth medium. Seeded grasses have become well established and are producing more herbage than is produced in a nearby burned-over spruce-fir community. Canopy cover of vegetation on the tailing ponds equals or exceeds that of the native community and plants appear to be well established and maintaining a productive stand. Therefore, wind and water erosion problems have been effectively mitigated.

Vegetation on reclaimed tailing ponds and road cut areas is not as diverse as that of naturally occurring communities. The reclaimed areas are dominated by a few species of grasses, and forbs occur only infrequently. However, species diversity has increased significantly with time since areas were seeded. Therefore, invasion of other species into reclaimed areas has occurred and diversity may be expected to continue to increase with time.

White clover was used in the seed mixture as this species has the capability to fix nitrogen. However, it is a weak perennial and has declined considerably on reclaimed areas during the past 10 years. Therefore, inorganic nitrogen may need to be topdressed occasionally on the reclaimed tailing to maintain site fertility. Fertilization with inorganic nitrate should, however, be carefully controlled to prevent the introduced tall grasses from becoming more dominant. If dominance of these grasses is encouraged, they may then reduce invasion and establishment of native species. Since it is desirable to maintain a naturally functioning community in the future, inorganic fertilizers should be used sparingly, even though this may result in a reduction in total community plant cover and production through time. When inorganic nitrogen fertilization is needed, then ammonium nitrate rather than ammonium sulfate is recommended, as sulfur is already high in the waste rock medium and ammonium sulfate might also cause a reduction in growth medium pH through time.

Some species in the seeding mixture did not appear, or only appeared infrequently, on the reclaimed tailings. Creeping foxtail (*Alopecurus arundinaceus*) and meadow foxtail (*Alopecurus pratensis*) are two grasses that occurred only rarely and might be eliminated from future seed mixtures. Red fescue (*Festuca rubra*) and redtop (*Agrostis alba*) occurred infrequently. Therefore, they might be either eliminated from the seed mixture or their proportion of the mixture should be increased if they are considered desirable. However, all of these grasses do occur more frequently around the developing wetland areas on the tailing reclamation area. If wetlands are desired, then these species should be maintained in the mixture. Cicer milkvetch has increased in stands and has become an important legume. Pine reedgrass (*Calamagrostis rubra*) is an important grass that occurs in rocky areas of the native burned-over community and should be considered as a possible addition to the seed mixture if seed for this species can be obtained commercially.

Heavy Metal Uptake by Vegetation

White clover concentrated chemical constituents in foliage much more than did smooth bromegrass on the Urad tailing reclamation area. Cicer milkvetch uptake of metals was often intermediate to that of white clover and smooth bromegrass. Younger plants appeared to have greater concentrations of both arsenic and molybdenum in foliage in 1979 than did older plants, but these differences were no longer evident by 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 might well be considered dangerous to ruminant animals using the forage resource. Molybdenum levels in cicer milkvetch and smooth bromegrass were also high, but not nearly as high as that in white clover. The extremely low Cu:Mo ratio in all three species might be expected to result in a physiological copper deficiency for ruminants using the seedings as a major forage resource. Therefore, it is recommended that ruminants not be allowed to concentrate on the tailing reclamation area for any extensive period of time. Large native ruminants (deer and elk) do occasionally graze on the reclaimed tailing ponds. However, even with the high levels of molybdenum in the forage, it is speculated that the reclaimed tailing vegetation does not comprise a high enough fraction of the total diet to become toxic. In other words, use of other forage from native communities would dilute the concentration of molybdenum ingested while the animals utilized the reclaimed tailing area. This, however, has not been studied to date.

The present study should be repeated in about five years to determine whether concentrations of these constituents decline in foliage as the plant growth medium weathers further, or as these toxic materials become incorporated into organic litter on the surface. The present study indicated little change in uptake of molybdenum among the four years of sampling (1979, 1985, 1992, and 1997) by plants growing on the reclaimed tailing. If pH of the plant growth medium (waste rock) becomes more acidic with time, this could cause molybdenum to become even less available for plant uptake, but uptake of other heavy metals might increase.

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USING THRESHOLD AND ALTERNATIVE STATE CONCEPTS TO RESTORE DEGRADED OR DISTURBED ECOSYSTEMS

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ABSTRACT

In the applied sciences, alternative state and threshold concepts are beginning to replace more traditional ideas involving linear succession. They are being used increasingly to describe the different vegetation states that exist on the landscape and to evaluate the role of natural and human disturbance in causing the different states. Recognizing the alternative states that exist following disturbance and defining the thresholds between the states can be an important step in evaluating the restoration potential of disturbed sites and in assessing the degree of restoration success. I discuss the use of alternative state and threshold concepts in restoration and then provide a case study involving the restoration of dry meadows degraded by sagebrush encroachment. In the case study, two environmentally similar ecosystem types, the dry meadow and basin big sagebrush/giant wildrye trough drainageways, were used as models for examining the restoration of sagebrush dominated areas to dry meadows. The restoration treatment involved a prescribed burn and seeding with dry meadow species, and the soil and vegetation responses to the treatment were used to define the threshold for restoration to dry meadows.

INTRODUCTION

Why Alternative States and Thresholds?

Over the past twenty years, there has been increasing recognition that succession is not deterministic and that successional trajectories are seldom linear (MacMahon 1980, Pickett et al. 1987, Westoby et al. 1989, Laycock 1991, Friedel 1991, Tausch et al. 1993, Pickett and Parker 1994). The implications are that there is no single equilibrium community as suggested by Clements (1919) and, that following disturbance, ecosystems may or may not return to their predisturbance state. For a given ecosystem type, multiple alternative states can exist on the landscape. The changes among states are usually triggered by natural and anthropogenic disturbance or management actions (Westoby et al. 1989, Laycock 1991, Friedel 1991, Allen-Diaz and Bartolome 1998, Rodrigeuz and Kothman 1997). Similar to geomorphic systems, abiotic and/or biotic thresholds exist between the different states that can be defined based upon the parameters that define the limits of natural variability within systems (Ritter et al. 1999). Threshold crossings result in changes in processes and/or structure that result in new states adjusted to the altered factors or processes. For vegetation communities, threshold crossings can be autogenic in nature, resulting from interactions among the biotic components. The processes involved can include competition, herbivory, and species invasions. They can also be allogenic, resulting from changes in environmental factors. The factors involved can include changes in hydrologic regimes, landforms, and soils. On longer time scales, climate change can also be involved.

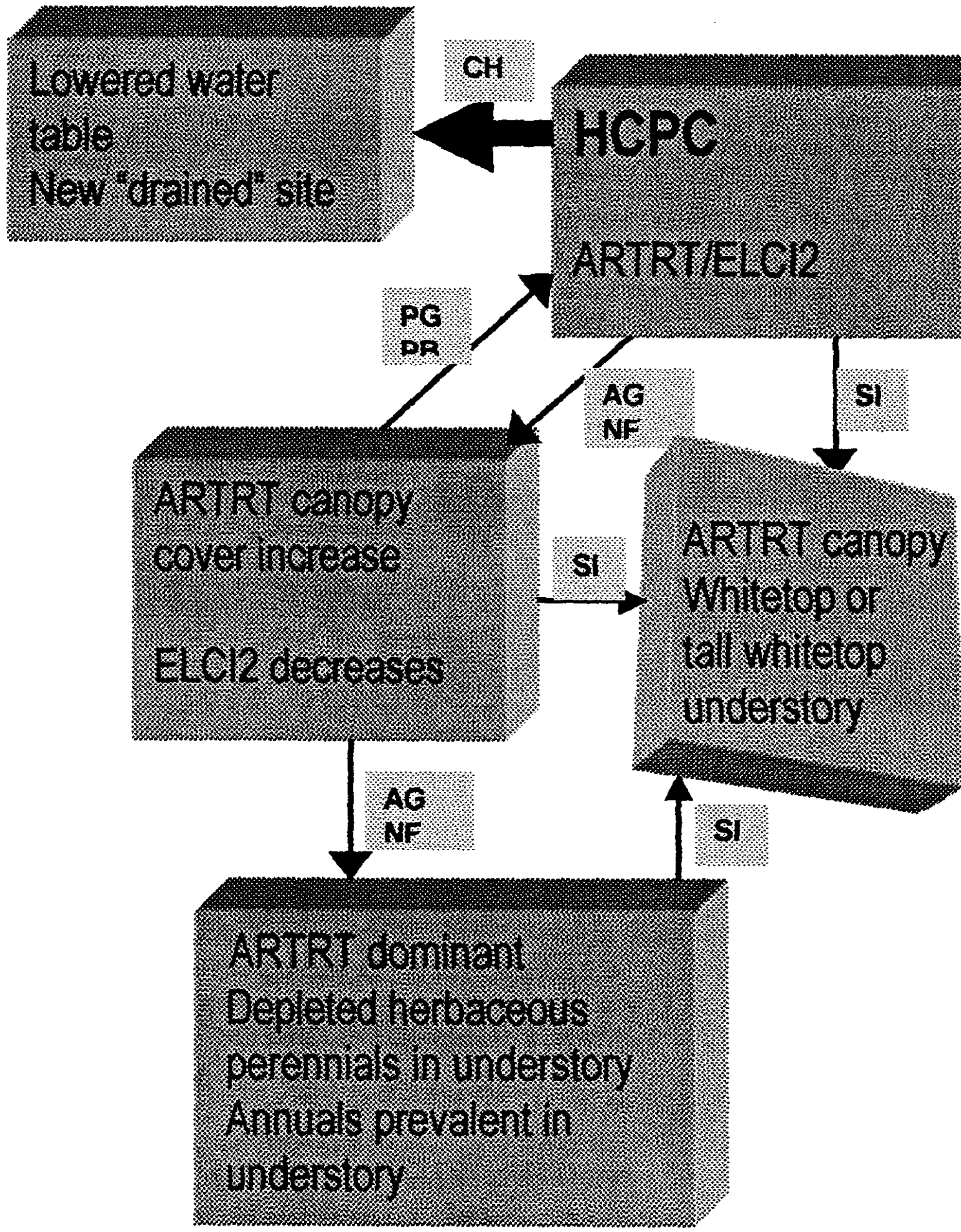

Figure 1. A partial alternative state and transition diagram for the basin big sagebrush/basin wildrye ecosystem type in the absence of fire. Transition pathways are: CH=changed hydrology; AG=abusive grazing; PG=proper grazing; NF=absence of fire; PB=prescribed burning; SI=noxious weed seed introduction. HCPC=high condition, potential community.

Utility of the Concepts

Alternative state concepts are being increasingly used to describe the vegetation communities that exist on the landscape. For example, the NRCS is currently revising its range site guides based on these concepts (Joel Brown, personal communication). Basically, the alternative states for a given vegetation or ecosystem type are cataloged and the relationships between them described. The alternative states include the high condition, potential community that is typically the management goal. They also include any other states that exist such as those that may have been degraded as a result of over grazing by livestock, altered fire regimes or weedy species invasions. Transitional states may also be included. The progression of one state to another is illustrated with a series of connecting arrows, and the type of disturbance or management action influencing the different states is indicated. For instance, in the basin big sagebrush/basin wildrye ecological site type, over grazing by livestock and lack of fire can result in an increase in sagebrush and decrease in perennial grasses (Fig. 1). Proper grazing coupled with prescribed burning can decrease the sagebrush and increase the perennial grass component. Regardless of the state, the introduction of seed of the Crucifer, white top, can result in the dominance of the site by this invasive perennial forb. This cataloging provides a convenient means of describing the various alternative states, the relationships between them, and the disturbances and management actions affecting the conversions between states. The limitations of this approach are that the underlying factors and processes are often ignored.

Relevance to Restoration

Alternative state and threshold concepts appear to have considerable utility for the restoration of disturbed or degraded ecosystems (Hobbs and Norton 1996). To use these concepts in a restoration context, it is necessary to both identify the alternative stable states that exist in the project area and define the thresholds that exist between them in terms of quantifiable ecosystem characteristics (Linnerooth et al. 1998, Linnerooth and Chambers unpublished data). Defining the thresholds that exist between states is necessary because the recovery potential of a given ecosystem depends on the type and magnitude of the threshold that exists between the alternative states. If a threshold has not been crossed, then the system should be able to recover to the original state with minimal intervention. In this case, simply eliminating the perturbation, such as over grazing, or reinstating natural processes, such as fire, may result in the return of the system to a less degraded state. If a threshold has been crossed, a new state exists that has a unique set of possible successional trajectories. It may be possible to return the system to the original state through some type of restoration activity if an abiotic threshold such as a change in soil properties or decrease in water table has not been crossed. This could involve using herbicides to eliminate exotic species, reseeding with native species, and deferring land uses until the ecosystem has reestablished. If an abiotic threshold has been crossed, in most cases it will be necessary to treat the system as a new state or even a new site type, and to develop the appropriate restoration or management methods for the new state or site type.

CASE STUDY

We used alternative state and threshold concepts to examine the restoration potential of degraded semi-arid riparian areas dominated by basin big sagebrush (*Artemisia tridentata tridentata*).

Riparian areas in the western U.S. are highly productive and have been extensively used as sources of livestock forage and agricultural water, and as recreational areas. Consequently, many of these areas are severely degraded – over 50% are in poor ecological condition (Armour et al. 1994). This degradation has led to the encroachment and dominance of basin big sagebrush largely as a result of stream incision and lowered water tables, over grazing by livestock and a decrease in competition from perennial grasses, and active fire suppression. The overall result has been a decrease in meadow and other grass dominated ecosystems and an increase in sagebrush dominated ecosystems. In some cases, a threshold has been crossed and a new stable state exists that can be defined by the abiotic and biotic characteristics of the site. Presumably, the potential for returning to the grass and sedge dominated dry meadows that the area formerly supported has been lost and restoration can not be achieved without a large expenditure of energy. In other cases, a threshold may not have been crossed. This may be the situation for dry meadow ecosystems exhibiting sagebrush dominance without a reduction in water table or a complete loss of the former vegetation. Restoration to the dry meadow does not require as large of an expenditure of energy and is both ecologically and economically feasible.

To evaluate the restoration potential of these sites, we identified two ecological types that occur within the drainages and that share similar soil and landform characteristics. These are the dry meadow ecosystem type dominated by grasses and sedges, and the basin big sagebrush/basin wildrye (*A. tridentata tridentata/Leymus cinereus*) type dominated by basin big sagebrush and basin wildrye. These ecosystem types are located in trough drainageways, are characterized by haplocryoll soils and similar water table depths, and exhibit considerable species overlap (Table 1; Weixelman et al. 1996). The lack of both basin big sagebrush and basin wildrye in the dry

Table 1. Species constancy (%) for the basin big sagebrush/basin wildrye and dry meadow ecosystem types in central Nevada (from Weixelman et al. 1996).

	Basin big sagebrush/ Basin wildrye	Dry Meadow
Grasses and Grasslike Plants		
Basin wildrye	72	0
Nevada bluegrass	50	86
Creeping wildrye	31	18
Douglas sedge	54	68
Mat muhly	59	54
Perennial Forbs	4-54	4-50
Shrubs		
Basin big sagebrush	77	0
Rabbitbrush	68	0

meadow ecosystem type indicated that it was probably a slightly drier ecosystem type. We used these types as models for examining the restoration of sagebrush dominated sites within the riparian corridor. Our hypothesis was that the threshold for restoration to the dry meadow type could be defined on the basis of water table. If a threshold had not been crossed, the sagebrush dominated site could be restored to the dry meadow. Our objectives were to: (1) quantify differences in the abiotic variables in response to different water table levels and to a restoration treatment that included burning and seeding, (2) evaluate how the abiotic variation affected plant establishment processes, and (3) use both the abiotic and biotic response to define the threshold maintaining sagebrush dominance.

Study Design

The study was conducted in the Toiyabe mountain range of central Nevada and the experimental design and methods are detailed in Linnerooth (1999). Basically, the experimental design included five different sites with three water table levels: (1) shallow (-120 to 200 cm); intermediate (-200 to –300 cm); and deep (>300 cm). A wet, intermediate, and dry site were located in the Willow Creek drainage; an additional wet site was located in the Marysville drainage and a dry site in the Ledbetter drainage. All of the sites were dominated by big sagebrush; only the wet and intermediate water table sites had understories dominated by dry meadow species (Linnerooth et al.1998). The restoration treatment involved a paired-plot approach in which one half of each plot was burned and seeded with native dry meadow species while the other half served as a control. The seeded species included Nevada bluegrass (*Poa secunda ssp. juncifolia*), mat muhly (*Muhlenbergia richardsonis*), creeping wildrye (*Leymus triticoides*), basin wildrye (*Leymus cinereus*), and western yarrow (*Achillea millefolium*). Additionally, blue flax (*Linum lewisii*) was used. The abiotic variables measured at each site included precipitation, water table depth, soil water content, and soil temperature. The biotic response was evaluated in terms of the seed bank, residual vegetative propagules (root sprouts), and seedling establishment. Seeded species adapted to wetter (Nevada bluegrass), intermediate (creeping wildrye), and drier (basin wildrye) conditions were used to evaluate the establishment response. Because of the importance of sagebrush in structuring the microenvironmental conditions in these communities, both the abiotic and biotic response was evaluated for undershrub and interspace microsites on both the burned and control plots.

Results

Both growing season conditions and initial water table depths significantly affected soil temperatures and soil water availability over the two-year study (Linnerooth 1999). The 1997 growing season was warm and dry and growing season precipitation (June-Sept) on the five sites averaged 38 cm. The spring and early summer of 1998 were cool and wet and growing season precipitation averaged 58 cm. This was reflected in higher water tables and soil water contents and lower soil temperatures in the spring and early summer of 1998 than of 1997. Soil water contents were higher and soil temperatures were lower on the wet sites than the dry sites during both years. The effect of burning on soil water availability varied by season. During the first growing season, soil water content was lower on the burned plots than the control plots early in the growing season as a result of snow removal by wind and earlier snowmelt. After the initiation of active plant growth, the burned plots had higher soils water contents than the controls. As expected, burning resulted in higher overall soil temperatures and there were significant microsite differences. The undershrub microsites on the control plots had the lowest temperatures, and the undershrub microsites on the burned plots had the highest temperatures.

The importance of the seed bank vs. vegetative regrowth was investigated for the wet and dry sites within the Willow Creek drainage (Mebine and Chambers, unpublished data). There were higher overall seed densities on the dry site than the wet site (Fig. 2). The seed banks of both sites were dominated by basin big sagebrush and annual species, primarily forbs. Burning significantly decreased seed numbers, especially in near surface soils and in the undershrub microsite. There was differential seed mortality and most shrub seeds were killed, while many annual forbs survived. Importantly, the grasses and sedges that dominate dry meadow systems were almost nonexistent in the seed banks of both sites. This was probably because seeds of these species tend to be short-lived. Also, these species had low initial abundances in the aboveground vegetation on the wet site. In contrast to the seed bank, the wet site had higher root sprout densities than the dry site (Fig. 2). The wet site had higher abundances of dry meadow species in the aboveground vegetation prior to the burn, and these species dominated the vegetative propagule pool. The number of root sprouts in the undershrub microsites was greatly reduced by burning. Despite this, vegetative regrowth was more important than seedling establishment in the recovery of these sites and determined the post-restoration species composition.

The seedling establishment response of the three species adapted to different levels of water availability provided important clues about the recovery potential of the sites. In general, seedling emergence was higher on the wet sites than the dry sites for all three species (Fig. 3; Linnerooth 1999). In 1997, emergence of all species tended to be highest in the control shrub microsite which had the coolest soil temperatures and highest soil water contents early in the growing season. Differences in emergence among microsites tended to be less apparent during the generally cooler and moister conditions in 1998. Lifespan estimates of the species adapted to mesic and intermediate conditions, Nevada bluegrass and creeping wildrye tended to be higher on the wet sites (Linnerooth 1999). In contrast the lifespan estimates of the species adapted to more xeric conditions, basin wildrye, was almost always higher on dry sites. Also, shrub establishment on the dry sites was higher than on the wet sites. Lower numbers of seedlings emerged on the burned plots, but those that did often had lifespans that equaled or exceeded those on the control plots. And although not quantified, seedlings that could survive the initially harsh conditions on the burn plots exhibited greater growth than those on the control plots, presumably due to higher water availability later in the growing season.

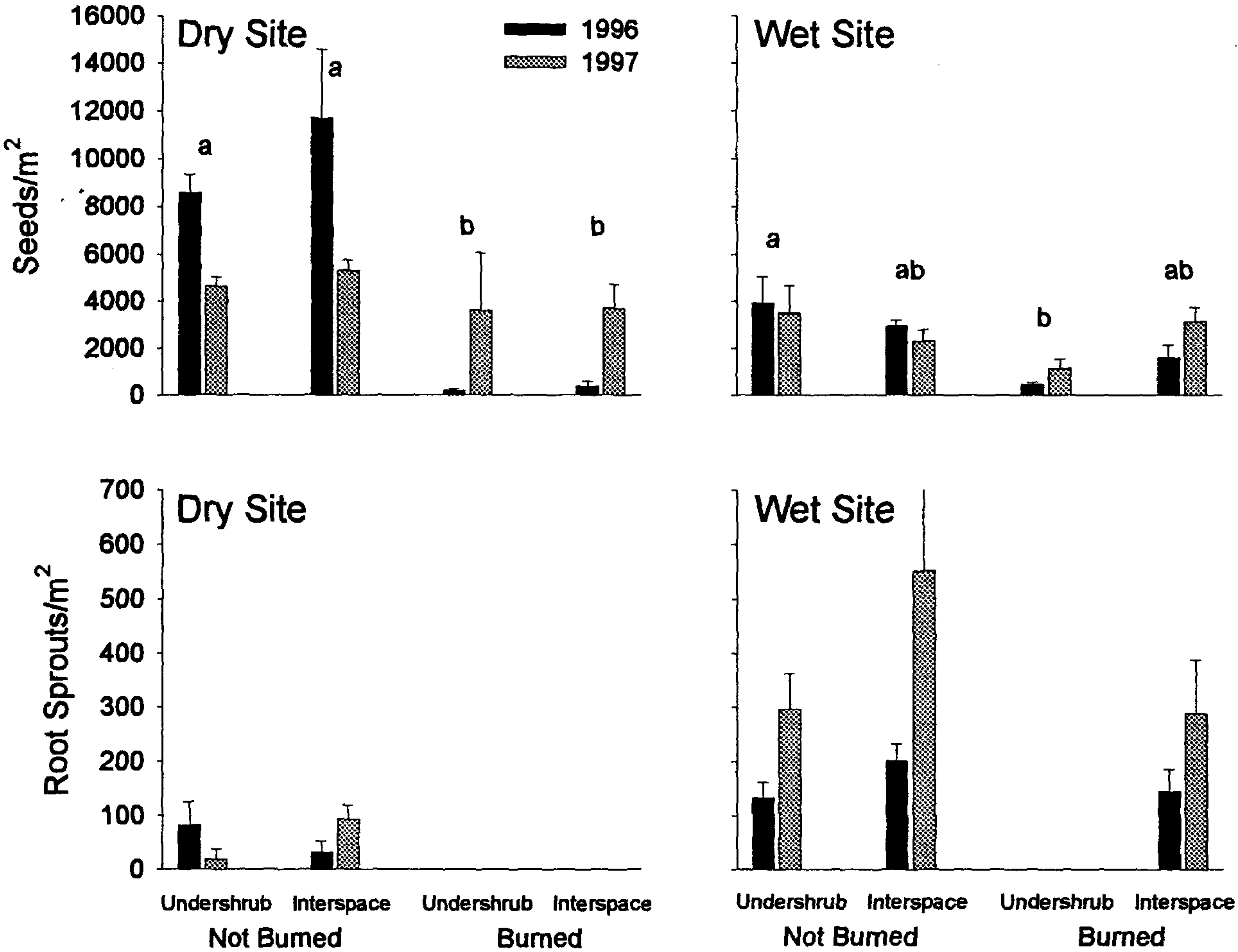

Figure 2. Numbers of germinable seeds and vegetative root sprouts (0-5 cm depth) on the dry and wet sites in Willow Creek for the undershrub and interspace microsites of plots that were either burned or not burned. Unlike letters indicate significant differences among burn/microsite combinations where present (lsmeans; $P \leq 0.05$).

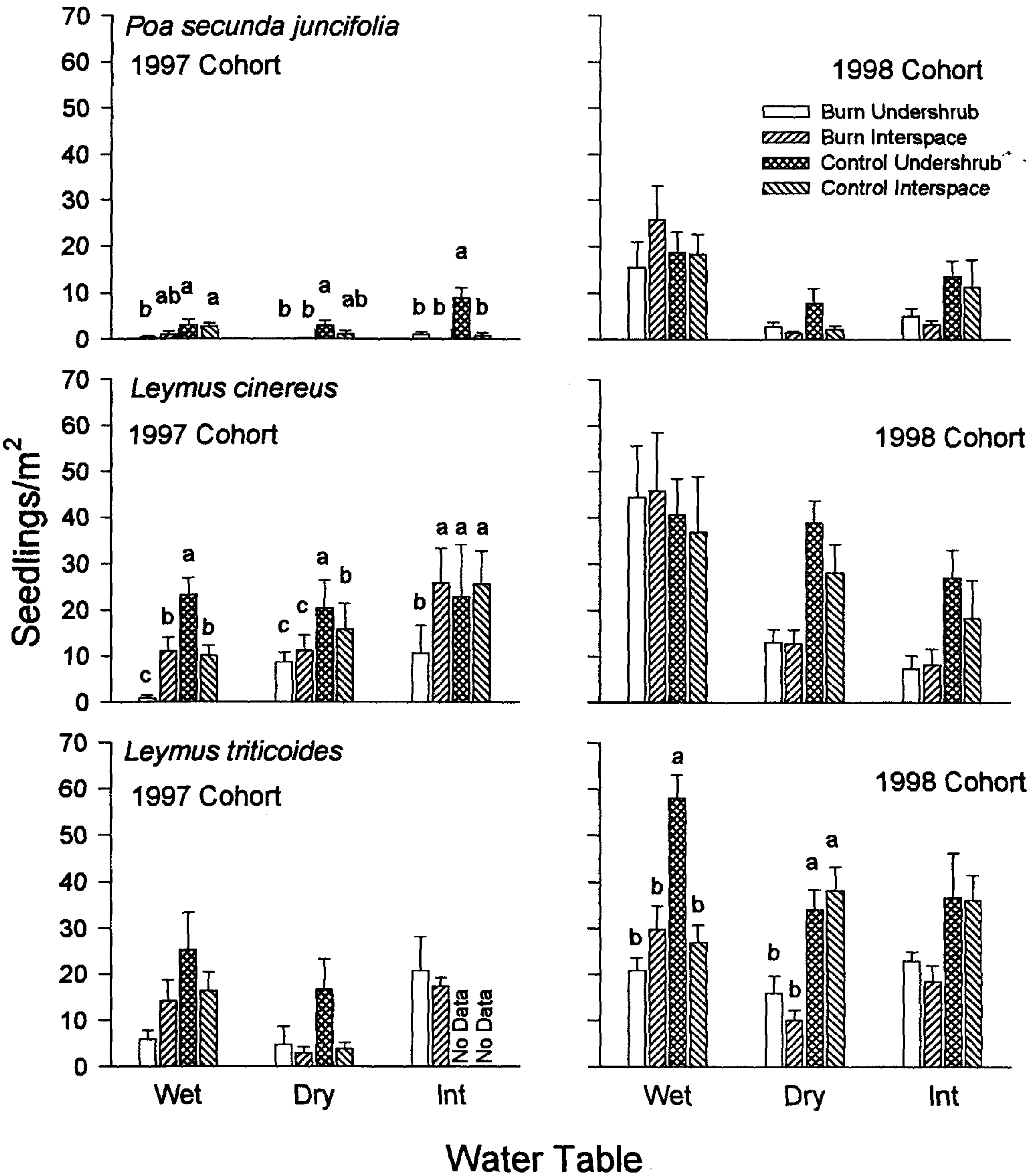

Figure 3. Numbers of seedlings of species adapted to wet (Nevada bluegrass), dry (basin wildrye), and intermediate conditions (creeping wildrye) that emerged in two different years. The study sites reflected wet, dry or intermediate water levels, and treatments included burned or not burned plots (controls) monitored in the undershrub or interspace microenvironments. Unlike letters indicate significant differences among treatment/microsite combinations within water levels (lsmeans; $P \leq 0.05$).

Implications

In general, the wet sites had more favorable environmental conditions for plant establishment than the dry sites. They exhibited both vegetative and seedling establishment of the dry meadow species. In contrast, the dry sites had little vegetative regrowth and appeared to lack the appropriate conditions for seedling establishment of more mesic dry meadow species. These results indicate that the dry sites have crossed an abiotic threshold and no longer have the potential to support dry meadow ecosystems.

A standard ball-and-trough diagram can be used to visualize the relationships between the alternative states that exist for these ecosystems (Fig. 4). Water table is shown as the driving variable determining both the potential for the different states to exist and for restoration. The "A" ecosystem represents shallow water tables dominated by grasses and sedges. The "C" ecosystem represents intermediate water table sites that have an equal probability of existing in either the grass and sedge or sagebrush dominated state. The "E" ecosystem reflects dry sites dominated by sagebrush. For sites characterized by relatively high water tables, such as "B" and "C", establishment of the dry meadow species is possible. If dry meadow species occur in sufficient abundance in the aboveground vegetation, then minimal restoration inputs are necessary. For sites that have deep water tables, such as "D" and "E", and that have been degraded due to stream incision or overgrazing, a significant amount of energy is necessary not only to convert the ecosystem from shrub to grass dominance, but also to maintain it in the new state. The logical alternative for degraded sites with sufficiently shallow water tables is to restore them to the alternative basin big sagebrush/giant wildrye site type. This may require seeding with species adapted to more xeric conditions, and ameliorating site conditions with treatments such as snow-fencing or mulch to improve soil-water relations and increase seedling emergence and survival. Knowledge of the abiotic and biotic thresholds that exist between the alternative states and of their implications for restoration can be used to create mosaics of graminoid-dominated dry meadows and sagebrush-dominated ecosystem types within central Nevada riparian corridors that are more similar to predisturbance conditions.

This case study shows the utility of alternative state concepts for identifying the different vegetation states that exist on the landscape and for evaluating their restoration potential. A critical aspect of the process is defining the thresholds that exist between the target states in terms of quantifiable abiotic and biotic ecosystem variables. This information can be used to evaluate the potential of the degraded site and to design the most effective restoration scenarios.

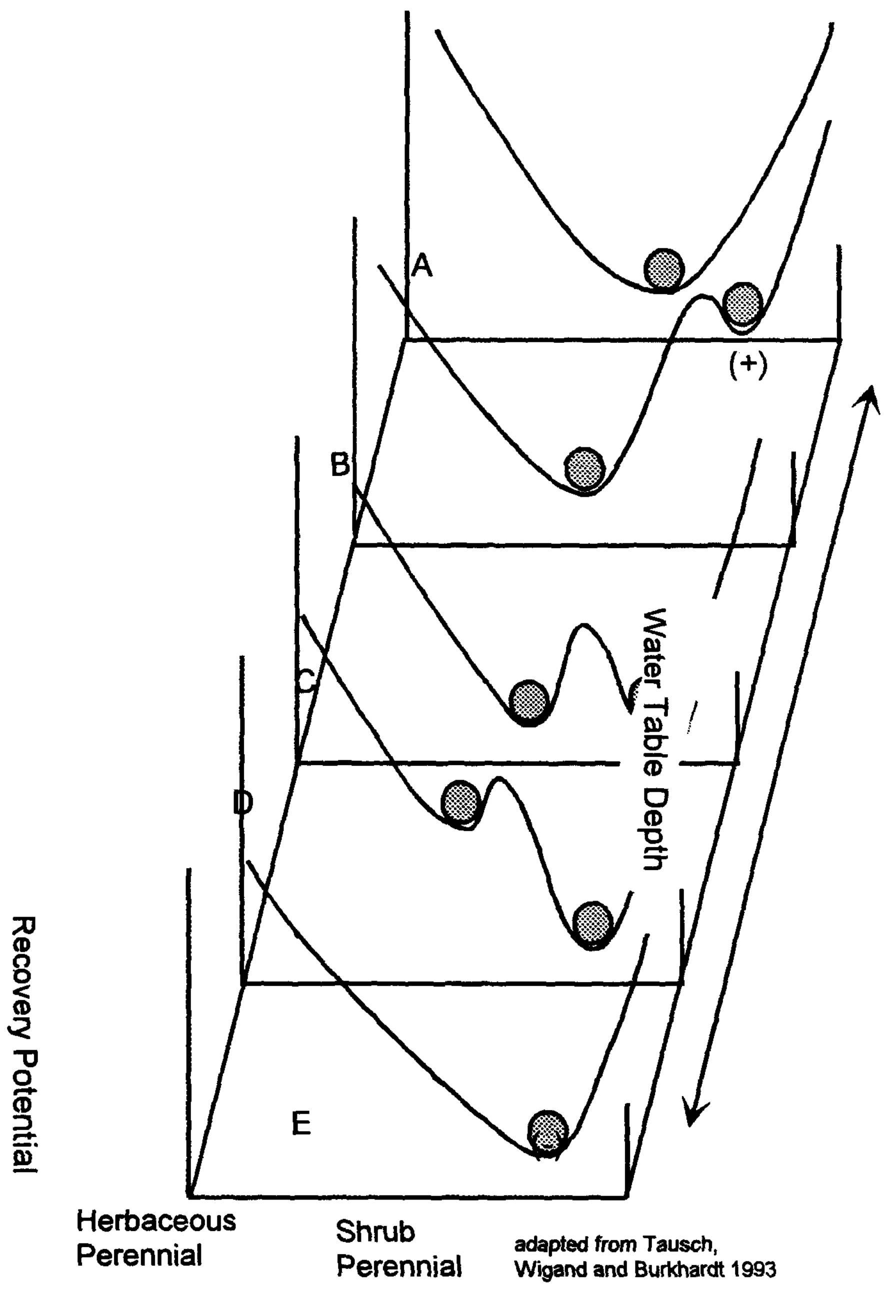

Figure 4. A simple ball and trough model schematically illustrating the change in community composition due to changes in water table. The ball represents the community and the low points represent stable states. Restoration potential depends upon water table. Further explanation is in text.

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ORGANIC AMENDMENTS FOR REVEGETATON OF DRASTICALLY DISTURBED SOILS

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ABSTRACT

Drastically disturbed sites commonly have lost their topsoil horizons during excavation or erosion. Composts are a potential source of organic matter to regenerate soil organic matter pools and are in abundant supply in California. Green materials (yard waste) composts currently account for over 30 percent of the volume entering California landfills. California statute requires waste-stream volumes to be reduced by 50 percent by the year 2000. In an attempt to meet these requirements, the California Department of Transportation entered into an agreement with the University of California, Davis to evaluate the potential for use of green materials composts and co-composted biosolids for use as primary erosion control amendments for revegetation of Caltrans roadsides. The objective is to characterize current compost products in California and to provide information to Caltrans staff for developing specifications for compost use during revegetation. Commercially available compost products were collected from 22 private and municipal producers in California during winter of 1998-99. Data summarized from a commercial compost testing service indicates that many of the soil nutrient characteristics are quite variable, making specification for agency use difficult. Improved methods are being developed for evaluating the potential of compost amendments to promote effective revegetation of degraded sites.

INTRODUCTION

A primary limiting factor in the revegetation of degraded soils is the loss of the erosion-resistant plant litter layer and reserves of soil nutrients during and after disturbance of the soil resource (Bradshaw and Chadwick, 1980). Loss of plant litter and mulch material results from erosion or physical removal during construction. During construction, the nutrient-rich topsoil horizons are typically deposited at the bottom of the fill during slope construction. The remaining soil surface is exposed and the nutrients in the previous topsoil horizons are buried beyond the reach of plant roots.

Revegetation of drastically disturbed sites often requires protection of the bare ground surface from erosion. The bare soil particles are vulnerable to raindrop impact, which detaches or close-packs the disaggregated fine particles. When the soil surface seals and becomes resistant to infiltration of precipitation, overland flow is increased, resulting in rill and inter-rill erosion. Composts are shown to reduce these types of erosion, as noted in the literature review below.

Loss of topsoil during disturbance also reduces the ability of the vegetative community to regrow because the soil's previous nutrient reserves are depleted. Inadequate pools of plant-available nitrogen (N) can be limiting in many types of sites, especially where precipitation leaches the soil profile. This can restrict plant growth on the site for extended periods of time because N is needed in relatively large amounts for regeneration of plant shoots, roots, and litter layers, and for microbial biomass needed to decompose plant litter. Because soluble fertilizer N is easily depleted from the soil by leaching or plant uptake, the regeneration of the plant community is expected to be improved by the application of larger, stabilized pools of N that mimic the organic matter lost during topsoil removal. Recent work in the Tahoe Basin suggests that these long-term, slowly available pools are better correlated with the soil's ability to support plant growth, than are soluble (KCl-extractable) N levels (Claassen and Hogan, 1998). Composts are being evaluated for their ability to supply plant nutrients as surrogate soil organic matter pools.

While many organic or chemically based soil amendments can provide N for early phases of plant establishment, few provide N for a long-term, multi-year period of community development. Composted plant materials, on the other hand, may provide this type of N release because the composting process converts readily degradable organic materials into stabilized, partially humified materials (Epstein, 1997). In general, the partially humified products mimic the soil organic matter found in the topsoils that previously existed on the site.

Composts are defined as the relatively stable decomposed organic materials resulting from the accelerated biological degradation of organic material under controlled, aerobic conditions (Storey, 1995, Epstein, 1997). Another definition is "the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial topsoil, growing medium amendment or other similar uses" (Texas Senate Bill 1340; Storey, 1995). This decomposition process converts potentially toxic or putrescible organic matter into a stabilized state that can improve soil for plant growth. Products made from green materials compost (yard waste) are abbreviated as GMC. Composted biosolids bulked with green materials are termed co-composted materials (CCM).

Composting organics has other beneficial effects, including diverting landfill wastes to alternative uses, removal of pathogen inocula or weed seeds and decomposition of petroleum, herbicide or pesticide residues. These aspects, though important, will not be considered here, nor will the potential for metal transport or accumulation by organic molecules. The focus of the project described here is to evaluate the benefits of using GMC as a mechanical aid for primary erosion control and as a nutrient source for sustainable revegetation of degraded soils.

Before evaluating GMC products in California, the practices and results from projects in other states will be reviewed.

POTENTIAL FOR USE OF COMPOST AS A PRIMARY EROSION CONTROL MATERIAL

Texas Transportation Institute

The Texas Transportation Institute, Hydraulics and Erosion Control Field Laboratory, affiliated with the Texas A&M University system, has developed a testing facility with large, life-sized experimental slopes for uniform testing of erosion control materials. A study on compost application (Storey, 1995) tested three materials on 1:3 slopes with both clay and sandy loam textured soils. Plot size was 6.1 m wide by 21.35 m downslope (1:3 slope plots). These materials included co-compost (mixed yard trimmings and municipal sewage sludge), shredded wood with polyacrylide tackifier (6.75 kg/ha), and shredded wood with a hydrophilic colloid tackifier (56 kg/ha).

Treatments were amended with organic materials to a depth of 76 to 101 mm (3 to 4 in) over clay or sandy loam soils. Soils were seeded with a warm season revegetation grass mix that is standard for the central Texas area. Vegetation establishment success criteria included a minimum coverage of 80 percent for the clay soils and 70 percent for the sandy loam soils within 6 months of seeding. Rainfall simulations were used to test for sediment loss on the plots, using 1-, 2-, and 5-year simulated storm events. The erosion control objectives are that the treatment should protect the seed bed from a short-duration, 1-year return frequency event (99 percent probability of occurrence within a given year) within the first month after installation, from a 2-year return frequency event (50 percent probability) within the first 3 months following installation, and from a 5-year return frequency event (20 percent probability) within the first 6 months of installation. Rainfall simulations were designed to model events within the Houston/Dallas/Austin region. To be included in the Texas Department of Transportation-approved Material List for Standard Specification Item 169 (Soil Retention Blanket), the sediment loss had to be 0.34 kg/10 m^2 or less from the clay soils and 12.21 kg/10 m^2 or less from the sandy loam soils.

Sediment loss from the compost-amended plots during simulated rainfall tests was right at 0.34 kg/10 m^2 from the clay plots and was 3.88 kg/10 m^2 for the sandy loam plots. Vegetation cover was 99 percent on the clay and 92 percent on the sandy loam. The two tackified wood chip treatments produced 0.15 and 0.30 kg/10 m^2 sediment loss on the clay soil and 11.27 and 10.97 kg/10 m^2 sediment loss on the sandy loam. Vegetation establishment was around 50 percent for several of the tackified wood chip treatments, disallowing them from approval under Texas Department of Transportation standards. The fact that much of the vegetative cover established in the compost treatment came from weed seed, not the desired seed mix, points out the need for quality control in compost products. Costs for the compost were below the average cost of synthetic or organic blankets tested by the facility.

Portland Metro, Portland Oregon

The goal of a Portland Metro project was to demonstrate that yard trimmings compost can be used effectively to control nonpoint-source pollution (Ettlin and Stewart, 1993; Metro, 1994). The project used both "coarse" compost materials (containing chunks of wood and branches up to 152 mm [6 in] in length) and "medium" compost materials, the fraction remaining following screening of the coarse compost through a 16-mm (5/8-in) trommel. Leaf compost was collected from residential streets in the city of Portland.

Thirteen test plots measuring 2.74 x 9.75 m (9 x 32 ft) were constructed on slopes of 34 and 42 percent. Surface runoff was collected in plastic sheeting at the base of the slope. A 76 mm (3-in) mulch layer was applied either as a uniform covering or as a barrier at the base of the plot. Two conventional methods, sediment fences, and wood fiber hydromulch with tackifier treatments were also tested and compared to untreated controls. During and after three storm events in March 1993, 364 samples were collected and tested for suspended solids, settleable solids, turbidity, total solids, metals, nitrate N, total N, and chemical oxygen demand. Suspended solids were lower on the compost treatments than with the sediment fences and similar to the wood fiber hydromulch. Composts also adsorbed metals, reducing metal runoff. The need for high-quality, mature compost was noted.

Subsequent to this study, field plots were constructed in the Portland area utilizing compost as erosion control material to demonstrate use and to increase the market demand for yard trimmings compost materials. Three field sites were established on roadside, housing development, and mobile home park projects. All compost materials were applied to a depth of 76 to 102 mm (3 to 4 in). Materials were brought to the top of the slope by tractor bucket or backhoe. Materials were then spread by hand. The first site (Springwood Drive, Beaverton) had a 14-degree slope at the bottom and a 7.6 m (25-ft) slope length, and the slope drains into an existing wetland. At the second site (Marylhurst, Lake Oswego), slopes ranged from 0 to 30 degrees. The third site (McLoughlin Boulevard, Portland) contained two areas with slope angles of 35 degrees and slope lengths of 3 to 18.3 m (10 to 60 ft). A third area had a slope angle of 15 degrees and a slope length of 4.6 m (15 ft), and a fourth area had a 1- to 5-degree slope and a slope length of 48.8 m (160 ft).

Results from the three demonstration projects suggest the following beneficial uses from compost application. A thick compost layer can provide a surface covering for foot or vehicle traffic onto soils that are otherwise too muddy and wet to support traffic. A compost layer at the exit of a site will reduce mud tracking onto local streets and into storm drains. A 76-mm (3-in) layer of compost was found to be effective. One demonstration site coordinator suggested using a specification of a "minimum" of 3 inches. Compost screened to 38 mm (1½ in) or less is recommended for erosion control on steeper slopes. Slopes of up to 35 degrees were effectively treated. The compost layer should be extended over the top of the slope for 0.6 to 1 m (2 to 3 ft) at a 300- to 450-mm (12- to 18-in) depth to diffuse ponded water entering the top of the slope. Compost that has been screened to 19 mm (¾ in) or less is recommended for slopes that are to be landscaped. A moisture content of less than 25 percent makes application most efficient and enables the compost layer to readily adsorb larger amounts of rainfall immediately after application. Mature compost will function to release nutrients into the soil more readily than immature compost. Contaminants (plastic, glass, undecomposed plant material) detract from the aesthetic benefits of compost amendment. As a result of the study and field plots, members of several local governments incorporated the use of compost into their specifications.

Caltrans Compost and Co-Compost Study

Caltrans developed a project entitled "Evaluation of compost and co-compost materials for highway construction" (Sollenberger, 1987) that tested sewage sludge composts and sludge/municipal refuse co-composts. The materials were found to be usable as fertilizers, soil amendments, and erosion control materials only if the quality was good (permissible contents of heavy metals, toxic organics, pathogenic organisms, and low content of glass, plastic and metal). Because the focus of the Sollenberger (1987) study was on sludge and municipal refuse composts, the data are of little use regarding the current erosion control project, except to illustrate the relatively clean, low- contaminant content of GMC compared to composted municipal solid waste materials.

Caltrans Green Material Mulch Demonstration

A second Caltrans-funded project addressed the use of green material for surface application on roadways (Pollock and Moreno, 1993). This project was developed in cooperation with the

California Integrated Waste Management Board for the purpose of determining whether green materials, including residential yard clippings, and similar clean organic refuse could be used for weed control, soil improvement, conservation of irrigation water, plant fertilization, and aesthetic improvement of landscape sites. The materials utilized were variously called "mulch" and "composted mulch" but were, in fact, not composted. Composted materials are those that have undergone thermophilic decomposition and organic matter stabilization. The materials used in this study contained particle sizes such that 82 to 99 percent (Caltrans District 3) or 62 to 99 percent (District 11) passed through a 9.5-mm screen. The District 3 materials were characterized as having a greater volume of 6.3 mm (1/4-in) particles, with smaller proportions of larger and smaller particles. The District 11 materials contained either fine-sized particles plus wood chips and cuttings less than 150 mm (6 in) in length (Miramar source materials), or particles from 150 to 450 mm (6 to 18 in) in length (Otay Landfill source materials).

Results from both districts indicate that plant growth was generally improved as a result of increased moisture retention, more moderate soil temperatures, and an enhanced habitat with greater fungal, insect, and vertebrate animal activity. The mulch materials were observed and measured to be very low in nutrient content. Quality control criteria were difficult to establish, but will be critical for widespread use of mulch materials. The reports advised that composted mulch materials should not be applied within the dripline of trees because of the observation of increased fungal rot of existing trees. Equal mixes of green materials and wood chips appear to benefit plant growth, and mulch depths of not less than 300 mm (12 in) are recommended. In conclusion, this study documented benefits of mulch materials for improved vegetative growth, but did not evaluate composted green materials. Even where the mulch materials were partially composted, their use and application was as a surface mulch rather than as an incorporated soil amendment.

SURVEY OF COMPOST PRODUCTS IN CALIFORNIA

Layout of Study

To evaluate the nutrient levels in current GMC and CCM products in California, 22 composted or co-composted materials and one uncomposted material were sampled in December 1998 and January 1999. The purpose of the sampling survey was not to check products against an existing criteria for quality, but to evaluate the range of material that would be available to Caltrans at a given point in time, should a revegetation project require GMC for use as a primary erosion control material and soil amendment.

Sampling and Analysis Methods

A standard sampling protocol was used for collection of material from producer sites. The "typical" material from each producer that would be shipped out to a large project was selected and then sampled from four evenly spaced points around the pile. Sampling points were typically about 50 m (162 ft) apart. A 4-liter (1.057-gal) volume was collected at each sampling point. Samples were collected at 1-m depths into the pile at a height of about 1–3 m from the base. Temperatures were measured at each sampling point to characterize whether the pile was still respiring or had cooled off. Surface samples were not collected because this zone made up relatively little of the volume of the bulk of the pile.

One composite sample was created for each source material and was submitted for commercial compost analysis (A91 compost evaluation, Soil and Plant Laboratory, Santa Clara, California).

These analyses were averaged by compost source material (green materials compost, biosolids/green material co-compost, agricultural byproduct composts, or other sources).

Results

Fourteen of the samples listed in Table 1 were green materials composts (GMC). Four samples were biosolids/green material co-composts (CCM). Three were agricultural byproduct composts (AGC). Two materials were listed as "Other": the Brea material was an uncomposted green material, and the Upper Valley material was a grape pomace/prunings compost. The 21 remaining compost materials were averaged by source material.

General Chemical and Physical Characteristics

GMC materials had much lower salinity than either CCM or AGC (Table 2). Much of the nearly 32 dS/m salinity measured in AGC came from KCl or NaCl. The salinity of the CCM was about half (16 dS/m) of the AGC. GMC had the lowest average salinity at 9.4 dS/m. The pH of the AGC was also the highest at 8.7. The pH of GMC averaged 7.6 while the CCM was slightly under 7.0.

The AGC was somewhat finer in particle size than either the GMC or CCM, having virtually all the material less than 1/2 in. Two-thirds of the AGC also passed the 1-mm sieve, while approximately half of the GMC and approximately a third of the CCM was that fine. Bulk density of the dry material was similar (726 to 840 lb/cu yd).

Macronutrient Contents

Total nitrogen was highest (1.9 percent) in the biosolids/green material co-composts (CCM) (Table 2). GMC and AGC were similar at 1.2 and 1.3 percent N. The amount of this N that will mineralize (release) and become available for plant uptake depends on the available C. These assays only provided an estimate of the C:N ratio. A ratio less than 20 is generally expected to indicate a material that will mineralize N, although this depends on the quality of the C. The GMC had a C:N ratio of about 19, the CCM of about 12, and the AGC of about 10. Extractable (immediately available, solution N) did not follow this trend. CCM had by far the highest extractable N at over 3100 ppm, followed by AGC at 353 ppm and GMC at 142 ppm. Further work is needed to adequately evaluate the ability of the compost to provide N for plant growth.

The variability of these N assays between producers within each source material group was moderate to high. Typical soil samples may have a coefficient of variation (CV) of about 20 percent. This is approximately the CV value of the total N for the GMC, while the variability of the CCM and AGC materials was much higher. This suggests that GMC samples will be more consistent between producers and can be characterized more reproducibly by specifications. In contrast, the extractable N levels for GMC and AGC had CVs greater than 100 percent, while for CCM the CV was 40 percent for nitrate and 26 percent for ammonium. A higher CV is expected from this soluble, easily changed N pool.

Table 1. List of compost and co-compost producers, in alphabetical order, with compost source material listed at right. See Appendix A for key to acronyms and abbreviations.

Producer	Source Material
1. Agri-Fuels, Inc., 24478 Road 140, Tulare, CA 93274	GMC
2. BFI Organics, Newby Island Composting Facility, 1601 Dixon Landing Rd., Milpitas, CA 95035	GMC
3. Brea Green Recycling, 1983 Valencia Ave., Brea, CA 92621	Other*
4. Cold Canyon Landfill, 2268 Carpenter Canyon Rd., San Luis Obispo, CA 93401	GMC
5. Community Recycling and Resource Recovery, 1261 N. Wheeler Ridge Rd., Lamont, CA 93241	CCM
6. Contra Costa Landscaping, P.O. Box 2069, Martinez, CA 94553	GMC
7. EKO Systems, Inc., 8100-100 Chino/Corona Rd., Corona, CA 91720	AGC
8. Foster Farms, 12997 West Highway 140, Livingston, CA 95334	AGC
9. Gilton Resource Recovery Transfer Station, 880 South McClure Rd., Modesto, CA 95354	GMC
10. Greenway Compost, 3210 Oceanside Blvd., Oceanside, CA 93056 (El Corazone)	GMC
11. Mt. Vernon Recycling Facility, City of Bakersfield, 2601 S. Mt. Vernon Ave., Bakersfield, CA 93309	GMC
12. New Era Farm Service, 23004 Rd 140, Tulare, CA 93274	AGC
13. North Valley Organic Recycling, P.O. Box 1159, Chico, CA 95927	GMC
14. Recyc, Inc., 114 Business Center Dr., Corona, CA 91720	GMC
15. Redding, City of, Transfer/Recycling Facility, 2255 Abernathy Ln., Redding, CA 96003	GMC
16. Sacramento, City of, Solid Waste Division, 20 28th St., Sacramento, CA 95814	GMC
17. San Diego, City of, Environ. Serv. Dept. 9601 Ridgehaven Court, Ste. 320, San Diego, CA 92123	GMC
18. San Joaquin Compost, 12321 Halloway Rd., Lost Hills, CA, 93249	CCM
19. Santa Rosa, City of, Laguna Treatment Plant, 4300 Llano Rd., Santa Rosa, CA 95407	CCM
20. Sonoma Compost, 550 Meacham Rd., Petaluma, CA 94952	GMC
21. Turlock, City of, 901 S. Walnut Rd., Turlock, CA 95380-5123	CCM
22. Upper Valley Disposal and Recycling, P.O. Box 382, 1285 Whitehall Ln., St. Helena, CA 94574	Other*
23. Zanker Road Resource Mgmt., 705 Los Esteros Rd., San Jose, CA 95134	GMC

*Source materials other than GMC, CCM, or AGC.

Table 2. Summary table of characteristics by source material from 21 compost producers, excluding source materials that are not GMC, CCM, or AGC. See Appendix A for key to acronyms and abbreviations. Analyses from Soil and Plant Laboratory, Inc., Santa Clara, CA (A91 Compost Evaluation).

Total Nutrient Contents and Other Characteristics

		Total nutrient contents												Other characteristics			
		% N	% P	% K	% Ca	% Mg	% Na	% S	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	TEC	half sat%	pH	ECe
All materials																	
	X	1.4	0.6	0.9	2.3	0.6	0.2	49.9	123.6	263.8	356.3	15363	58.4	513.3	60.8	7.7	14.0
	s	0.4	0.6	0.6	0.7	0.2	0.1	50.5	89.0	168.4	136.3	7261	19.3	156.8	25.2	0.6	9.2
	CV	30.5	97.4	64.8	30.5	34.5	61.8	101.2	72.1	63.8	38.3	47	33.0	30.5	41.5	8.1	65.6
Green material composts (GMC)																	
	X	1.2	0.3	0.8	2.0	0.6	0.2	20.5	75.4	182.5	343.9	14874	58.4	485.6	64.1	7.7	9.4
	s	0.2	0.0	0.3	0.5	0.2	0.1	21.7	31.0	50.5	125.7	7351	13.4	88.3	22.0	0.3	4.4
	CV	17.8	18.2	30.1	23.3	29.0	50.9	106.1	41.2	27.7	36.6	49	23.0	18.2	34.3	3.5	46.4
Co-composted biosolids/green materials (CCM)																	
	X	1.9	1.5	0.4	2.6	0.5	0.2	96.4	261.5	536.8	283.8	18785	48.0	691.5	66.0	7.0	16.8
	s	0.6	0.5	0.1	0.6	0.1	0.0	33.4	43.6	190.5	92.5	8939	19.0	241.4	39.2	0.7	5.8
	CV	29.4	29.9	32.8	21.9	22.9	26.4	34.6	16.7	35.5	32.6	48	39.6	34.9	59.4	10.3	34.4
Agriculture byproducts composts (AGC)																	
	X	1.3	1.2	2.1	3.0	0.9	0.4	125.2	164.7	279.3	511.0	13082	72.3	405.0	38.7	8.7	31.9
	s	0.5	0.6	0.7	1.2	0.3	0.1	43.2	115.4	130.2	150.5	4819	38.8	145.4	7.0	0.4	5.3
	CV	38.7	55.0	33.8	41.0	31.8	32.8	34.5	70.1	46.6	29.4	37	53.6	35.9	18.2	4.7	16.7

Available Nutrient Levels

		NaCl extract					Bicarb extract	DTPA extract				Sat ext			Dil acid % Fe
		ppm NO_3-N	ppm NH_4-N	ppm K	ppm Ca	ppm Mg	ppm PO_4-P	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	% ECe Na	meq/L Cl	
All materials															
	X	341.6	739.7	6587.0	4533.6	1436.6	493.8	17.0	78.6	72.8	265.6	2.7	29.3	53.4	0.4
	s	413.2	1239.6	2954.9	2366.1	432.0	526.3	23.2	45.0	39.7	203.0	2.3	27.3	44.4	0.4
	CV	121.0	167.6	44.9	52.2	30.1	106.6	136.0	57.2	54.6	76.4	84.2	93.0	83.1	103.4
Green materials composts (GMC)															
	X	199.5	142.4	6752.2	4578.6	1514.9	277.4	6.4	56.1	77.0	234.6	2.0	18.7	43.4	0.2
	s	272.6	176.7	1497.8	1654.0	471.2	108.8	3.8	20.2	37.6	187.4	1.6	15.7	25.5	0.2
	CV	136.6	124.0	22.2	36.1	31.1	39.2	58.8	35.9	48.9	79.9	83.4	83.7	58.7	96.2
Co-composted biosolids/green materials (CCM)															
	X	950.8	3119.8	2898.5	6448.5	1426.5	729.5	36.1	131.5	53.0	361.0	2.3	25.5	27.8	0.9
	s	384.1	816.2	1094.7	3564.6	186.9	686.3	6.8	37.1	46.0	257.1	1.3	12.9	21.7	0.5
	CV	40.4	26.2	37.8	55.3	13.1	94.1	18.9	28.2	86.8	71.2	57.2	50.4	78.0	57.9
Agriculture byproducts composts (AGC)															
	X	192.7	353.3	10734	1770.3	1084.3	1189.3	41.1	112.7	79.3	283.3	6.9	83.8	134.2	0.3
	s	293.9	337.8	4211.1	585.5	375.6	906.6	53.2	68.1	49.2	243.5	1.3	17.9	54.5	0.3
	CV	152.5	95.6	39.2	33.1	34.6	76.2	129.4	60.5	62.0	86.0	19.2	21.4	40.6	100.4

Physical Characteristics

				These analyses on 1/2" minus material													
		% Overs, 1"	% Overs, 1/2"	Bulk density, lb/cu yd	Moisture content, %	Water, lb/cu yd	Dry matter, lb/cu yd	Organic fraction, lb/cu yd	Mineral fraction, lb/cu yd	Organic %	% of material passing screen size listed (mm)						C:N ratio
											9.51 mm	6.35 mm	4.75 mm	2.38 mm	1.00 mm	0.50 mm	
All materials																	
	X	0.0	1.4	1222.8	35.7	424.7	798.8	285.1	513.0	35.7	97.7	92.4	88.0	73.2	48.7	29.8	16.4
	s	0.0	1.3	271.4	11.1	134.2	263.7	54.9	261.7		2.7	6.9	8.9	13.0	13.9	12.6	5.9
	CV		89.6	22.2	31.0	31.6	33.0	19.2	51.0		2.8	7.5	10.1	17.8	28.6	42.2	35.7
Green material composts (GMC)																	
	X	0.0	1.5	1168.6	38.0	442.4	726.4	283.9	442.6	39.1	97.7	91.7	87.3	72.6	49.0	30.3	18.9
	s	0.0	1.3	254.8	9.2	146.3	189.6	21.8	194.6		2.3	6.4	7.7	9.3	10.5	11.2	5.3
	CV		84.7	21.8	24.2	33.1	26.1	7.7	44.0		2.4	7.0	8.9	12.8	21.5	37.0	28.0
Co-composted biosolids/green materials (CCM)																	
	X	0.0	2.0	1295.3	38.0	457.0	840.3	313.5	524.5	37.3	96.3	89.9	83.0	61.7	34.5	19.1	12.5
	s	0.0	1.3	343.8	15.0	87.6	406.1	52.2	378.7		4.3	9.4	11.7	15.3	15.8	13.9	3.6
	CV		65.7	26.5	39.4	19.2	48.3	16.6	72.2		4.5	10.4	14.1	24.8	45.7	73.2	29.1
Agriculture byproducts composts (AGC)																	
	X	0.0	0.2	1378.7	21.9	298.7	1081.7	253.0	826.7	23.4	100.0	98.7	97.7	91.3	65.8	42.1	10.3
	s	0.0	0.4	264.0	2.1	34.0	233.0	140.6	203.2		0.0	1.5	1.8	5.2	1.1	4.0	3.6
	CV		173.2	19.2	9.5	11.4	21.5	55.6	24.6		0.0	1.5	1.9	5.7	1.6	9.5	35.4

Phosphorus (P) levels were 0.2 percent for GMC, 1.5 percent for CCM, and 1.1 percent for AGC. The high P level is typical for material containing biosolids. GMC had the lowest CV for total P, and would be the best characterized by a specification.

Potassium (K) was moderate (0.8 percent) in GMC and 0.4 percent in the CCM. The AGC had much higher total K (2.1 percent), which contributes partly to the high salt content. Sodium (Na) was also over twice as high in the AGC as in the other two materials.

Sulfur (S) was much lower in GMC (20 meq/l) than CCM (96 meq/l) or AGC (125 meq/l).

Calcium (Ca) was similar in all source materials (2 to 3 percent). Magnesium (Mg) was twice as high in the AGC (0.9 percent) as in the CCM and GMC (0.5 to 0.6 percent).

Micronutrient Contents

Total copper (Cu) and zinc (Zn) were much lower than the legal limits cited for these metals in municipal solid waste compost in Minnesota and New York (Hegberg et al., 1991). Within the products sampled from California, total Cu and Zn in GMC were about a third of those in the CCM samples. Bioavailable metals were measured by the DTPA extracts, which generally followed the same trends as the total levels. Similarly, baseline data in the Santa Cruz Green Waste Demonstration Project (Buchanan and Grobe, 1977) showed little evidence for excessive contamination for metals under California Title 14 and US EPA 503 regulations.

In general, the variability of the 21 compost samples was very high when viewed as a whole, but when the samples were separated by source material, the variability was reduced. Based only on the N assay data, specifications for total N in GMC should work reasonably well, although statistical evaluation of the data is still in progress. In contrast, the variability in the extractable N levels was greater than the mean, making this parameter difficult to specify. Typical CVs for other compost characteristics ranged from 40 to 80 percent, making specification of these characteristics difficult as well. Further data analysis will be done, perhaps to evaluate a "minimum content" type of specification rather than an average.

DRAFT CALTRANS SPECIFICATION FOR COMPOST

Compost shall be derived from green material consisting of chipped, shredded, or ground vegetation; clean, processed, recycled wood products; Class A, exceptional-quality biosolids composts, as required by U.S. EPA regulations (40 CFR, Part 503c); or a combination of green material and biosolids compost. The compost shall be processed or completed to reduce weed seeds, pathogens and deleterious material, and shall not contain paint, petroleum products, herbicides, fungicides, or other chemical residues that would be harmful to plant or animal life. Other deleterious material, plastic, glass, metal, or rocks shall not exceed 0.1 percent by weight or volume. A minimum internal temperature of 57°C shall be maintained for at least 15 continuous days during the composting process. The compost shall be thoroughly turned a minimum of five times during the composting process and shall go through a minimum 90-day curing period after the 15-day thermophilic composting process has been completed. Compost shall be screened through a maximum 6-mm screen. The moisture content of the compost shall not exceed 35 percent. Moisture content shall be determined by California Test 226. Compost products with a higher moisture content may be used, provided the weight of the compost is increased to equal the weight of the compost with a moisture content of 35 percent. Compost will be tested for maturity and stability with a Solvita test kit. The compost shall measure a minimum of "6" on the maturity and stability scale. (On culmination of this research, process based specifications will be replaced with specifications based on quality parameters). (Note: The screen size and the maturity/stability measurement may change, depending on the intended use of the compost.)

ACKNOWLEDGEMENTS

The author wishes to thank the California Department of Transportation and the California Integrated Waste Management Board for their support of this project.

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APPENDIX A: ACRONYMS AND ABBREVIATIONS

AGC.......... agricultural byproducts compost (manure, feathermeal, bedding)
bicarb........ bicarbonate extract (Olsen test)
Ca............ calcium
CCM......... co-composted materials (biosolids/green materials compost)
CFR.......... Code of Federal Regulations
cm............ centimeters
Cu............ copper
CV........... coefficient of variation [(s/X)* 100]
dil acid...... dilute acid extract
dS............. deciSiemens
DTPA........ diethylenetriamine pentaacetic acid
ECe.......... electrical conductivity measured on a saturated extract
extract....... the procedure of estimating the nutrient content of materials by mixing it with a specific solution and removing the solution for analysis
GMC......... green materials compost
ha............. hectare
half sat %...the half saturation percentage is the percentage of water equal to half of the saturated capacity of the compost
K.............. potassium
KCl.......... potassium chloride
kg............. kilogram
l................ liter
m.............. meter
meq.......... millequivalent
Mg........... magnesium
mg............ milligram
mm........... millimeter
N.............. nitrogen
Na............ sodium
NaCl......... sodium chloride
NH_4-N....... ammonium nitrogen
NO_3-N....... nitrate nitrogen
O.............. oxygen
P.............. phosphorus
pH............ negative log of hydrogen ion activity
PO_4-P........ phosphate phosphorus
ppm.......... parts per million
S.............. sulfur
s............... standard deviation
sat ext........ saturation extract
SO_4.......... sulfate
TEC.......... total exchangeable cations (measured on saturation extract, except for sodium)
X.............. mean
yd............. yard
Zn............ zinc

CLEAR CREEK BIOENGINEERING DEMONSTRATION PROJECT

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ABSTRACT

Soil bioengineering techniques combine engineering, biological, and ecological concepts to the construction of living structures for erosion, sediment, and flood control. These techniques are not new; they have been used in Europe since the 1500's. The science of soil bioengineering has been steadily developed and has recently gained wide acceptance in the United States.

The Urban Drainage and Flood Control District developed an interest in soil bioengineering and set up a demonstration project to evaluate various techniques such as brush layering, live booms, wattles, joint planting, and live stakes. The application of these techniques to the problem of stream bank erosion on a large urban stream was of particular interest. Evaluation of the effectiveness these techniques in an arid climate was a key concern, since the majority of successful bioengineering projects reviewed by the District were constructed in humid climates. In view of our limited experience with this type of construction, we hired Soil Bioengineering Corporation from Georgia to design the project and to supervise the installation.

This paper is a case study that describes the process that the District used to implement this demonstration project. Goals of the project and the various types of soil bioengineering techniques that were used will be described. Since this project was completed over 12 years ago, the paper will evaluate the long-term effectiveness of each of the different types of bank treatments that were used and the effects of downstream gravel mining on the project. Recommendations for use of soil bioengineering techniques on stream restoration projects will be described.

INTRODUCTION

Erosion control projects along urban drainageways have historically relied on riprap and concrete. The District had been using these hard approaches for years for erosion control and channel stability. As a greater understanding of the riparian and wildlife functions of drainageways developed, the need to look for more natural alternatives became apparent. Bioengineering techniques, which employ a combination of native species, natural materials, and hard structures, provided such an alternative. These techniques could help restore the riparian functions of the drainageways by providing erosion control, improving the wildlife habitat, and enhancing the aesthetics of the area.

The District became interested in the concept of soil bioengineering after staff members attended a seminar on the subject hosted by the University of Wisconsin. At that seminar, several speakers discussed on various techniques for stream restoration. One of the speakers, Robbin Sotir of Soil Bioengineering Corporation, offered to assist the District with set up of a demonstration project in our area. Recognizing the potential for its application on our projects, the District hired this firm to both design the project and supervise its construction in the field.

A major concern with the concept of soil bioengineering was its applicability to the arid climate of Colorado. Most of the projects presented at the seminar had been constructed in wet climates. These projects had relied entirely on willows to stop erosion and had been very successful with immediate growth. The District recognized that similar results could not be expected in Colorado. It anticipated that it would take several years for the project to stabilize, and for the willows to establish themselves to provide erosion protection. The District therefore wanted to design a project that incorporated both hard materials as well as willows to repair the erosion.

The District was also interested in the cost effectiveness of this type of construction compared with traditional methods, including riprap. The intent was to maintain a detailed cost record of the project and to compare it with a cost estimate for a riprap repair of the area. The hope was that the bioengineering techniques could prove cost effective and also provide a more environmentally friendly alternative to erosion control.

CLEAR CREEK DEMONSTRATION PROJECT

Site Conditions

Clear Creek is a major drainageway that starts in the mountains west of Denver and ends at the confluence with the South Platte River in Adams County. The project site is located upstream of the confluence area along a trail and adjacent to a pedestrian bridge over Clear Creek. The 100-year floodplain is approximately 850 feet wide in this location, and the 100-year flow is about 23,000 cubic feet per second. The slope of the channel is .6 % and soils in the channel are sandy and gravelly alluvial soils. Vegetation adjacent to Clear Creek consists primarily of native grasses, willows and cottonwoods.

This site was chosen for the demonstration project primarily because of the good access for equipment into the area, and the close proximity to a good source of willow material. The site was considered a good candidate because the natural surroundings afforded an opportunity not available in the majority of urban settings that the District worked in. Another factor included the immediate need of repair to the channel bank in order to prevent erosion of the trail. Additionally, the local government, Adams County, was supportive of the demonstration project.

The challenge at this project site was approximately 450 lineal feet of vertical bank erosion, 5 to 8 feet high in some locations. The erosion was on an outside bend of the channel and was threatening the trail to the north. The area had been a former dumpsite and the channel bank contained debris such as tires and old metal culverts. In addition to the debris onsite, Adams County had been dumping concrete and asphalt rubble along the bank in an attempt to slow down the encroachment of the creek towards the trail.

Approach

One of the main goals of the project was to study as many different bioengineering techniques as possible to determine how they compared in similar conditions. In reviewing the site conditions with the consultant, several factors were considered in selecting components for the project: the type of erosion taking place, the channel alignment in relation to the bridge and the trail, the creek hydrology, and the types of plant material in the immediate area. The techniques that were considered most appropriate were live booms, live soft gabion, joint planting, willow staking, and fascines. Fashines are bundles of willow cuttings of varying lengths tied together in a 6-inch diameter roll with twine. They are constructed in 20-foot lengths and cut to size with a chainsaw. Each of the techniques is briefly described below.

The primary technique utilized in the repair was the live booms. Nine of these structures were constructed to act as jetties to deflect the flow away from the eroded bank and to encourage sedimentation in the area between the booms. They were constructed using fashines in a grid fashion with soil compacted on top of the grid (Figure 1). These acted as lifts and each boom was comprised of 5 to 8 lifts to attain the desired elevation. The booms were constructed in close against the eroded bank and extended into the creek approximately 25 feet. Each boom was 12 feet wide at the base and 4 feet wide at the top. They were set at a slight angle downstream and were covered with small riprap and willow stakes upon completion. The purpose of the riprap was to provide some stability and erosion protection until the willows could be established.

In between each of the booms, live soft gabions were built. These consist of soil lifts wrapped in a geogrid material to provide stability. The lowest lift was constructed below the channel invert and was filled with riprap instead of soil to provide a base for the subsequent lifts. The geogrid material was staked down between each lift with wooden stakes (Figure 2) and layers of willow cutting were placed on top. The cut ends of the willows were placed in against the bank with the soft tips extending out past the lift (Figure 3). The purpose of the live soft gabion was to stabilize the bank and provide vegetation that would grow in the future.

Along the top of the bank a berm was constructed to intercept any flow coming from the over bank and trail area and direct it around the end of the project. On either side of the berm a trench was dug and willow bundles were placed in the trench, staked down with a wooded stake, covered with soil and lightly compacted (Figure 4). The intent here was that the flow the berm collected would provide enough moisture to help establish the willows.

At the upstream end of the project near the water level was a large flat area, which began the transition into the booms. This area was graded to provide positive drainage into the creek, seeded with native seed, mulched, and staked with willow stakes. The willow stakes were approximately 2 feet long and varied in diameter from ¾ to 3 inches. They were trimmed so that the large diameter end of the stake was cut at an angle and this end was put into the ground (Figure 5). The stakes were placed in 3 rows of varying elevation relative to the water surface (Figure 6).

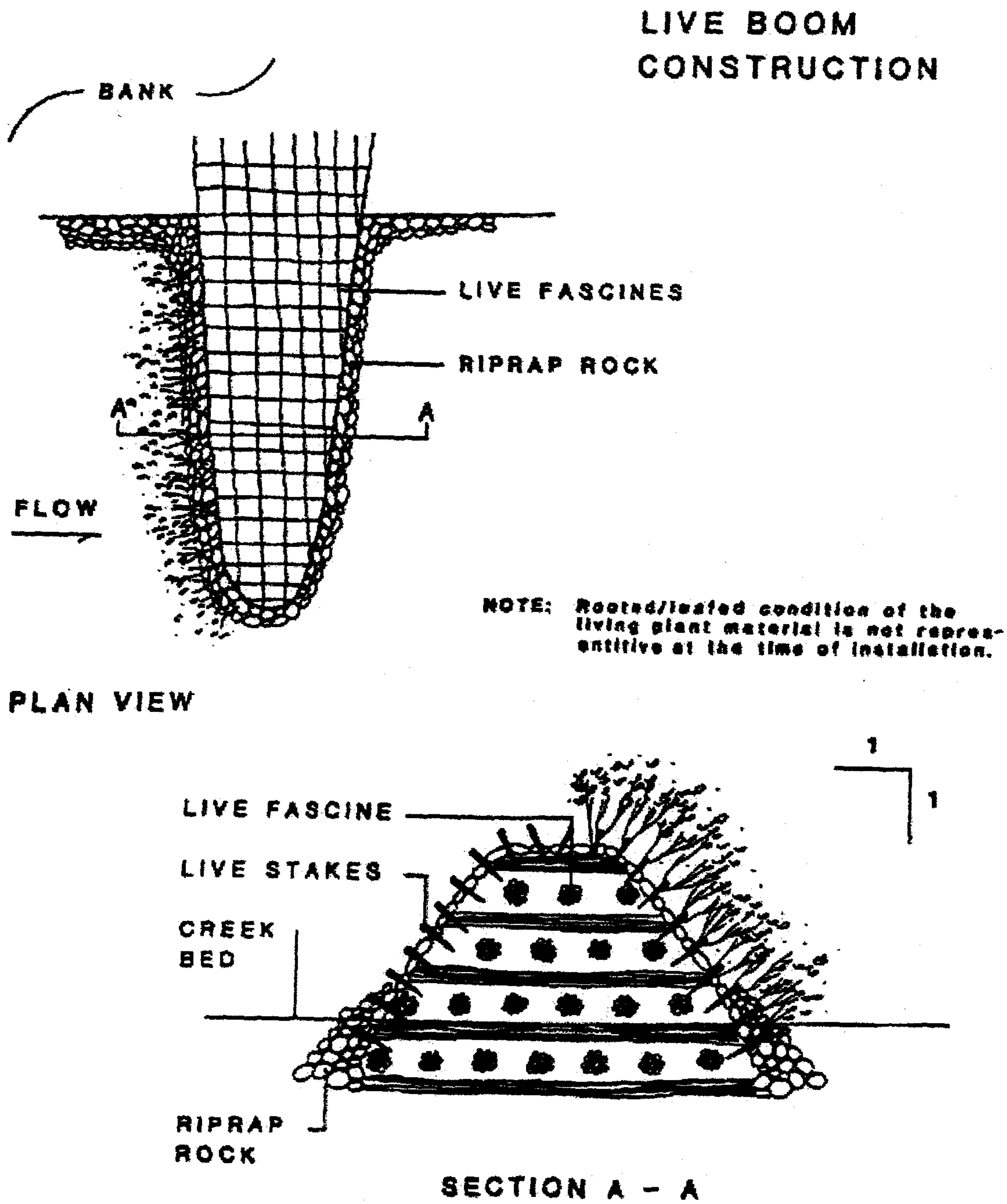


Figure 1. Details for Live Boom Construction.

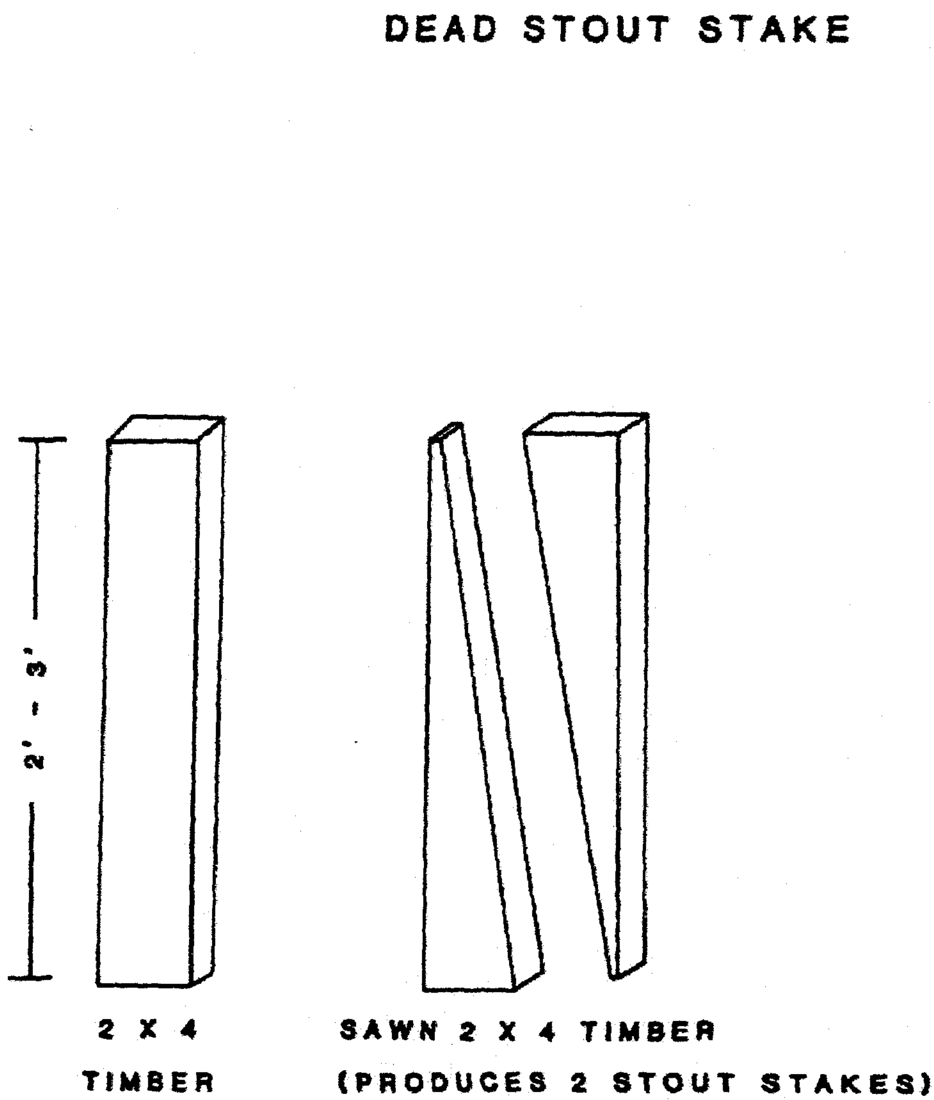
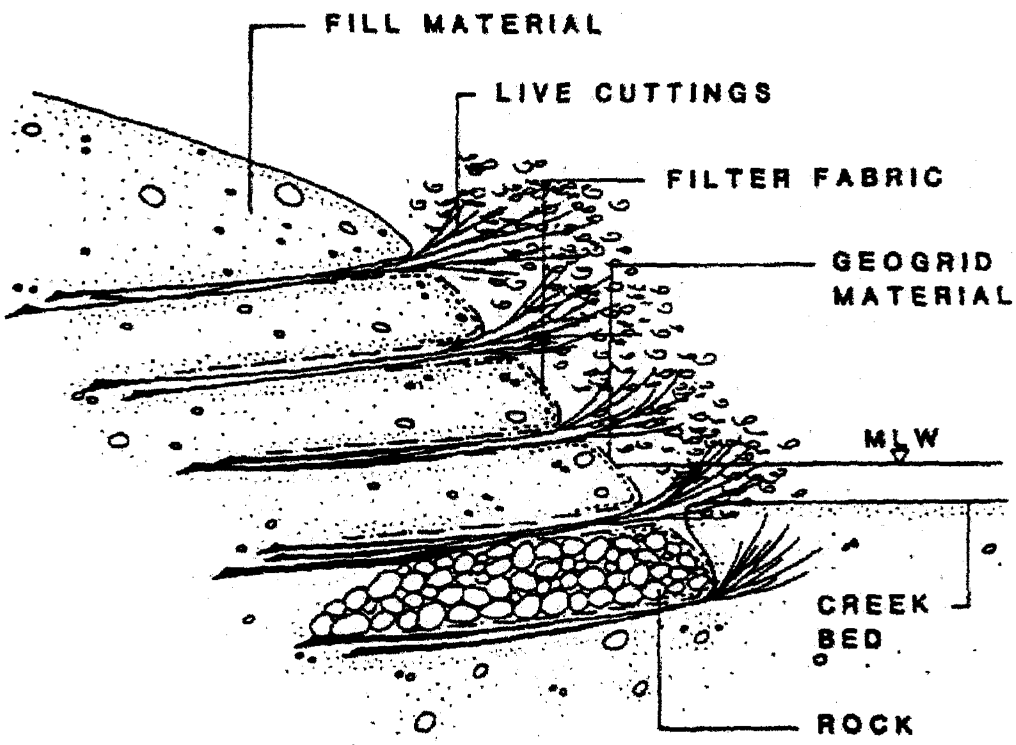


Figure 2. Dimensions for Stout Stakes.

LIVE SOFT GABION

SECTION



NOTE: Rooted/leafed condition of the living plant material is not representitive at the time of installation.

Figure 3. Design details for live soft gabion.

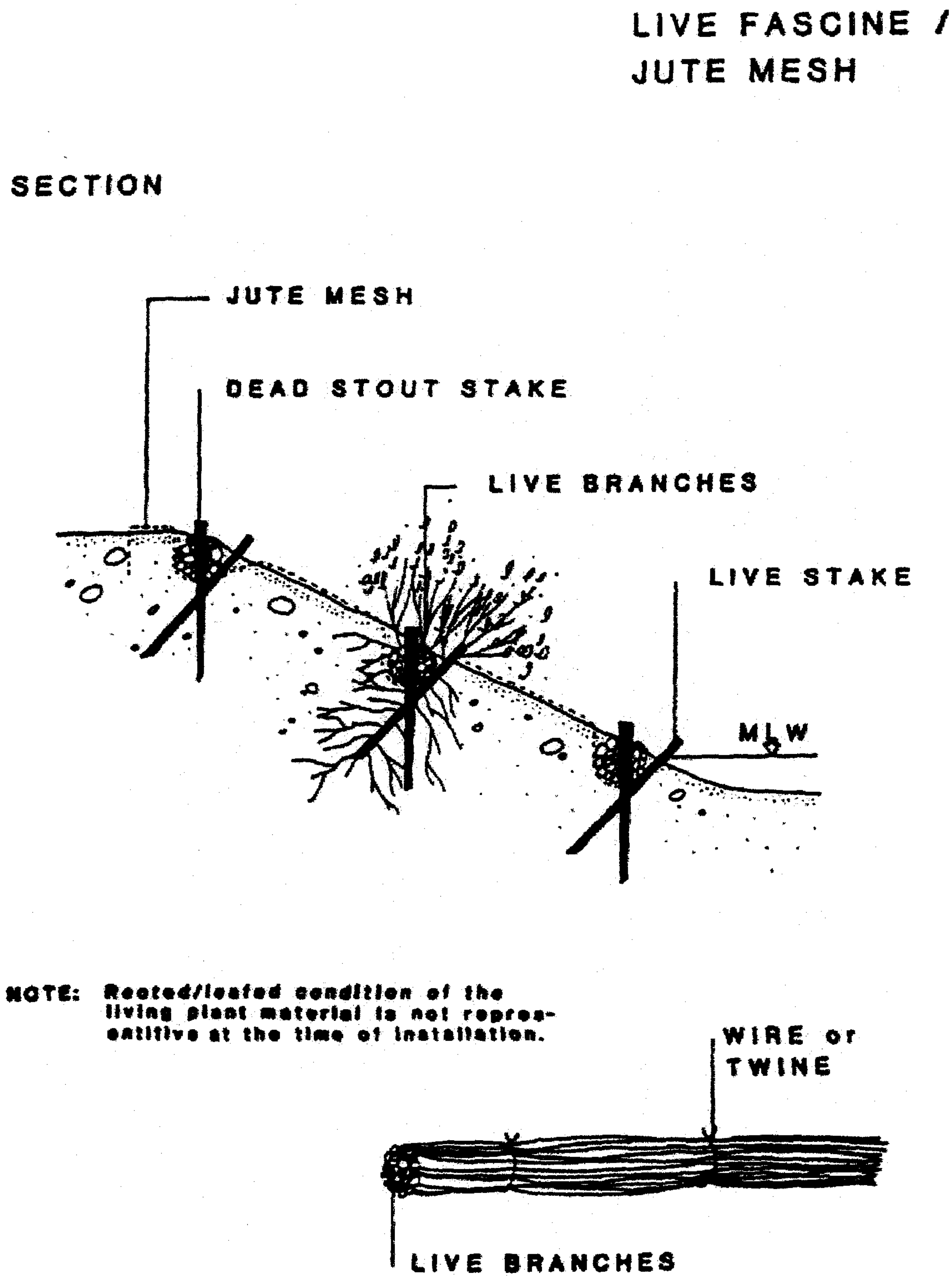


Figure 4. Design details for Live Fascine/Jute Mesh Installation.

Typical Live Stake Detail

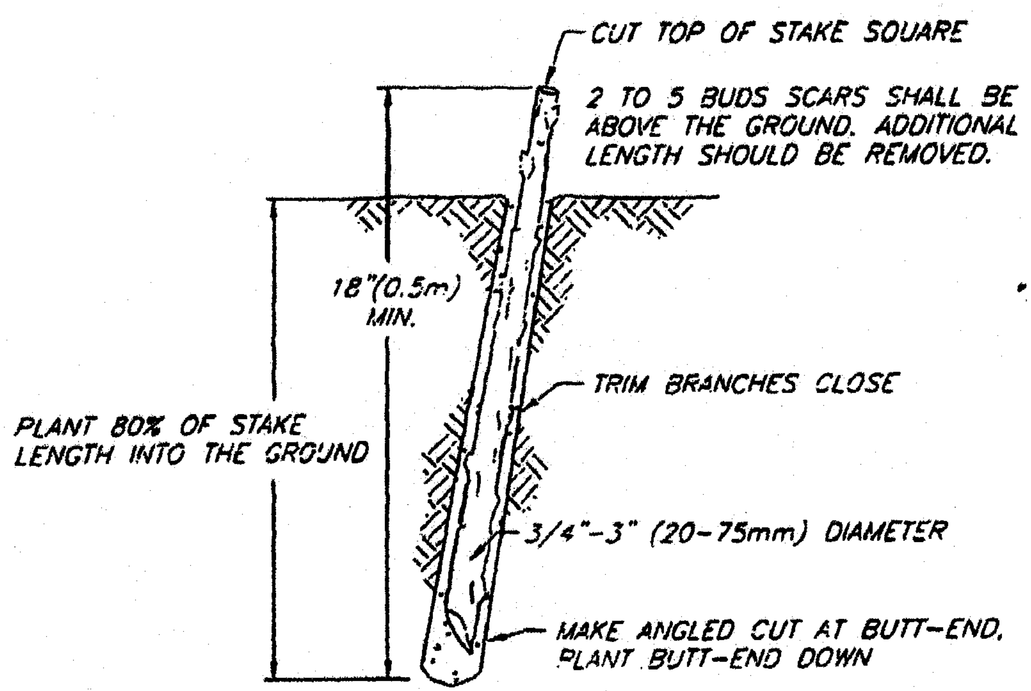


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Figure 5. Typical Live Stake Detail.

LIVE STAKE
(With Straw Mulch)

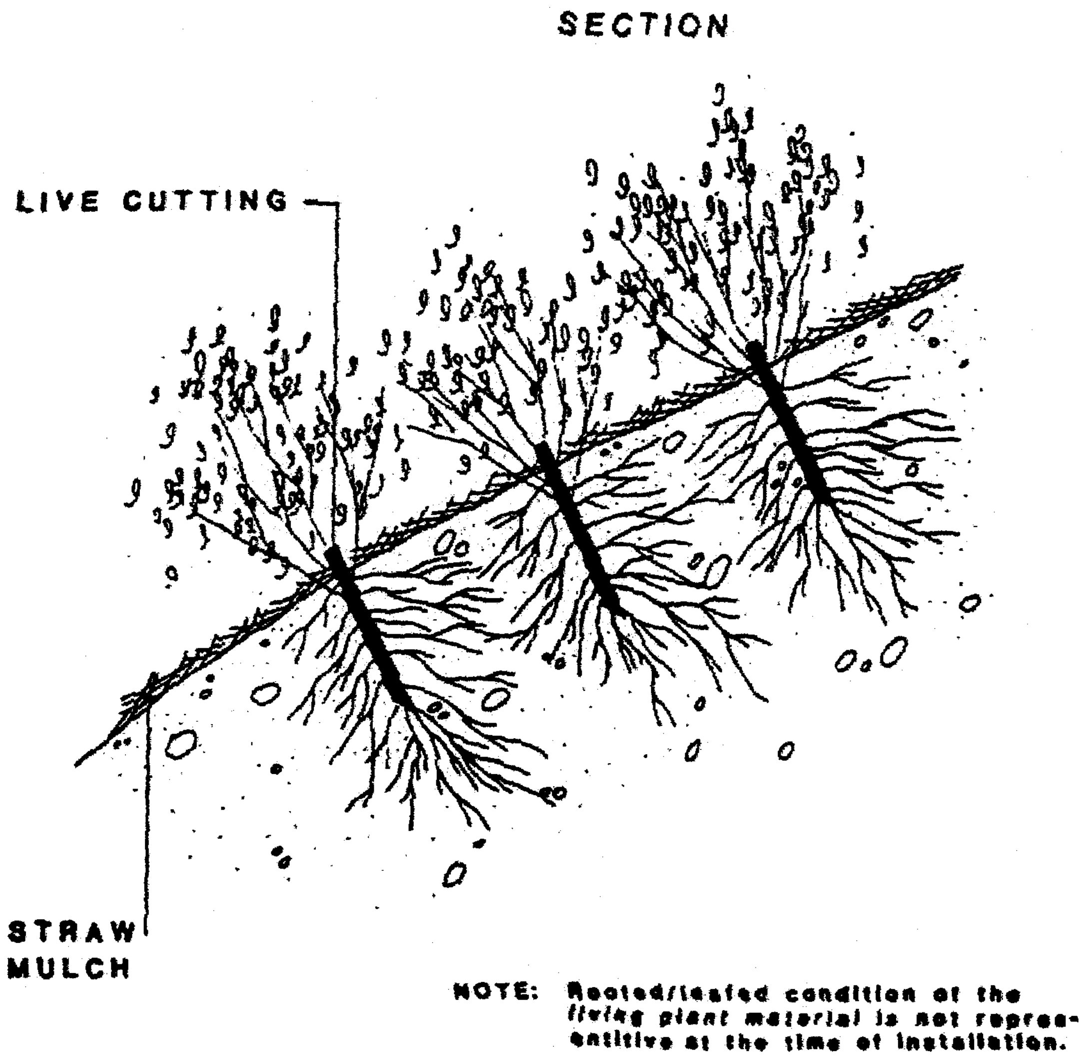

Figure 6. Design Details for Live Stake with Straw Mulch.

At the downstream end of the project, there was existing riprap that had begun to fail due to erosion and foot traffic below the footbridge. The riprap was repaired and then the area was joint planted with 3 rows of willow stakes (Figure 7). A pilot hole was punched with a piece of rebar to prevent damage to the stake when it was driven into the ground. The stakes were tapped into place with a dead-blow hammer.

Cost Analysis

A cost analysis was done at the completion of the project to compare the costs of this project with the cost of repairing the erosion with riprap. The total project cost for the bioengineering project was calculated to be \$ 122,000, excluding consultant costs. This number was compared with an estimate for a traditional repair including earthen booms covered in riprap and sloping riprap bank protection between the booms. This estimate was \$ 63,670. A break down of these costs is shown in Table 1.

Table 1. Cost Comparison.

COST COMPARISON

TYPE OF CONSTRUCTION	BIOENGINEERING PROJECT	TRADITIONAL METHODS
BOOMS	\$76,020	\$21,230
PROTECTION BETWEEN BOOMS	\$43,480	\$39,940
WILLOW STAKING	\$2,500	\$2,500
TOTAL COST	\$122,000	\$63,670

In analyzing these costs, the District noticed that over 62% of the cost of the bioengineering project were attributed to the live boom construction. The cost was higher because most of the construction of these booms was done by hand. When compared with the cost of traditional boom construction, it was apparent that this type of live boom construction technique could not be competitive on a cost basis.

The District attempted to devise a more cost effective construction technique. We estimated the cost of constructing the booms by the traditional method and then willow staking them. This in

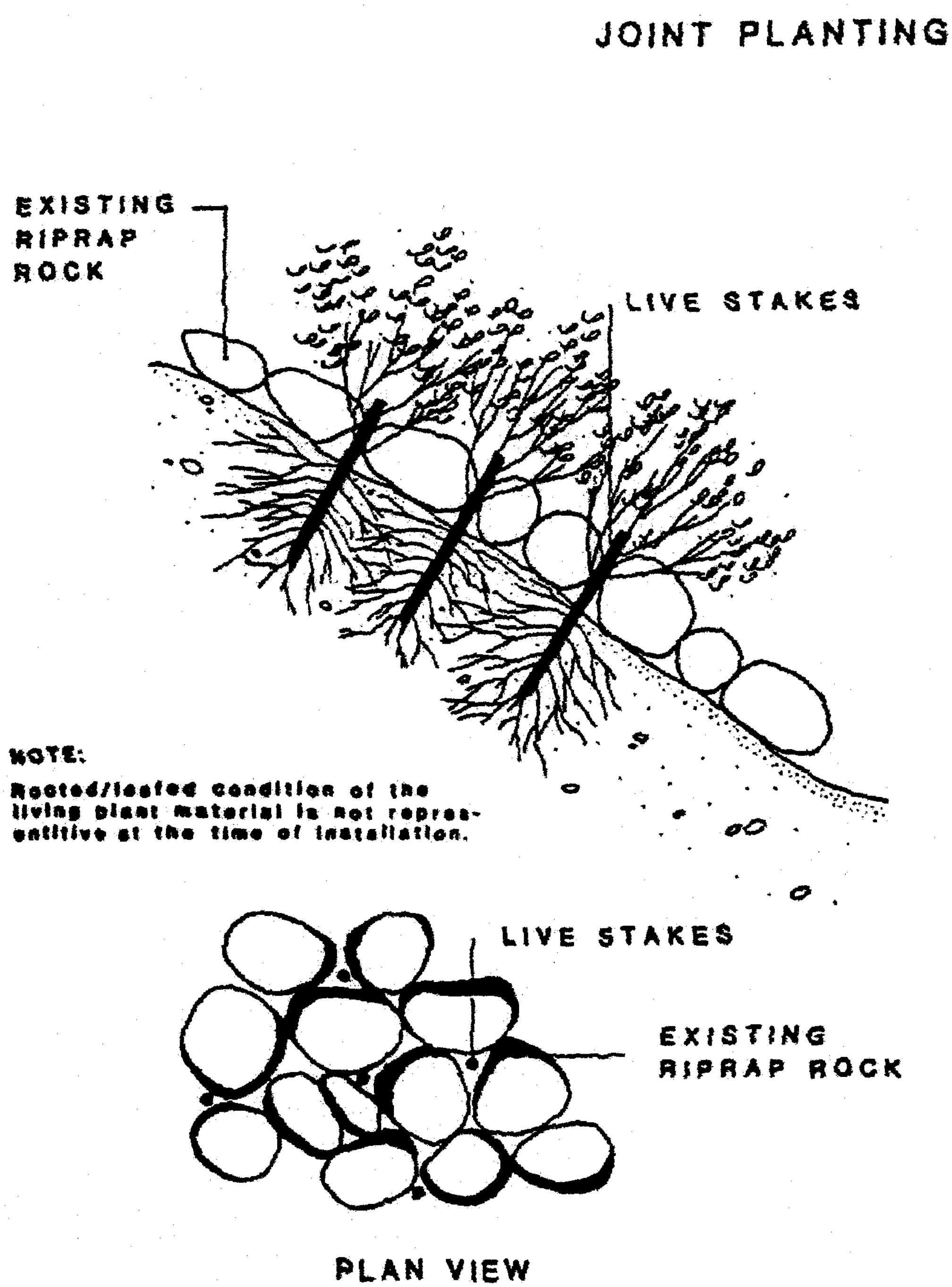

Figure 7. Design Details for Joint Planting.

essence would achieve the same effect at a lower cost. In comparing the cost of the revised method with traditional construction, the numbers were very close (Table 2).

Table 2. Revised Cost Comparison.

REVISED COST COMPARISON

TYPE OF CONSTRUCTION	REVISED BIOENGINEERING PROJECT	TRADITIONAL METHODS
BOOMS	$22,890	$21,230
PROTECTION BETWEEN BOOMS	$43,480	$39,940
WILLOW STAKING	$2,500	$2,500
TOTAL COST	$68,870	$63,670

Results and Discussion

The project was monitored closely for the first growing season. The area was mowed several times to control weeds, and regular site visits kept track of new growth of the willows. All indications pointed to a successful demonstration project. The booms had held the bank and deflected flow away from the bank. Sedimentation began to fill in the area between the booms. On the sediment between the booms, native grasses and willows had begun to establish themselves even though they were not planted as part of this project. Willow stakes on the booms, and at the upstream and downstream ends of the project started to sprout. As expected, the majority of significant growth was observed along the lower edges close to the water. After the first growing season the project was monitored infrequently.

The project area was reevaluated in the summer of 1999, 12 years after its completion. Debris was cleared from the area and all vegetation was mowed and the clippings were removed. A photographic record was made of the area and plant material was measured and counted. Most of the willow stakes on the booms, approximately 80%, were either dead or gone but the remaining willows were well established. In some instances the willows were 10 feet in height. The area in between the booms had completely filled in with silt. On the upper end of the project, the deposition between the booms was 5 feet in depth. Willows had grown from the base of the live soft gabions and native grasses covered all the silt deposition. Our primary observation, as anticipated, was that the plant material close to the water fared much better than the material further up the bank. In an arid climate such as Colorado's, planting close to moisture is essential to the success of this type of project.

Aside from the changes in the vegetation, we did note a complete failure of several of the lower live boom structures. A head cut several feet in depth was beginning to move through the project area. The origin of the head cutting was the South Platte River. Years of unregulated gravel

CROSS-SECTION UPSTREAM OF CLEAR CREEK

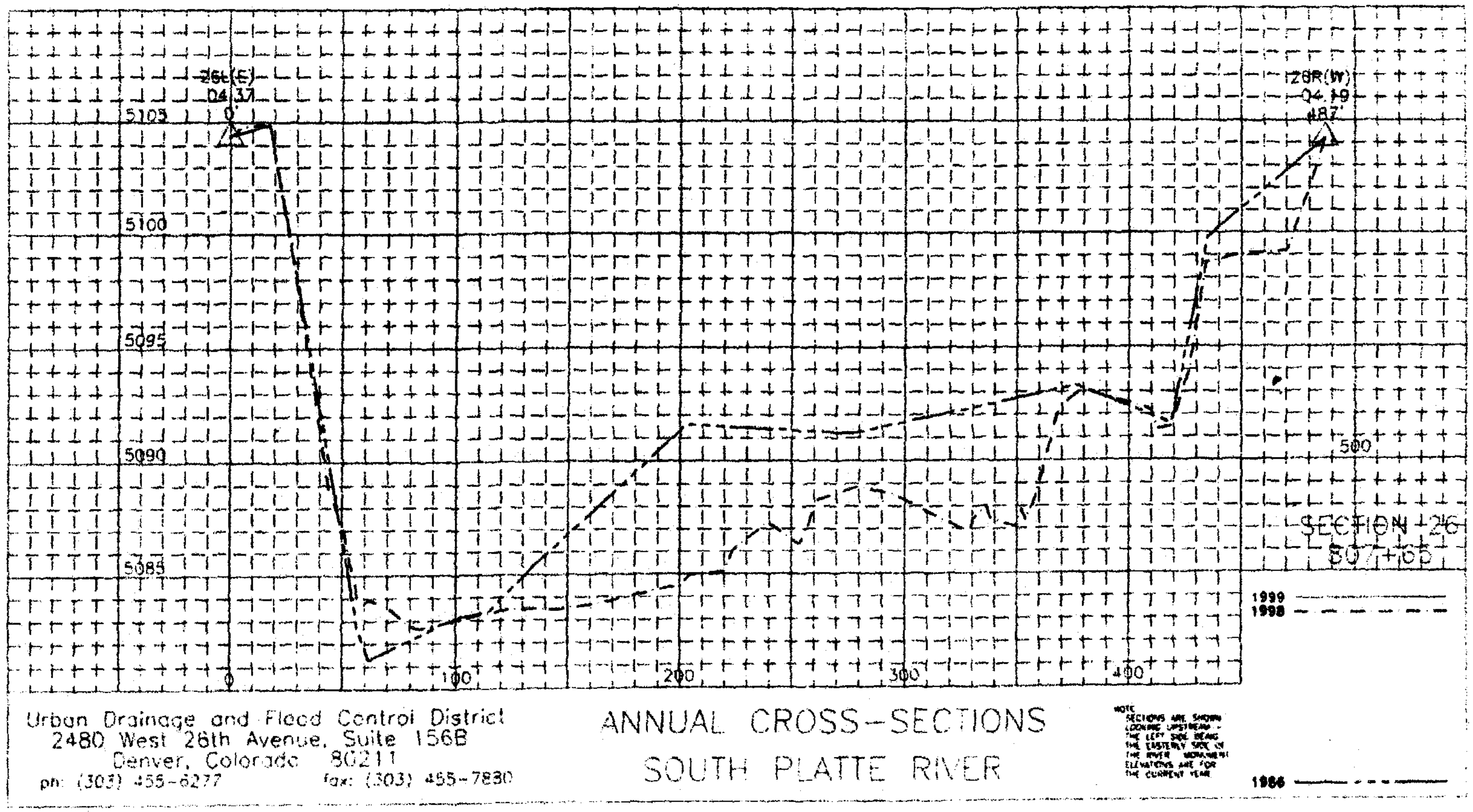

Figure 8. South Platte River Cross Section Upstream of Clear Creek.

CROSS-SECTION DOWNSTREAM OF CLEAR CREEK

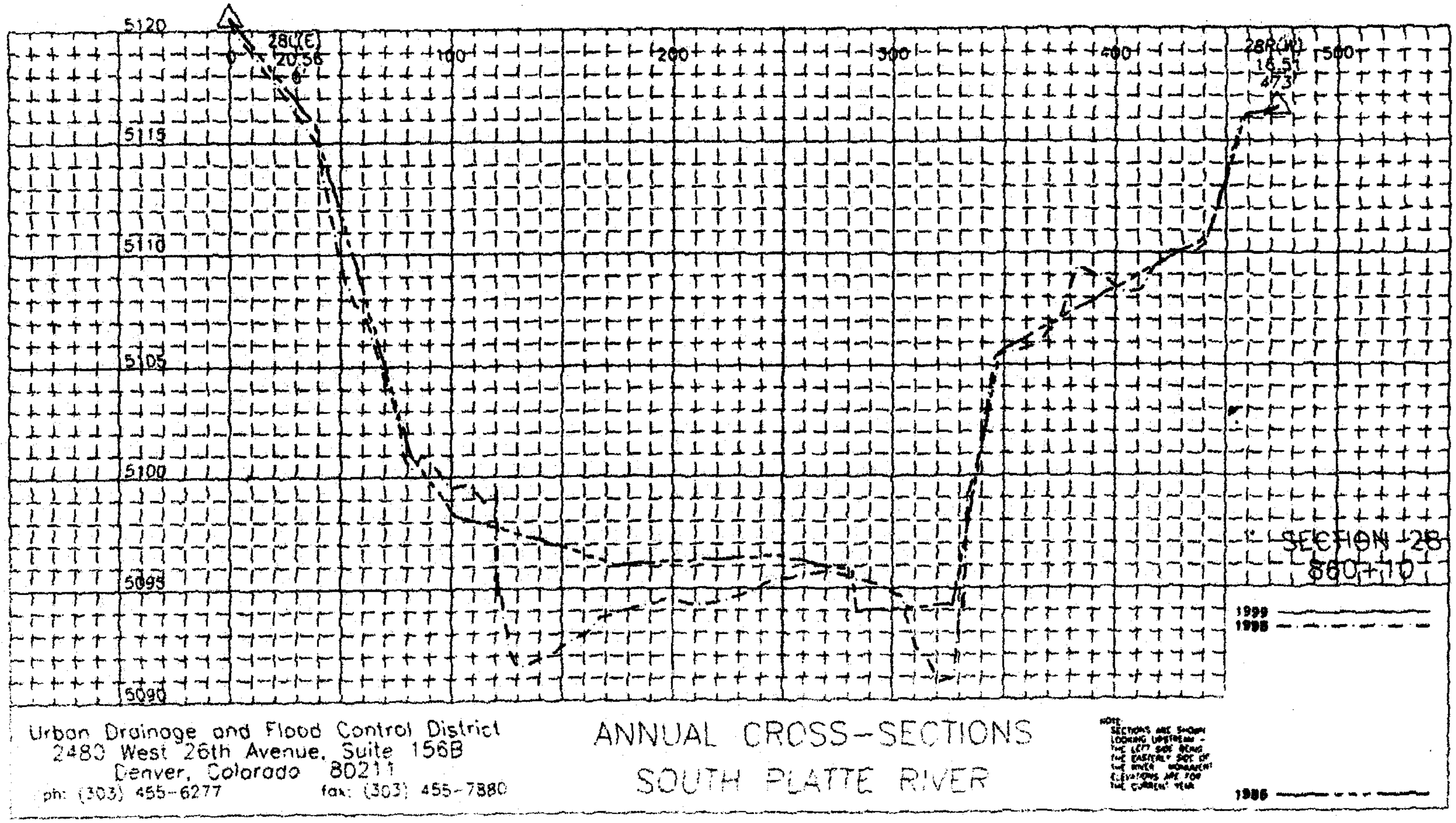

Figure 9. South Platte River Cross Section Downstream of Clear Creek.

mining on the river downstream of the confluence with Clear Creek had rendered the bottom unstable. Survey data from the South Platte River, both upstream and downstream of the confluence with Clear Creek, indicated that the channel bottom had dropped in elevation between 3 to 6 feet since 1986 (Figures 8 and 9). Drop structures have been placed on the Platte River since 1986 to stop the scour on the river but there was no structure to prevent the scour from moving up into Clear Creek. A drop structure will be needed to prevent the scour from moving upstream thus causing failure of other structures, and a repair will be needed on the structures that have failed as a result of the erosion.

Conclusions

Despite the recent setbacks described, which are a result of uncontrollable natural occurrences, we consider this project a success. The District has continued to develop and use many of the soil bioengineering techniques that were a part of this project. Willow staking is a standard component used on all erosion control projects in natural areas. The District has just completed another large bioengineering in Arapahoe County, and one is currently under construction on Boulder Creek. In conclusion, with proper design, soil bioengineering is a viable and cost effective technique that offers an attractive alternative to riprap.

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CAN BIOENGINEERING PROJECTS WORK IN SEMI-ARID ENVIRONMENTS?

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ABSTRACT

The latest cheer among many drainage professionals around the Country seems to be, "roots not rip-rap", "roots, not rip-rap". But what happens when you don't get enough moisture above the ordinary high water line to get those willow stakes to sprout? How well do bioengineering techniques really work in dry environments? What is more challenging for implementation, technical or institutional constraints? This presentation addresses these questions and then presents a recent case study where bioengineering techniques were used

The case study project is called the "Willow Creek Channel Improvements and Sedimentation Pond. The project is located in the Willow Creek Drainage Basin in a natural open space park. The drainage basin is fully urbanized in the lower half of the basin where the project is located, and is actively being developed in the upper half of the basin (Highlands Ranch area). The primary purpose of this project was to stabilize the Willow Creek channel and to repair a vertical channel bank approximately 30 feet in height. Through the creativity and willingness of all project sponsors, several bioengineering techniques were used instead of traditional stabilization techniques. The bioengineering is esthetic but also is being studied as a pilot project for future practical use on other projects.

ANIMAL IMPACT: CASHMERE GOAT HERD USED TO GRAZE, TILL, MULCH, FERTILIZE, AND TRAMPLE SEED

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ABSTRACT

Revegetation often is a major part of weed management. Weeds are symptoms showing that there is instability or stress on the land. Weed control *per se* is treating the symptom and not addressing the problem. A higher level of understanding is needed. Land management goals would target healing and stabilizing the ecosystem such that problem weeds cannot compete as well as preferred vegetation in a setting. Weeds can be stressed continuously while desired productive plants are benefited, thus the better competitors. Animal impact is a comprehensive tool that coordinates several processes simultaneously: selective grazing removes top growth; hoof action tills and mulches while trampling new seed and organic fertilizer into the soil. Goats especially are useful when restoring grasslands because of their natural diet preference as browsers as opposed to grazers. Revegetation at high altitude sites may be difficult because of characteristic short growing season, rough or steep terrain with limited access, or shallow soils with low organic matter. Goats are self-propelled units that are able to go where no machinery can and few humans dare. Goats work during all seasons; in fair weather as well as when it is windy, dark, snowing.

WEEDS ON THE LAND

'Weed' is a man-made word usually defined by economics. Plants do no care about the identity or location of their neighbors. Noxious weeds are legally defined and must be controlled by law. Typically, noxious weeds are non-native, invasive and aggressive plants that pose long-term threats to native ecosystems and adverse economic impacts; thus, concerns have reached national levels. Unprecedented growth in trade and travel in our global economy has escalated the need to protect American agriculture and natural resources from non-native, invasive species. In 1999, President Clinton signed an Executive Order to deal with invasive species and Colorado is the only state that has an Invasive Species Executive Order signed by its governor. Invasive species have no enemies or predators in new settings and easily out-compete native and desired plants once intentionally or accidentally introduced. A combination of their aggressiveness and our traditional management allows noxious weed infestations to expand rapidly. Leafy spurge (*Euphorbia esula* L.) is a superb example of the ideal noxious weed (Galitz & Davis, 1993). It is characterized by high seed production and high seed viability, with seeds germinating over an extended period of time occurring over wide ranges of environmental conditions from early spring through fall. Ripe seed pods abruptly burst catapulting individual seeds 15 feet in all directions from the parent plant, allowing 30 feet diameter expansion each season from seeds. Meanwhile, an extensive and persistent underground root system produces numerous vegetative buds that possess an immense regenerative capability to send new shoots at any time for rapid spurge patch expansion. Short-sighted chemical, mowing or grazing regimes serve only to stimulate vegetative root production. Furthermore, milky, rubbery latex exudes from all injured plant parts that repels wildlife, horse and cattle grazing (Hein & Miller, 1992; Lym & Kirby, 1987; Kronberg, *et al.*). Plant toxins are irritative, emetic, and purgative when consumed and cause loss of hair and inflammation to horses feet when walking through freshly mowed spurge (Messersmith, 1983). Leafy spurge infestation problems in the West are exacerbated by the fact that cattle and horses do not eat leafy spurge, thus traditional range management augments selection pressure heavily to favor leafy spurge.

ACCIDENTAL OR INTENTIONAL INTRODUCTION

Weeds become residents in plant neighborhoods by different avenues. Overgrazing is an abuse that stresses the land. Overgrazing may be caused by livestock, wildlife, and humans and is defined as when a plant is again bitten or broken before it has had time to recover from the previous bite, thus drawing on stored energy reserves for regrowth (Savory, 1988). Horses and cattle do not eat leafy spurge and partially or totally will avoid spurge infested sites, thus cattle graze grasses and forbs more frequently (Lym and Kirby, 1987). Overgrazed grasses and forbs become stressed and less competitive as root energy reserves are depleted and inherently aggressive leafy spurge quickly becomes the dominant plant species.

Another avenue is neglect, exemplified by excessive rest or watershed change without vegetation changes to match. Excessive rest is opposite to overgrazing, described as declining land health due to absence of grazing animals. Nature is whole and highly complex, however, ecosystem health may be measured by examining four building blocks: mineral cycling, energy flow, water cycling, and succession (NRC, 1994). These building blocks may be comprehended by simplified processes: green plants capture solar energy; nutrients are reused by living organisms, cycling between plants, soil, and consumers; effective water cycling needs covered soil and high biodiversity; succession progresses as plant communities naturally strive toward ever-greater complexity and diversity. When grazing animals are banned from lands, excessive rest may result in lowered plant vigor, lower production, lower litter abundance, distribution, and incorporation, diminished plant species diversity, fewer seed germination sites, increased bare soil, higher soil crusting, increasing erosion, plant pedestaling, and increased undesirable plants (Malmberg, pers. comm., 1999). Energy flow, nutrient and water cycling are negatively impacted from loss of animal impact from living, moving ungulates. As a result, grasses die out because previous years' standing growth prevents sunshine from accessing growing points and standing dead plant material is not knocked to the ground for litter cover which results in bare ground. Soil exposed to wind and sun becomes hard crusted or capped, not allowing new seeds to germinate or water to infiltrate. Soil exposed to weather elements without animals trodding on it may become fluffy and light, less conducive for soil-seed contact and water and nutrient absorption. There is zero production on bare ground.

An example of watershed mis-management is when natural water is re-routed or irrigation water regimes are changed. There may be a countywide invasion of noxious weeds following the recent sale of water rights from Rocky Ford, Colorado farmers to the City of Aurora. The immediate or radical change to a management program results in altered vegetation.

Another avenue is Mother Nature filling open niches. Humans and their activities, wind, water, birds, livestock, and wildlife may introduce a new species to a landscape. Noxious weeds are notorious for filling a niche. Leafy spurge has been introduced accidentally in transported hay or alfalfa seed and prospers in rangeland.
Finally, natural catastrophic events, deemed an 'Act of God', may cause drastic vegetation changes resulting in weed problems. A '100 year flood' may remove trees from stream banks

and deposit silt and debris from up-stream. Fires, mudslides, hurricanes all cause extreme stress to ecosystems and could provide ripe conditions for new weed problems.

There are two books that I've read lately that record history of land management over the last century for specific areas. They capture the dynamic moods, fads, and trends of the times that reflect decision making due to wars, the Depression, shortages/surpluses of manpower/resources, the Industrial Revolution, merging cultures, the Green Revolution, agricultural commodity prices, government programs, available technology and information, the Environmental Revolution, global economy, and the Information Revolution. Saga of the Modisett Ranch is a living history of a single ranch in the Nebraska Sandhills (Ickes Malmberg-Berndt, 1999). A family from the post Civil War ravaged South capitalized on Homestead Act opportunities to build their dynasty. The ranch sold twice during years of volatile cattle prices and was purchased in 1999 by media mogul, Ted Turner for his management focus and 21st century popular purpose of preserving and restoring native species in their native habitats. The hands of time in the American West are deflected backward and re-introduced bison herds are reminiscent of before white men blundered across the land. Another book, The Range, is about many ranches comprising the Rocky Mountain's eastern slope in Montana, Alberta, and Saskatchewan (Ewing, 1990). Historical first-hand tales focus on the land and human dependence on it as The Range has evolved from a primeval habitat for buffalo, wolves, and Indians to a current setting for livestock, wildlife, recreation, and crops. Both non-fiction books are excellent to help understand the forces that molded past decisions and prompt us to be less critical and more tolerant of our land managers, appreciating the constraints in which they must work.

WEED PROBLEM

Invasive weeds alter and destroy ecosystem functions to pose one of the greatest environmental and economic threats in the United States to rangelands, croplands, wildlands, and aquatic areas (Mullin, *et al.*, 2000). Noxious weeds infiltrate and aggressively may become monocultures such that diversity is lost for plants, animals, insects, birds, and land use. Productivity losses financially impact producers. Carrying capacity is reduced by half for livestock and wildlife habitat managers when leafy spurge cover is 50% of rangeland. Thorny weed problems or poison ivy negatively impact public use of recreational lands. Land instability results in increased erosion that affects stream health and aquatic life. Land values diminish as land use is restricted. Meanwhile, costs increase to these land managers as weed control expenses escalate. Most land managers have difficulty financing massive weed control efforts. Instability has a domino effect starting on the land with repercussions traveling through the family, the community, and on through food prices in New York City.

The element of risk to the environment and ecology should be considered equally in management scenarios and objectives (Lamming, pers. comm., 2000). For example, many feel the best management practice is to plant native plants in a revegetation regime. This practice may not be sound ecologically or economically when a non-native species has established itself. The native plant community will lose to the invasive species over time. A plant species that will better compete with the invasive plant should be considered for revegetation. Another high risk example is the decision to control weeds as a chemical only application because it is cheaper in the short-run. Noxious weed laws are in place federally and in most U.S. states. A mandated control of listed species is required by many states.

ADDRESSING THE PROBLEM

Typical weed control *per se* is treating the symptom and never addressing the problem. The root cause of range degradation is conventional decision making and management framework (Savory, 1999). Traditional management for the above mentioned leafy spurge in rangeland would be to keep running the same numbers of cattle (although carrying capacity has been halved) which quickly results in more leafy spurge followed by 75% reduction in cattle carrying capacity. The land manager then must pay fifty to several hundred dollars per acre to kill the weed. Leafy spurge control at Lander, Wyoming has cost land managers nearly $400 per acre over time while leafy spurge acreage has increased ten-fold in light of intensive chemical management (Baker, pers. Comm., 1999). Cattle, followed by the ranch family must leave the range because they cannot compete under this management regime. Children of working family farms and ranches should be listed on Endangered Species List as there are fewer sites for them to germinate, thrive, and reproduce.

We humans are very good at using technology to kill symptoms, repeatedly striving for 99% weed control. We Americans expect immediate techno-results and feel good when we watch a weed twist, turn brown and fall to the ground after chemical treatment. Knock-down victory is measured visually by counting remaining weed shoot numbers in the upper strata. However, judgements on weed control success should be made on a longer time frame and broader spectrum, i.e., 3-5 years and success should be measured by land health values: underground weed root mass reduction, soil water holding capacity, soil organic matter, bird counts, insect diversity, microbial activity, water quality, and farm family financial stability. Humans quickly and visually cannot assess these, so usually ignore them. In a chemical 'spray only' program, there is selective chemistry with selective times to use them. Costs associated every year involving herbicide application programs lock managers into continued use of the same chemistry. Herbicide applications are effective on target plants but also control non–target species which diminishes species diversity. Like an investment portfolio, a diversified ecology will be the savior to stabilizing the area from invasive plants. This is where a narrow focus becomes evident because over time, species resistant to selective herbicides merely propels frustrated managers into the next chemical battle. Goat grazing keeps species diversity at a managed-for level. It may be more expensive initially, but the healing of the land over time will exponentially overshadow the herbicide application technique. Many more facets of grazing including mulching, fertilizing, tilling, in addition to selective pressure put on targeted invasive species influences greater grass production. Increased grass cover competes heavily with invasive species for available water, nutrients, and space. Conversely, herbicides may stress grasses even though labels state there is no harm to grasses, especially under severe environmental conditions, i.e., drought. Grass stress in addition to lost forb diversity and open ecological niches works to lessen competitiveness against invasive plants. Long term observations of expenses will show that goat grazing costs less while giving a more stable approach to solving the problem when compared to continuous herbicide applications that treats the symptom.

Linear problem solving of 'killing the symptom' does not account for below ground weed mass nor the people factor in the scenario. A philosophical adjustment from a higher level of understanding is needed and long-term goals for the land including co-habitating human families need to be set (Matthews, 1998). Land management goals would target healing and stabilizing the ecosystem such that difficult weeds cannot compete as well as preferred vegetation in a setting. Parallel benefits would be seen in human fellowship where stable family farms and ranches can out-compete corporate farms and subdivisions resulting in economically sound, sustainable agricultural communities.

Another way to approach a problem weed patch is to utilize it. Harvest the natural resource that sunshine has produced instead of spending money and time trying to kill it, therefore, wasting a resource already there. For example, leafy spurge in rangeland could be harvested with a species that intrinsically prefers to consume it, sheep or goats (Olson, 1995). It is much simpler to change our management decisions (that we understand and can control) than alter the entire ecosystem with technology (that we do not understand entirely and cannot control). Management framework changes that include cattle and horses to harvest grasses and sheep or goats to harvest leafy spurge would result in 100% natural resource harvest. Traditional control costs would be transformed to diverse income sources (Edens, 1996). American Sheep Industry Association and North Dakota State University are currently funding two new research projects: the "Feasibility of a Sheep Cooperative for Grazing Leafy Spurge" and the "Economic Analysis of Controlling Leafy Spurge with Sheep" (Savage, 2000). Cattle ranchers who invest in sheep co-ops could realize a 16% return on investment while utilizing leafy spurge; quite a philosophical adjustment from several decades of trying to kill leafy spurge to no avail, albeit at great expense. This concept could be carried a step further by using a species that uses leafy spurge even better than sheep, goats. Differences between goat and sheep preferences and utilization for leafy spurge has been well researched (Hanson, *et al.*, 1993; Lacey, *et al.*, 1992; Kronberg and Walker, 1993).

GOALS

Goals must be set for the ecosystem that include primary producers (green photosynthesizing plants) and primary, secondary, tertiary, and quaternary consumers, i.e., animals, insects, birds, reptiles, humans, bacteria, and fungi. Environmental, social, and economic health of all players need to be addressed for stability at each level and the whole. If you take a pencil and cross the 'l' in goal, you clearly see that goat is the goal.

ANIMAL IMPACT

Animal impact is a comprehensive living tool that coordinates several life processes simultaneously: selective grazing removes top growth; hoof action tills, mulches, and fertilizes soils while trampling in new seed. Managed grazing is an especially effective weed control tool in arid environments. Goats especially are useful when restoring grasslands because of their natural diet preference as browsers as opposed to grazers. When goat grazing is managed for leafy spurge problems, the intent is to overgraze.....the spurge. Leafy spurge should be bitten again and again, never allowing for recovery and forcing the plant to draw on stored root reserves. Since goats prefer spurge over grasses (Hanson, *et al.*, 1993), selection pressure is reversed to continuously stress weeds while grass growth is augmented and left fertilized, tilled, and mulched to be stronger competitors in that scenario (Sedivec & Maine, 1993).

The best weed control is competitive exclusion, covering the ground with desired plants that compete for water, space, and nutrients. Traditional weed management requires several individual and complete steps: first get a good weed kill with chemicals, followed by soil amendments, soil tillage, revegetation, fertilizing and maintenance. These steps all together are very costly, are restricted to easily accessible terrain, and take several years to get desired grass cover. High altitude site revegetation may be difficult because of characteristic short growing seasons, limited herbicide choices, rough or steep terrain with restricted access, or shallow soils with low organic matter. Chemical management may remove all forbs, desired and undesired, thus diversity is lost and open niches are usually filled with the same or a new weed species (Matthews, 1998). A Russian knapweed (*Acroptilon repens* (L.) DC) revegetation study found that the chemical treatment that best suppressed knapweed also suppressed desired grass growth and encouraged a weed "species shift" to a different noxious weed (Benz, *et al.*, 1999). An 18-year study in Montana concluded that intensive grazing may be as effective as a herbicide for long term suppression of leafy spurge (Maxwell *et al.*, 1999). Intensive herbicide treatment shows immediate obvious initial reduction of leafy spurge however, over time, spurge returns exponentially but other plants do not; biodiversity is lost. On the other hand, managed grazing is a more gentle approach, maintaining species richness and over time diverse desirable plant cover competes with leafy spurge. Presumably, underground and invisible processes are augmenting land healing. Fast, immediate, step-wise results are not seen by the human eye but several complex processes work simultaneously. Synergism of these processes works to heal the land over long term.

ONE-STOP SHOPPING

Goats are trendy self-propelled units that are able to go easily across difficult terrain where no machinery can and few humans dare (CBS News, 1999). Targeted weeds may be stressed continuously due to natural diet preferences by goats while desired productive plants are benefited, thus the better competitors. Managed goat grazing performs all revegetation steps at once. My business uses cashmere goats because of their size, mellow personalities, handleability, and potential extra income. These goats are hired to ingest noxious weeds and manufacture three other saleable products while on the job: kids and fertilizer pellets from internal workings while producing cashmere fiber externally. Adjustable backpacks may be fitted to these sure-footed animals to carry supplies in rigorous terrain. Goats wake up each morning anxiously ready for work, which they do during all seasons, in fair weather as well as when it is windy, dark, snowing, raining, and all major holidays.

SOCIAL IMPACT

Managed goat grazing may be offered as a service by small businesses and gives land managers an additional choice for weed control that was not previously available. These creative services fill empty niches in economic and environmental arenas (Jackson Hole Guide, 1999). Innovative entrepreneurs employ rural citizens, displaced, semi-retired or immigrant agricultural workers who already have essential skills in animal husbandry and land stewardship. A great opportunity to educate the general public is exploited when managed goat grazing is used for weed management. Curiosity draws people to the land and they ask questions when they see Border Collie dogs masterfully working a large herd of goats in weed patches in urban, suburban, and rural sites (New York Times, 1999). Interested people leave the area enlightened in realms of weeds, noxious weeds, noxious weed law and compliance, noxious weed control difficulties, ecosystem function, environmental issues, and animal husbandry.

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INFILTRATION AND WATER FATE IN HIGH ALTITUDE ENVIRONMENTS

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ABSTRACT

Infiltration of precipitation water to groundwater in high altitude environments is a critically important portion of the hydrologic cycle. In general, high altitude environments are significant recharge areas for groundwater resources, on a local and regional scale. The water that infiltrates in these locations provides shallow groundwater flow to seeps and springs, baseflow to rivers and recharge to local and regional aquifers. The quantity of infiltration that occurs in these environments is of great importance to a wide variety of scientific and engineering endeavors, including mine permitting, mine reclamation, impact evaluation, groundwater flow evaluation, aquifer recharge, streamflow prediction and water supply. Despite this importance, very little quantitative information is available to evaluate the process, amount and timing of infiltration at high altitude.

In low altitude arid environments, infiltration is usually limited to precipitation that cannot be used by the stable plant community. Plants are quite efficient water-users, so low altitude infiltration generally averages 5 % to 10 % of total precipitation. In high altitude environments, this useful relationship can break down. Plant community uptake is often limited by low temperature, low productivity, short growing season, poor soil and frozen soil. Available moisture is highly seasonal, and the formations on which it becomes available are often highly porous, allowing rapid drainage to the subsurface. Infiltration rates as low as 1% of precipitation, and as high as 75% of infiltration have been observed in these conditions, and plant communities are rarely the controlling factor.

This paper explores the dynamics of high altitude infiltration, and explores a methodology for the evaluation of infiltration at high altitude, based on a number of carefully documented case examples in the Rocky Mountain region.

RECLAMATION OF THE WASP/BISMARCK MINE SITES, LAWRENCE COUNTY, SD

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The author would like to acknowledge Phil Barnes currently employed by AngloGold (Cripple Creek, CO) and Ron Waterland currently employed by Homestake Mining Company (Grants Project, NM). These two people were instrumental in development and start-up of this project. They deserve much of the credit for the project's success.

ABSTRACT

In 1997-98 Homestake Mining Company reclaimed the historic Wasp/Bismarck mine sites located approximately two miles SE of the Homestake Mine site in Lead, SD. The reclamation focused on removing 240,000-yards of tailing created by the Wasp/Bismarck mining companies that operated during the late 1800's and early 1900's. The tailing was situated on a steep hillside and floodplain adjacent to Upper Whitewood Creek and prone to erosion during storm events.

The reclamation included removing the tailing from the hillside and floodplain to Homestake's permitted Grizzly Gulch Tailing impoundment and revegetation of the slope and floodplain. A bulldozer initially situated at the top of the tailing pile, pushed the tailing down slope. A trackhoe followed upslope of the bulldozer removing the remaining tailing from ground surface with the objective of leaving the original topsoil veneer. The topsoil, covered with tailing for 100 years, was then hydro-mulched and seeded as the equipment worked down slope. Temporary piping, water bars and riprap channels were constructed to allow stormwater and groundwater to exit the slope without impacting the tailing or eroding the newly reclaimed area. The tailing pushed down slope was loaded into 12-yard trucks and hauled 2.5 miles to the Grizzly Gulch tailing dam for disposal. The overall cost of the project was approximately 2 million dollars.

INTRODUCTION

This paper describes the history and reclamation of the adjacent Wasp and Bismarck (Wasp/Bismarck) mine sites in Lawrence County, South Dakota. Homestake Mining Company performed the Wasp/Bismarck mine site reclamation during the summers of 1997 and 1998. The project consisted of removing of 240,000 yards of tailing and the revegetation of the soils underlying the tailing.

The Wasp/Bismarck mine sites are located approximately two miles south of Lead, SD. (Figure 1). The mines are in the southwest quarter of the northeast quarter of Section 9, Township 4 N, Range 3 E, of the Lead 7 ½ Minute quadrangle and situated in the northern Black Hills physiographic region of South Dakota. The terrain consists of forested hills and stream-incised valleys.

Both the Wasp and Bismarck sites are situated on a north-trending ridge that is bordered to the west by Whitewood Creek and to the east by Yellow Creek. The mine sites are approximately 300 meters apart and are separated by a small west-trending ridge. The site elevation ranges from 5200 to 5450 feet above mean sea level.

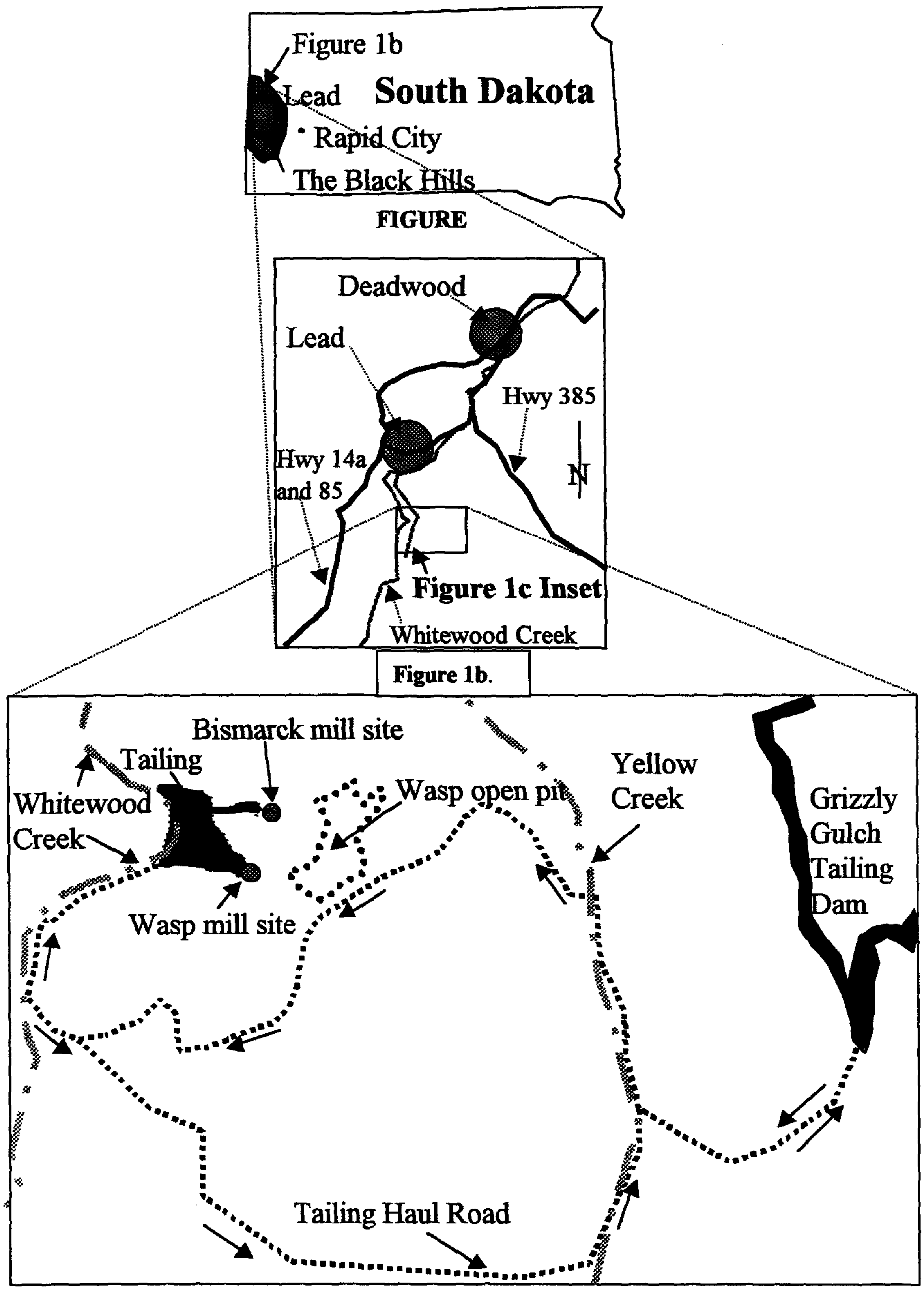

Figure 1c. Site Location Map

SITE GEOLOGY

The Wasp and Bismarck mine sites are located in the northeastern edge of the Black Hills uplift, a northwest trending anticlinal uplift formed during the Larimide Orogeny. The rock units that underlie the two mine sites from oldest to youngest are the Precambrian schists and shales of the Poorman and Ellison Formations. Cambrian sandstones, limestones, and dolomites of the Deadwood formation unconformably overlie the Precambrian units. The Deadwood formation contains a basal siliceous conglomerate, which hosted much of the gold/silver mineralization and was the focus of mining activity in the area (Waterland, 1987, p.110). Tertiary felsic dikes cut both the Cambrian and Precambrian Formations. Refer to Figure 2 for a simplified geologic section of the area.

SITE HISTORY

The Wasp Mine site operated from 1893 to approximately 1920. The site was initially operated by a small group of private investors that included Ed Donaldson, the McShane Brothers and M. Murphy (Fielder, 1972, p.166). In 1896 the site was sold to T.J. Grier, R. H. Driscoll and John Gray (Fielder, 1972, p.167) who owned the site until closure in 1920. The mine was principally an open pit mine. The siliceous gold bearing ore was mined along the top of the ridge that separates the Whitewood Creek and Yellow Creek drainages. Early production from the mine consisted of rail shipments of the gold/silver bearing rock to an off-site smelter. In 1900, a 40- stamp mill and a 100-ton/day cyanide processing plant were erected on the ridge adjacent to the open pit (Fielder, 1972, p. 167).

The Wasp Mine was one of the first gold mines to employ the technology of cyanide leaching. The stamp mill crushed the ore to less than ¼ inch (Waterland, 1987, p.112). This crushed rock was then loaded into vat leach tanks where a cyanide solution was added to remove the gold. The cyanide solution caused the gold (solid) to dissolve in solution. The gold-bearing solution was then drained from the vat and poured through zinc shavings. The zinc caused the gold to re-precipitate. The zinc and gold were then smelted in a small furnace to form a concentrate, or dore, that was sold to a refiner. The crushed rock, void of gold, known as tailing, was washed and trammed to the hillside, where it was cast over the edge (Waterland, 1987).

The Wasp mill and cyanide leach circuit were "modernized" in 1904 and 1905 to provide for a 200-tons/day capacity. This modernization included conversion from coal to electric power, utilization of compressed air drills (replacing double jack hand drilling), and new electric skips were installed to replace the mule teams that dragged the ore up to the mill (Waterland, 1987, p.113).

In 1910 the mill burned down and was rebuilt with a 500-tons/day capacity. The new mill consisted of electric skips, a gyratory crusher, electric rollers, conveyors, and six-420 ton leach tanks (Waterland, 1987 p. 113). The mill was considered one of the most efficient of the day. The total cost of mining, milling, and general expense was $1.24/ton of rock. These costs subtracted from the $2.00/ton of ore revenue resulted in a profit ranging from $0.50 to $0.75 cents per ton of ore (Waterland, 1987, p.114).

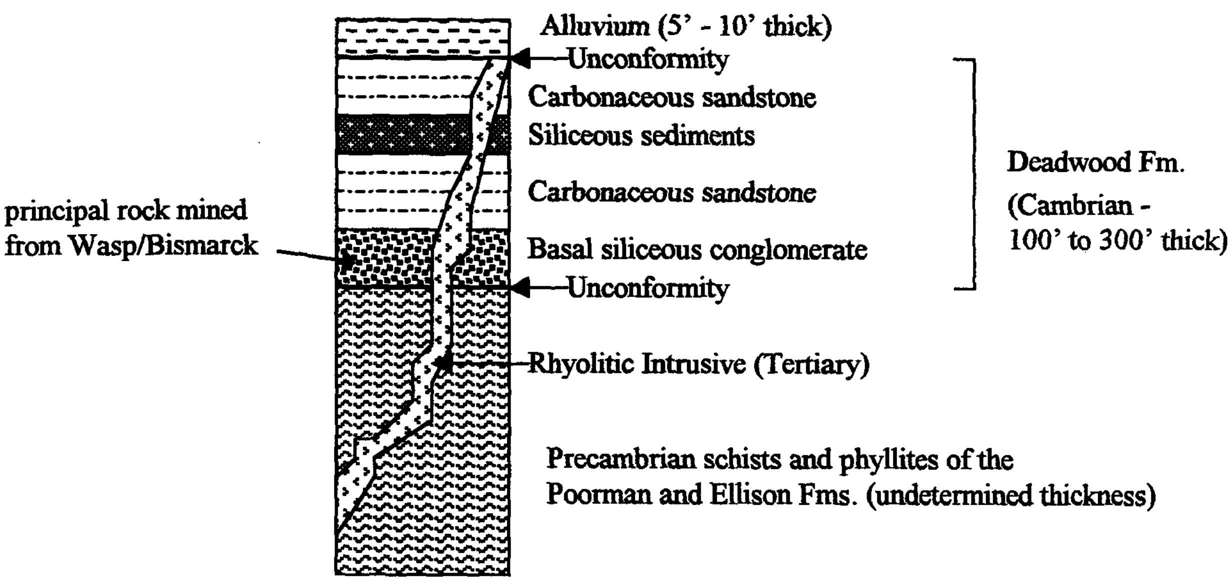

Figure 2
Simplified Geologic Section for the Wasp/Bismarck Site

The Wasp mine reached its peak production over the next five years, processing an average of 150,000 tons of ore/year (Waterland, 1987, p. 117). However, in 1915 the mine encountered several problems that foreshadowed its ultimate demise. These problems included a declining grade, greater amounts of overburden to remove, water shortages, and labor shortages (Waterland, 1987). In 1920 the mine closed. The final production accounting revealed that approximately 1.176 million tons of ore had been processed through the mill since 1900. This resulted in total production of 100,819 ounces of gold and 158,780 ounces of silver (Waterland, 1987, p. 117).

The Bismarck Mine or Alder Creek Mine was a marginally profitable producer of gold, silver and wolframite (a tungsten ore). The Bismarck was principally an underground mine which operated intermittently from 1893 to 1920 (Filder, 1972, p.170). The Bismarck shipped carloads of ore to the Deadwood and Delaware smelter in Deadwood, SD in the early production years. The ore was valued at $128/ton to $6/ton of rock. Lower grade ore was sent to the Golden Reward chlorination plant (Waterland, 1987, p.118).

In 1913 a 300-ton, dry crushing cyanide plant was constructed at the Bismarck site (Waterland, 1987, p.119) The cost of underground mining and milling was $1.25 per ton but ore value had dropped to $1.29 per ton (Waterland, 1987, p.120). Mine production in 1914 was 79,039 tons of ore. However, payments on the new mill were not made because of the low grade and the Bismarck was sold to the American Mining Company (Waterland, 1987, p. 120). In the years following the mine operated at a greatly reduced rate as evidenced by the amount of tailing associated with the Bismarck site and the lack of data for this period.

After 1920 no production was recorded at either the Wasp or Bismarck Mines. In 1926 the Wasp mill equipment was sold for $600 (Fielder, 1972, p.171). There was no record on the disposition of the Bismarck mill. The visual history of the mining effort was limited to the large wedge of tailing and the mill foundations that overlooked Whitewood Creek.

In 1921 the Wasp tailing experienced significant movement as a result of large rainstorms. The tailing, carefully built up during the previous 20 years so as not to impact the railroad line and Whitewood Creek, slid down slope and into and across Whitewood Creek and buried the railroad line. In September10, 1928 a second large tailing slide occurred as a result of heavy rain. In this instance the tailing dammed Whitewood Creek and a lake formed upstream almost a quarter mile wide and long. In removing the tailing from the Creek bed and the railroad line, gondolas, steam shovels and sluicing operations were employed. A train was operating on a temporary track laid over the slumped tailing. On September 13, 1928 the train was buried by tailing as a result of another storm. The train's fireman was killed by this incident (Fielder, 1972, p.171-172). The tailing movement and erosion seen by these events foreshadowed the future and influenced the remediation of the site almost 80 years later.

In the early 1930s Homestake Mining Company purchased the Wasp and Bismarck Mine sites to explore for gold and silver mineralization. The geology of the area was defined, exploration holes were drilled, and rock-chip sampling was performed during 1930 through 1950. No economic resource was discovered as a result of this effort and Homestake did not mine either the Wasp or Bismarck sites.

The Burlington, Northern and Quincy rail line ran along Whitewood Creek at the toe of the west-facing slope from the Wasp and Bismarck mill Sites. The rail line connected Custer, SD to Deadwood, SD and was a main rail access to the northern Black Hills and its mining community.

This rail line was abandoned in the early 1930s (Fielder, 1969, p.83). In the 1990's this railroad line/grade was converted to the George S. Mickelson Trail. Today thousands of people use this trail for hiking, bicycling, and snowmobiling.

EARLY RECLAMATION EFFORTS

The Wasp Bismarck mine site was idle in the years following 1930. In the early 1950's Homestake erected a six-foot berm adjacent to the Burlington Northern and Quincy railroad grade to help prevent tailing erosion from entering Whitewood Creek. In the 1980's this berm was enlarged and a pond was constructed inside the berm to contain sediment.

In 1994 Homestake Mining Company regraded, benched, and revegetated the Wasp tailing. The tailing demonstrated over the years that it could successfully support vegetation. Willows and Aspen had grown around the sedimentation pond and in the Whitewood Creek floodplain where there was a nearby source of water. Other tailing dominated areas, such as the tailing wedge on Wasp and Bismarck hillside, supported a variety of native grasses. The Wasp slope was hydro-seeded and mulched in conjunction with carefully planned erosion control structures that included water bars, benches and the deep-rooted vegetation. These measures helped stabilize the tailings.

In 1995 a series of heavy rainstorms swept through the Wasp/Bismarck site cutting several large erosion gullies through the newly vegetated tailing. The storms overwhelmed the water bars and benches and channeled the sandy tailing. The stormwater controls and vegetation were partially damaged by these storm events. It was clear that the tailing would require significant maintenance if vegetation and stormwater controls were to be effective.

THE RECLAMATION PLAN

The Wasp tailing erosion caused Homestake to re-examine the site reclamation. The large storm events showed that the tailing were prone to erosion despite good engineering and vegetative practices. The 350-foot slope length with an average grade of 2.5:1 was likely to result in constant and costly maintenance.

The analytical test work performed by the Homestake showed that state and federal water quality standards in Whitewood Creek were met upstream and downstream of the site. Healthy and unimpacted benthic macroinvertebrates and fish populations also evidenced good water quality. However, the tailings were found to contain elevated levels of metals typical of the mineralized rock. These metals were bound very tightly in the mineral form, typical of oxide carbonates, and very insoluble in water. Thus, the main issue at the Wasp site was the historical sediment loading to Whitewood Creek caused by runoff from the Wasp and Bismarck tailing. The concern was the ultimate fate of the remaining tailing at the sites and their stability.

Homestake decided to act. The plan was simple and involved the relocation of the Wasp/Bismarck tailing to Homestake's permitted Grizzly Gulch Tailing impoundment. A construction stormwater permit application was filed with the state of South Dakota. The permit specified that the tailing removal would be accomplished as part of the best management practices under the storm water plan requirements. These best management practices included minimizing sediment runoff from the site using a variety of techniques that included sediment ponds, check dams, silt fence, and many other erosion control techniques. The effectiveness of these sediment control practices was measured by regular water quality sampling along Whitewood Creek.

This stormwater permit allowed for State oversight of the tailing removal. Homestake and the state advised the EPA of the proposed action.

The initial reclamation plan consisted of two phases. The first phase removed the tailing from the hillside below the Wasp mill site and the second was to remove the tailing from the hillside below the Bismarck mill site as shown in Figure 3. There was a potential third and fourth phase that included removal of the tailing in the Whitewood Creek floodplain and the removal of tailing from the West Side of Whitewood Creek. The aerial extent of the tailing removal and its associated four phases are shown in Figure 3.

The tailing removal commenced at the top of the Wasp mill site. A Caterpillar D-9 dozer pushed the bulk of the tailing down slope. The dozer was followed closely up-slope by a Cat 320 trackhoe that peeled the remaining tailing from the original ground surface. At the base of the Wasp mill site slope a Cat 980 5-yard loader placed tailing into 12-yard dump trucks. The small trucks were used to minimize the impact to the haul route and county road. These trucks hauled the tailing approximately 2.5 miles to the Homestake tailing facility through a winding historical logging and snowmobile trail and county road. The trucks then returned to the site using an alternate route. The complete truck cycle was 4.7 miles.

Initially, Homestake intended to place a thin veneer of topsoil over the newly exposed hillside to provide a medium for vegetation. However, it was discovered that topsoil was not necessary since the original ground surface was suitable for vegetative growth. This concept placed a premium on the skill of the trackhoe operator. This individual was required to carefully discriminate tailing from topsoil and leave the original topsoil on the hillside. Fortunately, the topsoil was of a different color and consistency from the tailing. The topsoil was dark brown and fine-grained as opposed to the tailing which was brown and coarse-grained.

Both the dozer and track hoe moved the tailing down slope from a tailing bench. The bulldozer operator maintained this bench to allow the trackhoe to operate from a level surface and to allow for the exposed hillside to be hydroseeded.

The hillside was hydroseeded every 30 vertical feet as the equipment worked its way down slope. The loaded hydroseed truck was pulled up the tailing slope by the D-9 bulldozer. The hydroseed truck then drove along the flat tailing bench making two passes. The first pass laid the seed and fertilizer. The second pass included the tackifier and long fiber wood mulch. Homestake's experience in other reclamation projects showed that the two-pass hydroseed method improved seed germination and helped minimize erosion. The hydroseed truck often had to be pulled up the slope twice in one day.

The contractor was required to hydroseed within two days of exposing the original topsoil. Soil that was allowed to bake and crust over through exposure did not provide a good seed bed. The contractor was required to rake the soil with the trackhoe teeth before hydroseeding in cases where the soil was not seeded within the two-day time frame.

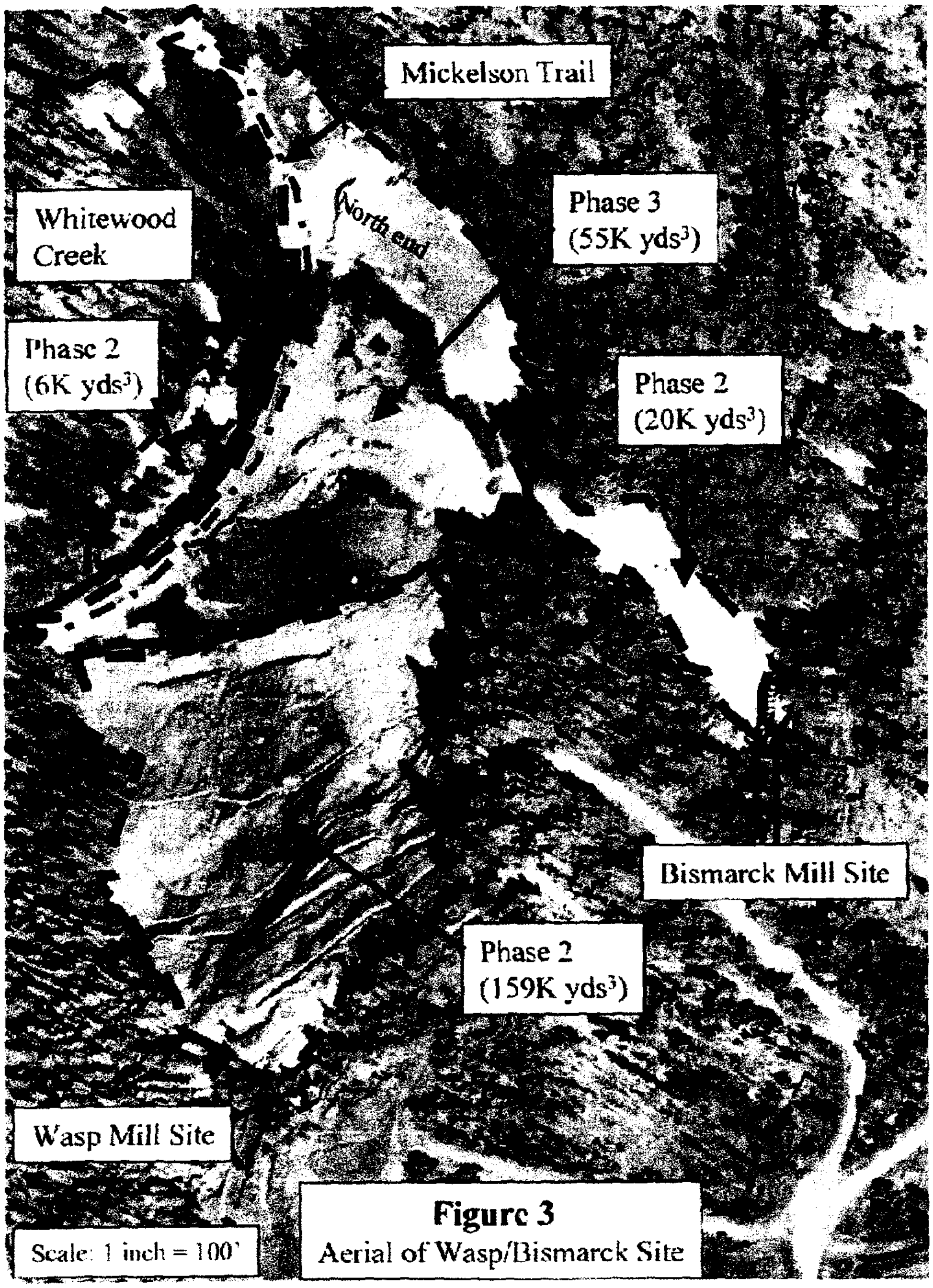

Figure 3
Aerial of Wasp/Bismarck Site

The seed mix for the both the Wasp and Bismarck hillside reclamation is found in Table 1. The fertilizer rate was 200 pounds per acre of 20-20-10 (phosphorous, potassium, nitrogen). Tackifier application was 200 lbs. per acre. Mulch was applied at 2,000 lbs. per acre.

Table 1. Seed Mix for the Wasp/Bismarck Hillside Reclamation.

Species	Lbs PLS/Acre
Smooth Brome	6
Orchardgrass	3
Western Wheatgrass	7
Slender Wheatgrass	6
Timothy	3
Canada Wildrye	4
Durar Hard Fescue	3
Red Fescue	3
Kentucky Bluegrass	3
Red Clover	4
Regreen	8
Total	50

One of the most important considerations of the Wasp/Bismarck tailing removal project was spring water and stormwater management. A primary project goal was to minimize the interaction of water and tailing as required by good management practices and permit condition. It was important not to let the tailing interact with water that issued from various springs on the Wasp and Bismarck hillsides in order to prevent erosion and promote vegetation growth. Spring water and stormwater control were accomplished by several measures that included piping spring water issuing from the hillside directly to Whitewood Creek, and installing rip-rap channels that would channel spring water once the project was complete. Stormwater controls included installing water bars on the newly exposed slope, rip-rapping stormwater channels on the uncovered slope, canting the loading area toward the toe of the slope, and construction of various ponds, check dams and silt fences to prevent sediment from entering Whitewood Creek.

Sediment control was also important on the haul road to and from the Grizzly Gulch tailing impoundment. Approximately 24 check dams and 400 yards of silt fence were used to minimize fine dirt and sand particles from entering Whitewood Creek during storm events. In addition, trucks were prevented from hauling on rain days. All sediment control structures were examined and repaired after precipitation events.

Approximately 140,000 yards of tailing was removed from the Wasp hillside during the first construction season. This aerial extent of tailing removal corresponds to the Phase 1 polygon shown in Figure 3. Various historical artifacts were found buried in the tailing and included a rail-boxcar, a small ball mill, various hand tools, an ore car, rollers, piping and wood. All these items were cleaned and stored for a future interpretative center to be erected on the site after reclamation.

The start of the second construction season began by intercepting the Alder Creek drainage. Base flow to Alder Creek is from a perched aquifer issuing from the historical Bismarck Mine portal. The water was intercepted by constructing a small detention pond. A pipe was inserting through the clay face of this pond. The water was transported through a 1400-foot section of flexible 4-

inch hose that flowed into Whitewood Creek. The removal of water from the Bismarck mill drainage allowed tailing removal from the mill foundation and hillside with minimum impact to Whitewood Creek. A water rights permit was obtained for rerouting Alder Creek.

The Bismarck tailing removal process mirrored the Wasp mill site tailing removal. The D-9 dozer operated in tandem with the trackhoe and hydroseeding truck. Tailing was again loaded into trucks bound for Grizzly Gulch dam. A bowl shaped riprap channel was placed into the Alder Creek drainage as the equipment worked its way down slope. The riprap minimized erosion once the Alder Creek drainage was returned to its natural course.

Approximately 25,000 cubic yards of tailing were removed from the Bismarck mill hillside (Alder Creek drainage) as shown in Figure 3, Phase 2.

Removal of tailing from areas where there was well-established vegetation presented a difficult choice: leave the tailing and vegetation, or remove both. As mentioned above, the tailing supported a wide variety of vegetation that included willows, aspen, pine and various grasses. The tailing under the well-established stands of vegetation was not likely to erode and impact Whitewood Creek. However, consultation with South Dakota Game, Fish and Parks and South Dakota Department of Environment and Natural Resources resulted in a voluntary action to remove all exposed tailing from the project site. The decision was based on removing as much tailing from the sites as reasonably possible, establishing a wetland in the Whitewood Creek floodplain, creating a better wildlife habitat, and performing a thorough and complete reclamation project.

This decision allowed the tailing removal project to extend to the floodplain of Whitewood Creek and the small portion of tailing on the west side of Whitewood Creek, as shown on Figure 3, Phase 3 and 4.

The removal of the floodplain tailing was divided into two steps that again centered on water management and minimizing sediment runoff. The first step was to determine the tailing depth in the floodplain by digging a series of test pits. A tailing thickness or isopatch map was created and it was found that the north end of the floodplain contained the thickest and deepest extent of tailing. This showed that when the project was finished stormwater would flow to the northern portion of the floodplain and enter Whitewood Creek.

A plan was devised to divert water from the Wasp/Bismarck hillside to the southern portion of the floodplain and into a series of sediment ponds. The water from the last sediment pond was discharged to Whitewood Creek through a sand-filter check dam. Tailing was removed from the north side of the project during this step with a two-fold purpose. In the short-term a pond was created to serve as sediment collection pond. In the long-term this pond provided a shallow wetland and provided wildlife habitat.

Step two of the floodplain excavation involved diverting water to the excavated north side of the floodplain while tailing was excavated from the south side of the floodplain. As the excavation worked toward the railroad grade, the tailing soil contact was observed to be below the Whitewood Creek stream channel and water from Whitewood Creek seeped through the grade and into the newly excavated floodplain. This suggested that the current Whitewood Creek channel may have been man-made and that the original stream channel may have been more proximal to the toe of the Wasp/Bismarck slope.

Approximately 55,000 cubic yards of tailing was removed from the Whitewood Creek floodplain below the Wasp/Bismarck mill sites as seen in Figure 3, Phase 3. The floodplain was ideally suited for wetland vegetation since there was a constant water source from Whitewood Creek and the Alder Creek drainage. A large rip-rap spillway was constructed between the north floodplain pond and Whitewood Creek. Ten to twenty-ton boulders were used in constructing the spillway and helped to provide a constant pond elevation and erosion protection from a 100-year storm event.

The last phase of the tailing removal consisted of peeling a 1 to 6-foot veneer of tailing from the West side of Whitewood Creek and performing careful tailing removal from the Whitewood Creek stream bank. The tailing not adjacent to the stream was removed by trackhoe and loaded into the dump trucks. The Whitewood Creek crossings north of the site allowed trucks to cross over the creek without disturbing the creek. The tailing along Whitewood Creek was hand shoveled into the trackhoe bucket. One ton nylon super sacks filled with gravel were used along the water margin to prevent erosion into Whitewood Creek. Approximately 6,000 yards of tailing were removed in the phase 4 portion of the project.

A total of 240,000 yards of tailing were removed from the Wasp Bismarck sites. The total cost of the project was approximately $2,000,000. This included tailing removal, engineering and construction management, stormwater controls, and revegetation. Ayres Associates of Ft. Collins, CO performed the engineering and construction management service. Summit Construction of Rapid City, SD performed the tailing removal and related site work. Both these firms contributed greatly to the success of this project.

The tailing removal from the Wasp/Bismarck mine sites was completed in October 1998. The haul road was regraded and seeded. However, all sediment control structures were temporarily left in place to minimize erosion. These structures included the pond created by the tailing removal in the floodplain and various check dams and silt fences associated with the haul road, the hillside and floodplain. The check dams and silt fences will be removed once vegetation is well established. The floodplain area was hydroseeded in the fall of 1998 with 40 pounds per acre of an annual rye (Regreen). The rye acted as a cover crop to stabilize the soil until the floodplain planting was completed in the summer of 1999. Additionally, a burlap woven soil control mat was installed along Whitewood Creek where tailing had been removed.

Homestake and South Dakota Game, Fish and Parks (GFP) worked cooperatively to complete the Wasp/Bismarck reclamation. A planting plan for the wetland area of the Wasp Bismarck sites was needed to promote wildlife habitat and further stabilize soils. Homestake and GFP contracted Bitterroot Restoration of Corvallis, MT to draw up a floodplain revegetation plan. This plan, presented in Figure 4, portrays the various types of vegetation and planting density in the floodplain area. Rocky Mountain Reclamation of Laramie, WY installed the wetland vegetation in June 1999. Plants of the Wild, Tekoa, WA provided the 3-inch to 10-inch containerized wetlands plants.

Finally, GFP and Homestake also worked together to relocate the Mickelson trail to allow the reclaimed floodplain to revegetate without disturbance while simultaneously allowing people to view the site and the old railroad grade. The trail was moved to the West-side of Whitewood Creek and provides an excellent view of the Wasp/Bismarck mill sites. An interpretative center will be constructed on this new section of the Mickelson trail in spring and summer of 2000. This center will document Wasp/Bismarck mine site history and reclamation.

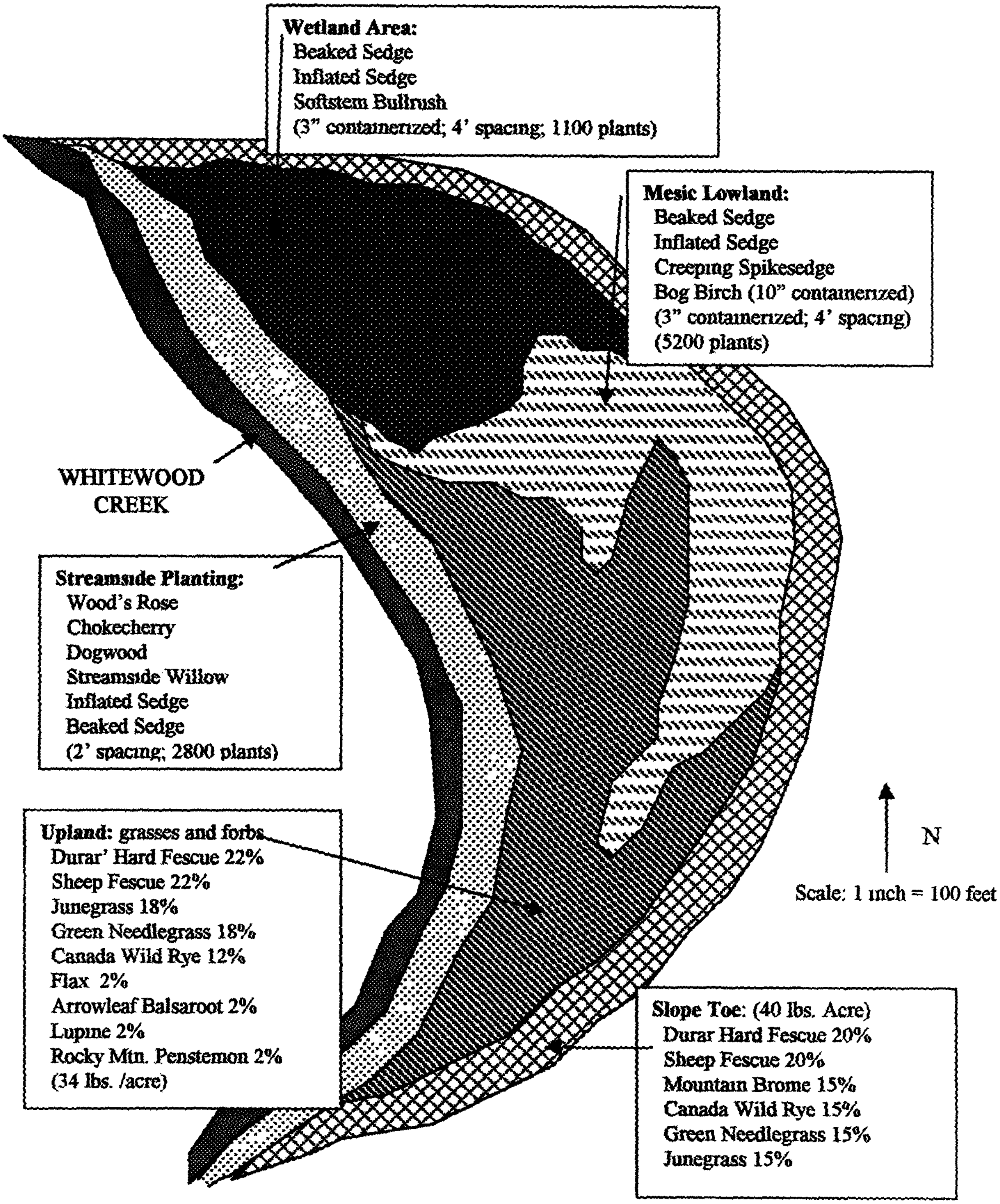

Figure 4
The Wasp/Bismarck Wetland Planting Design

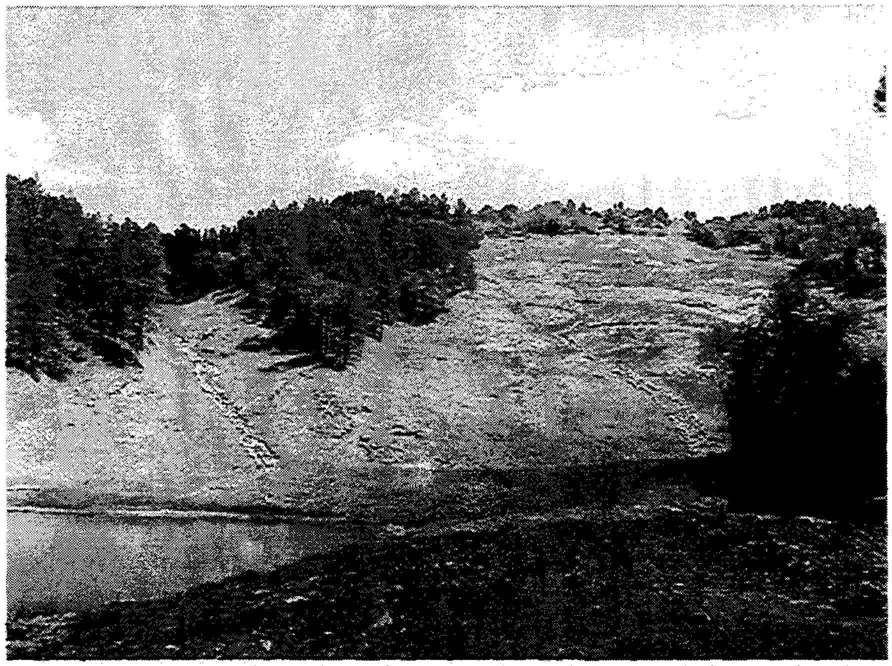

Plate 1. A post reclamation photograph of the Wasp/Bismarck mine sites. The Wasp mill site foundation is situated top of the hillside on the upper right side of the photograph. The Bismarck mill foundation is not pictured but exists on the left side of the photograph just behind trees in the Alder Creek drainage. Note the pond in the foreground.

Plate 2. A post reclamation photograph of Whitewood Creek in the fore-Ground and the Bismarck mill site in the background. The Alder Creek drainage follows the rip-rap channel to the Whitewood Creek floodplain.

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ENVIRONMENTAL PLANNING AND PERMITTING AT THE CROWN JEWEL MINE

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ABSTRACT

Discovered in 1988, the Crown Jewel deposit in northcentral Washington's Myers Creek Mining District contains about 1.6 million ounces of gold. To develop this resource, Battle Mountain Gold (BMG) commenced baseline environmental data collection in 1990, completed feasibility analyses, and submitted a mine plan of operations in January 1992. A draft environmental impact statement (EIS) was prepared by the US Forest Service (USFS) and Washington Department of Ecology and released for public comment in June 1995. The final EIS and Record of Decision were issued in January 1997. Following the final EIS, permit decisions and issuance commenced in 1997. The plan of operations was revised to reflect requirements of the EIS and certain permits and was approved by the USFS and Bureau of Land Management in June 1999. Containing 17 individual plans, the plan provides detailed information for reclamation, stormwater management, mitigation, and other features. During the permitting process, several significant regulatory changes affecting the Project occurred. As of I January 2000, nearly all of the permits for construction had been issued to the Company.

INTRODUCTION

Buckhorn Mountain is within the Myers Creek Mining District in northeastern Okanogan County, in the north–central part of Washington, and lies in the Okanogan Highlands physiographic province of the northern Rocky Mountain Region. The District was established in 1896 following opening of the former north half of the Colville Indian Reservation to mineral entry (Moen 1980). Initial discoveries of gold, silver, and copper in the District were made near the town of Chesaw and followed shortly with discoveries of lead, molybdenum, and iron as well as precious metals, at Buckhorn Mountain. Active historic-period mining spanned more than 50 years from 1896 to 1950 (Luttrell 1999). The earliest phase of development was by individual prospectors exploring for vein-type deposits and the resulting associated production. Between 1900 and the 1930s, capitalized ventures consolidated claims and developed several operations. During this period, a rail spur was constructed to the Myers Creek valley to allow for the transportation of copper, gold, and silver ores, as well as iron ore, to mills in the northwest. No fewer than 12 mines produced ore during this time. The next phase of historic mining occurred from the mid-1930s until 1951 with the production of iron ore from the Magnetic Mine on Buckhorn Mountain (Luttrell 1999, Moen 1980). Since the 1950's most mineral activity at Buckhorn Mountain and in the District has been of an exploratory nature (Hickey 1990).

The Crown Jewel gold skarn deposit at Buckhorn Mountain was discovered by Crown Resources Corporation in 1988 (Stiles, *et al.* nd). Exploration resulted in a delineated gold resource of about 500,000 ounces by early 1990. A joint venture agreement with Battle Mountain Gold (BMG) was established in March 1990 and the two companies continued exploration activities. By the end of 1991, BMG had delineated an additional 1 million ounces of contained gold for a total defined resource of more than 1.6 million ounces of gold. An economic feasibility analysis was completed in early 1992 (Bateman 1992). BMG then commenced the permitting phase of development with the submittal of a mine plan of operations in January 1992 (Battle Mountain Gold 1992).

PROJECT DESCRIPTION

The Crown Jewel Mine is located on the eastern flank of Buckhorn Mountain. The mine site and associated facilities are in an area of rolling, glaciated mountains with elevations ranging from 2750 to 5598 feet above mean sea level. Site precipitation is about 20 inches annually with most coming as winter snow and spring rain. Summers are warm and dry with high temperatures of about 85°F and winters are cold and moist with lows typically around -10°F. Soils are shallow to moderately deep and support a mixed conifer forest of douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), and western larch (*Larix occidentalis*) with an understory of pinegrass (*Calamagrostis rubescens*). Openings in the forest canopy are vegetated by shrub-steppe communities comprised of sagebrush (*Artemisia tridentata*) and snowberry (*Symphoricarpos albus*) with bunchgrass (*Psuedoroegneria spicata – Festuca idahoensis*) understory. In some areas bedrock outcrops occur. Narrow riparian corridors occur along the few small ephemeral, intermittent, and perennial streams in the area. Many cavity nesting birds are present in the area and there are scattered areas of snow intercept thermal cover for mule deer (*Odocoileus hemionus*). Private land owned by BMG provides critical, high-use deer winter range. Much of the Project area has been logged and historically was and presently is used for domestic livestock grazing, timber production, mineral exploration and development, recreation, and wildlife habitat. The mine site encompasses private land and public land administered by the US Forest Service and the Bureau of Land Management as well as Washington State Land administered by the Department of Natural Resources (ACZ, Inc. 1990, US Forest Service and Washington Department of Ecology 1997, Battle Mountain Gold 1998).

The Crown Jewel Mine is designed as a surface mine. The mining operation will include a single open pit and two waste rock disposal areas. About 9 million tons of ore will be mined over the 8.5 year mine life. To access this ore, about 97 million tons of waste rock will be removed in accordance with a waste rock management plan. Mining will be by conventional bench and highwall techniques. The mine plan calls for a fleet of 100-ton haul trucks and 16 cubic yard loaders moving up to 60,000 tons per day (Battle Mountain Gold 1998).

Mine ore will be fed directly to a sub-surface crusher or stockpiled for blending and later crushing. Crushed ore will be stored in an underground ore pass and transferred to the mill grinding circuit by conveyor. The grinding circuit includes both a semi-autogenous grinding (SAG) mill and a ball mill. Following grinding, the ore slurry is thickened and gold and silver recovered through tank cyanidation and carbon-in-leach. After carbon removal, the tailings would be detoxified using the INCO sulfur dioxide-oxygen cyanide destruction process. Following detoxification, the tailings are piped to the tailings disposal facility where they are deposited sub-aerially (thin layer). The tailings disposal facility includes two earthen embankments (full downstream construction) and is completely lined with engineered native material overlain by two geomembrane layers interleaved with a drainage net. At design capacity, the mill will process an average of 3000 tons of ore per day on a 24-hour per day/seven days per week schedule. Average production will be about 170,000 ounces of gold per year for about 8.5 years. Presently, total planned production is about 1.45 million ounces of gold over the life of the mine (Battle Mountain Gold 1998).

The mine will require about 495 acre-feet of water per year during operations and up to 650 acre-feet per year during reclamation. Water will be acquired from a combination of sources including temporary transfer of existing irrigation rights, new surface water rights for diversion and storage of surplus flows from spring runoff, and new ground water rights for domestic supply and limited pit dewatering. The new surface diversions are constrained by instream flow and temperature requirements for fisheries protection. A water supply reservoir northwest of the minesite will be constructed as well as a pipeline from the reservoir to the mine. The water supply system is an innovative and flexible system which was based on water resource management guidelines and regulatory and resource constraints (Battle Mountain Gold 1998, Washington Department of Ecology 1997b).

During operations, an average of 144 employees will work at the mine. Transportation of the majority of the workforce will be by van pool or bus from sub-regional hubs. Consumables will be delivered to the mine generally only during daylight hours during mid-week periods. Electrical power will be supplied by the local Public Utilities District through both new and existing transmission and distribution lines. Total land disturbance, including rights-of-way for power lines and water supply pipelines, for mine facilities is about 765 acres.

A substantial environmental management, monitoring, and mitigation program has been developed for the Project. An impact monitoring program has been established with Okanogan County to evaluate predicted socioeconomic effects. Over 700 acres of private land have been acquired and will be managed for wildlife habitat. Wildlife habitat improvements on these as well as adjacent public lands are planned (ENSR 1998). An aquatic resources mitigation plan has also been prepared and will be implemented to address unavoidable impacts to wetlands and waters of the United States. A comprehensive waste rock management plan will be followed during mine operations. Water quality and quantity will be monitored at over 100 surface and ground water sites. A series of fugitive dust control plans will be implemented. Meteorological and air quality monitoring will be conducted throughout the life of the mine (Battle Mountain Gold 1998).

Reclamation activities will commence with construction and continue throughout the life of the mine. Major closure and reclamation activities will, of course, be conducted following cessation of mining and milling. The former pit will be modified through reclamation blasting, selective backfill, and pumping of water to enhance natural filling of the north zone. Waste rock dumps will be recontoured and the tailings disposal facility capped with a layer of glacial till material. The mill and other structures will be demolished and, following pit lake filling, the reservoir will be removed. Recovered and stored soil will be replaced over most surfaces except for certain areas in the pit. Coarse woody debris and lichen encrusted rocks are to be placed on resoiled surfaces to enhance reclaimed community structure and function. In addition to seeding native grasses and forbs, 325 tree and 400 shrub seedlings per acre will be planted to aid in the development of the desired plant communities planned for the site. Resource monitoring will continue for at least some parameters for 60 years following reclamation (Battle Mountain Gold 1998).

ENVIRONMENTAL PLANNING

Throughout Project planning and design activities, environmental considerations were of great importance. BMG-imposed environmental constraints as well as those dictated by site characteristics and regulatory requirements interacted to result in a compact facility footprint. This phase of Project planning was – by its nature – iterative. As an issue or impact was identified, modifications were developed and evaluated to address the concern. In some cases, reasonable changes could be made to avoid or greatly reduce the potential impact. In other cases, despite BMG's best efforts, certain impacts simply could not be avoided due to other considerations. Thus, the Company worked with the agencies to develop management, mitigation, and monitoring measures to address these impacts. Many of the measures were included in BMG's proposed plans (Battle Mountain Gold 1998) while others were the result of environmental review (US Forest Service and Washington Department of Ecology 1997) and permitting (*e.g.* Washington Department of Ecology 1999, US Army Corps of Engineers 1999).

Because of the iterative nature (indeed it was often heuristic!) of both planning – on the part of the Company - and permit application processing – on the part of the agencies – it is difficult to clearly define the demarcation between the two activities. Environmental planning and permitting activities were, in many cases, so intermixed that it was difficult to differentiate between the two. Confounding the environmental planning effort were the constraints imposed on the lead federal agency by the Federal Advisory Committee Act (FACA) thus limiting functional and productive technical exchanges between the Company and the US Forest Service during preparation of the environmental impact statement.

Despite the procedural difficulties, BMG designed and implemented an environmental planning process to facilitate permitting and address environmental matters while maintaining sufficient flexibility in operations. This process was applied in virtually all resource areas (*e.g.* air, water, wildlife, *etc.*). The following describes just a few aspects of this effort in regard to one resource area, that of wetlands (aquatic resources).

During facility planning, the Company evaluated many sites for both the water storage reservoir and the tailings disposal facility. The criteria for suitable sites for both facilities included proximity and potential impacts to wetlands. For the water storage reservoir, seven candidate sites were evaluated in terms of avoiding or minimizing impacts to wetlands, as well as storage efficiency, geologic conditions, and other factors. In the final evaluation of the sites, the primary environmental consideration was the presence of wetlands (Golder 1992).

BMG investigated seven potential locations for the tailings disposal facility in both site evaluation and selection (Golder 1995) and as part of facility design (Battle Mountain Gold 1998). The tailings disposal facility was the facility potentially directly impacting the largest area of aquatic resources. Siting criteria included minimization of impacts to aquatic resources.

As part of the EIS, and as required by RCW 78.56, the Department of Ecology also prepared a tailings site selection report. In addition to the sites evaluated by BMG, four other potential sites were evaluated for tailings disposal but all were eliminated for several reasons, including potential aquatic resource impacts. In addition, the agencies involved in preparation of the environmental impact statement evaluated other options for tailings disposal but these were found impractical or resulted in unacceptable environmental impact (US Forest Service and Washington Department of Ecology 1997).

In the Project area and adjacent areas there are about 50 acres of identified wetlands (US Forest Service and Department of Ecology 1997). Mine construction and operation will result in both permanent and temporary unavoidable impacts to aquatic resources. A total of 3.76 acres of aquatic resource sites and their respective aquatic functions will be directly affected by filling or excavation. To address these impacts, BMG proposed the implementation of a series of avoidance, minimization, and mitigation (creation, enhancement, restoration, and protection) measures. Mitigation of impacts is provided by management actions at 15 sites in the vicinity of the mine and provides for nearly 40 acres of aquatic resource sites. These actions include avoidance and minimization of impact, wetland creation, enhancement, and restoration, stream channel enhancement and restoration, and fish and wildlife habitat creation on approximately 700 acres of private land as well as at various locations on US Forest Service-administered land.

Other avoidance and minimization actions have been taken during the planning and design of mine facilities. Potential impacts to wetlands due to minor reductions in water flows from an existing abandoned mine adit will be avoided through the implementation of a streamflow mitigation plan (Battle Mountain Gold 1998). Another impact resulting from the development of the mine pit will be the shift of a small area of land from one sub-watershed to another. On an annualized basis, this will result in about 6 gallons per minute of water – the output of a garden hose – flowing into drainages on the east side of Buckhorn Mountain rather than those on the west side. Both sub-watersheds are within the same watershed – one with a mean annual discharge in excess of 900,000 gallons per minute! The minuscule change was nonetheless addressed through a streamflow mitigation plan which also provides supplemental flows to streams to ensure no depletion – regardless of how small – to surface waters during or after mining (Battle Mountain Gold 1998).

As previously mentioned, part of the water for mine operations is from diversion and storage of spring runoff. In order to protect fisheries habitat in the subject stream, an incremental flow – instream methodology (IFIM) study was conducted. Diversion limits were developed and incorporated into the water supply plan to meet the desired protection level. Further, instead of the diversion limitations being based solely on calendar dates regardless of habitat use, an adaptive management approach was proposed and ultimately permitted. Thus, stream biological activity governs diversion period and rate instead of a rather arbitrary calendar date and ensures protection of desired instream habitat values (Battle Mountain Gold 1998).

ENVIRONMENTAL REVIEW AND ANALYSIS

Environmental baseline data collection commenced in 1990. Water quality and quantity monitoring stations were established and preliminary cultural resource investigations were conducted. Basic wildlife, soils, and vegetation inventories were completed. A National Environmental Policy Act (NEPA) Environmental Assessment for exploration activities was prepared and completed in June 1990 (ACZ 1990). BMG's exploration activities were conducted under the operating plan and associated mitigation measures developed during this NEPA review.

By late 1991 it was evident that a world-class gold deposit had been discovered and would likely be developed. A preliminary mine plan of operations was prepared and in January 1992 submitted to the US Forest Service, Bureau of Land Management, and the Washington Department of Ecology (Battle Mountain Gold 1992a). This action initiated formal environmental review and analysis under NEPA and the State Environmental Policy Act (SEPA). In February 1992, additional information was added to the submitted operating plan. In April 1992, a Supplemental Plan of Operations (Battle Mountain Gold 1992b) was provided to the agencies.

Following some public scoping and Project planning activities, an Integrated Plan of Operations (Battle Mountain Gold 1993a) was prepared and submitted to the US Forest Service, Bureau of Land Management, Washington Department of Ecology, and Washington Department of Natural Resources. In mid-1993 a detailed reclamation plan (Battle Mountain Gold 1993b) to supplement the previously submitted reclamation information was developed and provided to the agencies. The various operating plan submittals were typical of mine plans of operation prepared in accordance and compliance with federal surface management and minerals management regulations, specifically 36 CFR 3809 and 43 CFR 228.

Formal public scoping, as required by both NEPA and SEPA, began on 14 February 1992. With concurrence from BMG, the scheduled 45-day scoping period was extended an additional 21 days. Four public scoping meetings were held during the scoping period. To aid in elevating the knowledge of the general public concerning mining and the Project, a series of 14 separate public meetings were also held over the next 18 months. At each of these meetings, comments were actively solicited, effectively continuing the scoping process.

From early 1992 through mid-1995, the agencies, their environmental impact statement contractor (ACZ, Inc. – later to be renamed TerraMatrix), and a myriad of subcontractors prepared baseline resource inventories, Project alternatives, and impact analyses. In June 1995, the lead agencies released their work product: the Draft Environmental Impact Statement for the Crown Jewel Mine (US Forest Service and Washington Department of Ecology 1995). This draft environmental impact statement (EIS) presented seven alternatives – including BMG's proposal – to allegedly meet the purpose and need for the Project. Only one alternative however, was actually capable of achieving the Company's purpose in developing the Crown Jewel orebody. The draft EIS – including a Spanish summary - was circulated for 60 days for public comment. During that period three public information meetings and two public hearings were held. By the close (more or less!) of the comment period 4,533 written and oral responses had been received from the public, agencies, organizations, and BMG. The responses contained 11,732 individual comments on various topics. Comments ranged from legitimate concerns (*e.g.* "How does the range of calculated noise levels relate to possible human health impacts?") to misleading ("...the air will be dirty and dusty from smokestacks...") to entertaining ("...this [mine proposal] is like a bad LSD trip...not that I'd know what that was like!") to hateful ("...miners [are]...dirty old men with their ignorant wives and children living in trailers..." Many statements of support (*e.g.* "[the proposal] represents an opportunity to generate high paying jobs without sacrificing the area's environmental quality.") were included in the comments received (US Forest Service 1997, US Forest Service and Washington Department of Ecology 1997).

Agency efforts to solicit comment and public participation were thorough and could even be considered excessive. In addition to the previously mentioned meetings and extended comment periods, special meeting opportunities were provided for those "not comfortable in traditional meeting settings" to ensure few opinion stones were left unturned. Further, Project opponents applied for and were awarded by the Department of Ecology a multi-thousand dollar grant to conduct workshops to allegedly "educate" the public about mining and environmental review and analysis. In practice, these publicly funded workshops became tools for the opposition.

The agencies and their EIS contractor worked to review and prepare responses to these comments. BMG also reviewed the comments and carefully considered those with merit in regard to Project modification. As a result, certain aspects of the proposed mine were modified. These changes, such as modifications to waste rock disposal area slopes and tailings disposal facility embankment construction method, were incorporated into revisions of the proposal and submitted to the US Forest Service and Washington Department of Ecology (Battle Mountain Gold 1995, 1996). The revisions were part of BMG's continuing effort to address and respond to agency and public concerns as well as further refine and improve the Project.

During this part of the environmental review process, two new state regulations pertaining to mining were enacted by the Washington State Legislature. In 1993, the Surface Mining Act (Revised Code of Washington 78.44) became effective. This set of regulations established new requirements for surface mining operations primarily in regard to reclamation. The Metals Mining and Milling Operations Act (Revised Code of Washington 78.56) was enacted in 1994. This regulatory package was initially directed at the Crown Jewel Mine Project in an effort to preclude its development. Ultimately, various interests reached a level of agreement on certain issues and developed regulations that included tailings facility siting and design criteria, waste rock management planning and approval, bonding requirements, as well as mitigation and reclamation requirements. The enacting of these new laws necessitated Project design modifications by BMG as well as agency interpretation and incorporation into the ongoing NEPA and SEPA analysis.

In January 1997, the lead agencies (US Forest Service and Washington Department of Ecology) and the cooperating agencies (Bureau of Land Management, US Army Corps of Engineers, and Washington Department of Natural Resources) issued the final EIS (US Forest Service and Washington Department of Ecology 1997). The final EIS, contained in four volumes and a separate summary, was over 2,000 pages in length and weighed 16 pounds! The Forest Service and Bureau of Land Management also issued a Record of Decision (US Forest Service and Bureau of Land Management 1997) approving the mine as presented as Alternative B in the EIS and as modified by specific sections (mitigation, monitoring, and management) of the EIS. The Record of Decision also required BMG to revise the mine plan of operations to incorporate these additional requirements (US Forest Service and Bureau of Land Management 1997).

Certain modifications to the Project mitigation plans from permitting activities resulted in the preparation of an addendum to the EIS in 1997 (Washington Department of Ecology 1997a). Another addendum to the EIS, for additional mitigation measures, also resulting from permitting, was prepared in 1998 (Washington Department of Ecology 1998). The addenda were used to ensure compliance with SEPA requirements to describe minor changes to a project and present clarifications to a proposal as a result of the permitting process. The addenda added analyses and information about the Project but did not substantially change the analysis of significant impacts and alternatives in the EIS.

An unusual aspect of environmental review influenced both process and outcome in regard to the Crown Jewel Mine. Political acceptability, based in part on perception, was a major factor in the rate at which environmental review was conducted. Despite the fact that Washington has significant mining activity, few elected state legislators were well informed of the modern mining industry. Indeed, BMG expended considerable effort in educating state senators and legislators about mining and minerals in general and the Crown Jewel Mine specifically. Other mining companies and associations also participated in these activities.

Localized opposition to the Project began during exploration activities. While relatively few in number, these opponents were intelligent, well-funded, and inter-connected with other anti-mining efforts. During the EIS preparation and permitting process, opponent groups had threatened – and then brought – judicial and administrative appeals of permit decisions. Throughout the environmental review process, BMG made considerable effort to address legitimate concerns expressed by neighbors to the Project, county residents, government agencies, and opposition groups. However, after many failed efforts to develop functional communications with the opposition - initiated both by the Company and by community groups, including the local chamber of commerce, - little doubt remained that the opposition was not interested in cooperative efforts to develop a mutually acceptable project. But rather, theirs was a philosophical difference that was not to be resolved through reason and application of sound engineering, management practices, modified plans, nor technological innovation. Theirs was a cause of different values and beliefs. This indeed is unfortunate as the economic benefits to the area – not to mention the production of a commodity - have been postponed by the selfish actions of nationally and internationally funded groups.

Local support for the Project was, however, overwhelming. An opinion survey conducted during the latter-stages of the environmental review process found that 92 percent of those who were familiar with the mine proposal were in favor of its development. There are several organizations, including chambers of commerce, local resource user groups, and even local governments who have – and continue – to vigorously support the development of the Crown Jewel Mine. There is substantial interest in employment with the Project – as on 1 January 2000, over 1000 applications for employment had been submitted yet BMG had not yet advertised for a single position. Most of those in the region are eager to see the mine in construction and operation.

ENVIRONMENTAL PERMITTING

During the construction, operations, and closure phases of the Project the Crown Jewel Mine will require 70 permits, approvals, or authorizations. These permits are issued and administered by county, state, and federal agencies. The 12 county permits include the conditional use permit, building permits, noise monitoring program approval, an impact mitigation agreement, approval of a fiscal and economic impact analysis, pipeline franchise, and, of all things, a cattle guard permit. Included in the 46 state permits are water rights, air permit, approval of fugitive dust control plans, stormwater permits, National Pollutant Discharge Elimination System/State Waste Discharge Permit, Dam Safety permits, surface mine reclamation permit, hydraulic project approvals, water quality certification (Clean Water Act Section 401), forest practice permits, and survey monument replacement permits. The 12 federal permits include the plan of operations approvals, Department of the Army Permit (Clean Water Act Section 404), Endangered Species Act Section 7 consultations, and, of course, an explosives permit from the Bureau of Alcohol, Tobacco, and Firearms. While no permits were required of Canadian federal or provincial agencies, the Company worked with representatives of appropriate agencies to ensure technical concerns they might have were addressed by design or permit or both.

For the purposes of environmental review and analysis, certain permit applications (*e.g.* the air permit and water rights) were prepared and submitted before the EIS was complete. The information contained in these applications was necessary for NEPA and SEPA compliance activities. The remaining permit applications were submitted or, if previously submitted, considered complete after the final EIS was issued in January 1997. The first state permit – an hydraulic projects approval – was issued in March 1997 (Washington Department of Fish and Wildlife 1997). Over the next 27 months, the majority of the permits (53 of 56) needed to commence construction were issued.

In 1995 the Washington State Legislature enacted the coordinated permit process (RCW 90.60) to "assist businesses and agencies in complying with the environmental quality laws in an expedited fashion without reducing protection of public health and safety and the environment." BMG carefully evaluated the apparent benefits of requesting participation in the coordinated permit program. In an effort to develop some certainty for permit decision schedules, BMG requested participation in the program in December 1995. As the first private entity to be involved in the new program, BMG found it potentially advantageous to have some assurance – albeit limited – of when permit decisions were to be made. The coordinated permit process – while well intended – was challenging for both the agencies and BMG.

A provision of the Metals Mining and Milling Operations Act states that "the Department of Ecology shall not issue necessary permits to an applicant for a metals mining and milling operation until the applicant has deposited with the Department of Ecology a performance security which is acceptable to the department of ecology" for compliance, reclamation, postclosure monitoring, and possible remediation (RCW 78.56.110) ("necessary permits" suggests unnecessary permits are also pursued!). Thus, prior to any permit decisions by the Department of Ecology, BMG emplaced financial securities – termed Environmental Protection Performance Securities (EPPS) – with the agency. Being the first Project subject to this new regulation required considerable coordination among Ecology, the State Attorney General's Office, and BMG. Nonetheless, as of 1 January 2000, the Company had posted some $57 million in EPPS for water rights, wetlands mitigation, stormwater, dam safety, wildlife mitigation, and water quality certification.

As required by the Record of Decision (US Forest Service and Bureau of Land Management 1997), BMG revised the operating plan. The resulting greatly expanded and extremely detailed Crown Jewel Mine – Plan of Operations (Battle Mountain Gold 1997) was submitted to the US Forest Service and Bureau of Land Management for "approval" in June 1997. The current operating plan is a physically massive document – filling seven three-inch binders – and contains all the major Project plans. In addition to what could be termed a 'traditional' plan of operations, the Crown Jewel Mine Plan of Operations includes the following:

- Reclamation Plan
- Integrated Transportation Plan
- Hydrologic Monitoring Plan
- Waste Rock Management Plan
- Stormwater Pollution Prevention/Erosion and Sediment Control Plan

- Construction Phase Stormwater Pollution Prevention/Erosion and Sediment Control Plan
- Tailings Disposal Facility Design
- Oil Spill Prevention, Control, and Countermeasures Plan
- Water Supply Plan
- Streamflow Mitigation Plan
- Materials Handling Plan
- Groundwater Quality Evaluation Plan
- Noxious Weed Management Plan
- Aquatic Resources Mitigation Plan
- Fish and Wildlife Habitat Mitigation Plan
- Wildlife Mitigation and Monitoring Plan for Ore Processing and Tailings Disposal Facilities

The Crown Jewel Mine – Plan of Operations also incorporates – by reference and/or approval condition – several other plans. These include:

- Pit Water Monitoring Plan
- Construction Phase Fugitive Dust Control Plan
- Operations Phase Fugitive Dust Control Plan
- Reclamation Phase Fugitive Dust Control Plan
- PM_{10} Sampling and Meteorological Monitoring Plan
- Fish and Wildlife Habitat Mitigation Plan Standard Operating and Monitoring Procedures
- Timber Settlement Agreement

In early February 1999 Battle Mountain Gold was asked by the US Forest Service to plan to pick up signature-ready plan of operations approval documents from the local office. Shortly after that, the agency advised the Company not to do so as the decision was under further consideration in Washington, DC. On 26 March 1999, the Company received a letter from the US Forest Service and Bureau of Land Management which vacated the previously issued Record of Decision. The agencies' explained that their action was based on the 7 November 1997 "Millsite Opinion" of the Department of Interior Solicitor even though it was prepared nearly a year after the Record of Decision for the Crown Jewel Mine was issued.

Congress reacted and passed a law prohibiting the Department of Interior from applying the mill site opinion to the Crown Jewel Mine and ordering that the Record of Decision be reinstated and the plan of operations approved. The Record of Decision was reinstated on 28 May 1999 and the plan of operations approved by the US Forest Service and Bureau of Land Management on 1 and 2 June 1999, respectively (US Forest Service 1999, Bureau of Land Management 1999).

Environmental review and permitting of the Crown Jewel Mine has been extremely thorough and painstaking. In reference to the Water Quality Certification issued in January 1999 (Washington Department of Ecology 1999), the Director of the Department of Ecology said: "The 401 Certification and all the permits that preceded it reflect the most rigorous environmental analysis the state has ever conducted on a project of this type. No other proposal has received this level of environmental scrutiny" (Fitzsimmons 1999). As of 1 January 2000, the only outstanding permits, approvals, or authorizations were three actions from the Department of Natural Resources: a commercial easement, a land exchange, and a surface mine reclamation permit.

Numerous challenges to the Project, in the form of administrative and judicial appeals, have been brought by opponents. As of 1 January 2000, all appeals had either been withdrawn (*e.g.* challenge to air permit, hydraulic project approvals), decided in favor of the Company and/or agency (*e.g.* EIS, solid waste), or were pending decision. On 19 January 2000, however, the Washington Pollution Control Hearings Board reversed the water rights reports of examination (water rights) and vacated the water quality certification (Pollution Control Hearings Board 2000). (Appeal of this decision is, at the time of preparation of this paper, under consideration by the Washington Department of Ecology, Washington State Attorney General, and Battle Mountain Gold.)

CONCLUSION

The Crown Jewel Mine Project development effort could be interpreted as an extreme state of affairs in regard to mine permitting in the United States. This may or may not be the case, depending upon an individual's base of reference. Regardless, it is simply not enough to have a world-class orebody, sound engineering, robust planning, innovative reclamation, extensive mitigation and environmental safeguards, financial securities, thorough regulations, and local support to bring a mine into production. Clear emphasis on product – as well as process – by regulatory agencies is necessary. Mechanisms for addressing legitimate public concerns are necessary. Efforts to effectively counter misinformation campaigns on local as well as national levels are vital. Political acceptability is of significant importance.

While mineral resource development and mining will continue to be inherently risky, and industry will continue to accept this risk in producing goods and services demanded by society, certainty in outcome – both result and schedule – is necessary in order to continue to have a viable domestic minerals industry.

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COMPANION CROPS: BENEFIT OR DETRIMENT

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ABSTRACT

Companion crops are thought to be needed and especially beneficial under conditions of environmental stress such as: limited moisture, high temperatures and salty soils. These conditions are typical of many disturbed sites in the arid and semi arid sections of the western US.

However, seeding of annual companion crops for stabilization can led to a lower percent of perennial species than plots seeded only with perennials. It may be more cost effective not to use a nurse crop in many situations. However, benefits of annual species in terms of stabilization weed inhibition and organic matter production may outweigh adverse impacts on perennial species. There are advantages and disadvantages of different types of: 1) companion crops, 2) nurse crops and 3) preparatory or cover crops. Successes depend on, land condition, management techniques, restoration objectives and location of the specific revegetation project.

"Preparatory or cover crops" are a kind of "nurse crop" used to maximize the advantages and minimize the disadvantages. Cover crops can be used to stabilize soils where delayed permanent seedings are part of the revegetation plan and would follow during the best seeding window of opportunity. Fast establishing adapted perennial species may also serve as good cover crops.

INTRODUCTION

Companion or nurse crops are usually fast growing species and have been used to establish a perennial species. This presentation will discuss the advantages and disadvantages of different types of companion crops, nurse crops and preparatory or cover crops. I will define some of the terminology that is used with different crops and management techniques relating to companion crops. We will look at research and historical applications. I will illustrate some of the specifications and successes of different methods that have applied to land restoration, conservation, reclamation, roads and other areas disturbed by man's activities.

I would also like to discuss several case studies using companion crops with native species. These projects are: Buffalo Creek fire, Vail ski area, Highway 34 between Greeley and Loveland, and tailing revegetation at Silverton, Colorado.

Companion crops are thought to be needed and especially beneficial under conditions of environmental stress such as: limited moisture, high temperatures and salty soils. These conditions are typical of many disturbed sites in the arid and semi arid sections of the western United States. Potential for wind erosion is generally more prevalent in this region than in the east. Conventional mulching may be preferred to cover crops in some areas.

WHY A COMPANION CROP? (Advantages)

- Reduce evaporation and conserve moisture
  upward movement of salts also may be reduced.
  Surface mulch traps and retains moisture better than bare ground.
- Reduces wind and water erosion
  Restricts air movement and allows higher relative humidity at the surface of the soil.
  Reduces water diffusion from soil into the atmosphere.
  Mulch causes the kinetic energy of raindrops to break and dissipate and thereby reduces "splash" erosion where soil particles are dislodged from the surface and carried down slope.
- Modify extremes in temperatures at the soil surface
  Light colored mulches typically help lower temperatures at the soil surface.
  Dark mulch applied in early spring can help warm surface soils sufficient to cause earlier seed germination.
- Reduces soil sealing over and crusting
  Surface mulch can add organic matter and improve infiltration.
- Reduces frost heaving
  Frost heaving is caused by the differential of night and day freezing temperatures combined with certain soil types.
  Frost heaving up-roots seedlings causing plant loss.
- Reduces weeds
  The more competition of desirable plants the less opportunities for weeds.
- Visual perception
  Often success is measured by the visual appearance of "green plants" on the surface.
  Green color gives the perception that plants are becoming established.
  However, judgment is often made with very little knowledge of the species identification.

WHAT ARE THE DRAWBACKS? (Disadvantages)

- Competition with slow growing perennial
  Where annuals are used, they become too competitive and reduce stands of perennials.
  Annuals are generally larger seeds and have stronger seedling vigor then most perennials.
- Competition with slow growing native species.
- Competition for soil nutrients.
- Often reduce stands of desirable perennials.
- Volunteer seedlings from the nurse crop may persist year after year.

RESEARCH

Basic research on companion crops has been done over many years. The Year Book of Agriculture 1948 on Grasses states. "Unless they are needed to protect the soil, companion or nurse crops should not be used with grass or legume planting in the northern Great Plains. If nurse crops are used, they should be seeded at very low rates; otherwise competition for moisture and shade by the companion crop is likely to be too great for the survival of seedlings".

In Seeding Colorado Range Lands, published by Colorado State University in the 1958 it says, "Ordinarily the production of the cover crop will deplete the soil moisture to such an extent that it is risky to seed perennial grasses until at least the top 18 inches of soil moisture have been replaced. If late summer rains are sufficient, fall planting of cool season grasses, such as wheatgrasses, may be done. More frequently it is wise to withhold seeding until after the winter and spring moisture. If winter and spring soil moisture is deficient, it would be less risky to repeat planting of a forage or cover crop and delay planting of grass until soil moisture conditions are favorable."

Ed Depuit, and others, 1978 Research on Revgetation of Surface Mine lands at Coal Strip Montana reported: "Seeding of annual cover crops for stabilization led to a lower percent of perennial grass biomass than plots that were seeded initially with the desired perennial species. This would indicate at least an initial inhibition of seeded perennial grass in cases where annual temporary stabilizing species are concurrently seeded, although benefits of such annual species in terms of stabilization, weed inhibition and organic matter production may outweigh adverse impacts on perennial species".

DEFINITIONS

I would like to review some terminology used to define different practices and systems in applying and managing companion crop seedings. These definitions are taken from the Society for Range Management, glossary of terms and illustrate different management technology. I would like to use these terms for comparison.

- Companion crop. "A crop sown with another crop (perennial forage or tree or shrubs) that is allowed to mature and provide a return in the first year".

  This would indicate the use of annual species and harvest of a crop.

- Nurse crop. "A temporary crop seeded at or near the time primary plant species are seeded to provide protection and otherwise help to insure establishment of the later".

  This may be an annual or perennial seeded with the mixture but protection is the main purpose.

- Preparatory crop (Cover Crop). "A residue-producing temporary crop utilized as part of seedbed preparations to provide mulch into which forage plants can be direct seeded ".

  Preparatory or cover crop is a kind of "nurse crop" where one can maximize the advantages and minimize the disadvantages.

  Cover crops can be used to stabilize soils where delayed permanent seedings are part of the revegetation plan and would follow during the best seeding window of opportunity.

  Cover crops can be used on steep slopes to prevent soil erosion while permanent vegetation is established.

HISTORICAL

- Forestry – legumes and ground cover are planted to hold the soil while slower trees become established. This may take several years.
- Landscaping – Annual cover and color plants are used to fill in while slower permanent vegetation becomes established.
- Agronomic – Annual crops are often used in combinations for economical returns. One variety seeded into the stubble of another usually under irrigation. Companion crops are used with new seedings of alfalfa, clovers and pasture grasses with irrigation. Economic returns are often the motivating factor.

APPLICATION

With preparatory/cover crops, annual species, such as sterile forage sorghum, Sudan or forage millet, are planted the growing season prior to permanent seeding. After crop maturation, native seeds are sown in standing dead material.

Preparatory/cover crop method differs distinctly from use of a "nurse crop". With a nurse crop, the annual grain and the perennial mix are planted simultaneously. The nurse crop usually out competes the slow perennial. In relatively few locations the method may be beneficial but sufficient moisture is required to support both the companion crop and the new seedlings.

Seedings without a "nurse crop" often provides better stand, even higher yields and more vigorous plants. It may be more cost effective over the life of a stand not to use a nurse crop in many situations.

G. E. Schuman and others 1980 "Standing Stubble versus Crimped Straw Mulch for Establishing Grass on Mine Lands. "Straw, hay or other organic mulch is often used as a protective cover on newly seeded mined areas to protect soil and seedings from wind and water erosion. Successful reclamation of mined lands depends upon rapid establishment of vegetative ground cover to prevent the erosion of top soil spread over regarded spoils". "Small grain stubble seeded in the spring and a grass mixture fall-seeded into that stubble has advantage over use of crimped straw or hay residues as a mulch for wind and water erosion control on mined land". These studies were conducted on a topsoiled, regraded spoil dump at Shirley Basin Wyoming.

"Overall the crimped straw resulted in 48.6 grass seedlings per 3.05 meters. The stubble treatment resulted in 54 seedlings per 3.05 meters". " Soil water losses measured by solar distillation were reduced 16, 33 and 49 percent (%) over a 20 day period with surface application of 1,120, 2,240 and 3,360 kg. per hectare of straw respectively".

"This stubble provided longer lasting protection, contributes organic matter to the soil profile and ultimately made the soil more porous". "The year following seeding, 47 percent (%) of the applied mulch remained on the surface in comparison 94 percent (%) of these stubble residue remained during the same period".

"Despite its lower total mass, the upright oriented stubble trapped more snow during the winter and protected the soil better". "Cost comparisons of these two treatments favored the stubble treatment."

"Chances of weed infestation are much less with a small grain planted for stubble. The staw mulch may be contaminated with weed seed."

Several million acres in Colorado have been seeded to perennial species during the CRP program beginning in 1986. Several studies indicate a better than 85% success rate. Generally the Natural Resources Conservation Service (NRCS) specification required a "Preparatory/Cover crop". These specifications required "seeding the perennial mix into standing mulch and weed control". Grasses were successfully established using corn, grain and sorghums. The success was outstanding given the fluctuating annual weather patterns in Colorado.

Control of voluntary wheat is essential, when grass is planted into wheat stubble. Chemical control of volunteer wheat can be achieved by application of a herbicide such as Round-up in January or February prior to grass plant emergence. Apply as per label directions.

Economic impact and cost effective analysis should be considered before seeding a cover crop. A cost of $1,300 to $10,000 per acre (and higher) to revegetate some roadsides, ski slopes, parks, and mine lands. Seed cost alone can be over $ 1,000 an acre and then the cost of seedbed preparation. The companion crop may look very good but the perennial mix may suffer. Is a 60 to 80 percent reduction in the perennial mix worth a fast green appearance if it isn't needed? There could be a substantial economic loss due to competition from the nurse or companion crop.

There are some good fast growing short-lived native species that are good alternatives in a mixture. We have native species such as slender wheatgrass, mountain brome, sideoats, and lewis flax that have good seedling vigor and can provide quick cover where they are adapted. These species are cost effective and environmentally sound alternatives to an annual cover crop.

Case study personal observation

- Buffalo Creek fire: Oats (Avena Sativa) was broadcast seeded by helicopter yet unseasonably hard rains washed most of this cover down the river.
- Vail ski area: Vail seeds approximately 45 lbs. of a grass and clover mix per acre and 5 lbs. of winter wheat as a nurse crop. Winter wheat at these elevations and at these seeding rates is not competitive and usually does not volunteer or persist. Seeding winter wheat at heavier rates did reduce the stand.
- Highway 34 Greeley to Loveland: Highway 34 between Greeley and Loveland compares seeding a native grass mixture planted and mulched with straw and crimped, to seeding the same grass mixture with a small grain nurse crop. The stand of grass in the mulched area had 2-10 plants per lineal foot while the stand with the nurse crop was hard to find, possibly not existing.
- Silverton tailing trials: A 1976 trial planting with many grasses and forbs. The only successful plant to establish was Louisiana sage (A. ludoviciana). The second and following years native grasses moved into the Louisiana sage stands. Louisiana sage provided protection and nitrogen for the grass to survive. The Silverton site was in an area with 21 inches precipitation. It was pretty phenomenal.

SUMMARY

Are companion or nurse crops needed? Research and experience indicate that nurse crops and companion crops are used too often. A better alternative would be to establish a cover crop prior to seeding the desired perennials species. Seeding the perennial mix of grass, forbs and shrubs into an existing stand of stubble avoids competition from quick growing annual nurse crops. If nurse crops or companion crops are used the seeding rate should be one to five pounds per acre on dry land and ten to twenty pounds per acre on more favorable precipitation sites.

The solution to establishing perennial grasses are not nurse crops but well designed mixtures that include fast growing perennials which protect the soil from wind and winter erosion and compliment the establishment of all species in the mixture.

IMPLICATIONS OF NATURAL SUCCESSION AND ADAPTATION OF ECOTYPIC POPULATION TO ARTIFICIAL RESTORATION PRACTICES

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ABSTRACT

Selection and use of site adapted ecotypes to restore disturbed communities is usually advisable. Studies of most native species demonstrate that individual populations or geographic ecotypes exist, and are specifically adapted to particular sites and habitats. Individual ecotypes posses certain growth attributes that favor their existence in specific environments or locations. Defining separate ecotypes of individual species and determining their areas of occupation normally requires extensive studies. Certain ecotypes have or may be defined based on morphological or physical features. In addition, description of phenological responses to environmental stimuli can be used to separate different ecotypes. Studies with antelope bitterbrush *(Purshia tridentata)* began in the early 1940's to determine if separate ecotypes exist and if specific growth factors could be used to correlate adaptation with environmental factors. Reciprocal plantings with over 250 accessions revealed that initial establishment, growth rates, growth form, flowering habits, seed production and early survival differ among populations, but these factors did not correlate with collection origin. Antelope bitterbrush is a taxon with broad genetic features and has evolved to occupy a wide and diverse array of sites and habitats. Although separate and distinctly different growth forms occur which undoubtedly favor their existence, utilizing morphological and phenological features to correlate adaptive populations with specific sites was not always possible. Success of individual populations is dependent upon the ecological relationship of each population growing with associated species. Growth and survival responses of separate populations to edaphic, climatic and biotic features can be used to define areas of adaptation of some but not all populations.

INFLUENCE OF HERBICIDES AND SEEDING TECHNOLOGY ON PLANT COMMUNITY DYNAMICS IN THE CONSERVATION RESERVE PROGRAM

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ABSTRACT

The effects of herbicides and seeding technology on seeded grasses in the Conservation Reserve Program were evaluated. Seeded species were blue grama *(Bouteloua gracilis)*, sideoats grama *(Bouteloua curtipendula)*, western wheatgrass *(Pascopyrum smithii)*, switchgrass *(Panicum virgatum)*, and sand dropseed *(Sporobolus cryptandrus)*. Herbicide treatments included sulfonylureas, growth regulators and mowing. Impacts of seeding methodology were evaluated for cultivar performance, cover crop type, intensity of seedbed preparation, drill type, planting season, seed quality and seed mixture composition. Sideoats grama responded positively to sulfonylurea herbicides, whereas switchgrass and western wheatgrass were adversely affected. Blue grama and sand dropseed were least affected by herbicide treatment. Plant diversity was reduced under sulfonylurea treatment. Growth regulator treatment resulted in 70 percent increases in diversity over sulfonylureas, primarily attributable to increased annual forbs. Seral stage was more advanced under sulfonylurea treatment, however, because of increased frequency of perennial forbs, grasses and half-shrubs.

Improvement in establishment occurred with use of named cultivars versus native harvest seed. Few differences in response to planting season and cover crop type were detected. Most species responded positively to seedbed tillage. Drill type, seed quality, and seed mixture composition also affected individual species establishment and uniformity, but effects were often mitigated by herbicide interaction.

GREENHOUSE PROPAGATION OF NATIVE PLANTS AS A SHORT-CUT TO SUCCESSFUL RESTORATION

- a preliminary study using common native species in high arctic and alpine restoration

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ABSTRACT

The Svalbard archipelago (78^{0}N) and the Dovre mountain (62^{0}N) in Norway are perceived as pristine land, but are locally characterised by settlements, mining, tourism and military activity. Geographical position and local climate conditions contribute to very slow recovery rates after disturbance. Is it possible to develop a method for restoration in this vulnerable and species-poor vegetation, using native species? This paper will focus on some preliminary results conserning propagation. Further experiments focusing on survival and growth after outdoor-replanting and effects on natural recovery are carried out during the project.

Seeds, bulbills or cuttings were collected from 12 common, native species and propagation ability were tested in the greenhouse. Three of the four seed-propagated species have high germination rate and survival, and plants were cultivated for later outdoor replanting. Five of the eight cutting-propagated species have high rooting and survival rate, and were cultivated for outdoor replanting.

This result makes it possible to set up an outdoor restoration experiment with native species at one high arctic and one alpine locality in Norway.

INTRODUCTION

The arctic and high altitude vegetation survives in marginal conditions, with extensive environmental fluctuations and natural disturbances. Adaptations to different kind of disturbances are an essential part of the life history strategy of arctic plants (Oksanen & Virtanen 1997, Grime et al. 1990). In addition many arctic and high altitude plant communities also suffer from growing anthropogenic disturbance.

The availability of seeds is presumed to slow the colonisation of disturbed communities (Oksanen &Virtanen 1997). Also the speed and reliability with which the plants establish from propagules (ecesis) is slow and periodic in tundra vegetation (MacMahon 1987). Greenhouse propagation and planting of the propagated individuals at the disturbed site can elude the most critical stages of the establishment process.

MATERIALS AND METHODS

Study areas

The Svalbard archipelago is situated at 78^{0}N and the study site is located close to Longyearbyen, the biggest settlement in Svalbard. The Dovre mountain is situated at 62^{0}N, and the study site is a military firing range at 1000 m a.s.l. The areas have low yearly precipitation (400 mm). Both the geographical position and the local climate conditions contribute to very slow recovery rates after disturbance. The study areas are perceived as pristine land, but are locally characterised by settlements, mining, tourism and military activity.

Propagation and cultivation

Seeds, bulbills, and cuttings of native species were collected from the study areas (Table 1). The seeds were stored at three different temperatures (+4^{0}C, -1^{0}C and −20^{0}C). The germination experiment was carried out at 22^{0}C during three periodes separated by close down periods with 4^{0}C and no watering. Cuttings of evergreens were planted immediately after collection in two different greenhouses, and cuttings from deciduous species were stored at 1^{0}C for four months before planting. The new individuals were further cultivated in the greenhouse following ordinary gardener principles, and then put outdoors for acclimatisation.

Table 1: Seeds, bulbills and cuttings collected at Svalbard and Dovre for greenhouse propagation.

Species	***Origin***	***Propagation unit***	**N**
Arctostaphylos uva-ursi	Dovre	cuttings	756
Bistorta vivipara	Svalbard	bulbills	1200
Cassiope tetragona	Svalbard	cuttings	687
Dryas octopetala	Svalbard	cuttings	674
Dryas octopetala	Svalbard	seeds	1200
Empetrum nigrum ssp.herm.	Dovre	cuttings	756
Luzula confusa	Svalbard	seeds	1200
Oxyria digyna	Svalbard	seeds	1200
Papaver dahlianum	Svalbard	seeds	1200
Salix herbacea	Dovre	cuttings	390
Salix polaris	Svalbard	cuttings	640
Saxifraga oppositifolia	Svalbard	cuttings	644
Vaccinium vitis-idaea	Dovre	cuttings	601

RESULTS

Seeds and bulbills

There is no effect of storage temperature on germination for any of the species (ANOVA, p = 0,56) (Figure 1). The germination differs significantly between every pair of species (ANOVA, p<0,01), with the exception of *Oxyria digyna* vs. *Papaver dahlianum* (p=0,9). Germination over time shows different pattern for the different species (Figure 1). All germination of *Bistorta vivipara*, *Dryas octopetala* and *Luzula confusa* happened during the first and second period. *Oxyria digyna* and *Papaver dahlianum* have similar curves, though *P. dahlianum* is a bit subsequent to *O. digyna*. Both species reached maximum germination during the third period. The small plants of *Bistorta vivipara* have very high mortality, and most plants died during the first two weeks after germination. The few seedlings of *Dryas octopetala* have very slow growth, but survived cultivation. The species *Luzula confusa*, *Oxyria digyna* and *Papaver dahlianum* grow very well, and are cultivated for the later outdoor planting.

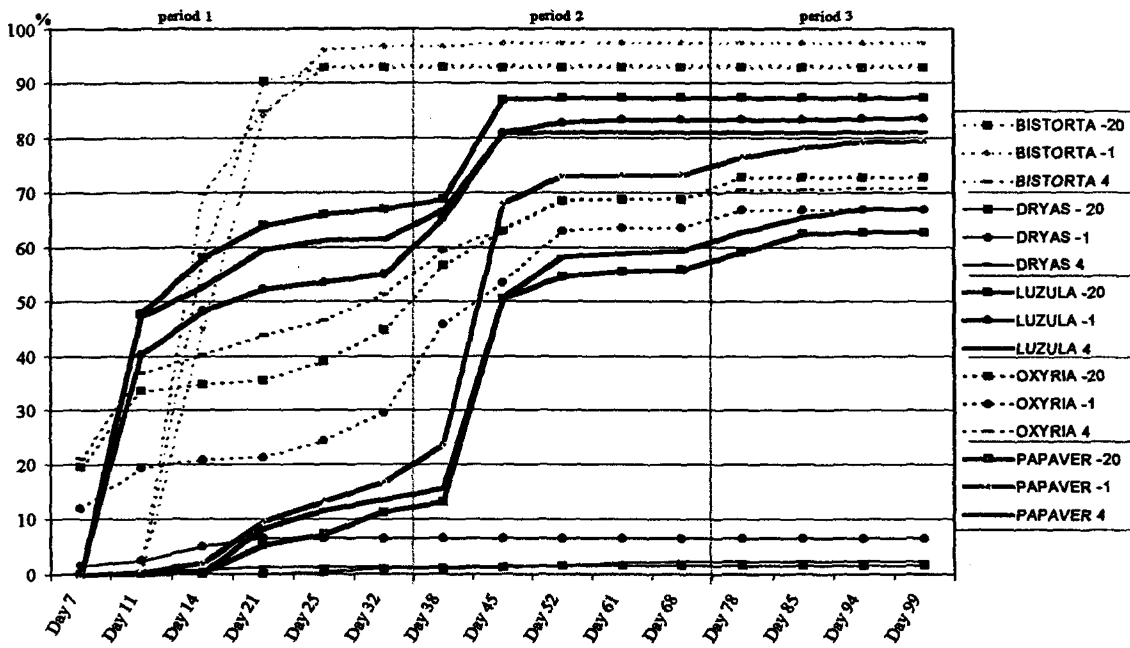

Figure 1. Germination (%) of seeds and bulbills in greenhouse, stored at three different temperatures before sawing (-20^{0}C, -1^{0}C and +4^{0}C). The germination experiment was carried out at 22^{0}C during three periodes à 5-6 weeks, separated by close down periods with 4^{0}C and no watering. Day numbers referres only to the active experiment periods.

Cuttings

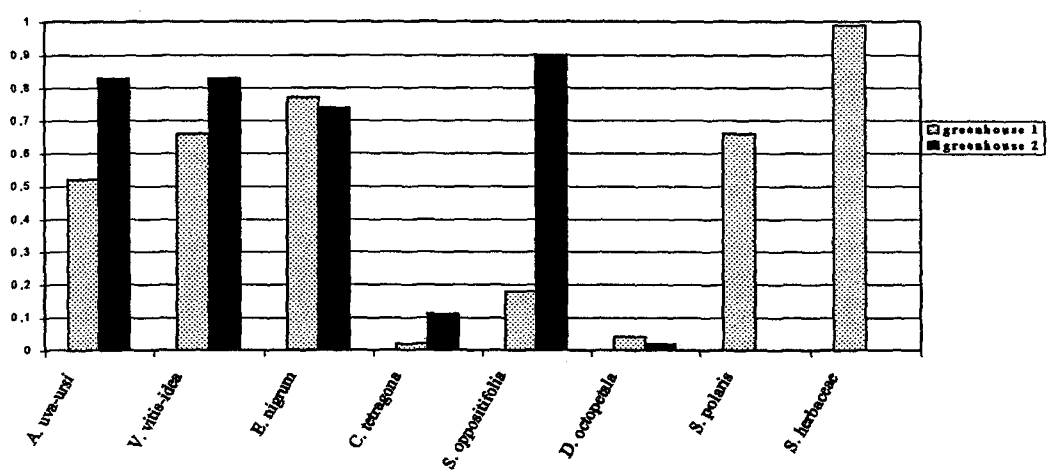

Figure 2. Rooting rates of species propagated by woody cuttings. The deciduous species *(Salix herbacea* and *S. polaris*) are propagated in one greenhouse, and the evergreen species are propagated in two greenhouses.

At the end of the propagation period the deciduous species *Salix herbacea* and *S. polaris*, and the evergreens *Arctostaphylos uva-ursi, Empetrum nigrum ssp. hermaphroditum* and *Vaccinium vitis-idea* have a rooting rate exceeding 0.5 (Figure 2). All these species survived cultivation and acclimatisation properly, and will be used in the following outdoor plantings.

DISCUSSION

Among arctic species we find both good and weak germinators (Eurola 1972). Generally arctic species have weak or no dormancy mechanisms (Gartner 1983), but enforced dormancy related to winter temperature is in effect (Densmore 1979). Storage temperature had no effect on germination in this experiment. This indicates that even a storage temperature of +4^{0}C can be sufficient to break dormancy. +4^{0}C is demonstrated to be an important temperature for destruction of delay mechanisms (Deno 1993).

Development of vegetative units is an adaptation to stress and disturbance, and increases the plant ability to successful reproduction (Billings 1974). The quick establishment of bulbills is thus expected. The high mortality of small plants of *Bistorta vivipara* can be caused by slow growth. Observations in disturbed and undisturbed communities also demonstrate high germination and high mortality of *B. vivipara* (unpublished data).

A separation into pioneers and late successional plants is difficult in arctic and alpine vegetation. The persistence of pioneers until late succession stages is reported from other alpine studies (Mattews & Whittaker 1987). *Oxyria digyna* and *Luzula spicata* are among the most common species in both early and late succession stages in the study area at Svalbard.

The rooting ability of cuttings varies within families, genera, and even species (Hartmann et al. 1990). Several families and genera with arctic members (e.g. *Salicaceae, Rosaceae*) are reported to be easily propagated by cuttings, and the high rooting ability of *Salix herbacea* and *S. polaris* is expected from previous studies on *Salix* (Chmelar 1974, Densmore et al. 1987). Published results concerning the rooting availability of cuttings from the other species is not revealed. *Saxifraga oppositifolia* have very different rooting ability betwen the greenhouses in this experiment. This species also shows much ecotypic variation (Brysting et al. 1996, Crawford 1997), but differences in rooting ability between ecotypes have not been tested in this project.

Relevance to restoration

During the total greenhouse propagation period (lasting between two growing seasons) it was possible to produce new plant individuals attaining a size of several years old congeners propagated in nature. On the basis of these results it is possible to set up an outdoor restoration experiment using the propagated plants in the study areas. The future task of the project is to study the survival and growth of propagated plants following outdoor replanting, and how the plantings will influence on the natural recovery. The influence and effect of mycorrhiza during the restoration experiment will get special attention.

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PLANT MATERIALS CENTERS PROVIDE VEGETATIVE SOLUTIONS

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ABSTRACT

Many of today's environmental problems can be addressed through the use of plants. Current land management practices are highly complex involving holistic approaches to achieve good land health and environmental quality. The Natural Resources Conservation Service provides conservation planning and program administration to private landowners. Plant Materials Centers (PMCs), together with a multitude of partners, select plant materials and provide technology regarding their use. To date, about 475 cultivars and natural germplasm of improved plants have been released by PMCs. Most have been placed into the commercial seed and plant production industry with great success. About 100 million dollars in revenue was generated from commercial sales in 1998. Today, 26 PMCs are conducting nearly 500 studies related to plant selection, propagation, establishment and management. More than 90 percent of the plants currently being tested are native species. Current technology development provides information for many environmental concerns, such as revegetation of disturbed areas and critical habitats; buffer strips; soil bioengineering; waste management; wetland and riparian area enhancement; windbreaks; prairie ecosystem restoration; and noxious-invasive plant suppression. PMCs released 25 new grass, grass-like, and shrub cultivars/germplasm in 1998, including the technology for their use on the rangelands of the United States and potential use in other areas of the world.

PHYTOREMEDIATION OF EFFLUENT FROM THE LEADVILLE MINE DRAINAGE TUNNEL

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ABSTRACT

The Leadville Mine Drainage Tunnel (LMDT) is used to treat mine drainage from working and abandoned mines around Leadville, CO, at an elevation of 3048 m (10,000 ft.). The effluent from the tunnel represents a mixture of high concentrations of various metals and trace elements posing unique treatment issues. Two phytoremediation designs will be investigated as possible pre-treatment options for the water treatment facility at the LMDT. The first will utilize combinations of quinoa (*Chenopodium quinoa)*, Indian mustard (*Brassica juncea*), and yarrow (*Achillea millefolium*). Use of Indian mustard represents the first field testing of transgenic plants developed under an EPA-sponsored project. The second will work with duckweed (*Lemna minor*). The goal is to derive a treatment design capable of treating 38-63 L s^{-1} (600-1000 gal min^{-1}) of influent. Secondary goals include identifying post-treatment markets for the plants, and metals recovery. The LMDT allows for complete control of environmental conditions, thus maximizing phytoremediation efficiency. The project represents a new use for underground structures and may lead to completely new options for mining reclamation and recovery.

INTRODUCTION

The stories and legends of Leadville's colorful and rich mining history are matched only by today's environmental pollution. Million-dollar mining fortunes were made and broken overnight. Although many of the contaminated areas were also seemingly created overnight, their cleanup will take far longer. One possible suggestion has been the use of plants (phytoremediation). An area where these plants may be used is another relic of Leadville's mining past, the Leadville Mine Drainage Tunnel (LMDT). The LMDT is a 3.2 km tunnel used to drain water out of the mining district. The influent from this drainage tunnel is significantly contaminated with metals.

Phytoremediation

Phytoremediation is the use of plants to remediate environmental pollution. Of principal concern for this investigation will be phytoextraction and rhizofiltration. Other processes, such as phytovolatilization, are important secondary mechanisms.

Table 1: Price Ton^{-1} of Selected Metals

Metal	$\$ t^{-1}$
Zn	1192
Mn	1700
Cu	1964
Cd	3750
Ag	152113

Source: Brooks, 1998

In phytoextraction, metals are bioaccumulated in the shoot. The shoots are then harvested, at which time, any metals recovery (phytomining) occurs prior to proper disposal. Table 1 illustrates the 1998 price per ton of five of the metals currently being removed by the treatment plant at the LMDT. It is evident that phytomining is an aspect that needs to be considered, especially with the removal of traditional mining costs.

Rhizofiltration is similar to phytoextraction, except the location of accumulation is in the roots. This process requires the plants to be grown in a liquid medium, which will occur in our hydroponic growth channels.

During phytovolatilization, contaminants are converted to gases and released to the atmosphere.

Species selection for phytoremediation is based on biomass, bioaccumulation of the contaminant of interest and potential recovery of the contaminant and its subsequent market value. The three species chosen are quinoa (*Chenopodium quinoa)*, Indian mustard (*Brassica juncea*), and yarrow (*Achillea millefolium*).

Quinoa (*Chenopodium quinoa*)

Because of quinoa's high productivity and nutritional values, it was considered for use in NASA's Controlled Ecological Life Support System (CELSS) (Shlick, et al., 1996). Quinoa has gained attention due to its high amino acid and mineral contents (Shlick, et al., 1996). It is unclear to what extent metals accumulation will affect nutritional properties. This will be one area of Duane Johnson's investigations.

Indian mustard (*Brassica juncea*)

Several options exist to make phytoremediation more efficient. One of those is the genetic manipulation of the host plant. To date, efforts have focused on overexpressing genes for particular enzymes in the necessary metabolic pathways. Elizabeth Pilon-Smits has developed transgenic lines of Indian mustard that overproduce heavy metal binding peptides and show enhanced Cd accumulation and tolerance.

In an EPA-sponsored project, the transgenics are now being tested for their metals tolerance and accumulation of other metals.

Work in the tunnel will represent the first time that these transgenics are tested outside of laboratory conditions.

Yarrow (*Achillea millefolium*)

Yarrow was used in Mr. Burcik's initial experiments and displayed promise for metals removal. Yarrow is a medicinal plant, which has been used for a variety of ailments, from nosebleed to anti-inflammatories. One of its historic names is Soldier's Woundwort, for its ability to stop bleeding. It is unclear how elevated metals' concentrations will affect its medicinal properties.

Duckweed (*Lemna minor*)

Duckweed is a generic term for several species of small, aquatic plants. With approximately 90% water content, duckweed allows for extreme concentration of contaminants after drying of the plant matter, greatly reducing the amount of material to be properly disposed of.

Several laboratory investigations have shown duckweed's promise concerning phytoremediation of heavy metals. Dirilgen, et al., showed that *Lemna minor* was capable of plant concentrations of 4000 ppm Zn, as measured by dry weight. Cu accumulation has been recorded at 6714 ppm, as measured by dry weight (Jain, et. al., 1989). Zayed et al., found the following maximum concentrations: 1.33% Cd and 0.427% Se by dry weight (Zayed, et. al, 1998). However, its field usage has been restricted to wastewater treatment of municipal, livestock, and industrial origins.

Leadville Mine Drainage Tunnel (LMDT)

The LMDT was built in support of the World War II and Korean War efforts. The purpose of the LMDT was to lower the water levels (and thus increasing the depth of mining operations) in the mining district of Leadville, CO, home to numerous mines (primarily Pb, Ag, Mo and Zn). In 1959, the Bureau of Reclamation (BOR) purchased the tunnel from the Bureau of Mines for $1.00.

Starting in 1992, the BOR has treated the tunnel effluent before releasing it into the Arkansas River. The treatment plant currently removes Zn, Mn, Al, As, Cd, Cu, Fe, Se, Ag and adjusts the pH of the drainage water.

Project

The goal is to design a phytoremediation system capable of treating 38-63 L s^{-1} (600-1000 gal min^{-1}) over the course of a 137 m (450 ft.) section of the tunnel. If successful, the system will allow the treatment plant to treat wastewater from several Superfund tailings ponds in the area.

An advantage of the project is that the tunnel allows for complete control of environmental conditions. Air/water temperature, water pH, growth medium, humidity, and light intensity/duration are all possible growth factors that can be controlled by project staff to maximize plant growth and thus, remediation.

The project represents an interdisciplinary and interagency effort in research and development. From CSU, three different departments are represented (Departments of Environmental Health, Biology, and Soil and Plant Sciences). Private industry, represented by Frank Burcik of Water Treatment and Decontamination International, has been a driving force in this project. Federal government involvement includes the EPA and the BOR (for use of their facilities and represented by Brad Littlepage). Local and state government representatives, as well as concerned citizens, are not only informed of the project, but are involved in discussions. Colorado Mountain College, a local community college, is also involved by providing its students with internship opportunities at the site. Lastly, the Leadville Institute of Science and Technology (led by Robin Littlepage), a non-profit organization, has secured the funding for the project and brought all of the involved parties together.

METHODOLOGY

Mix-Plant Design

Source plants will be provided as follows: quinoa from Duane Johnson, Indian mustard from Elizabeth Pilon-Smits, and yarrow from Frank Burcik. Indian mustard will also be tested in the greenhouse on water collected from the LMDT, in a separate pilot experiment.

The combination of quinoa, Indian mustard, and yarrow will be grown in three sets of 15.24 m (50 ft.) long hydroponic channels, each four channels across. The total project will stretch 45.72 m (150 ft.). Three of the four channels in each set will possess a single species (quinoa, Indian mustard or yarrow) and the fourth channel will contain a mix of the three species. Each channel will be divided into thirds, dependent on the growth medium, either sand, nutrient film technique (NFT) or glass beads. Each tier will possess a different ordering of the media (i.e. one tier will be sand, NFT, then glass beads, the next channel will be NFT, glass beads, then sand, etc.) The three systems will be connected together, so that treatment can occur over the entire length. The flow rate through each channel will be decided on site.

All channels will be supplied with constant levels of fertilizer and light. The plants grown in the NFT will be grown in the greenhouse at CSU, first on agar nutrient and then on sand, before transfer to the LMDT. Sand and glass bead plants will be sown directly into the media at LMDT.

Samples of water and plant material (roots and shoots) will be taken, and analyzed for metals content by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES).

Duckweed

Treatment water used for the initial *Brassica juncea* will also be used for preliminary testing of the duckweed. Duckweed will be grown in static trays of the LMDT water. Samples of water and duckweed tissues will be taken every 12 h for 14 d for acid digestion and ICP-AES analysis. The results will be used to generate a time-concentration curve, which will indicate the optimal time for future retention times for treatment.

Should greenhouse experiments show promise, the duckweed procedure will be repeated at LMDT during summer, 2000.

Phytomining

Mr. Burcik has developed a process for recovering metals from plants and will be investigating the feasibility of its utilization at this site. If successful, it will allow the metals to be sold, further offsetting the cost of phytoremediation.

DISCUSSION

Several issues will need to be decided on-site. Harvesting time will be one such issue. It is unclear the amount of time necessary for optimal accumulation and will have to be tested. The photoperiod and quantity and constituents of fertilizer will also need to be decided upon viewing of the actual working project.

This project breaks new ground in several exciting areas. The first is the use of the LMDT itself. Although underground structures have been used for waste disposal (most notably the Waste Isolation Pilot Plant for radioactive materials), they have yet to be utilized to remediate waste rather than simply storing it. As mentioned earlier, underground structures allow for complete control of environmental conditions. This also includes the isolation from pests, diseases, and wildlife that pose problems to other field studies of phytoremediation. Isolation from the outside world also allows the use of transgenics.

Transgenics have been used in field studies, however, there are issues to be considered when using genetically-engineered organisms, such as cross-pollination with native phenotypes and outcompetition of natives (Glass, 1999). The isolation of the LMDT allows for use of any transgenic or foreign species, however noxious and competitive. While there are still significant ecological factors to be considered for every use of transgenics, regulatory pressures are being eased (Glass, 1999).

Although the regulatory use of transgenics is understood, the regulatory requirements for use of agricultural and medicinal plants for phytoremediation and subsequent introduction to the consumer market are still unclear. Regulatory acceptance will require adequate testing to ensure that the elevated levels of metals do not pose a threat to human health. The second hurdle is consumer acceptance of the product. However, should these two obstacles be overcome it would further offset the cost of phytoremediation.

In this project, equally amazing to the breadth of species (transgenic, medicinal, agricultural), is the breadth of entities involved (academia; federal, state, and local government; private enterprise; and the community). Inherent in this number of involved parties are divergent interests and sometimes, competing interests. At the same time, there are incredible resources and vast amounts of experience to draw from to ensure the success of the project.

CONCLUSIONS

Phytoremediation of the Leadville Mine Drainage Tunnel represents a potential new use for underground structures. Use of these structures allows for a more secure use of transgenic plants. Expansion of the use of plants beyond phytoremediation to post-treatment medicinal and agricultural markets will be explored. As many as 11 different entities are involved in the research and successful completion of this project.

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RESTORATION MONITORING —
A SIMPLE PHOTO MONITORING METHOD

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ABSTRACT

One of the most important aspects of any revegetation or restoration project is monitoring. In cases where regulatory compliance or the need for detailed monitoring does not exist, the use of photographic monitoring is often an acceptable alternative. In 1999, a photographic monitoring project was begun at the Rocky Flats Environmental Technology Site, to visually document the restoration of a disturbance created after a pipeline was buried across part of the site. An additional project goal was to make the information available to users in an interactive electronic form using web browser technology. After the disturbance was seeded with native species and hydromulched, the perimeter of the disturbance and seven permanent photo locations were mapped with a geographic positioning system. This information was used in a geographic information system to produce an electronic map of the project area. Using both photo points and photo quadrats, both landscape and ground view photographs were taken twice during 1999 to document changes as restoration efforts began. A simplified photo quadrat methodology was used that did not involve complicated efforts to precisely position the camera over the quadrat for repeat photographs. Final photographs were scanned electronically and used with the electronic map to produce an interactive display of the results using web-browser technology. This simple, yet visually effective technique allows clients to open the map in a web browser and view the photographs taken at each location by simply clicking on a photo location. As new photographs are taken in the future, they can easily be added to the collection and continue to update the monitoring results. The project has demonstrated that through the use of a simple photo monitoring design it is possible to visually document, with both landscape and ground views, the progression of a restoration/revegetation project in a repeatable, cost-effective manner. The use of web browser technology can display the results in a simple, informative, professional manner, suitable for presentations and displays.

INTRODUCTION

One of the most important aspects of any revegetation or restoration project is monitoring. When detailed monitoring is necessary, especially for regulatory compliance, the expense of sending a field crew out to collect the data, and the associated costs of analyzing and reporting the results, can add up quickly. In the absence of legal requirements, such a level of detail may not be necessary, and in these cases, simple photographic monitoring might be a practical, cost-effective alternative.

The idea of photographic monitoring is not new, nor is there any lack of methods. Photo points and photo quadrats have often been used to document change over time in plant communities (Turner, 1990; Sharp et al., 1990). Photo points are used to document landscape changes by taking a series of photographs over time from the same location and looking in the same direction (Brewer and

Berrier, 1984). Photo quadrats evaluate the vegetation in permanently marked plots by taking photographs from directly above the plot. Typically, photo quadrat methods have involved elaborate schemes to get the camera in exactly the same position above the plot, often so that quantitative analyses can be made from the photographs (Wandas, 1986; Schwegman, 1986). For many applications, however, especially for general restoration documentation, these elaborate, time-consuming methods are not needed because extremely precise photographs that allow for quantification of the photo data are not required. A simple, cost-effective, repeatable method of visually recording the progression of a restoration project through time is all that is desired. Additionally, a map of the restoration area that shows the photo point and photo quadrat locations is also important to assist in relocating points for future monitoring.

During the summer of 1999, approximately 3400 feet of native prairie was disturbed where a water diversion pipeline was buried across a portion of the Rocky Flats Environmental Technology Site (Site). The Site is a former nuclear weapons component production facility, south of Boulder, Colorado, owned by the U.S. Department of Energy. At the completion of the pipeline burial, the disturbance area (approximately 11 acres) was drill seeded with native species and hydromulched to prevent wind and water erosion. Photo monitoring was chosen to visually document the progression of the restoration effort for Site managers and ecologists.

The goals of this monitoring were to:

- Provide photographic documentation of vegetation progression through both landscape and ground surface views
- Provide an accurate map of the restoration area and locations of photo points and photo quadrats
- Make the information available to users in an interactive electronic form using web browser technology.

METHODS

A map of the restoration area was generated by walking the perimeter with a geographic positioning system (GPS) unit. GPS data were added to the Site's geographic information system (GIS) to produce a map in ArcView (Figure 1). Seven photo locations were chosen to use as both photo point and photo quadrat monitoring locations. These locations were marked permanently with rebar and tagged with their respective location codes; then their GPS coordinates were added to the GIS map. At each photo location, a minimum of two landscape photographs were taken, in addition to a single quadrat photograph. Photographs were taken with a 35-mm SLR camera with a 35-mm wide-angle lens, using Kodacolor 100 film. Photograph information, including date, photo location code, photo aspect, lens length, and film type were recorded on a data sheet for each photograph. Landscape photographs were taken so that the horizon was visible where possible to assist in future photograph positioning. Quadrat photographs were taken using a 50×100-cm quadrat made from PVC pipe. The quadrat was positioned with its southwest corner touching the rebar (Figure 2). The 100-cm side of the quadrat was aligned east-west with a compass for repeatability. A small blackboard showing the date and quadrat number was included in the quadrat photographs. Quadrat photographs were taken standing over the center of the quadrat from the north side of the quadrat to prevent shadows. No attempts were made to precisely position the camera above the quadrat each time, because quantitative analysis was not a goal. The purpose was simply to visually document the vegetation inside the quadrat. Photographs were taken twice during 1999, once in July and again in September.

After the photographs were processed, the prints were scanned electronically. To produce the web-browser interactive display, an electronic version of the map was created in the GIS showing the restoration area and photo locations. The electronic image of the map was converted to an image map using web-browser development software such as Microsoft FrontPage98. An image map allows the user to create hot links to other documents or photos by clicking on selected areas of the image. Each photo location on the map was linked to the time series of photographs taken at that location, which had been combined into single web pages. Thus, by opening the map in a web browser, the photographs taken at each location could be viewed by simply clicking on a photo location. As more photographs are taken during 2000, these will then also be linked to the map to continue documenting the progress of the restoration effort.

RESULTS AND DISCUSSION

The use of the GPS and GIS worked very well for the production of an accurate map of the restoration area and photo locations (Figure 1). This information can be used for future evaluation of the project area. On the computer, using only a web browser, the photo point and photo quadrat photographs for each location are accessed by clicking on one of the photo locations on the map. The examples of selected time series photographs taken in 1999 (Figures 3-6), show how the photographs can depict changes in the restoration area. After only 2 months, the restoration area was already beginning to green up. As photo monitoring continues in 2000 and beyond, additional photographs can easily be added electronically to update the monitoring summary.

From a practical standpoint, many benefits can be obtained from a simple monitoring effort such as this. A minimum amount of time and effort are needed. Initial setup of this monitoring design took 3–4 hours, including taking the initial photographs. Retaking the photographs took less than 2 hours, and adding the photographs to the web pages only another couple of hours. The use of a digital camera would eliminate film and processing costs, as well as scanning time. For documenting the changes in the restoration area, photographs are very simple and easy for anyone to interpret. The use of web browser technology presents the results in a simple, easily accessible, informative, and professional-looking manner. The final product could also be used for presentations.

CONCLUSIONS

Through the use of a simple photo monitoring design it is possible to visually document, with both landscape and ground views, the progression of a restoration/revegetation project in a repeatable, cost-effective manner. The use of web browser technology can display the results in a simple, informative, professional manner, suitable for presentations and displays.

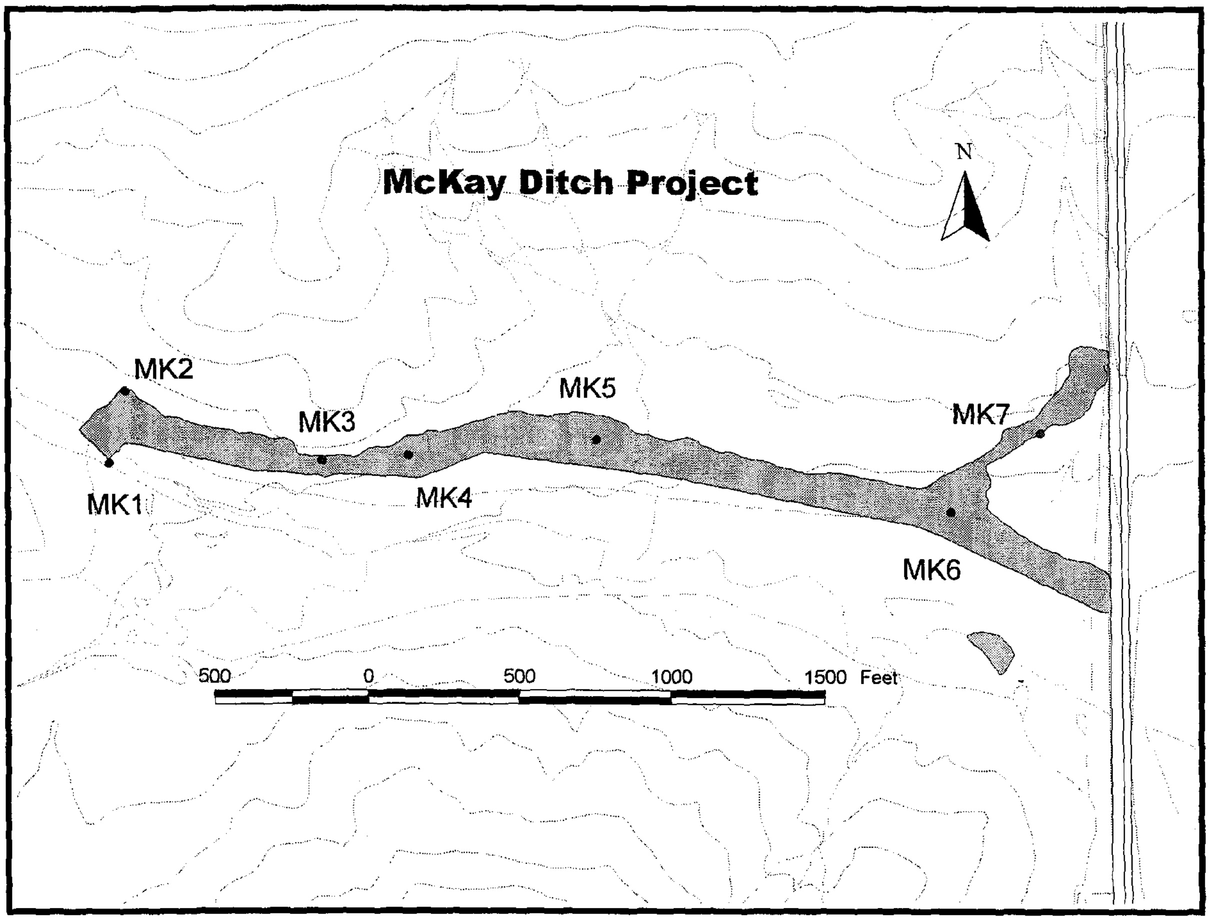

Figure 1. Map of McKay Ditch restoration area and permanent photo monitoring locations. North is towards the top of the map.

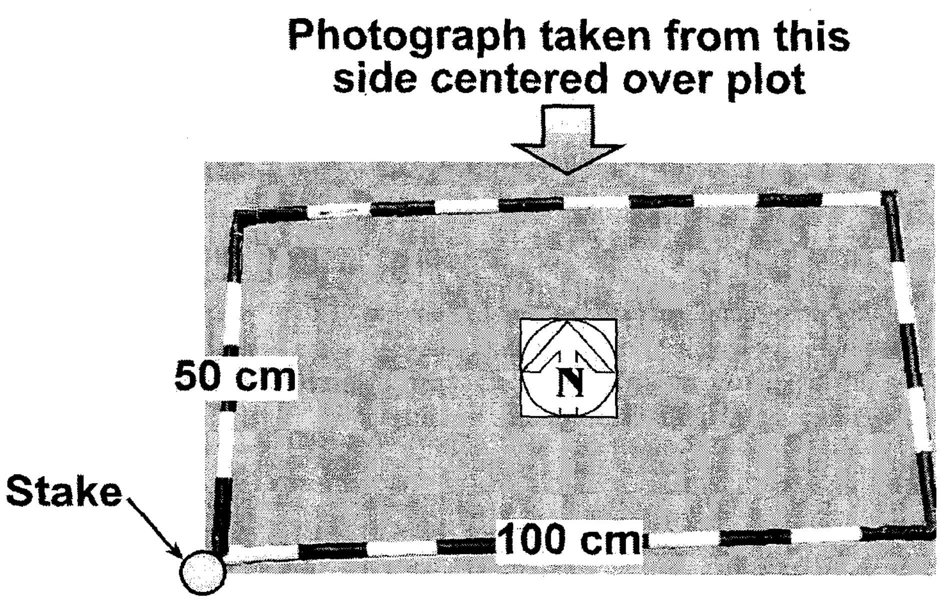

Figure 2. Photo quadrat set against the stake and aligned north-south for repeatability.

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Figure 3. Photo quadrat photographs taken at location MK2. Note how the vegetation has already begun coming up after only 2 months.

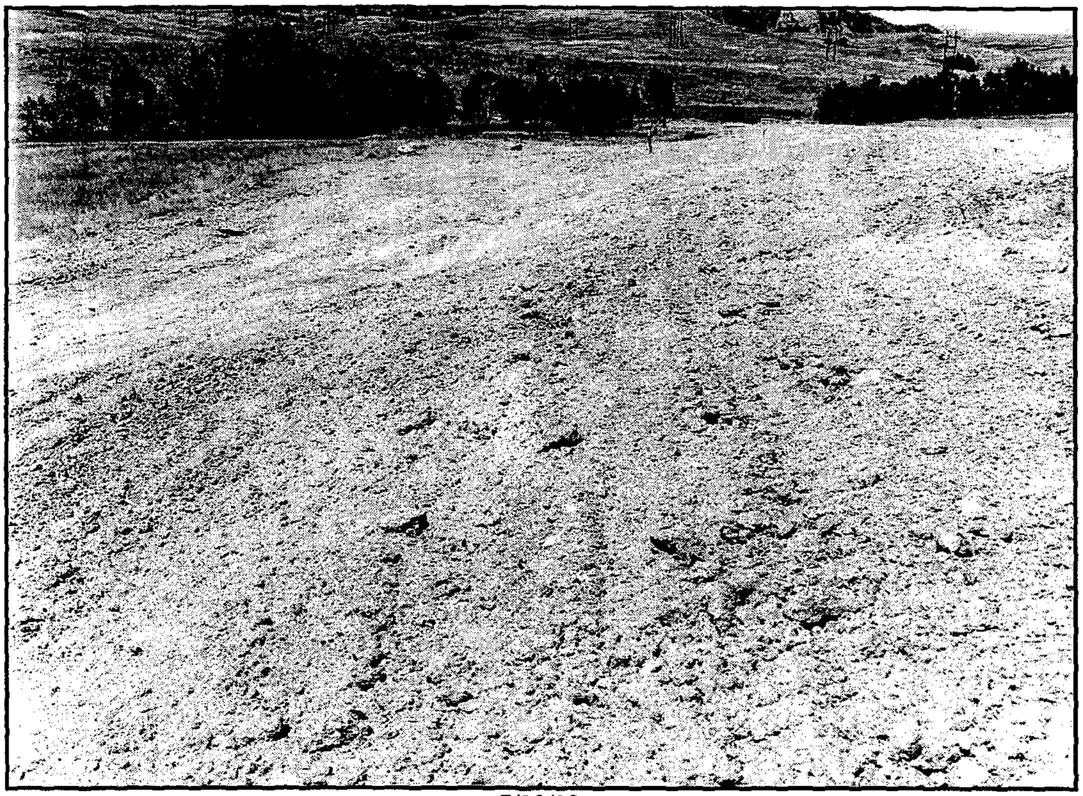
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Figure 4. Landscape photographs taken looking west from MK3.

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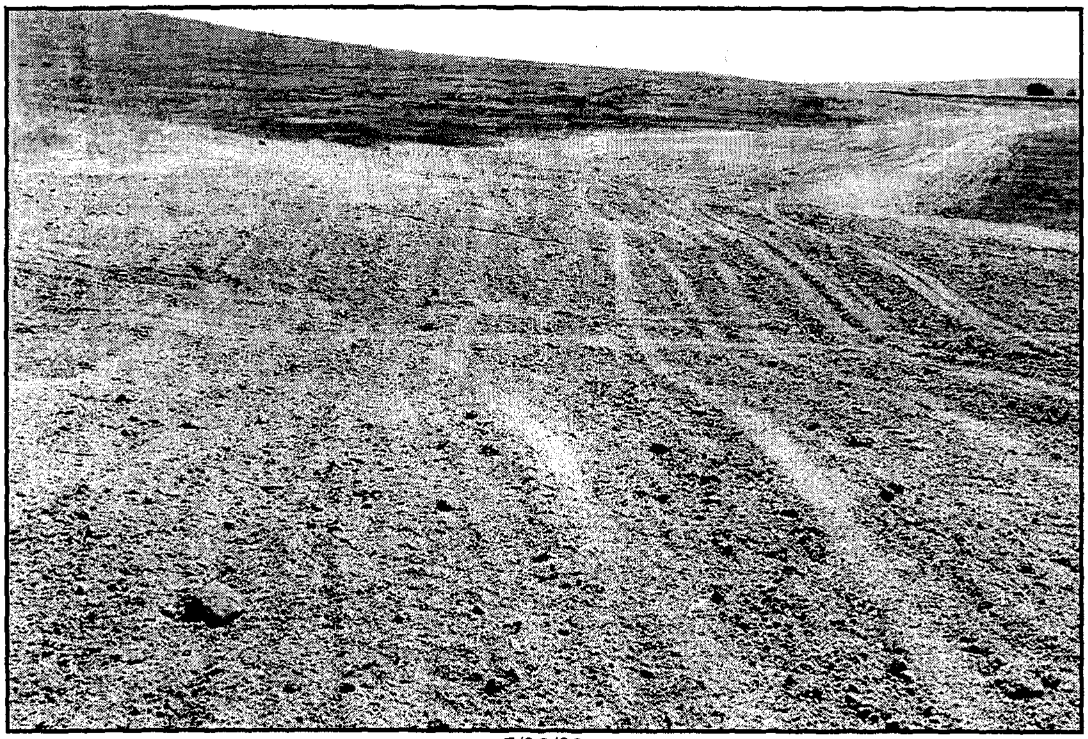
Figure 5. Photo quadrat photographs taken at MK7.



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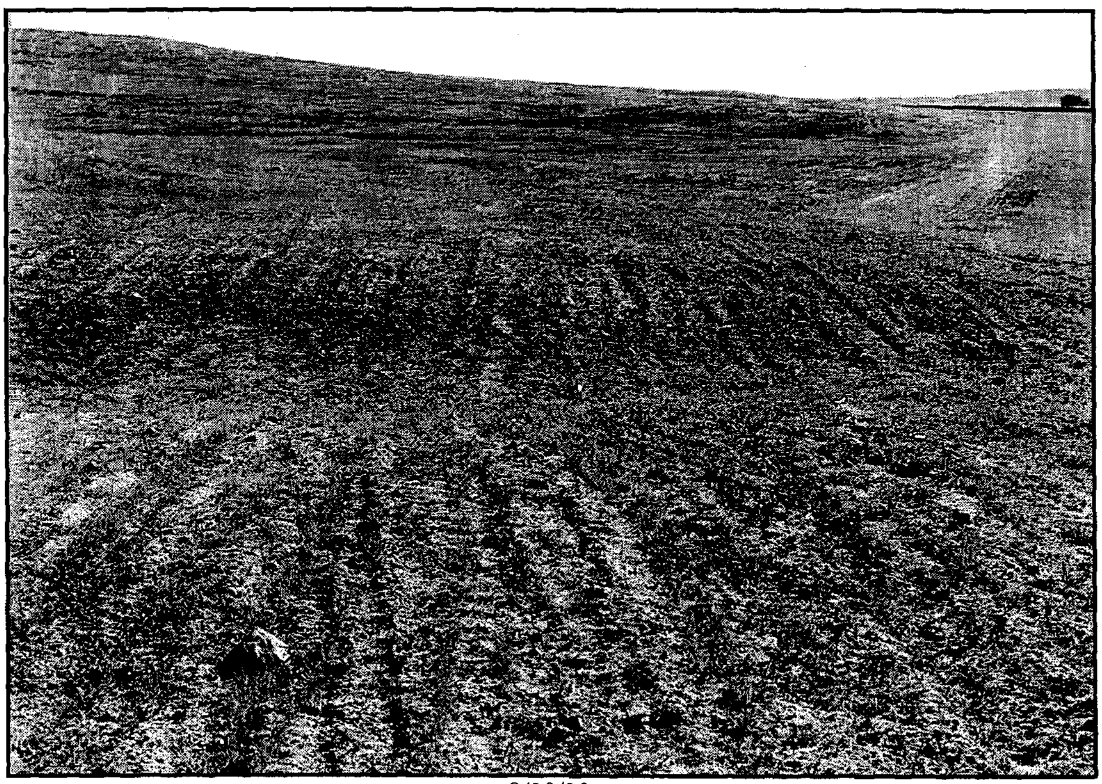

9/30/99

Figure 6. Landscape photographs taken from photo location MK4.

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COMBINED EFFORTS BETWEEN CLIMAX MOLYBDENUM MINE AND COLORADO MOUNTAIN COLLEGE FOR HIGH ALTITUDE RECLAMATION

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ABSTRACT

In the fall of 1996, Bryce Romig of Climax Molybdenum Mine, consulted with Pete Moller, Environmental Technology Professor, at Colorado Mountain College (CMC) in Leadville, CO. Climax offered CMC's Environmental Technology Program a project that would allow students to participate in producing an actual reclamation plan. The project site consists of 25.4 disturbed acres 6 miles northwest of Leadville. This site is known as the Jones Gravel Pit. The gravel pit has been in a dormant stage since 1985, and with a reclamation plan in place, Climax can start the process of reclaiming the site.

In the fall of 1996, several students started the preparations to obtain base-line data for the site. Since this time, students have incorporated the interrelationships of various environmental classes taught at CMC, and with added guidance from their professor, they were able to utilize what they had learned to their advantage.

This reclamation plan, prepared by students, was accepted by Climax, with state approval. The plan is being implemented for future students to do the actual reclamation. The students, who worked on the plan, have moved on and now work in related fields and play a major role in the world of earth sciences.

INTRODUCTION

The Jones Gravel Pit is located at Leadville Junction, six miles outside of Leadville, Colorado. The East Fork of the Arkansas River crosses the southeast corner of the property. The property consists of 80 acres in which 25.4 acres are disturbed from a sand and gravel pit operation. The history of the pit goes back to the late 1970's and early 1980's. At this time the owner Chuck Webster, who had made a major excavation for sand and gravel, then relinquished his ownership to Climax.

Climax bought the property for many uses including road construction. The Colorado State Highway Department (CDOT), has also removed sand/gravel from the pit at different times, as has Lake County for different roads and highway uses. For the last several years, Climax has been current with the permit fees so that they can in turn reclaim their $ 27,000 bond back from the state. Through out the mid to late 1980's through the mid 1990's, Climax has mainly left the pit in a dormant state.

Bryce Romig, Environmental Coordinator at Climax, came to CMC with an attractive offer for Pete Moller and the Environmental Technology program, to give students in the program, the opportunity to actually participate in the making of a real reclamation plan. As expected, several students jumped at the opportunity of gaining real on the job training. In April of 1997, a conceptual plan was submitted to Climax and was accepted as a start in the right direction.

Inside the pit are a haul road and an old sediment pond for washing down what was excavated. On the northwest and northeast corners of the pit there are three wetlands, formed from the percolation of ground water. There are signs of aquatic life and different types of vegetation growing in the and around the pit. There are several topsoil piles that has been brought in and stored for the site to be reclaimed sometime in the future. Several gravel piles also exist in the pit area.

The slopes of the pit range from 2:1 to 3:1 in some areas and at the steeper areas from vertical to 1:1. where serious erosion has occurred. The property has a variety of vegetation. In the southern section, there are willows along the East Fork of the Arkansas River along with sagebrush, forbs, and several types of grasses. In the northern section there are also a few lodgepole pines as well as different forbs and grasses.

There are several signs of wildlife in and around the pit. Elk, deer and coyote tracks are visible inside the pit. On the south wall of the pit, there is evidence of one or more badgers along with other burrowing animals. There also is a good chance that different types of fowl take advantage of the wetlands. It is certain that a wolf or wolf mix was sighted on the property.

OBJECTIVES

The objectives of this plan was to submit a reclamation plan that Climax could use either as guidelines for their own plan, or to implement the final plan that the students at Colorado Mountain College wrote. Two classes of students, between the years of 1996–1999, developed a reclamation plan for the Jones Gravel Pit. Students first had to obtain base-line data. This included various tests to determine the physical and chemical characteristics of the soil and water in the pit area. The vegetation in and around the pit was also analyzed by the point-quarter technique. All samples and data were taken back to the lab for final analysis.

Other factors played a major role in producing an accurate reclamation plan. Social and cultural factors were considered in all facets. Research and interviews were conducted with adjacent landowners as well as with the general public. Due to several different views from the community, students had to put aside issues and maintain their focus at the job at hand.
Research was also obtained regarding legal permits and other pertinent legal factors.

METHODS

Several methods were used to obtain accurate base-line data in order to obtain a firm foundation to work from. Included in these methods were research, sampling, test analysis, and fieldwork.

Research

There were many concerns from private parties, as well as the community itself, regarding the future of the Jones Gravel Pit. As far as Climax was concerned, they wanted to sell the property and let whoever bought the property carry out whatever future use they saw fit. This in turn, brought up potential conflicts between property owners adjacent to the Jones Pit and the community, who had interest in the pit for economical and recreational uses. This also brought about pros and cons related to the issues set forth.

- No action plan. Pros: lower bottom-line costs. Cons: public interest and community desires.
- Extension of a nature preserve. Pros: low environmental impact, could be developed as a wildlife observatory. Cons: desires of community.
- Motorized Bike Trail. Pros: economic revenue for the community. Containing dirt bikes to a localized area. Cons: high noise levels. High environmental impact on revegetated land (erosion, wildlife concerns)
- Non-Motorized Bike Trail. Pros: community desires to institute the National Bicycle League (BMX) into the site. Increase recreation for all ages. Economic revenue for the community (hotels, restaurants, shops) from external customers. Cons: impact on revegetated land
- Cross Country Skiing. Pros: limited environmental impact. Cons: limited size, lack of timber and shelter.
- Playground and Skateboard Park. Pros: give kids a local and legal place to use their skateboards. Cons: noise level concerns. Supervision of children and high impact on revegetated land.
- Snowmoblie Track. Pros: community recreation Cons: High environmental impact on revegetated land (high noise levels, erosion, wildlife concerns)
- Native Plant and Seed Nursery. Pros: entities doing reclamation work in the Rockies would be able to get their products locally. Cons: zoning problems and high costs.

Legal Factors

There is only one permit (112c Construction Materials Operation) that Climax has to maintain. Climax does not need a NPDES permit since there is no discharge into any waterways. No 404 permit is needed since there will be no activity in the wetland areas.

Costs

There are several different cost factors to be taken into consideration in regards to the reclamation of the Jones Pit. In order to make the reclamation of the Jones Pit economical for Climax, we put together what we felt was the best possible cost effective approach.

- The heavy equipment will be bid by a private contractor
- The topsoil from the upper A horizons on the ledges of the pit will be salvaged. There is also stockpiled topsoil on the property. With the topsoil and the sand/gravel mix, we feel that this will make a good growing medium to cover the pit. Since the pH of the soil in the pit is of a basic nature, the use of lime and other amendments should not be needed. This method of obtaining a simple growing medium will allow the soil to hold onto available water and nutrients as well as providing aeration. Only a basic mulch will be added due to the fact that the area in question is arid.
- Seed companies were contacted for prices on a selected seed mix researched for this type of climate, topography, and soil medium.
- The Buena Vista Department of Corrections was contacted in regards to making the interpretive signs for the nature trail.

- Companies were contacted on the purchase price of four hand broadcaster seed slingers.

Wetland Delineation

An entire wetland delineation report of the three wetlands in the pit was prepared by an outside consultant, Maureen O'Shea-Stone.

Sampling and Test Analysis

Several soil and water samples were taken from in and around the perimeter of the pit.

Soil Sampling

Twenty soil samples from 5 different areas in the pit were taken and placed in sample containers and taken back to the lab for chemical analysis. The samples were mixed together to get a homogenous blend. The LaMotte Soil Test Kit was used to determine amounts of available nutrients needed for plant growth. The Soil Survey of Chaffee-Lake County Area, Colorado, was used to determine what the soil series is at the Jones Pit.

Water Sampling

Water samples were taken from three wetlands and from the flow of surface water going into the wetlands. The water analysis tests were performed on site using a HACH Water Test Kit. The pH, temperature, and several water properties tests were recorded.

Field Work

A point quarter vegetation sampling technique was done to determine the species, dominance, frequency, and total composition of cover. Measurements were counted and recorded for a statistical analysis.

The entire disturbed area (25.4 acres) of the pit was surveyed in the fall of 1997. There was a total of four reference points. A total of 351 shots were recorded using the Theodolite and EDM guns. This data was taken back to the drafting tables and the points were calculated and plotted on surveying paper. A topographic map of the disturbed area was completed after all data was recorded. A topographic map was also created using the CAD computer program.

RESULTS

Soil Properties

Available Nutrients	
Soil Attribute	**Amount or Value**
Humus	Medium
pH	7.8 su
Ammonium Nitrogen	Very Low
Nitrate Nitrogen	20 lbs/acre
Nitrite Nitrogen	1 ppm
Available Phosphorus	150 lbs/acre
Chloride	25 ppm
Available Potassium	300 lbs/acre
Replaceable Calcium	1000 ppm
Magnesium	Low
Sulfate	50 ppm
Available Manganese	Medium Low
Active Aluminum	Low
Ferric Iron	15 lbs/acre
Organic Matter	2.53%
Soil Texture	Gravel 15%
	Sand 77%
	Silt and Clay 8%

Water Properties

Wetlands and Stream	
Attribute	Amount or Value
Dissolved Oxygen	7 mg/L
Alkalinity	5 mg/L
Hardness	11 grains/gal
Average Mean Temperature	7°C
pH	7.5 su

Point Quarter Vegetation Analysis

The cover is dominated by big sagebrush (*Artemisia tridentata*), elk sedge (*Carex geyeri*), and nodding brome (*Bromus porteri*). There are also other species of grasses, sedges, rushes, forbs, shrubs, and an occasional lodge pole (*Pinus contorta*). There are also noxious species that inhabit the pit area.

Vegetation Totals	
Unit Area	18,500 sq. ft.
Cover	81.9%
Species	61
Total Composition	97.9

Wetland Habitat

Wetlands created by mining provide habitat for waterfowl and many species of aquatic wildlife. Narrow leaf elder and cattail are prominent in the wetland areas. A low diversity of biota was found including, protozoa, stone flies, and various other microorganisms. The groundwater that feeds the wetlands shows no detrimental effects from the mining operations.

RECLAMATION COST ESTIMATES

Company Name & Address	Quantity Needed	Price Per Unit	Total Price
ITEM: Seed Slinger	4	$240	$960
Truax Company, Inc. 4821 Xerxes Ave. N Building B Minneapolis, MN 55422 (612) 537-6639			
ITEM: Straw Blower	1 for 2 days	$200/day	$400
ITEM: Erosion Blanket (8' x 67')	10 rolls	$36/roll	$360
Revex Revegetation Exchange, Inc. P.O. Box 208 Hygiene, CO 80533 (800) 666-4050			
ITEM: Straw Bales	1,666	$2.50	$4,165
ITEM: Solar Power for Electric Fence (12 volt, 3 mile range)	1	$111.12	$111.12
ITEM: Wire for Fence	3 miles	#31.80/mile	$95.40
ITEM: 8' Steel Fence Posts	25	$2.75	$68.75
ITEM: Clips for Wire	24	$0.50	$12.00
Mountain Feed and Coal US Hwy. 24 Leadville, CO 80461 (719) 486-3566			
ITEM: Heavy Equipment (Labor & Transport)	1	$200,000	$200,000
KC Excavation 123 Hwy. 91 Leadville, CO 80461 (719) 486-2597			

ITEM: Interpretive Signs for Nature Trail

Buena Vista Correctional Facility (Contact, Capt. Gary Puckett, (719) 395-2404)

The Buena Vista Correctional Facility can make the signs for the proposed nature trail at the Jones Pit. If the project at hand is for a non-profit entity, the facility will more than likely do the signs for little or no money. They may only ask for the cost of the materials.

ITEM: Selected Seed Mix	1	$2551.00	$2551.00

Western Native Seed Company
P.O. Box 1463
Salida, CO 81201
(719) 539-1071

Selected Seed Mix

The following is a selected seed mix that was researched to grow at 9900 feet above sea level in a Tomichi sandy loam. The price per pound is included:

FORBS		
Achillea lanulosa	Western Yarrow	$60/lb
Cleome serrulata	Rocky Mountain Beeplant	$28/lb
Delphinium ramosum	Showy Larkspur	$100/lb
Epilobium angustifolium	Fireweed	$640/lb
Ligusticum porteri	Lovage	$480/lb
Lupinus argenteus	Silver Lupine	$80/lb
Potentilla gracilis	Slender Cinquefoil	$320/lb
Sedum rosea	Rose Stonecrop	$5/gr.
Thermopsis montana	Golden Banner	$50/lb
GRASSES, SEDGES, RUSHES		
Agropyron smithii	Western Wheatgrass	$12/lb
Agropyron spicatum	Bluebunch Wheatgrass	$20/lb
Andropogon gerardii	Big Bluestem	$16/lb
Bouteloua gracilis	Blue Grama Grass	$24/lb
Carex aquatilis	Aquatic Sedge	$300/lb
Carex rostrata	Beaked Sedge	$100/lb
Deschampsia cespitosa	Tufted Hairgrass	$20/lb
Festuca brachyphylla	Alpine Fescue	$28/lb
Hilaria jamesii	Galleta Gross	$28/lb
Phleum alpinum	Alpine Timothy	$18/lb
Sitanion hystrix	Bottlebrush Squirreltail	$40/lb
Sporobolus airoides	Allcali Sacaton	$12/lb
Sporobolus cryptandrus	Sand Dropseed	$14/lb
TREES, SHRUBS, WOODY PLANTS		
Chrysothamnus nauseosus	Rubber Rabbitbrush	$8/lb
Fallugia paradoxa	Apache Plume	$42/lb
Philadelphus lewisii	Mockorange	$3/gr.
Pinus contorta	Lodgepole Pine	$55/lb
Potentilla fruiticosa	Shrubby Cinquefoil	$48/oz

TOTAL RECLAMATION COST FOR THE JONES GRAVEL PIT____$208,723.27
RECLAMATION COST BREAKDOWN_____$8,217.45/acre

STEPS AND PROCEDURES FOR RECLAMATION OF THE JONES GRAVEL PIT

The first step in the plan is the surface and subsurface preparation. Climax or an outside contractor will bring in heavy equipment. The topsoil will be removed from the top of the slopes and stockpiled with the existing piles on the outside perimeter of the pit. After all topsoil has been moved, the heavy equipment will then bring down the steep slopes to a 4:1 or 5:1 contour. This soil that is removed will be used for the subsurface of the pit area. The steepest slope on the north face of the pit will be benched. After the slopes are cut down, the heavy equipment will then grade and contour the entire pit back to a natural state. The soil will then be compacted and certain areas will be remodified to allow for natural drainage. No other surface or subsurface drainage should be needed for this project. The most important factor to consider with the surface preparation is to avoid disturbing the wetland areas.

After the surface preparation is complete, the topsoil will be mixed with the sand and gravel piles that remain on site. This should provide for a sufficient soil medium that will sustain plant growth and allow for good drainage. The topsoil will then be used for a surface cover over the entire pit area. There should be enough topsoil on site to cover a depth of 4 to 6 inches. No other fill material should be needed. After the final cover is complete, the seed can then be sown. The soil tests that were done show that this soil medium has most of the available nutrients needed for plant growth. The seed can be sown with the hand broadcaster. Using this method will help to eliminate further compaction caused by a hydroseeder. Species selection can also be controlled better. Certain species can be planted in a specific area. After the seed has been sown, the straw can be applied with a straw blower. After the straw has been applied, Climax can use their own implements to crimp the straw into the soil. There should be no need for irrigation. The seed will be planted in the fall so that it can obtain moisture from the winter and spring snows. The ground water supply and the soil medium should also help the plants obtain water.

After the final reclamation of the pit is completed, an electric fence will be put in place. This will prevent larger animals from grazing on the new growth. This fence should be kept in place for three years so that vegetation has a chance to get fully established. After this time, the fence can be removed if the vegetation is holding its own.

One of the major steps in this plan is on going maintenance. Weed control may be needed to keep out noxious weeds, like Canadian Thistle. Reseeding the pit area may need to be done. The fence and solar power source should be checked frequently. Trespassing is also another problem that may need to be monitored more closely. The maintenance and monitoring of the reclamation will be an on going project for years to come.

After all reclamation work is completed and good vegetative growth is established, the nature trail can then be made. Large rocks that are on site can be utilized, outlining the trail borders. The interpretive signs can be installed and final touch-ups can be made. The nature trail and preserve can then be opened to the public.

CONCLUSIONS

After gathering all the baseline data and reviewing all the different angles pertinent to the Jones Gravel Pit, we put together the final reclamation plan for Climax. One of our main goals in this project was to make the reclamation as simple as possible and to avoid any unnecessary costs. Another goal is to return the Jones Pit back to its natural state.

Our proposed plan for the Jones Pit is to make it into a nature trail and wildlife preserve. We feel this is the most logical decision for this area. The beauty that surrounds the pit is an experience all in itself, not to mention the abundance of wildlife that dwell in and around the pit. Once the reclamation is completed and vegetative growth is well established, visitors from all over will be able to enjoy the nature, wildlife, and historical aspects this area has to offer.

The nature trail will be made as natural as can be. Large rocks will border the trail, not only for looks, but to keep visitors on the trail itself. This trail will wind in and around the pit area. The wetland areas will also have trail access so that visitors can enjoy the abundance of waterfowl that inhabit the area. Along the trail will be interpretive signs informing visitors of points of interest, the many types of vegetation growing, historical facts about what the area was in the past, and information about the reclamation itself. This trail will be a nature lover's paradise. The highest mountain peaks in the continental United States surround the area. These mountains are the beginning of the upper Arkansas Valley, in which its waters flow east, to the Gulf of Mexico. This area also has a wide diversity of plants and animals. There is a parking lot with public restrooms already on site. Picnic tables can be put around the borders of the parking lot so that visitors can enjoy a snack before their journey. This nature trail will be for foot traffic only. In the winter months, many can enjoy snowshoeing and cross-country skiing.

Once again, the main goal is to keep this project simple and economical for Climax. There major concern is to get the reclamation completed so that they can get their bond back from the state and sell the property as they wish. One way that Climax can cut reclamation costs considerably is by using their own equipment. Another cost efficient practice would be to utilize the students at CMC to do the seeding, put the erosion control materials in place, put up the fencing, and to actually build the nature trail. Students in the Environmental Technology program in the years to come can also do the follow-up work that may be needed. This will not only help Climax out, but students can utilize what they have learned plus understand the interrelationships from the variety of classes offered in the Environmental Program. Students may also have the opportunity to pursue an independent study or an internship working on the Jones Pit project. This will allow students actual, hands-on experience in the field of reclamation.

- When Climax introduced the idea of CMC's participation in the actual reclamation of the Jones Gravel Pit, the faculty and several students took this proposal very seriously. Since 1996, students have put forth an enormous effort to make sure a feasible reclamation plan can be implemented. Now that we have completely familiarized ourselves with all aspects of this project, we feel that CMC students should be able to follow through with the work until reclamation has been accomplished. As students, we would like to thank United Rentals Inc. for the use of heavy equipment, the faculty for their guidance and support, and most of all to Climax for the challenge and opportunity.

A DIFFERENT APPROACH TO HIGH ALTITUDE REVEGETATION: ESTABLISHING MOSSES ON THE GRASBERG OVERBURDEN, IRIAN JAYA

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ABSTRACT

P.T. Freeport Indonesia (PTFI) will have about 900 ha of overburden stripped from the Grasberg copper mine in Irian Jaya (4°S 137°E, altitude ~4000m). PTFI wish to revegetate this overburden with native species found growing on nearby habitats.

However, low levels of organic matter and plant nutrients, pH extremes, the presence of heavy metals, and the difficult environment all hinder plant establishment. An initial site examination indicated that mosses could be useful as initiators of plant succession on the overburden:

- Mosses were among the first plant colonizers of newly-exposed surfaces;
- Vascular plants appeared to establish successfully through moss mats;
- Mosses established first in "safe" sites, particularly in the shelter of large rocks;
- Temperatures inside a moss mat averaged 1°C higher than on the adjacent scree surface;
- Some mosses were growing on soils with extremely low pHs (e.g. 2.5).

Mosses are known to be tolerant of heavy metals. Many researchers have noted mosses naturally establishing on mining overburdens, but no one appears to have developed methods to enhance this process.

Trials using moss fragments have been established in the field and in a New Zealand controlled environment room. Protocols for revegetation using mosses are being developed.

INTRODUCTION

P.T. Freeport Indonesia (PTFI) will have about 900 ha of overburden stripped from the Grasberg copper mine in Irian Jaya (4°S 137°E, altitude ~4000m). PTFI is committed to the use of native plants found growing on nearby habitats, due to proximity of Lorenz National Park. However, plant establishment is hindered by a number of factors. The climate is cool, with mean maximum temperatures ranging between 7 and 12°C and mean minimum temperatures ranging between 2 and 6°C. Frosts are possible throughout the year. Rain occurs on about 80% of the days and the light available for photosynthesis is low. The overburden material has negligible organic matter, high heavy metal concentrations, low nutrient content, and some portions have very low pH (Table 1).

Natural revegetation is very slow in these conditions, and hand planting of native species (e.g. *Deschampsia klossii*) has been time consuming, expensive and not always very successful. Germination of native species has so far been very low (e.g. less than 2% germination for *Deschampsia klossii*). It is not practical to incorporate topsoil or mulches into the overburden surface because of difficult access and lack of a local supply.

Table 1: Characteristics of rocktypes used on Grasberg overburden

	Limestone	Mildly acid-generating diorite	Strongly acid-generating diorite
Acid generation (kg/ton)	0	0-35	35-60+
Total P (%)	0.012	0.28	0.19
Total N (%)	0.04	0.04	0.04
Mg (%)	0.27	1.7	0.87
Ca (%)	40	0.22	0.24
Na (%)	0.08	0.15	0.13
K (%)	0.05	1.96	2.53
Al (%)	0.16	4.2	6.4
Fe (%)	0.33	4.0	3.8
B (ppm)	2.7	16	7.7
Co (ppm)	4.4	25.9	18.5
Cu (ppm)	12	1920	730
Mn (ppm)	600	110	72
Zn (ppm)	11	85	460
pH	8.9	8.6	4.9

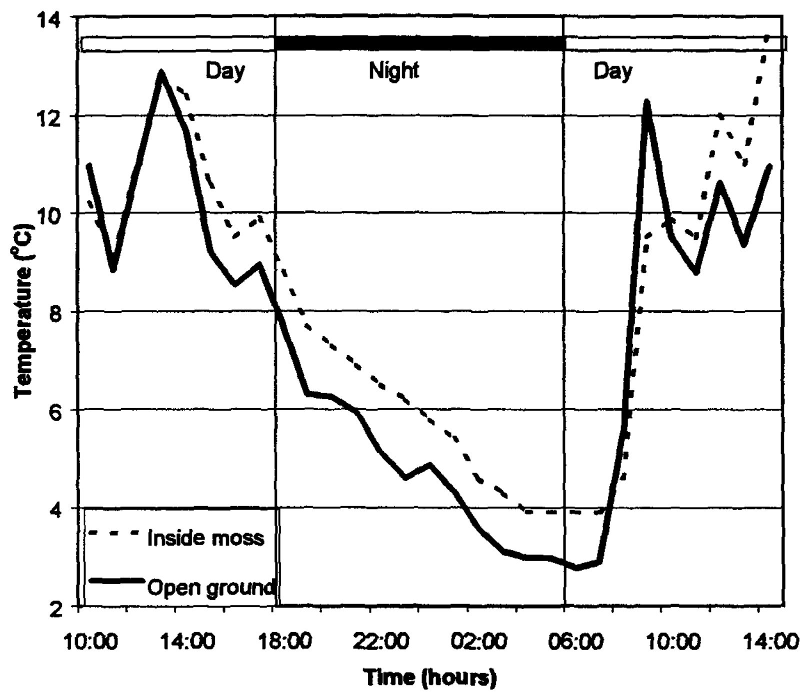
WHY USE MOSSES FOR GRASBERG REVEGETATION?

Engelman & Weaks (1985) suggested the idea that mosses could be used in an initial revegetation plan, but there appears to be no record of this being attempted. Mosses are common colonizers of metal-contaminated habitats (e.g. mine tailings) and survive in some of the most toxic of microsites (Shaw, 1990). Shaw (1990) reports that gametophytes of several mosses accumulate about 5 to 10 times the concentration of iron as grasses and 2 to 3 times the concentrations of copper, zinc and manganese, when grown under the same conditions. During & Van Tooren (1990) and Sohlberg & Bliss (1984) observed that mosses assisted the establishment of vascular plants in many cases. Others have suggested that establishment of a moss mat could contribute to soil formation (Arnold & Gobat, 1998). Miller (1991) commented that early establishment of ground cover plants such as the mosses and lichens would do much to provide a seed bed suitable for naturally recruited plants at the PTFI mine site.

An initial site examination indicated that mosses could be useful as initiators of plant succession on the Grasberg overburden:

- Mosses were amongst the first plant colonizers of newly-exposed surfaces, e.g. Two years after a slip occurred, mosses were virtually the only plants established;
- Vascular plants appeared to establish successfully through moss mats e.g. plants growing through moss at one site included *Anaphalis, Epilobium, Cyathea, Coprosma, Deschampsia, Rhododendrons* and *Acaena*;
- Mosses established first in "safe" sites, particularly on the downhill side of rocks and in the shelter of large rocks. On scree slopes, the establishment of mosses stabilised the ground and trapped silt, soil and vascular plant seeds;
- Mosses grew successfully on rocktypes with high levels of heavy metals (Table 1);
- Some mosses could tolerate low pH levels e.g. *Splachnobryum c.f. novae-guineae* was growing successfully on rock with pH 2.5;
- Temperatures inside a moss mat averaged 1°C higher than on the adjacent scree surface, ameliorating the environment for germinating vascular plants (Fig. 1).

Figure 1: Temperatures inside a moss mat and on the adjacent scree surface.



REVEGETATION TRIALS USING MOSSES

1. Controlled environment trials

Trials on utilising moss for revegetation on Grasberg overburden are being conducted in the National Climate Laboratory in Palmerston North, New Zealand. The conditions in the controlled environment rooms were based on 5 years of meteorological data at the Grasberg mine. The daily maximum/ minimum temperatures were 10/4°C (±0.5°C), with the day/night and night/day temperature changeovers taking 6 and 2 hours respectively. The daily maximum/ minimum relative humidity levels (RH) were 100/85%, with the day/night and night/day changeovers taking 6 and 2 hours respectively. The night/day RH changeover began when the temperature reached 10°C. The lights were on for 4 hours at 680 µmol m^{-2} s^{-1}, then dropped to 220 µmol m^{-2} s^{-1} and remained at that level for 7 hours. Fine misting was applied to the pots for 10 hours, on a cycle of 6 seconds on and 60 seconds off. This was calculated to provide approximately 10 mm rainfall per day.

Screening trials

Aim: To identify a restricted number of promising protocols for subsequent testing at the mine site. The trials enabled a large number of combinations to be tested including:

- Moss species (tested individually and two species combined together);
- Rocktypes;
- Propagation methods;
- Nutrient application;

- 'Seeding' densities;
- The use of covers (straw or mesh);
- Mixing the moss with hydroseeding stickers.

Results

- On some treatments, there was good moss growth evident within 11 weeks;
- After 23 weeks, significant differences amongst treatments enabled some combinations to be identified for further evaluation;
- Moss species performed differently on different rocktypes;
- *Racomitrium subsecundum*, *Splachnobryum c.f. novae-guineae* and *Bryum spp.* showed the best establishment on the Grasberg overburden rocktypes;
- *Racomitrium subsecundum* growth after 11 weeks was poor but it was one of the best performing mosses after 23 weeks;
- Chopping the moss into small fragments using a food processor, together with drying the moss either before or after chopping, appeared to be beneficial;
- Whilst the application of nutrients had little effect in general, the high level of leaching may have removed any influence of the nutrients at an early stage in the experiment. Long-term slow release fertilisers may be more likely to show effects;
- There was a positive effect from addition of pellets of a sewage sludge by-product, which could be due to an enhancement of biological activity;
- There was no advantage in using straw or mesh in the controlled environment trials, but jute matting would be worth testing in the natural environment;
- Doubling the density of moss fragments generally resulted in more than double the area of moss established.

Development trials

Aim: To determine the potential of biological elicitors to enhance moss growth and to determine whether these moss species are generally tolerant to heavy metals or have metal-tolerant ecotypes. Established in December 1999. Trials are currently in progress.

2. Field trials

The main approach to speeding up moss establishment is to distribute moss fragments onto the overburden surface. Field trials were established in November 1999 on 3 overburden types, based on results from the screening trial results. Trials are currently in progress.
Factors being considered:

- Slow release fertilisers;
- Biological elicitors;
- Moss species;
- Surface roughness or use of jute matting;
- 'Seeding' density (volume of moss fragments applied to 1 m^2);
- Addition of vascular seeds.

DISCUSSION

The environment at Grasberg appears very suitable for moss establishment and observations indicate that this would enhance plant succession. The controlled environment trials suggest that using moss fragments would speed the establishment of moss considerably as long as suitable protocols were used. In particular, selecting moss species suitable for propagation by fragments and suitable for a particular rocktype is vital. Field trials need to be evaluated before the development of further revegetation phases. A possible revegetation programme would proceed as follows:

- Prepare the overburden surface to provide a diverse landscape including hummocks, hollows and a range of rock sizes;
- Apply the moss fragments and biological enhancers and/or slow release fertilisers (and possibly vascular seeds);
- Once mosses have established (e.g. after 12 months), spread vascular seeds (and fertiliser) by helicopter if not previously applied, and/or plant small "islands" of vascular plants (e.g. 1-2% of area) to provide seed sources for further plant establishment;
- In areas where there has been no moss establishment, it may be necessary to test the soil pH and apply moss fragments and/or plant with mosses specifically adapted to that pH (e.g. *Splachnobryum c.f. novae-guineae* for very low pH). Alternatively, if considered worthwhile, overburden of a different pH (or even topsoil) could be applied to specific small areas along with moss fragments and/or vascular plant seeds.

In other countries, where it is easier to modify the topsoil for vascular plant establishment, the need for utilising mosses may not be as great. However, mosses usually play an important role in alpine ecosystems, particularly where there are high levels of heavy metals. As part of a revegetation programme, speeding the establishment of mosses by using moss fragments of suitable species, at least in small pockets, may be a positive step towards restoring a balanced alpine ecosystem. Mosses may also be useful in revegetation of steep rocky roadside cuttings, where establishment of other plants is difficult.

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METAMORPHOSIS OF A HIGH MOUNTAIN STREAM
BRUSH CREEK RESTORATION PROJECT
SNOWMASS VILLAGE, COLORADO

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ABSTRACT

Brush Creek has a long history of water quality problems caused directly and indirectly by anthropological impacts. Additionally, natural background levels of bedload and suspended sediment would be considered high due to the large area of Mancos shale that underlies the watershed. Water quality was severely impacted by storm water drainage runoff from the Brush Creek Road and from the parking lot paralleling the streambanks. In addition, the most severe impacts to water quality was from the sediments scoured from the unstable stream banks towering over the incised stream channel. Water quality sampling and monitoring of the stream channel concluded that the stream banks were the most significant contributor of suspended sediments to the stream during the spring runoff period. The primary challenge of the project was to effectively integrate ecological restoration with community recreational opportunities within the watershed. The incised channel was raised ten feet in some areas and eroded upland landforms sloped back, reconnecting the stream with its abandoned flood plain. In addition, sediments levels have been reduced, streambanks have been stabilized resulting in a notably improved aquatic environment, as shown by a significant increase in macroinvertebrate abundance and diversity.

INTRODUCTION

Brush Creek is a small, high mountain tributary of the Roaring Fork River within the Upper Colorado River Basin. The headwaters of Brush Creek originate on Mount Baldy in the Elk Mountain Range and flows seven miles northwest to its confluence with the Roaring Fork River near Woody Creek, Colorado. The stream transitions from a A1a and A2a on Mount Baldy to a B3 channel in the lower reaches of the valley. Normal stream-flow ranges from 10 cfs to 43 cfs and the 100-year average is 400 cfs.

Mount Baldy is also the home of the Snowmass Ski Area with the community of Snowmass Village located at the base and along the Brush Creek Valley. Snowmass Village is located approximately 180 miles west of Denver and eight miles west of Aspen, Colorado. The ski area based economy expanded from Aspen to the Brush Creek Valley in 1967. Agriculture dominated the landscape prior to the ski industry's prominence in the valley. Brush Creek's hydrological modifications began when the agricultural community moved into the valley in the late 1800's to produce food for the growing mining community of Aspen.

With the expansion of the ski industry from Aspen into Brush Creek, the agrarian character of the valley began to change. Construction of new roads, hotels, lodges, large parking lots, removal of hillside vegetation for ski trails and culverting of stream crossings contributed to changing patterns in natural drainage courses and increased the overall volume of drainage during spring runoff and during significant weather events. Adjustment of drainage patterns and volume caused considerable impact to the natural channel characteristics of Brush Creek. The stream incised as much as 12 vertical feet through the underlying and highly erosive Mancos shale formation. Eroding below the protection of deep-rooted riparian vegetation, the stream began moving laterally under the abandoned flood plain.

During the early stages of ski resort expansion, the Snowmass Village population was largely seasonal, increasing with the opening of the ski area and dropping off to levels that could be characterized as a modern ghost town at the end of each ski season. Not many were present to witness the gradual degradation of the Brush Creek stream corridor.

The population base increased and extended beyond a single season as more visitors came to the valley and discovered the serenity of the other three seasons. Higher demand for year-round housing started transitioning Snowmass Village from a winter resort to year-round community. With the increased year-round population came awareness and sensitivity to the impacts on the valley's natural resources. The community members began promoting values that encouraged preservation and corrective stewardship of the local natural heritage (Ben Thompson & Associates).

The Town Council hired a professional design firm to help the community re-evaluate the way the town was developed and identify ways to functionally and aesthetically correct the impacts created over the past thirty years. The design firm developed a community enhancement plan called <u>A Road, A Creek, and a Community in Maturation</u> (Ben Thompson & Associates) which provided Council with the necessary conceptual guidance. The plan encouraged the community to recognize and appreciate the presence of Brush Creek as a community asset and begin respecting, restoring, and managing the stream corridor. The plan served as the justifying basis for appropriating funds in 1993 to begin studying the stream corridor. The stream study identified and analyzed the stressors on the stream corridor that led to developing recommendations for proper corrective measures for future enhancement projects.

PROJECT DESCRIPTION

True restoration of Brush Creek is not achievable because of encroachment into the stream's flood plain by roads, parking lots and building structures. Restoration in the true sense of the term would require relocating these features making the project unaffordable and politically unpopular. Therefore, the term "restoration" is used in the sense of restoring hydrological stability and ecological viability to the stream corridor.

Studies were conducted over a three-year period to develop a thorough understanding of how the stream functioned naturally and the development impacts that caused the stream to adjust to the condition as it is presently found. Studies included the physical analysis of the existing stream channel, monitoring of the annual hydro-graph, land use impacts, water quality sampling, and assessment of the aquatic biology.

After the three-year study period, the Town had the information needed to begin designing and implementing stream improvement projects. Being located in a quasi-urban resort based community, the stream projects included improvements that extended beyond traditional natural resource restoration. In addition to correcting the impacts to the stream, the Town was interested in creating small, passive pocket areas along key locations within the community that include recreational access trails, picnic tables, park benches, and environmental interpretive displays.

The first project was designed and implemented in 1995, which involved stabilization of 400 feet of eroding stream bank along a stream reach that flowed by the Snowmass Chapel and Community Center. The project being centrally located near a community focal area provided the Town Council with a model project demonstrating the value of stream restoration projects to the community. This project also included the park-like amenities that interested the Town Council, including an environmental interpretive display explaining the importance of such projects. The enhanced area was named Yarrow Park and was funded in part by a Great Outdoor Colorado Grant. The project was awarded a Grand Award by the Associated Landscape Contractors of Colorado in 1997.

The first project stabilized and enhanced only four percent of the stream corridor located within the Snowmass Village Town boundaries, but was critical to garnering public support for future projects. Constructing the first project in a highly visible location and receiving an award recognizing the efforts of the community cultivated the political will to move onward to the next challenge.

The second project is located 600 feet upstream from the Yarrow Park project and encompassed 980 feet of stream corridor. This reach of stream was considered one of the more heavily impacted. The stream corridor is constrained on one side by the primary arterial in Snowmass Village, appropriately named Brush Creek Road, and on the other by a multi-family residential development parking lot. The stream had eroded downward twelve feet and as much as eleven feet laterally. Water quality was severely impacted by storm water drainage off of Brush Creek Road and from the parking lot paralleling the other bank. While the storm water drainage heavily impacted the water quality, the most severe impact to water quality was the sediment scoured from the unstable stream bank towering over the incised channel during high water. Water quality sampling and monitoring of the stream channel led to the conclusion that the stream bank was the most significant contributor of suspended sediments to the stream during the spring runoff period (May through June).

The findings of the study served as the basis for seeking financial assistance from the Colorado Non-Point Source Task Force. The Town applied for a Non-Point Source 319 grant sponsored by the U. S. Environmental Protection Agency and administered by the Task Force. The Town was successful in their application and received a grant for $142,500 in 1996. The grant was critical for the continuance of the second stream project. The Town appropriated the necessary matching funds in 1998 and construction began in late September of 1998.

WATER QUALITY AND HYDROLOGY DATA

Brush Creek has a long history of water quality problems. Natural levels of bedload and suspended sediment would be considered high due to the large area of Mancos shale that underlies the watershed (Earth Resource Investigations, 1998). This coupled with other urban, recreational and agricultural activities in the watershed have placed Brush Creek at the top of the list as a sediment producer in the

Roaring Fork Watershed. The Water Quality Control Commission has classified Brush Creek as "Aquatic Life Class 2" and "Use Protected". This is a step down from other tributaries in the watershed.

The objective of the 1998 Earth Resource Investigations study was to identify problem areas and main sources of sediments within the watershed. This study addresses the following areas:

1. Suspended sediment, bedload and discharge in Brush Creek.
2. Suspended sediment from various land use activities.
3. Bank erosion within the main stem of Brush Creek.

HYDROLOGY DATA

Data collection began in the spring of 1993 with the collection of bedload, suspended sediment and streamflows at a site adjacent to the Snowmass Chapel referred to as the Yarrow Park Staff Gauge (NP-7)(Earth Resources, 1998). The Yarrow Park Gauge on the main stem of Brush Creek drains approximately 2,196 acres. Elevations range from 8,160 to 10,620 feet. Data collections focused on spring runoff, snowmelt, and rainfall events.

Similar flows regimes were observed at the Yarrow Park Site (NP-7) during 1994, 1996, and 1997. Streamflows increased to approximately 40 cfs during runoff (May through June) and decreased to less than 10 cfs during the summer. Higher streamflows were observed during the 1995 runoff, streamflows ranged from 50 cfs to 88 cfs in June. Lower streamflows of less than 10 cfs were recorded from August to October (Earth Resources, 1998).

Suspended Sediment and Bedload

Suspended sediment data collected showed that bedload and suspended sediment levels in Brush Creek are directly related to streamflows and are considered high for a stream of this size, when compared with data for other streams in the Rocky Mountains. For example, in June 1995, Brush Creek carried 126.15 tons of suspended sediment and 29.2 tons of bedload, with a streamflow of 70 cfs. Under lower streamflows (51.5 cfs, May 1996), suspended sediment was 73.35 tons and bedload was 13.2 tons per day. The Roaring Fork River, at streamflows of 484 cfs, may only carry 25 tons of suspended sediments, likewise, West Tenmile Creek, at 61 cfs, will carry 11 tons and East Middle Fork Parachute Creek, at 41 cfs, will carry 11 tons of suspended sediments (USGS Database).

A total of 24 land uses were sampled from March 1994 through May 1997. The sediment production figures from land uses were consistent with those for other studies of mountain resort areas. The main sediment producers (Producers Figure) are as follows:

1. Construction Sites.
2. Unpaved parking.
3. Unpaved roadside ditches.
4. Ski runs.
5. Unpaved roads.

These sediment producers are activities that relate to recently disturbed soil with little or no erosion control protection. The erosion and sediment production typically occurs during thundershowers, snowmelt, or spring runoff.

Stream Bank Erosion

During the summer of 1993 cross sections were established at 17 permanent locations on the Main Stem of Brush Creek. The objective was to evaluate the type of erosion taking place. It was unclear if Brush Creek was degrading (erosion of streambed or banks), aggrading (deposition of sediments), or meandering laterally. The established cross sections were re-surveyed each year and compared with previous year's data. A stream is described as stable if its cross-sectional geometry remains relatively constant over time. The results of the survey showed that serious bank erosion was occurring from lateral meandering (Earth Resources, 1998). For example, at numerous transects there was a distinct change in the stream cross-sectional profiles, particularly at the stream banks. These data show that Brush Creek is moving laterally and eroding streambanks. It appeared that degradation had slowed down as the channel bottom became armored , which forced the creek to adjust by meandering laterally (Earth Resources, 1998). This added an area of concern to the list of sediment producing activities outlined previously.

Effects of suspended sediments

Published reviews (Cordone and Kelly 1961) on the effects of suspended sediments on salmonids (trout and salmon species) indicate that suspended sediments may have multiple impacts on the aqautic environment. Suspended sediments may (1) act directly on free-living fish by killing them or reducing growth rate; (2) interfer with the development of eggs and young fish; (3) modify natural movements and migrations; (4) reduce the abundance of food organisms available to the fish; and (5) decrease the efficiency of methods used for catching fish. These data show numerous responses from salmonids to increased levels of suspended sediments; these responses range from lethal, sublethal, and behavioral responses to suspended sediments.

In addition to trout population, macroinvertebrates can also be affected by increased levels of suspended sediments. Many macroinvertebrates are grazers and feed on periphyton[1] attached to the substrate. Changes in suspended sediment concentrations may adversely affect algal growth, biomass, and composition, which inturn will affect macroinvertebrates dependent on periphyton for food. Because some macroinvertebrates are filter feeders, increased sediments may impede feeding structures, reduce feeding ability and therefore reduce, stress, or kill these organisms (Hynes, 1970). The scientific data suggest that aquatic macroinvertebrates are at least as sensitive to high levels of suspended sediment as trout.

Suspended sediment data from Brush Creek indicate that the concentrations of sediments ranging from 0 to 668 mg/l depending on duration of exposure, these levels are capable of impacting both the trout population and macroinvertebrate communities to some degree. It is possible that the existing populations have adjusted to these increased sediment concentrations and that, after restoration and reductions in sediments, a significant and beneficial change in aquatic populations will be observed. During post-restoration monitoring, one indicator of success will be a more diverse community of macroinvertebrates, including numerous Ephemeroptera species.

PROJECT DESIGN AND IMPLEMENTATION

The primary challenge of the project was to effectively integrate ecological restoration with community recreational opportunities in a manner which do not compromise the sustainability of

[1] Collective term for the attached organisms, usually includes microscopic algae and small plants species.

the restoration effort. Design objectives include:

1) stabilize the stream banks and minimize the volume of stream bank sediment to the system,
2) aesthetically enhance the visual presence of the stream,
3) re-establish the stream's aquatic biology, and
4) provide recreational opportunities and access to the project.

Measurements and analysis of the existing channel classified the stream as a G-3 channel type. As stated earlier, the pre-development condition of the stream is theorized to have been a B-3 channel type. The encroachment into the stream's flood plain and confinement of the site made designing and constructing the pre-development stream channel type impossible. A new channel type needed introducing that would withstand the scour associated with peak spring runoff, which the natural surface materials were obviously not able to withstand.

An A-2 stream channel type was selected with stream gradients that range from 2 to 8 percent. Heavy riprap was required to adequately reinforce the stream channel and stream banks against erosion. Five thousand yards of large riprap material was needed to construct the design. Since large rock was not a common material in the existing stream channel or within the project boundaries, all of the riprap material was imported to the project to fill in the cavities and reinforce the new channel.

Construction access was difficult when considering the depth to which the stream had eroded and the development density around the site. The only available access was to excavate a construction road to the bottom of the streambed and turn the stream into the construction access. The site needed de-watering in order to use this approach. Majority of the flow was diverted into an upstream irrigation diversion structure. Since 80% of the project was a fill operation, the remaining flow was routed through an eighteen-inch corrugated plastic pipe under the project fill. This opportunity allowed the project to be constructed without any sediment discharge into the stream system. It also maximized the construction efficiency of the project by allowing the haul trucks to drive into and up the stream corridor to deliver materials to the backhoe.

Our greatest challenge was the fact that terrain and the chosen construction technique allowed only one opportunity to construct the channel correctly. There was no going back to adjust any segment of the channel. Everything had to be completed as the equipment moved through the site. The construction equipment backed down the construction road removing it and shaping the stream channel, re-grading the upland slope, and planting the stream bank vegetation all as one operation. Upland slopes were planted and seeded and erosion control fabric installed on the slope after wards. Large tree plantings were also installed at a later date using a crane for access.

Some rock was present in the streambed, but was void in the remainder of the site. Therefore, the oversized riprap (3-6 foot boulders) used to construct the new stream channel and to reinforce over-steepened slopes had the appearance of an introduced material. Boulders were incorporated into the upland landform grading, in order to visually naturalize the introduction of the boulders into the project area. Using boulders in the upland grading also enabled the slopes to be varied in angle, creating character and allowing larger trees to be planted on the slopes.

The streambanks were planted with willows that were cut from the site the spring before and rooted in one-gallon pots by a local nursery. The rooted one-gallon willows were returned to the project and planted as the stream channel was regraded. The willows were incorporated into the stream bank in two manners 1) planted directly in the topsoil voids in the rip rap, and 2) planted in soil-filled Coir blanket reinforced lifts over the riprap.

The Coir blanket confined wetland soil lifts were constructed over the top of the underlying riprap channel at bank-full stage to soften the rocked channel and re-establish the vegetated stream edge. In addition to the willows, sedge plugs and a wetland seed mix was planted into the soil before layering back the Coir blanket.

Wetland soils excavated from the site during construction were stockpiled and used as topsoil to fill voids between the rip rap banks to allow planting of willows, cottonwoods, alders and other riparian/wetland species to revegetate and naturalize the introduced boulder materials. The incised channel was raised ten feet in some areas and eroded upland landforms sloped back, reconnecting the stream with its abandoned flood plain. The flood plain soils were excavated and replaced with a riprap plating to minimize the potential of a reoccurrence up to a hundred-year event. The native soils were placed back over the riprap and planted and seeded with appropriate species. As much as possible of the existing riparian vegetation, primarily willows and alders, was preserved. Those not preserved were transplanted.

The upland slopes were graded back to a 2:1 slope where possible. Some conditions made the 2:1 objective unreachable, in which case a 1.5:1 mechanically stabilized earthen wall was constructed. The wall was constructed using large boulders on the slope surface and reinforced with a geotextile fabric grid, which extended thirteen feet back into the filled slope. Graded structural backfill was compacted in eighteen-inch lifts between the geotextile fabric layers. Voids were left between the boulders allowing for topsoil to be pocketed and planted with native shrubs and trees, which would eventually grow over the boulders and provide added slope stability with their deep roots.

The upland slopes were planted with larger trees to age the appearance of the project. Blue spruce *(Picea pungens)*, narrowleaf cottonwood *(Populus angustifolia)* and aspen *(Populus tremuloides)* were planted in strategic locations for this aesthetic purpose. Over five hundred upland shrubs were planted on the regraded slopes. Shrub species selection included chokecherry *(Prunus virginiana)*, saskatoon serviceberry *(Amelanchier alnifolia)*, Bearberry honeysuckle *(Lonicera involucrata)*, mountain snowberry *(Symphoricarpos oreophilus)* and redtwig dogwood *(Cornus sericea)*. The slopes were seeded with an upland mix of native grasses and local wildflowers at a rate of 23 pounds of pure live seed per acre. The seed slopes were mulched with straw. The planted and seeded slopes below the road were further reinforced with erosion control blanket.

Where appropriate, concave depressions were incorporated into the new landform to hold plowed snow or to intercept storm water drainage encouraging infiltration of the runoff. This technique assisted with re-establishing the sedge wetland along the fringe of the restored wetlands, while minimizing the direct discharge of storm water drainage into the new channel.

When completed, the project received a very positive community reaction and local newspapers published favorable reports. Community members began entering the site walking along the stream, mothers were observed taking their young toddlers to the stream edge and anglers were witnessed fly fishing the new channel. All these activities had been foreign to this particular stream reach for over thirty years. In the community's eyes, this project is viewed as a success, leading to additional appropriations to fund more projects related to storm water drainage, watershed management, and another stream restoration project.

While human appreciation remains strong, the real question is: How well did the aquatic biology acclimate to the reconstructed channel? The primary objective was to stabilize the channel in a method that complemented the habitat needs for the fishery and benthic macro-invertebrates. Their response to the new environment will be the true measure of success.

BIOLOGICAL ASSESSMENT

A biological assessment was performed on this section of Brush Creek to evaluate existing aquatic communities (Figure 1), prior to enhancement projects. This assessment was required to determine and quantify the potential ecological impacts from habitat degradation on the aquatic population, and to evaluate potential enhancement and/or restoration projects for Brush Creek.

The overall objectives of this assessment were to evaluate the existing biological state and to establish a baseline condition for all future monitoring programs. The aquatic biology of the creek was evaluated in the context of the stressors placed on the system, including sediments, erosion, water quality, and habitat degradation. To accomplish these objectives, we conducted two types of distinct biomonitoring studies (Figure 1.): benthic invertebrate inventories and a fish population study.

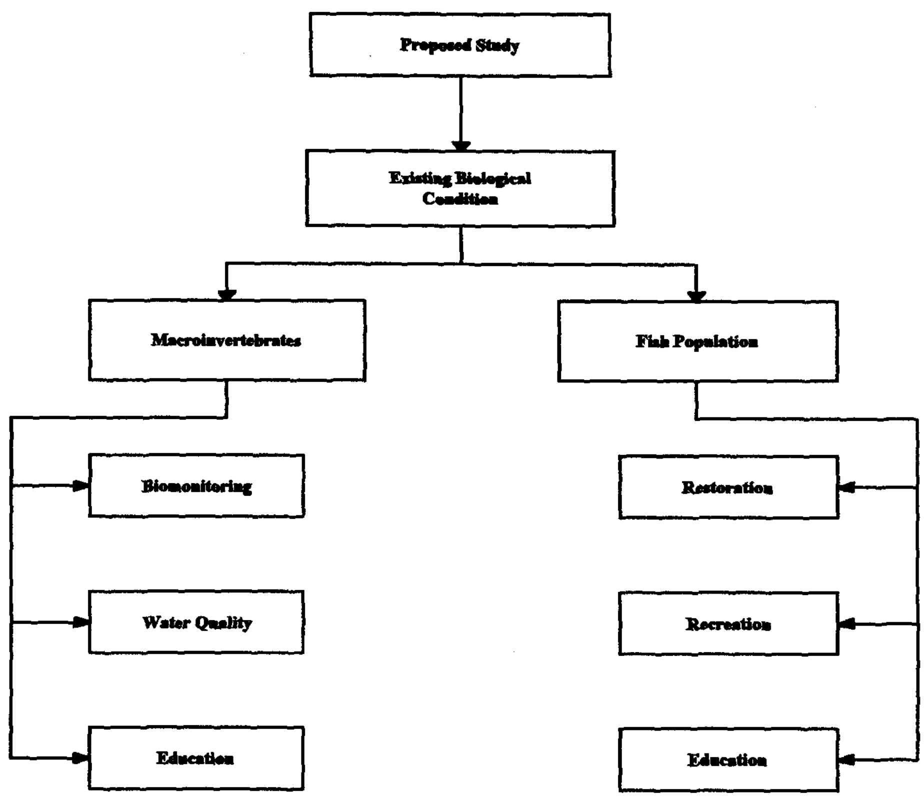

Figure 1. Outline of our study plan to collect biological data on a section of Brush Creek. Some of the potential uses of these data are also given.

BIO-MONITORING APPROACH

One of the most fundamental ways to assess the condition of Brush Creek is through the monitoring of benthic macroinvertebrates. The use of benthic macroinvertebrates as indicators of stream "health" goes back at least to the early 1900s (La Point and Fairchild 1992). More recently, stream biotic indices have been developed that allow for quantitative estimates of stream health based on benthic macroinvertebrates (Hilsenhoff 1988; U.S.EPA 1989). Benthic macroinvertebrate biomass, abundance, number of species, and relative abundance of pollution-sensitive and pollution-tolerant species or groups all have been documented as effective biomonitoring indices for assessing stream conditions (Sprague et al. 1965; Clements et al. 1988; Leland et al. 1989).

In addition to exhibiting a wide range of sensitivity to stream conditions, benthic macroinvertebrates are excellent biomonitoring tools because: (1) they are in intimate contact with sediments or substrate; (2) they occupy limited home ranges and thus are indicative of local stream conditions; (3) they are integral components of the aquatic food chain, serving as the primary food source for fish species; (4) they are relatively easy to monitor.

Fish population monitoring in conjunction with a macroinvertebrate study is valuable because: (1) the fish population is indicative of longer-term and wider-scale stream quality than macroinvertebrates; (2) fish tend to integrate effects at lower trophic levels; and (3) fish are recreational, aesthetically, and economically important; (4) they provide useful data for restoration and enhancement projects.

Besides macroinvertebrate and fish surveys, other stream measurements will be central in a biomonitoring study of Brush Creek. Stream physical habitat, such as stream size, flow, gradient, substrate, and water quality, are particularly important, since habitat defines the aquatic community.

Collecting information on both macroinvertebrates and fish populations provided a robust assessment of the existing biotic conditions in Brush Creek. These data were valuable in identifying sources and causes of habitat degradation and will also be useful in establishing a foundation for enhancement or restoration plans. Finally, biological baseline data will be a significant component for evaluating the effectiveness of any restoration or enhancement projects in Brush Creek.

TECHNICAL APPROACH

Our biological assessment involved four sampling during periods: (1) Low streamflow, to evaluate biological attributes prior to winter; (2) Pre-runoff, to assess over-wintering survival; (3) Post-runoff, to evaluate effects of high flows and summer rearing conditions, and (4) Post restoration, to evaluate the effectiveness of restoration projects. During all four sampling periods biological data were collected on both macroinvertebrates and fish populations. Under this study, macroinvertebrates were used as indicators of water quality and in assessing the Likewise, trout population data were used to evaluate restoration or enhancement projects.

The overall objectives of this biological assessment were to:

- collect data on the benthic invertebrate communities;
- evaluate species diversity and relative abundance;
- collect data on the fish population within the study reach;
- analyze both data sets to provide information on baseline or pre-restoration conditions;
- establish a robust baseline data set to assess the effectiveness of the enhancement projects.

Macroinvertebrate data were collected from five Brush Creek sites; two sites (Site 1 and Site 2) were sampled within the project area. One site was located 25 m downstream of the project (Site 3); one site was sampled upstream of Yarrow Park (Site 4); the fifth site was located 30 m upstream from the Snowmass Water and Sanitation District's water treatment ponds (Site 5). Data on the fish population was only collected from within the project assessment area; the entire area was sampled for fish.

Sites 1 and 2 were within the restoration area. Site 1 was de-watered and physical habitat completely restored during the project. Site 2 was partially impacted during restoration by de-watering; however, physical habitat was not altered. No restoration occurred at other stream sites. We used and compared the data from Sites 1 and 2 as indicative of the effects of restoration, site 1 as complete restored habitat, site 2 as a control for de-watering and subsequent re-colonization and site 5 as an overall control and unimpacted area.

POST RESTORATION

Macroinvertebrates were collected from two sites within the restoration area (sites 1 & 2); initial sampling during April 1999, (six months after restoration was completed) indicated that aquatic insects were returning to this creek section (Table 1).

Table 1. Macroinvertebrate abundance and diversity six months after restoration. (Sites 4 & 5 were not restored under this project).

	Mean Abundance	**Total Taxa**	**Total Number**	**Pre-Restoration April 98. Mean Number**
Site 1	14.3	5	43	46
Site 2	17.7	8	53	55.6
Site 4	19.6	10	59	53.6
Site 5	148	11	445	212

Additional macroinvertebrate samples were collected in July 1999, (nine months after restoration); these data (Table 2) indicated a significant improvement in macroinvertebrate mean abundance at Site 1. Data collected from Site 2 indicated that mean abundance was similar to pre-restoration samples (Table 2). Site 2, was dewatered during the project, but the physical habitat, in terms of substrate or streambanks, was not altered or enhanced during the project.

A component of this increased abundance, may have resulted from natural variability as indicated by the increased abundance at Site 5, $p = 0.09$ (Table 2). However, from the observed lack of a significant increase at Site 2, we conclude that clean substrates from restoration and run-off, has significantly improved macroinvertebrate abundance at the restoration area. In addition, we found very little difference in abundance between Sites 1 and 2 prior to restoration (Table 3); however, after restoration, mean abundance at Site 1 was significantly higher relative to Site 2 (Table 3). Both these results suggest that the introduction clean un-embedded substrate can significantly increase macroinvertebrate abundance in Brush Creek.

Table 2. Comparison of mean abundance of macroinvertebrates at three sites in Brush Creek before and after restoration projects.
(Site 2 represents restored control conditions and Site 5 represents non-restored conditions).

	July 98 Mean Abundance	July 99 Mean Abundance	Significance
Site 1	45	99	$p = 0.036$
Site 2	28	30	$p = 0.325$
Site 5	26	71	$p = 0.09$

Table 3. Between site comparison of mean abundance of macroinvertebrates in Brush Creek before and after restoration projects .

	Site 1 Mean Abundance	**Site 2 Mean Abundance**	**Significance**
July 98	45	28	$p = 0.201$
July 99	99	30	$\mathbf{p = 0.034}$

The relative abundance of the main families of macroinvertebrates are outlined in Figures 2a to 4b. Due to natural variability and significant changes in population structure between sampling, these data are difficult to interpret. For example, data from Site 5 (Figures 4a, 4b) indicated that four taxa were dominant in July 1998, however, in July 1999, only one family of macroinvertebrate, the Elmidae beetles, was dominant (Figure 4b). As these aquatic beetles (*Heterlimnius corpulentus*) also dominated the community in previous samples (Figure 4a), these changes in community structure are indicative of natural variability in aquatic populations.

However, the restoration sites (site 1 and 2; Figures 2a/b and 3a/b), did show some changes in community structure. For example, prior to restoration, *Baetis* mayflies were rarely collected at Site 1 (Figure 2a), these mayflies only composed 8 % of macroinvertebrates collected; in contrast, in post-restoration samples, *Baetis sp.* composed 26 % of all macroinvertebrates collected. Generally, mayflies and in particular *Baetis sp.* are considered indicators of good water and habitat quality. Community conditions also changed at Site 2 (Figures 3a/b), from a single taxon dominated community, prior to restoration, to a more diverse community after restoration. A community dominated by relatively few families is usually an indication of environmental stress. As no physical habitat alternations occurred at Site 2, this community structure may be indicative of re-colonization patterns by macroinvertebrates. Over-time, the community at Site 2 may revert back to being dominated by fewer taxa.

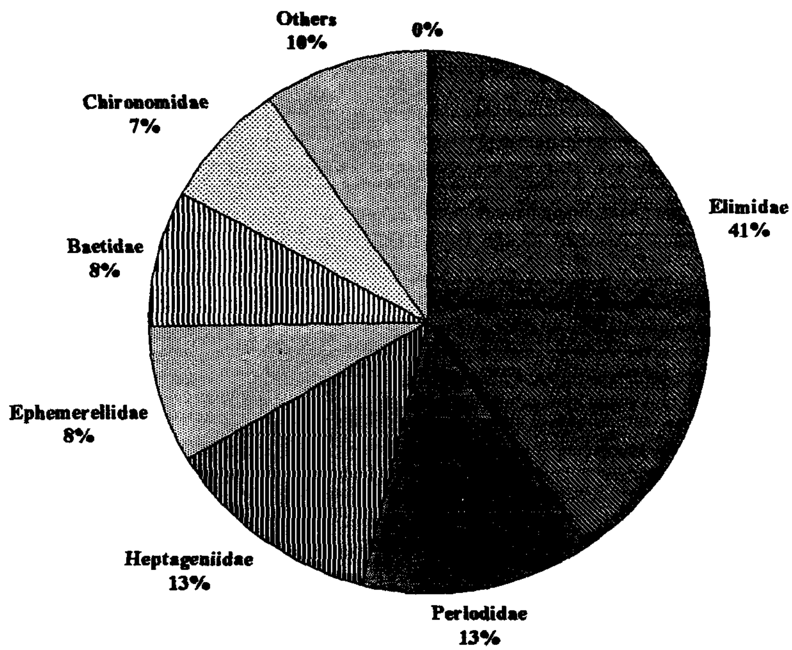

Figure 2a. Aquatic community structure at Site 1 (July 98) prior to restoration.

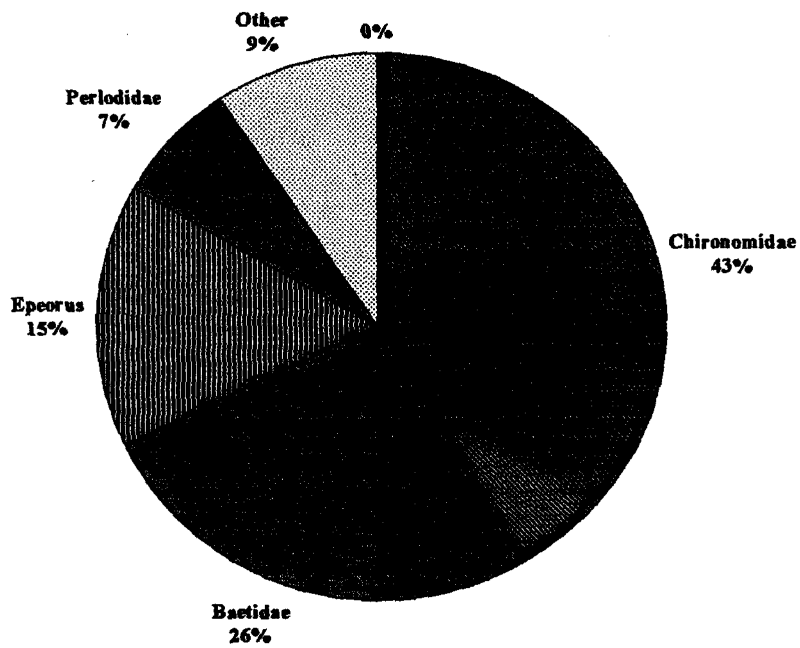

Figure 2b. Aquatic community structure at Site 1 (July 99), post-restoration sampling. (Note the increased abundance of *Baetidae* mayflies).

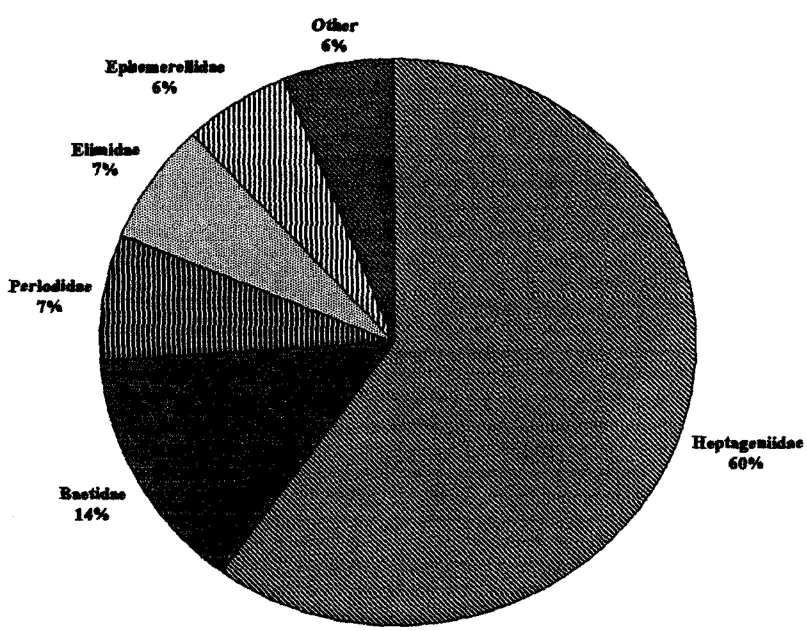

Figure 3a. Aquatic community structure at Site 2 (July 98) prior to restoration. (Note the domination by a single taxon).

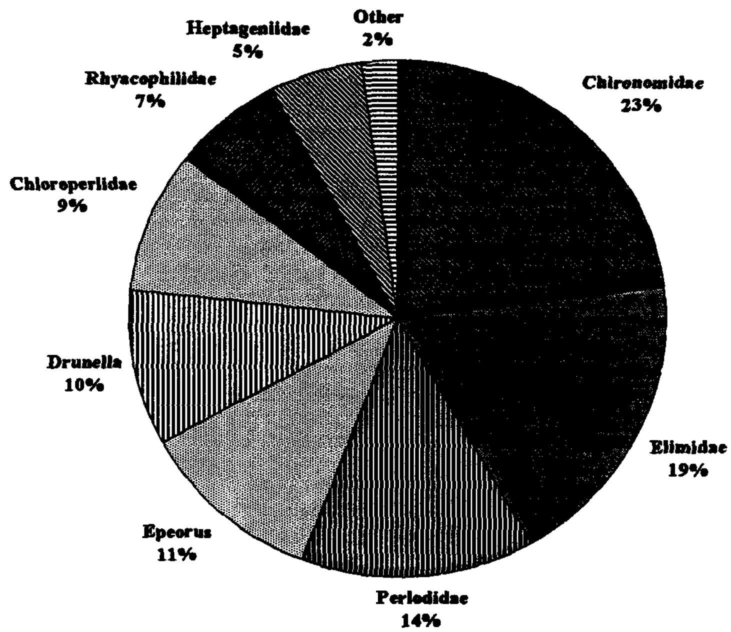

Figure 3b. Aquatic community structure at Site 2 (July 99) post-restoration sampling.

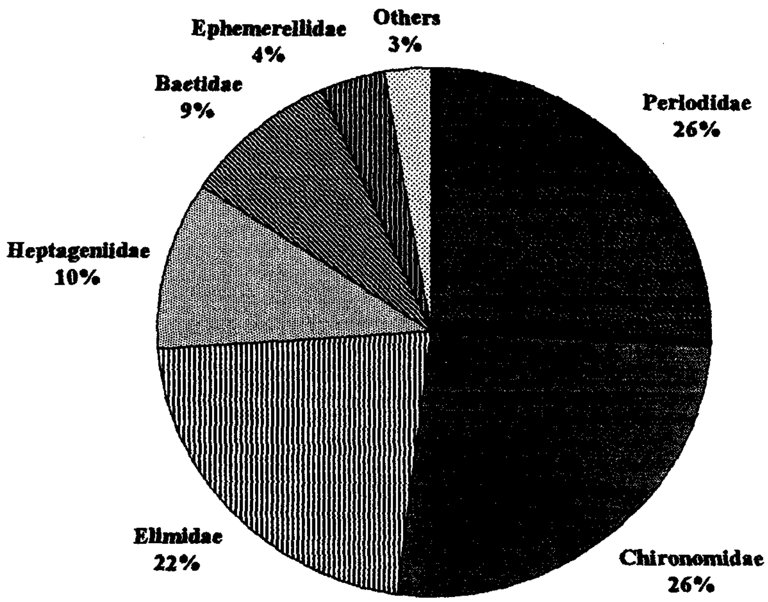

Figure 4a. Aquatic community structure at Site 5, July 98, Brush Creek.

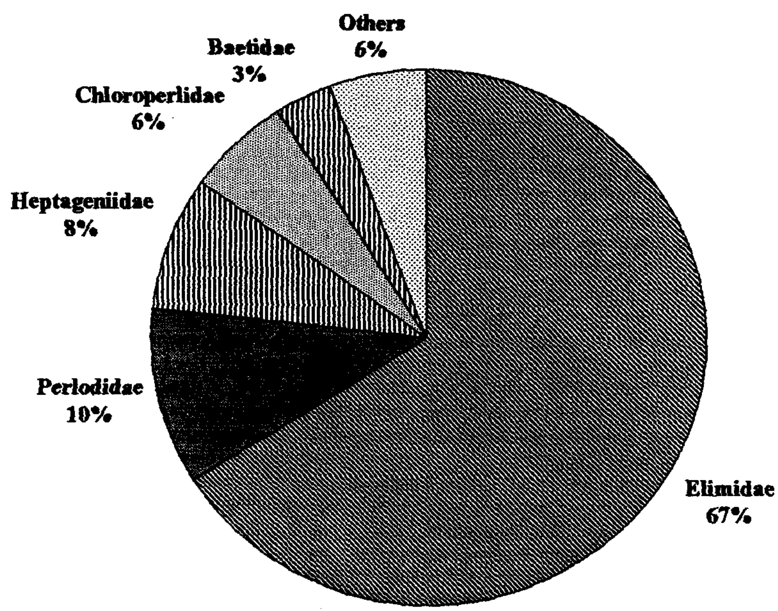

Figure 4b. Aquatic community structure at Site 5, July 98, Brush Creek.

FISH POPULATION

Brush Creek project area was electrofished during three sampling periods: winter, spring, and summer. These data were used to estimate the potential brook trout population and number of fish per m^2 within the project area.

Our electrofishing results are outlined in Table 4. Only brook trout were recorded from the sampling area; during all three sampling periods similar size fish were collected. The mean fish length were 19.8 cm, 21.8 cm, and 20.2 cm, respectively, for the winter, spring, and summer samples (Figures 5, 6,& 7). These data indicate that the existing brook trout population in this section of creek is relatively stable and survival over the winter period and during run-off appears high. For example, no apparent changes occurred in terms of fish numbers or fish size distribution between winter, spring or summer sampling periods. Brook trout were abundant in all habitats that contained abundant overhead and instream cover in the form of logs, root masses, or overhanging willows. Fewer fish were sampled from open riffle habitats that lacked these attributes.

Table 4. Population estimates of Brook trout electrofished during the April sampling in Brush Creek. Mean trout length and trout number per meter are also given.

Unit	Length (m)	Fish Num.	Mean Length (cm)	Pop. Est.	SE	Fish/m^2
1	33	11	21.1	16.3	10.3	5.5
2	50	19	21.9	19.7	1.2	6.8
3	46	16	21.9	16.9	1.6	7.3
4	29	7	16.9			
5	28	18	22.7	24.4	8.5	3.2
6	43	17	22.9	17.3	0.7	6.7
7	50	17	20.0	18.8	2.6	7.2
Total	279	98	21.8	106.9	5.7	7.04

The length frequency distributions for collected brook trout are presented in Figures 5, 6, and 7. Length frequency distributions of brook trout collected by the Colorado Division of Wildlife (CDOW 1993) are presented in Figure 8. Our data (Figures 5, 6, and 7) indicate that the population is entirely composed of adult fish (20 - 22 cm). No young of the year fish (< 5 cm) were collected during the summer sample, indicating that spawning is occurring in a different stream section. In addition, the lack of smaller fish or juveniles (< 10 cm) may indicate that initial rearing for fry and juvenile trout does not occur in this stream section. The larger brook trout may migrate downstream or move upstream from adjacent spawning and rearing habitats.

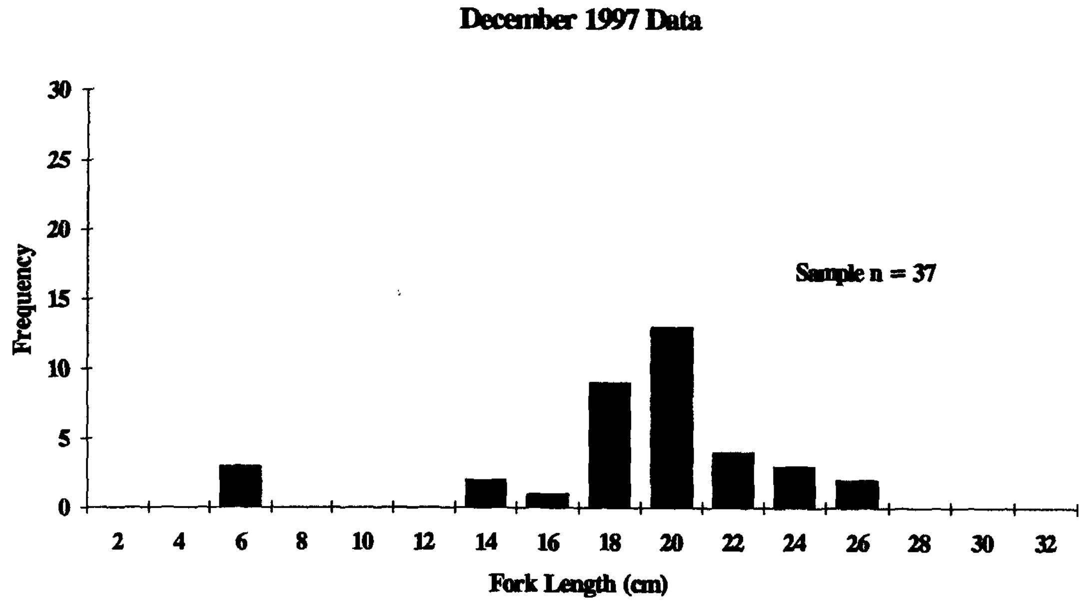

Figure 5. Length frequency of brook trout collected during winter sampling of Brush Creek, Colorado.

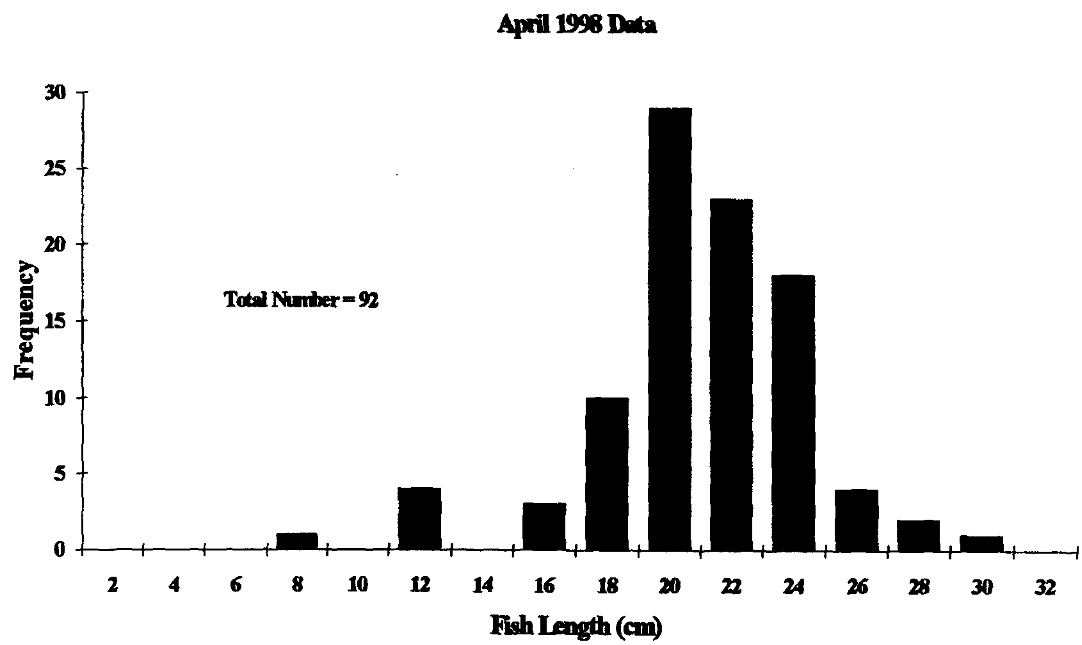

Figure 6. Length frequency of brook trout collected during the spring sampling of Brush Creek, Colorado.

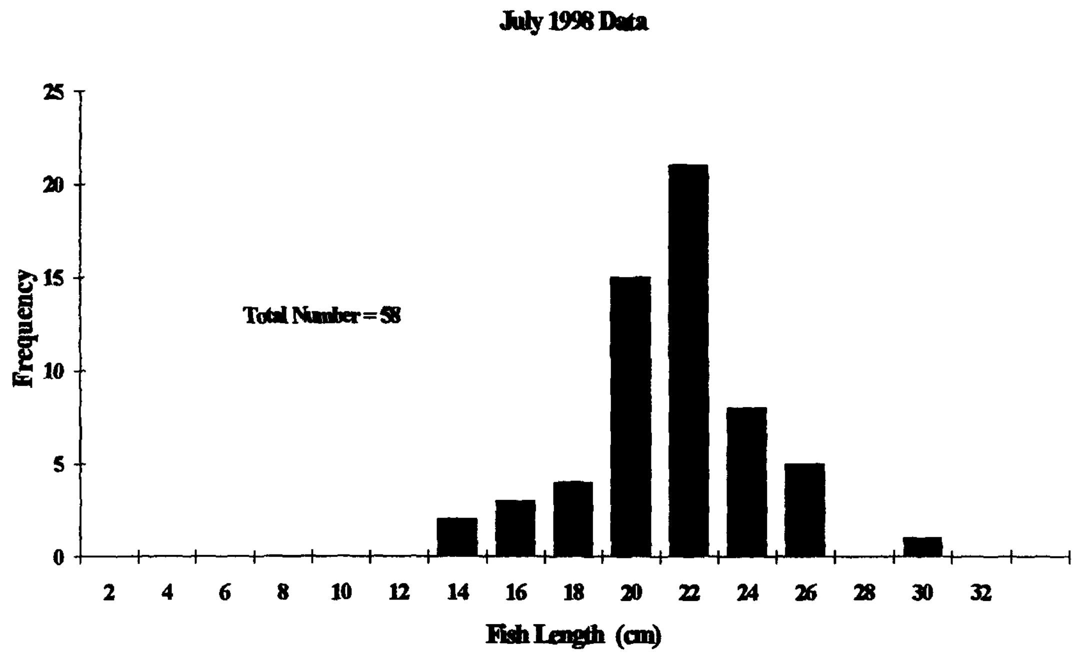

Figure 7. Length frequency of brook trout collected during the summer sampling of Brush Creek, Colorado.

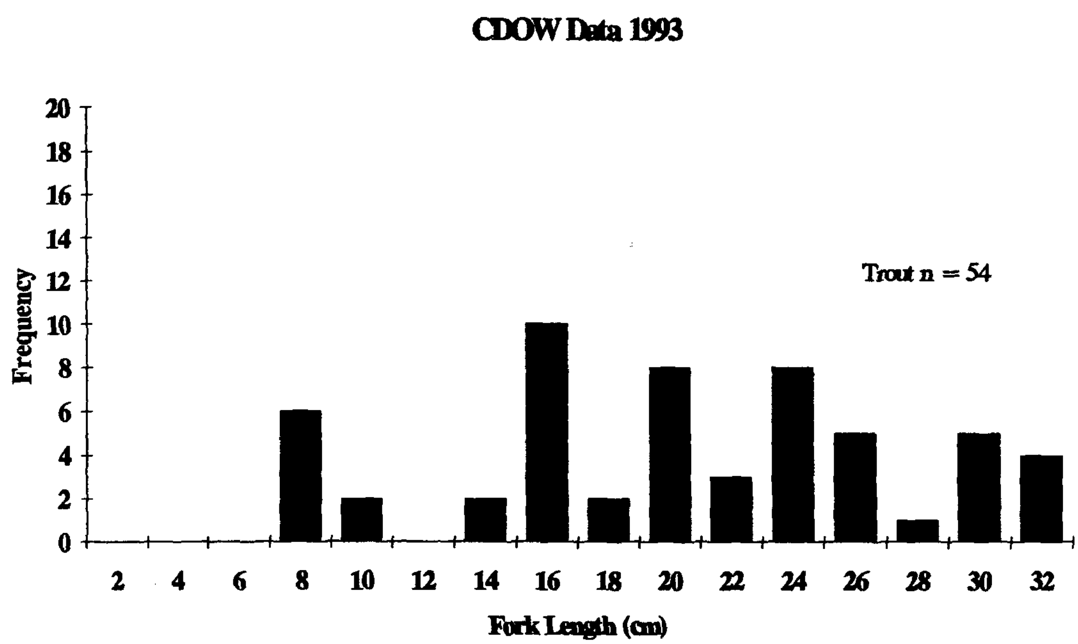

Figure 8. Length frequency of brook trout collected by the CDOW in Brush Creek, Colorado.

The length frequency data collected by CDOW in 1993, also indicate that only larger brook trout existed in Brush Creek. The apparent differences (absent of a bell-shaped curve) between CDOW length data with our present data is probably due to an inconsistency in sampling methods.

POST RESTORATION FISH POPULATION

In terms of the fish population, we conducted three additional electrofishing surveys of the assessment area in Brush Creek (279 m) after restoration was completed. The first survey was completed six months after restoration in April 1999, additional surveys were conducted in July 1999 and October 1999. Within the restored stream section reach all microhabitats (runs, riffles, or pools) and all possible fish refugia were sampled to quantify the numbers of trout and other fish species.

During our first survey after restoration (April 1999), we collected 21 brook trout, ranging in length from 6 to 26 cm (Figure 8). In previous surveys, some 92 trout, (mean size 21.9cm) were collected from the project area; these data indicated that 22.8% of the original population had already returned to the site. The majority of these trout were captured in the downstream section of the project area, indicating that fish may be moving from downstream locations.

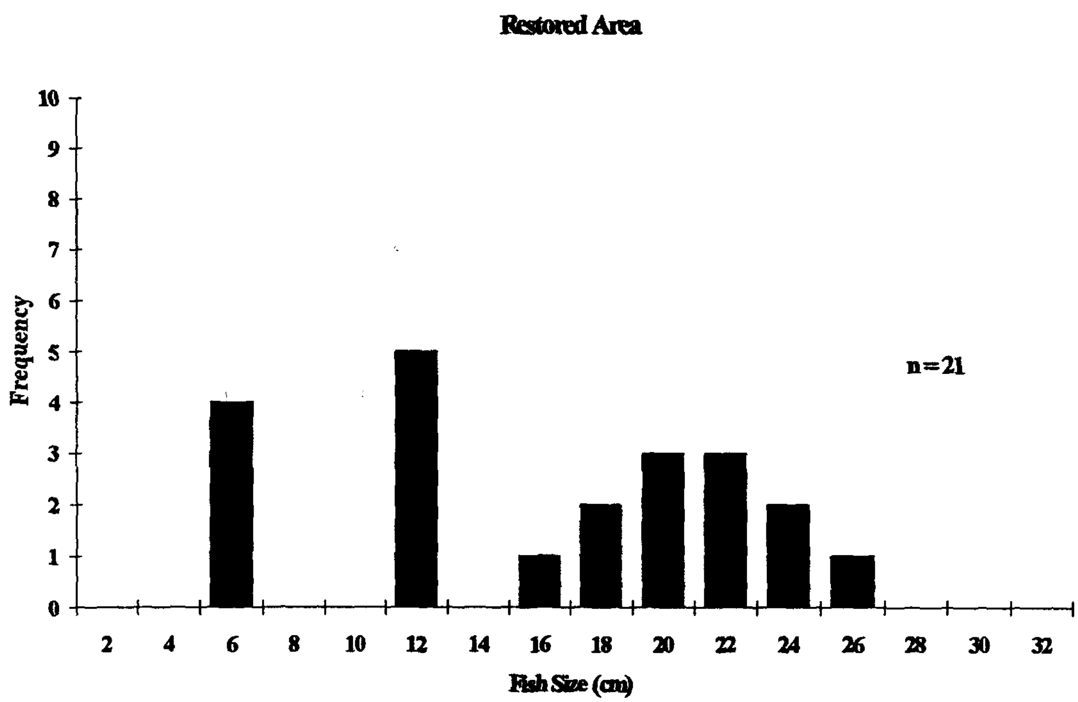

Figure 9. Length frequency of brook trout collected during post restoration sampling of Brush Creek, Colorado. April, 1999.

Prior to restoration, this creek section lacked abundant and/or adequate pool habitat for the fish population. Restoration included the construction of a system of relatively large step-pool structures to provide suitable to optimum habitat for trout. In the higher gradient areas, boulders were used to provide pocket-water pools and other refugia sites for trout moving through these areas. We anticipated, that after spring run-off and additional summer movements of trout from both upstream and downstream, that the trout population would be significantly increased in the restored section.

During our July 1999 sampling, a total of 105 brook trout and 6 rainbow trout were captured from the project area. However, only 5 brook trout were classed as resident to Brush Creek; the remaining trout, including the rainbow trout, carried the characteristic attributes of hatchery trout. This unofficial stocking of brook trout and rainbow trout into the restoration section invalidated and jeopardized these fish data or any conclusions based on the fish population surveys. Data from additional electrofishing surveys, downstream at Yarrow Park indicated that the trout population was also dominated by stocked trout.

Currently, we are monitoring the impacts from these stocked trout. It is probable, that over-wintering survival will be low among stock fish and that resident trout will gradually repopulate this stream section. In recent fish surveys (October 1999) of the project area, 117 brook trout were collected, 74 trout (63%) were stocked fish and 43 trout (36%) were classed as resident fish. Until some equilibrium in the fishery is reached, overall conclusions on the effectiveness of habitat improvements in Brush Creek will be ambiguous and misleading.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Stream systems are composed of a complex interactive combination of chemical, physical, and biological properties. In general, a self sustaining trout population will require a high degree of aquatic habitat diversity to support the different life stages. For example: riffles provide spawning sites, rearing habitat for fry and juveniles, and macroinvertebrate production for food; pools provide summer rearing habitats for juveniles and adults and are critical for over-wintering habitat. The quality of each of these habitats will depend on the physical attributes of water depth, velocities, habitat or bank stability, instream cover, temperature, and competition between fish.

In productive natural streams these physical attributes are widely available and dispersed throughout the stream's ecosystem. However, even in naturally productive streams, it is important to remember that these attributes are not evenly distributed within stream reaches. For example, trout may move upstream to spawn and downstream to over-winter. Therefore, in designing enhancement projects, the entire stream ecosystem or watershed must be considered even if the majority of the stream is outside of the project zone.

In terms of the Brush Creek enhancement area, macroinvertebrate abundance and taxa diversity has been increased by improving the substrate quality in this stream section. Prior to restoration, the substrate was composed mainly of embedded large cobble and boulders. By reducing the sediment and fine material loads to the stream through stream bank stabilization and instream restoration, the existing substrate composition provides optimum habitats for macroinvertebrate communities, as indicated by our data. However, if high sediment loads are allowed to drain into the creek, we expect that these present clean substrates will become embedded again and the aquatic community may be significantly altered or reduced again.

Adult brook trout are abundant in this stream section; as outlined in Table 4, density of fish ranged from 3.2 to 7.3 fish/m^2 and fish length ranged from 20 to 24 cm (Figures 5, 6, and 7). The enhancement of this stream section has provided optimum habitats for all life stages of brook trout, including the construction of a number of pool structures. Our initial data indicated that fish had returned to this stream section. However, releasing stocked fish into the creek has produced an unnatural environment for the existing fish population. Therefore, drawing any conclusions based on these fish data would not be a true reflection on the effects (either beneficial or detrimental) of the restoration project on the trout population.

Based on our ecosystem approach, we should not attempt to provide all these physical requirements for optimum habitat in one enhancement reach. Instead, the enhancement design should be based on the available biological data (present report) and channel morphology, within the framework of a watershed approach. Increasing the numbers of pools, overhanging banks, willow riparian corridor, and, most importantly, increasing instream wood debris, will provide additional and optimum habitats for adult brook trout.

In an effort not to over-extend the carrying capacity for this section, we also suggest, incorporating numerous riffle habitats, with smaller substrate, to provide for macroinvertebrate production and a stable food resource for the increased fish population. Under future enhancement projects within the watershed and in more favorably channel types (lower gradients), habitat enhancements can focus on providing additional spawning and rearing habitats for brook trout. In short, this enhancement project should focus on providing optimum summer and over-wintering habitat for adult trout.

In conclusion, the restoration project has significantly improved the aquatic environment in Brush Creek, which is further supported by the Colorado Water Quality Control Commissions decision to upgrade Brush Creek's classification from Class 2 to Class 1 waterway. The following is a list of the overall beneficial effects resulting from the project.

SUMMARY OF PHYSICAL ATTRIBUTE ENHANCEMENTS

- Increased macroinvertebrate abundance and diversity;
- Initial recovery of the trout population;
- Stabilized stream banks, reduced erosion;
- Reduced sediment loads of fine materials, improved substrates;
- Increased habitat diversity, provided more suitable pools;
- Improved the substrate for spawning and macroinvertebrates; reduced embeddedness;
- Increased the numbers of pools to provide more fish habitat;
- Increased refugia from high flows and velocities to protect YOY fry;
- Provided abundant instream cover and overhanging banks;
- Enhanced environmental awareness and social support for future improvement projects.

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PARTICIPANT LIST

We were pleased to have a total of 232 participants at the Fourteenth High Altitude Revegetation Conference. Representatives from six foreign countries and 16 states attended the conference (Table 1). As can be seen from the data presented in Table 1, most of the participants came from Colorado, however, people from both coasts and from as far away as New Zealand and Indonesia were present.

For all of you that came, thank you for your participation. Make plans for attending in 2002. The High Altitude Revegetation Conference will be held in February or March, 2002 in Ft. Collins, Colorado. Pass the word to your colleagues, so that the 2002 conference will be a great success.

For current information on upcoming High Altitude Committee events, visit our website at www.highaltitudereveg.com.

Warren R. Keammerer

Table 1. Geographical distribution of participants at the Fourteenth High Altitude Revegetation Conference (March 8-10, 2000).

Geographic Entity	Number of Participants	Percent of Total Participants
CANADA		
Alberta	1	0.43
INDONESIA	1	0.43
NEW ZEALAND	1	0.43
NORWAY	1	0.43
PERU	1	0.43
SWITZERLAND	1	0.43
UNITED STATES		
Arizona	1	0.43
California	4	1.72
Colorado	181	78.02
Florida	1	0.43
Idaho	3	1.29
Minnesota	1	0.43
Montana	10	4.31
Nebraska	1	0.43
Nevada	2	0.86
New Mexico	2	0.86
Ohio	1	0.43
Oklahoma	1	0.43
South Dakota	1	0.43
Utah	6	2.59
Washington	1	0.43
Wyoming	9	3.88
Total	232	100.00

Participant List
14th High Altitude Revegetation Workshop
Colorado State University -- Fort Collins, CO
March 8-10, 2000

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SUMMARY OF SUMMER TOURS 1974-1999

Assembled by Wendell Hassell

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:

YEAR	AREA TOURED	SITES TOURED
1974	Vail/Climax, CO	Vail Ski Area, AMAX Climax Molybdenum Mine
1975	Empire, CO	AMAX Urad Molybenum 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 Ten Mile Creek Channelization, Copper Mountain Ski Area, AMAX Climax Molybdenum Mine
1981	Crested Butte/Gunnison, CO	AMAX Mt. Emmons Molybdenum Project, Western State College, Homestake Pitch (Uranium) Mine, CF&I Monarch Limestone Quarry
1982	Steamboat Springs, CO	Mt. Werner Ski Area, Howelson Hill Ski Jump, Colorado Yampa Energy Coal Mine, P&M Edna Coal Mine
1983	Rifle/Meeker, CO	CSU Intensive Test Plots, C-b Oil Shale Project Upper Colorado Environmental Plant Center, Colony Oil Shale Project
1984	Salida, CO Questa, NM	Domtar Gypsum Coaldale Quarry, ARCO CO_2 Gas Project Molycorp Molybdenum Mine, Red River Ski Area
1985	Cooke City, MT	USFS Beartooth Plateau Research Sites Bridger Plant Materials Center
1986	Leadville, CO	Peru Creek Passive Mine Drainage Treatment, California Gulch/Yak Tunnel Superfund Site, Colorado Mountain College
1987	Glenwood Springs/Aspen, CO	I-70 Glenwood Canyon Construction, Aspen Ski Area
1988	Telluride/Ouray/Silverton, CO	Ridgeway Reservoir, Telluride Mt. Village Resort, Idarado Mine, Sunnyside Mine
1989	Lead, SD	Terry Peak Ski Area, Glory Hole and Processing Facilities of Homestake Mining Co., Wharf Resources Surface Gold Mines Using Cyanide Heap Leach
1990	Colorado Springs/Denver, CO	Castle Concrete's Limestone Quarry, Cooley Gravel Quarry (Morrison), E-470 Bridge and Wetland near Cherry Creek. Littleton Gravel Pit Restoration to Parkland

YEAR	AREA TOURED	SITES TOURED
1991	Central Colorado	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
1992	Northern Colorado	Rocky Mountain National Park, Harbison Meadow Borrow Pit, Alpine Meadow Visitor Center, Medicine Bow Curve Revegetation, Hallow Well Park
1993	Central and Southern Colorado	Mary Murphy Mine, Summitville Mine, Wolf Creek Pass, Crystal Hill Project
1994	Northeastern Utah	Utah Skyline Mine, Burnout Canyon, Huntington Reservoir Hardscrabble Mine, Royal Coal, Horse Canyon Mine
1995	North Central Colorado	Eisenhower Tunnel Test Plots, Henderson Tailing Test Plots, Wolford Mountain Reservoir, Osage and McGregor IML Site Seneca II and 20 Mile Coal Mines (Steamboat Springs)
1996	Southwest Colorado	UMTRA Site (Durango), Sunnyside Mine (Silverton), Idarado Mine (Telluride), Southwest Seed Co. (Dolores)
1997	Southwest Colorado	Cresson Mine (Cripple Creek), San Luis Mine, Bulldog Mine (Creede)
1998	Lead, SD	Richmond Hill Mine, Wharf Resources, Homestake's Red Placer, Sawpit Gulch, WASP Reclamation Project
1999	Northern New Mexico	Molycorp's Questa Mine, Hondo Fire Revegetation Work, Pecos National Monument, El Molino Site, Cunningham Hill Mine

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