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Edited by

Warren R. Keammerer and Jeffrey Todd

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PREFACE

The 16th biannual High Altitude Revegetation Conference was held at the University Park Holiday Inn, Ft. Collins, Colorado on March 3-5, 2004. 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 207 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 responsibilities among the members of the HAR Committee.

In addition to the invited papers and poster papers presented on March 3-4, a “field tour” of the Hydraulics Laboratory on the Foothills Campus of Colorado State University was conducted on March 5, 2004. 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 15 papers and 6 abstracts grouped into eight conference sessions, 7 poster papers and 2 poster paper abstracts.

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

Warren R. Keammerer and Jeffrey Todd
Editors

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COTTONWOODS AND CRANES: A PLATTE RIVER NEXUS

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ABSTRACT

The long-running conflict over water and endangered species on the Platte River is fundamentally a vegetation issue. Detailed knowledge of vegetation history and current dynamics of cottonwood-dominated riparian woodlands is needed to assist managers in understanding the past causes of woodland expansion and to prescribe flows to maintain or increase channel widths for migrating cranes. Results from a 20-year study of tree demography address these needs by providing linkages between flow parameters and tree recruitment and seedling survival in the active channels of the river. The demography results indicate that the current channel to woodland balance can be maintained even in low flow years by making small, but critical changes in flow regime. This approach of "letting the river do the work" is recommended over the massive clearing of riparian vegetation that has indisputable value to nesting and migratory songbirds but unproven benefit to crane populations.

Editors' Note:

Please refer to the following published sources for more information on Platte River research studies conducted by W. Carter Johnson:

Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: patterns and causes. Ecological Monographs 64: 45-84.

Johnson, W. C. 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte River, Nebraska. Regulated Rivers and Management 13: 403-415.

ALPINE VEGETATION RESPONSE TO ATMOSPHERIC N DEPOSITION AND FEEDBACKS TO ECOSYSTEM FUNCTION

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ABSTRACT

Environmental conditions in the alpine have selected for plants with low growth rates, small stature, high resource allocation to belowground organs, and low rates of resource capture. As a result many dominant plants respond relatively slowly to changes in resource supply. However some more rare, ruderal species are able to respond more quickly to enhanced resource availability, and thus increased nitrogen (N) supply alters the composition of plant communities in the alpine. Significant changes in plant species composition and soil nutrient cycling occur at relatively low inputs of N. The Front Range of the Southern Rockies has experienced significant increases in atmospheric N deposition over the past 5 decades as a result of increased agricultural, industrial, and dispersed housing development. Long-term vegetation records indicate plant species composition is changing in a manner consistent with a N fertilization effect, although multiple factors may be responsible. Because plant species exert significant control over spatial variation in ecosystem properties, a shift in community composition may have important consequences for the response of the alpine to environmental change. Rates of soil N cycling may be enhanced, leading to increased fluxes of inorganic N to aquatic systems, and interannual variation in primary production may increase. Thus understanding the response of vegetation is important to predicting the functional response of the alpine to environmental changes (e.g. climate, air pollution).

INTRODUCTION

The alpine is characterized by low temperatures, high winds, and periodic drought. From a human perspective the environment is inhospitable, yet the organisms that exist in the alpine are well adapted to these conditions, and may not thrive when transplanted to other habitats. Alpine plants generally have low growth rates, high ratios of belowground to aboveground biomass, and conservative patterns of resource use and uptake (Körner 1999). As a result changes in resource availability, whether associated with interannual variation in climate (Walker et al. 1994) or by fertilization (Bowman et al. 1993, 1995, Seastedt and Vaccaro 2001) result in relatively little change in the abundance or biomass of dominant alpine plant species. Even when subjected to experimental conditions of nutrient limitation under controlled growth conditions, some dominant alpine sedges remain unresponsive to increased nitrogen supply (figure 1a, Bowman and Bilbrough 2001). Thus alpine vegetation, along with arctic tundra, show low interannual variation in primary production relative to other graminoid dominated ecosystems (figure 1b, Knapp and Smith 2001).

NITROGEN DEPOSITION

Any environmental perturbation in the alpine that increases the supply of soil nutrients will alter the composition of the vegetation. Increased soil fertility may occur due to climate change, soil disturbance or herbivory, or increases in atmospheric N deposition. Greater nutrient supply enhances the success of rarer, ruderal species, potentially at the expense of the dominant species (Theodose and Bowman 1997).

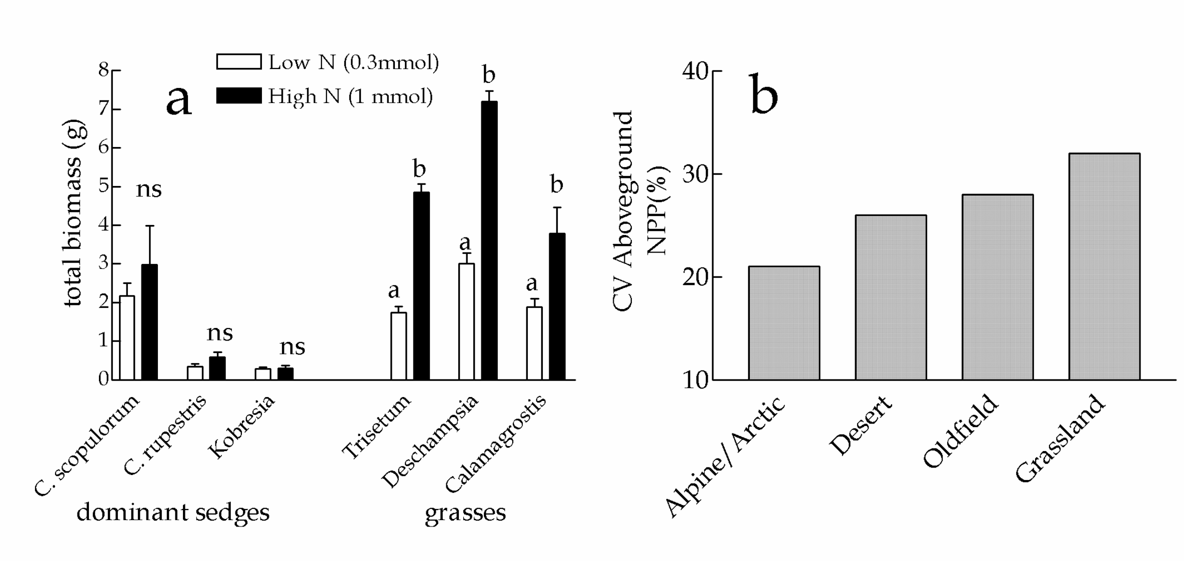

Figure 1. Growth constraints of dominant alpine plants are evident in both growth chamber and field conditions. a) Results of a growth chamber experiment where all abiotic variables except soil N supply were kept optimal, and N was varied between suboptimal (0.3 mmol) and optimal (1 mmol). Only grasses showed a release from the N limitation on growth, while dominant sedges did not (after Bowman and Bilbrough 2001). b) Interannual variability in aboveground net primary productivity in North American herbaceous communities is lowest in the alpine and Arctic (after Knapp and Smith 2001). The lower variability is explained in large part due to the constraints on growth of the dominant species.

As a result diversity changes, increasing in the more nutrient poor communities, while decreasing in the more nutrient rich communities, possibly as a result of changes in competitive interactions among species (figure 2). Changes in plant species composition may therefore be a portent of changing environmental conditions, and understanding the response of alpine species to specific environmental changes may be a useful tool.

Regional changes in N deposition

The Front Range of the southern Rocky Mountains has experienced significant increases in atmospheric N deposition over the past several decades, due to increased agricultural, industrial, and suburban development (Burns 2003, Baron et al. 2000, Williams and Tonnessen 2000). While the rates of N deposition are low relative to the northeastern U.S. and Europe, the high elevation ecosystems of the Rockies are more susceptible to ecological change as a result of lower capacities to take up inorganic N in biological and physical sinks (Williams and Tonnessen 2000, Fenn et al. 2003). Thus it takes lower input of N before alpine systems may begin to experience adverse environmental effects.

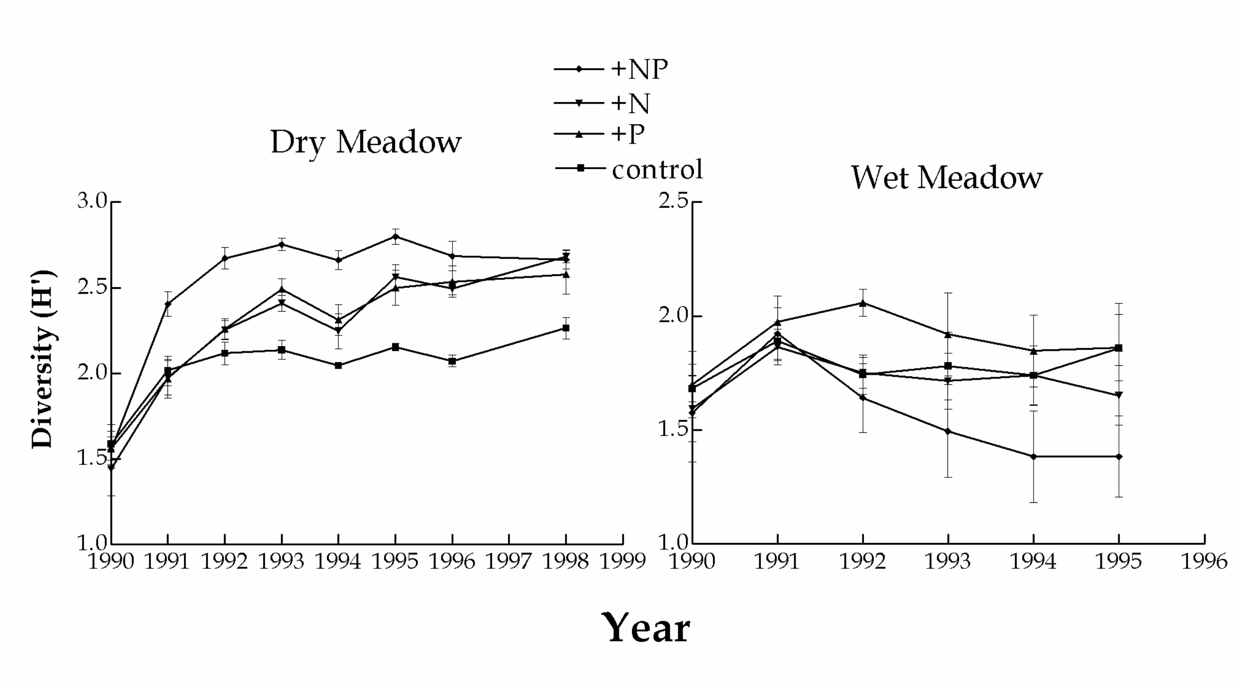

Figure 2. Temporal changes in plant species diversity (H', Shannon-Wiener index) for experimental plots in 2 alpine communities, receiving N, P, and N+P treatments (see Bowman et al. 1993 for experimental details). Diversity in the more resource poor dry meadow increased significantly, while a trend towards lower diversity was observed in the more resource rich wet meadow. (Theodose and Bowman 1997, Bowman, unpublished data)

A recent experiment examined the response of dry meadow alpine soils and vegetation on Niwot Ridge to relatively low N inputs (0 (ambient control), 2, 4, and 6 g N m^{-2} yr^{-1}) to evaluate the threshold for ecological responses to atmospheric N deposition. The results thus far indicate low levels of N input (<2 g N m^{-2} yr^{-1}) will cause changes in community composition, with changes in production and soil processes at inputs $\geq$ 4 g N m^{-2} yr^{-1}. Aboveground production increased, but only after 2 years of fertilization, and only as a result of an increase in sedge biomass (figure 3a). While plant uptake of N increased with fertilization, there was an increase in soil solution NO_3^- with fertilization (figure 3b), indicating that the plant pool did not sequester all of the added inorganic N. Rates of net N nitrification increased with N fertilization, but showed a distinctly non-linear response, reaching a maximum at intermediate levels of N addition (figure 3c). Species composition changed relatively early after initiation of the experiment, and at the lowest rates of N input. Diversity increased in the fertilized plots (figure 4a), primarily as a result of an increase in the abundance of 2 *Carex* species (figure 4b), and not as a result of the appearance of new species. This experiment has demonstrated that ecological change occurs at relatively low inputs of N in an alpine community hypothesized to be the most resistant to the influences of directional environmental change (Seastedt et al. 2004). Similar changes should occur in other alpine communities, potentially at lower N inputs.

Is the alpine of the Front Range already responding to N deposition?

In a recent evaluation of N deposition effects on high elevation catchments, Baron et al. (2000) provided compelling evidence that alpine aquatic ecosystems had experienced significant biotic changes over the last 3 decades. Phytoplankton abundance and diversity had changed in lakes on the eastern slope, concomitant with a period of increased N deposition. Additional evidence is presented for biogeochemical changes in high elevation forests in this volume.

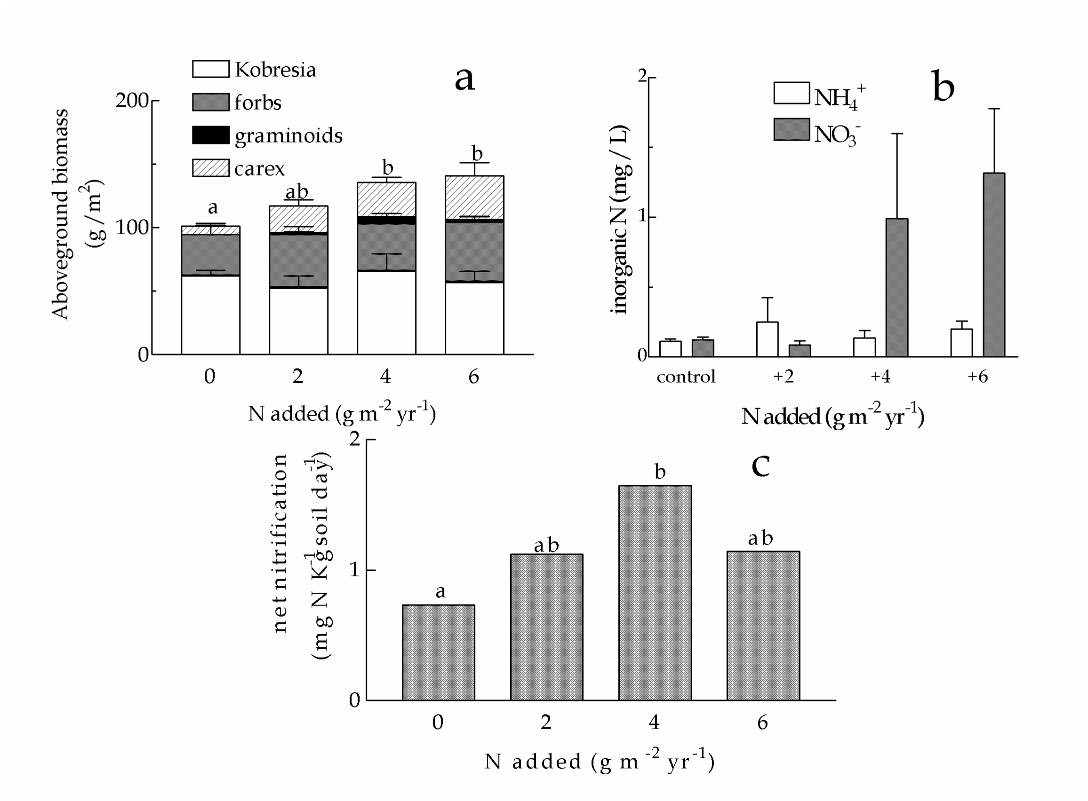

Figure 3. Alpine plant and soil responses to added inorganic N. Experiment initiated in 1997 in a dry meadow community, Niwot Ridge. a) Biomass increased significantly (2002 growing season), due to increases in *Carex* species biomass. b) Soil inorganic N concentrations, as estimated using tension microlysimeters (June 2001, prior to initiation of fertilization). c) Rates of net nitrification in soils (2003 growing season). (Bowman, unpublished data)

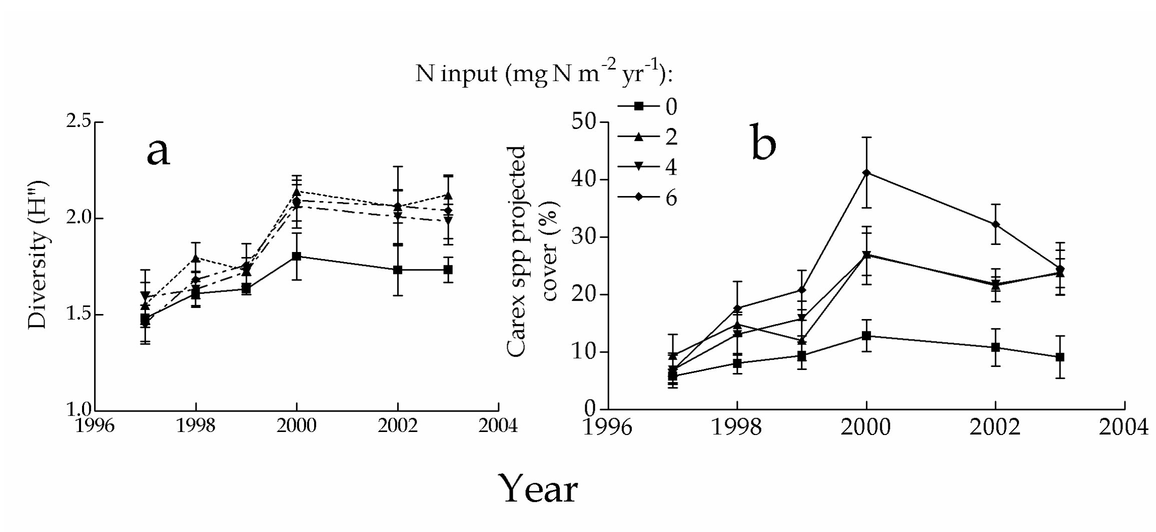

Figure 4. Vascular plant diversity (a) has increased significantly in N fertilized plots in a dry meadow community on Niwot Ridge, CO. The increase is due primarily to an increase in the abundance of *Carex* species (b). (Bowman unpublished data).

Given our experimental work on the susceptibility of alpine terrestrial ecosystems to changes from N deposition, and the evidence of biotic and biogeochemical changes in aquatic systems (Baron et al. 2000, Williams and Tonnessen 2000), we can ask if changes are already occurring? Vegetation change in long-term monitoring plots indicates a trend consistent with predictions made from experimental plots. Korb and Ranker (1998) reported an increase in the occurrence of species associated with N fertilization in alpine plots initiated by John Marr in the 1950's. We analyzed changes in the abundances of species in long-term plots established as part of the Niwot Ridge Long Term Ecological Research program, which have been monitored more intensively, but for a shorter period of time than the Marr plots. There is a strong correspondence between species that increased in abundance over the short-term in fertilized plots and species that have increased in abundance in long-term, unmanipulated monitoring plots (figure 5). This result would appear to provide strong evidence that ecological change is occurring in response to N deposition, yet we can not rule out other factors that could be influencing the abundance of species. Precipitation has increased significantly at high elevation sites on Niwot Ridge (Greenland and Losleben 2001), and changes in winter snow cover can potentially influence species composition (Turner 2002). In addition soil disturbance associated with pocket gophers (Sherrod 1999), and outbreaks of microtine rodents can significantly alter plant species composition.

Implications of biotic change in the terrestrial alpine associated with N deposition

While we can not be absolutely certain that changes in plant species composition are occurring as a result of N deposition in the alpine, the probability of such a change is high. A shift in composition of plants from more "conservative" to more "responsive" species has important implications for the functional response of the alpine to N deposition. In general plant species that are more responsive to increases in resource availability have tissue and growth characteristics that tend to enhance rates of nutrient cycling in the soil (van der Krift and Berendse 2001). These responsive species may also enhance interannual variability in primary production, since their growth is more sensitive to resource variability (Knapp and Smith 2001).

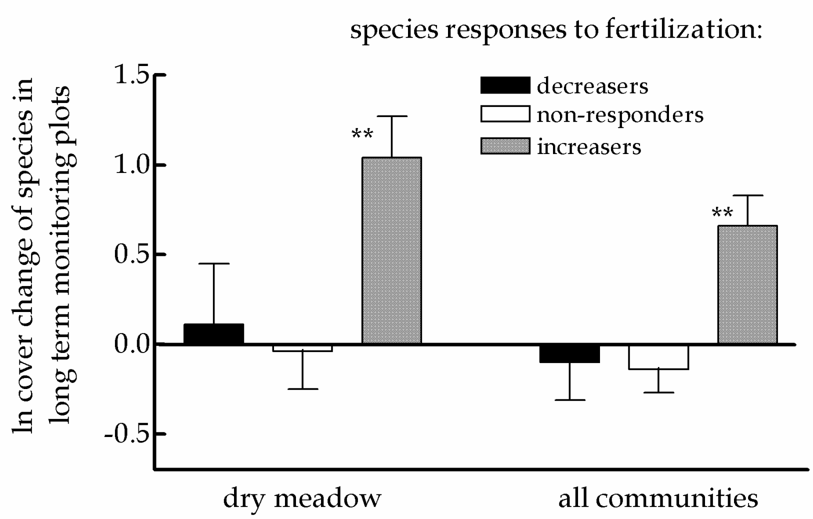

Figure 5. Correspondence between alpine plant species responses to fertilization (increase in cover, no change, or a decrease in cover) and their change in cover in long-term, unmanipulated monitoring plots (dry meadow and all communities combined) on Niwot Ridge, CO. (Suding, unpublished data)

Species compositional changes in the alpine may actually enhance the environmental problems associated with N deposition. This hypothesis is supported by a conceptual model of N deposition effects in moist meadow communities (Bowman and Steltzer 1998), which are the most probable sites of biotic impacts. Alpine moist meadows receive greater inputs of N deposition than other alpine communities. This is due to the entrainment of approximately half the annual N deposition input in snow, the uneven distribution of snow across the alpine landscape due to strong winter winds, and the positioning of moist meadows at the base of the snowfields that form during the winter (Bowman 1992). Moist meadow plants are capable of taking up a significant amount of the N leaching out of snow during the early spring flush, potentially meeting 1-12 % of their growth demand for N from this source (Bilbrough et al. 2000). Up to 1.5 g of anthropogenically derived N m^{-2} is input into moist meadows annually from snowmelt on Niwot Ridge, despite an annual spatially averaged input of 0.8 g N m^{-2}. Fertilization experiments in the moist meadow demonstrate that graminoids, primarily *Deschampsia caespitosa*, responded positively to N additions, while forbs, dominated by *Acomastylis rossii*, are unresponsive or respond slowly (Bowman et al. 1995). Thus the potential for species shifts associated with N deposition is high in moist meadows, and may already be occurring.

Spatial variation in N cycling in soils of the moist meadow is strongly controlled by plant species effects. The co-dominants, *Acomastylis* and *Deschampsia* have divergent influences, with rates of net N mineralization 10-fold,and net nitrification 4-fold higher under soils of *Deschampsia* (Steltzer and Bowman 1998). As a result, changes in species composition may enhance rates of N cycling in moist meadow (and probably other communities) soils and accelerate N loss from the terrestrial alpine (figure 6). Enhanced NO_3^- loss from alpine soils may occur for at least 3 reasons: 1) greater NO_3^- inputs into the system from deposition, 2) greater rates of net nitrification due to the direct effect of deposited N and 3) greater rates of nitrification due to changes in species composition. Greater NO_3^- loss from alpine soils may eventually cause cation depletion and acidification in both soils and nearby aquatic ecosystems.

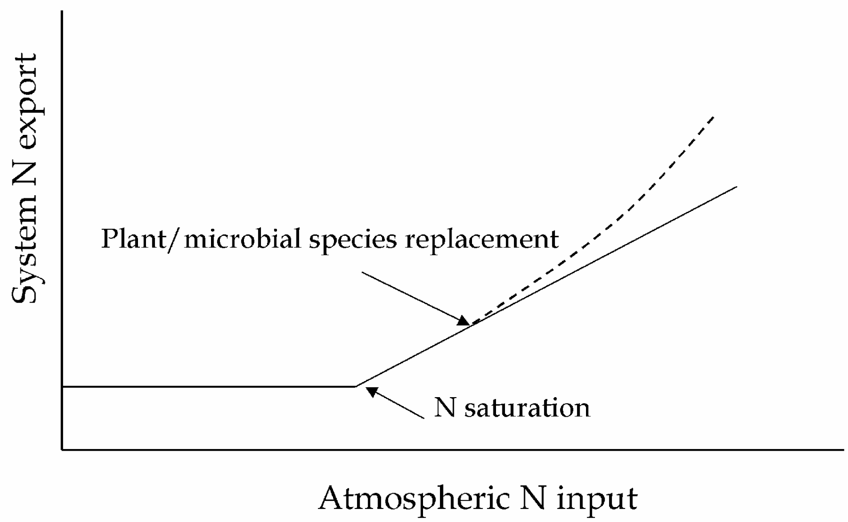

Figure 6. Hypothetical response alpine terrestrial N export as a function of increasing N deposition. At some level of N input, changes in plant and microbial communities increase loss of inorganic N, due to greater rates of soil nitrification (from Bowman 2000).

SUMMARY

Change in alpine vegetation composition is a sensitive indicator of soil resource supply, and may be useful in monitoring ecological effects of atmospheric N deposition. Additional recensusing of long-term vegetation plots in potentially impacted areas will facilitate evaluation of whether changes are ongoing. It is likely that the impacts of environmental change in the alpine will occur due to the direct effects (e.g. warming, greater N availability) as well as the effect of plant species changes on the control of ecosystem processes. Revegetation of alpine areas in this context presents a dilemma. Stabilization of soils requires the use of fast growing species, typically graminoids. However these species may not be as effective in stabilizing nutrient losses. A strategy involving a mix of soil stabilization and nutrient retention might involve sowing both fast growing native graminoid species, along with more slow growing forbs that promote higher nutrient retention.

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EFFECTS OF ATMOSPHERIC NITROGEN DEPOSITION ON HIGH ELEVATION COLORADO FORESTS

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ABSTRACT

Engelmann spruce and subalpine fir forests cover about 12% of the Southern Rocky Mountains, much of which is protected on public lands. Atmospheric nitrogen deposition from energy, automobile, and agricultural emissions acts as a fertilizer to these forests, but fertilization alters natural ecosystem processes. We have compared old-growth forest characteristics from the east side of the Colorado Front Range, where nitrogen deposition ranges 3-6 kg N/ha/yr, to characteristics from the west side, where nitrogen deposition is several times lower. We have also conducted fertilization experiments on east- and west-side forest stands. Higher nitrogen deposition has led to greater nitrogen accumulation in needles, greater soil microbial activity, and accumulation of N in soil floors. Fertilization of east-side forests caused microbial activity and nitrogen leaching to increase, since these forests are close to nitrogen saturation. Fertilization of west-side forests increased organic and foliar nitrogen concentrations. Understory vegetation differs across the east- and west-side plots, with east-side vegetation being much more diverse than west-side. Preliminary evaluation suggests there has been an increase in cover on fertilized plots, but no change in total species diversity.

INTRODUCTION

Nitrogen emissions have been increasing in many parts of the world, due to fossil fuel combustion and increasing agricultural activities, including abundant application of synthetic N fertilizers to croplands and growing intensive animal feeding operations (Galloway and Cowling 2002). Nitrogen (N) deposition has concurrently increased in some parts of the world, with ecological consequences. These consequences include shifts in terrestrial plant assemblages and aquatic algal communities, and lake and stream acidification (Vitousek et al. 1997; Aber et al. 1998). We have been exploring the response of high elevation U.S. Rocky Mountain ecosystems to nitrogen deposition for a number of years. We have taken advantage of a natural meteorological barrier at the mountain crest to compare alpine lakes and subalpine forests and soils on the east side, where N deposition ranges from 3-6 kg N yr^{-1}, with similar systems on the west side, where N deposition is lower. Although the amount of N is low compared with other regions of the world receiving chronically high N deposition loads, high mountain ecosystems are sensitive to change due to harsh climate, large expanses of exposed bedrock and shallow soils, very low vegetation biomass, dilute waters, and a snowmelt-driven hydrology (Baron et al. 2000, Fenn et al. 2003). Mountain environments are generally considered to be oligotrophic, so even the slight introduction of a limiting nutrient can lead to marked change. Increased plant productivity is expected, but may lead to changes in species composition. When N saturation occurs excess N will begin to influence soil cation exchange, ultimately depleting soils of base cations, leading to lake acidity (Figure 1).

The Colorado Front Range is the easternmost front of the Rocky Mountains in Colorado. It is part of the South Platte River basin, where the Great Plains are home to more than two million people and extensive crop and animal agriculture. Paleolimnological reconstructions of nitrogen deposition proxies (diatom species assemblages) suggest increases began around 1950, commensurate with post-war immigration to Colorado and increased agricultural activity (Baron et al. 2000; Wolfe et al. 2001). Air masses carrying aerosols and gases rise into the mountains against the prevailing winds primarily in spring and summer months (Parrish et al. 1992; Williams et al. 1996). At the highest elevations air masses curve back to the east as they become entrained in prevailing westerly winds, creating the circumstance of greater N deposition east of the mountain crest (Baron et al. 2000, Williams and Tonnessen 2000). Our study sites were located between 3000 and 4000 m elevation on public lands that have not been logged or otherwise disturbed. Subalpine forests are composed of 300-700 year old *Picea engelmannii* and *Abies lasiocarpa*. Our investigations in the Colorado Front Range have looked for ecological and biogeochemical changes in otherwise undisturbed forest and lake environments. We have examined forest and soil biogeochemical properties in regions of low and higher N deposition (Rueth and Baron 2002). We have also conducted fertilization experiments in high- and low-N deposition regions from 1996 to the present to determine the responsiveness of forests with differing nutrient status (Rueth et al. 2003). We report here on changes observed in soil and foliar nitrogen status, soil cation response to fertilization, and forest understory plants. Methods are described in Rueth and Baron (2002), Rueth et al. (2003), and Gieck (2003).

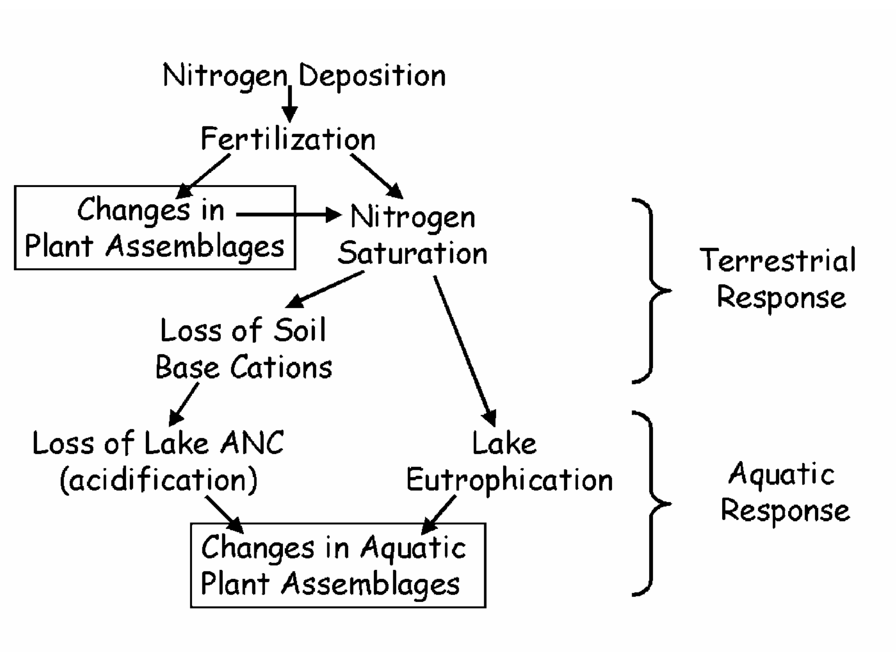

Figure 1. Conceptual model of how nitrogen deposition influences high elevation ecosystems.

RESEARCH FINDINGS

Forest stands showed significant differences in soil and foliar chemistry, and microbial activity depending on their location east or west of the mountain barrier (Rueth and Baron 2002). Six forest stands east of the mountain crest received greater N deposition than five forest stands located west of the mountain crest, but the stands were otherwise similar in exposure (northeast-facing stands), elevation (between 3000 and 3500 m), and mean January and July temperatures. West sites were drier than east sites (860 vs. 1040 mm yearly precipitation), but as the difference was in amount of precipitation that fell as snow, soil moisture remained high through July at all sites. East (high N) sites had greater foliar N and lower C:N ratios than west sites. East sites also had lower lignin:N ratios, and higher potential net mineralization rates. When C:N ratios dropped below 29, as they did in east-side organic horizon soils, mineralization rates increased linearly, an indication of greater N availability (Table 1).

Fertilization Experiments

When a fertilization experiment was conducted in two old-growth coniferous forests, one east and one west of the mountain barrier, the responses differed by location. East side soils with greater total soil N (991 kg ha-1) and low C:N ratios (C:N of 24) showed significant increases in microbial mineralization rates and inorganic soil N over neighboring controls, but foliar N and organic layer soil N remained unchanged. In contrast, fertilization of west side stands (soil C:N ratio of 36, total soil N pool of 605 kg ha-1) showed no change to microbial mineralization rates, but significant increases in foliar and organic soil percent N.

Table 1. Foliar and soil chemistry, and soil microbial responses from six high N and five low N deposition forest stands of the Colorado Front Range. Values are means (std. dev.), and an asterisk (*) denotes significance at 0.05.

	High N (East Side)	**Low N (West Side)**
FOLIAR CHEMISTRY		
% N	1.14 (0.1)	0.99 (0.1)*
C:N	45.6 (4.2)	52.1 (6.6)*
N:Mg	11.9 (1.7)	9.66 (1.6)*
SOIL CHARACTERISTICS		
Organic soil %N	1.39 (0.2)	1.08 (0.2)*
Organic soil %C	38.8 (4.8)	34.2 (5.9)
Organic soil C:N	25.9 (2.7)	32.5 (5.0)*
Lignin:N	22.2 (3.1)	28.3 (5.7)*
Microbial mineralization rate (:g N g-1 d-1)	3.42 (2.7)	0.69 (1.0)*
Microbial nitrification rate (:g N g-1 d-1)	0.57 (1.5)	0.06 (0.3)
RESPONSE TO FERTILIZATION		
Foliar %N	No Change	Significant Increase
Organic soil %N	No Change	Significant Increase
Inorganic soil %N	Significant Increase	No Change
Mineralization rate	Significant Increase	No Change

The difference in the size of the soil organic N pool and C:N ratio between east and west sites is attributed to N deposition, and these characteristics control the responsiveness of coniferous forests and soils. Additional N inputs to the east (high N) site will enhance N mineralization rates and leaching losses. The west site is still N-limited, and additional N from fertilization is used to enhance biomass. We predict continued fertilization will narrow the C:N ratio to a point where increased biogeochemical N cycling and fluxes will be detected (Rueth et al. 2003).

Soil Cation Responses to Fertilization

Accelerated cation leaching from soils was observed with nitrogen saturation. In the east-side forest stands, calcium, potassium, and magnesium cation concentrations were accelerated with fertilization (Table 2). Concentrations correlate with nitrate concentrations with correlation coefficients of 0.925, 0.915, and 0.929. Sodium concentrations did not increase in fertilized plots and results for aluminum are not conclusive. Cation concentrations did not correlate with precipitation either on a yearly or seasonal time scale. In the low deposition west-side forest stands, neither cations nor nitrate were elevated in soil solutions, presumably because these forests are nitrogen limited and added N was taken up biologically.

Table 2. Median cation concentrations and range for east-side (Loch Vale: LV) and west-side (Fraser: Fr) separated by treatment (control=C, fertilized=F). Values are medians (ranges), and an asterisk (*) denotes significance at 0.05.

		Ca (mg/L)	**K (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**Al (mg/L)**
		Median	Median	Median	Median	Median
Site	**Treatment**	*Range*	*Range*	*Range*	*Range*	*Range*
LV	C	2.66	0.68	0.42	0.44	0.50
		30.01	*4.38*	*2.38*	*5.17*	*7.01*
LV	F	3.53*	1.08*	0.52*	0.48	0.33*
		54.41	*21.02*	*8.68*	*7.64*	*3.79*
Fr	C	7.03	3.48	1.16	0.52	0.64
		51.11	*23.19*	*4.78*	*2.72*	*5.76*
Fr	F	4.75	1.32	0.76	0.60	0.53
		41.39	*21.97*	*4.58*	*4.23*	*2.67*

Understory Vegetation

A survey of understory plants was conducted in 2001. Plants were identified to species, numbers of stems and percent cover of each was enumerated. Although results are still under analysis, we found a total of 130 species in the east-side forests, although both east- and west-side forests were dominated by *Vaccinium spp.* Only one non-native plant species (*Taraxacum officinale*) was discovered. Fertilized plots on the east-side showed a tendency for greater percent cover and greater numbers of species, although results were not significant. No similar pattern was observed for west-side plots. Repeated surveys through time will be needed to show whether there is a lasting change to understory from N fertilization treatments.

SUMMARY

Aber et al. (1998) have suggested a sequence of events that occurs when atmospheric nitrogen increases: increased soil nitrogen concentrations, increased microbial N mineralization and nitrification, increased plant available N leading to greater foliar N concentrations and reduced C:N ratios, decreased soil C:N ratios, and increased nitrogen and cation leaching. These have been observed with increasing intensity in our study of low N deposition (west-side) to higher N deposition (east-side) to east-side fertilization treatments, strongly indication that alteration of the nitrogen cycle is a significant cause for ecological change in Rocky Mountain forests.

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REVEGETATION STRATEGIES AND TECHNOLOGIES FOR RESTORATION OF NATIVE SHRUB/GRASS COMMUNITIES ON XERIC SALTCEDAR (*TAMARIX* SPP.) INFESTATION SITES

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ABSTRACT

Critical knowledge gaps exist regarding vegetative recovery in xeric, monotypic saltcedar (*Tamarix* spp.) stands with no (desirable) understory. Formulation of revegetation strategies that provide site stabilization, resistance to further saltcedar and secondary weed infestation, and acceptable habitat values for affected wildlife species becomes particularly problematic in monotypic saltcedar stands under biological, fire and herbicidal (i.e., non-mechanical) control scenarios. Amount and density of standing biomass (live and dead) remaining after control poses limitations in relation to seeding and planting techniques, seed interception in aerial (broadcast) applications, and seedbed preparation methods. Undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky micro-relief, and nutrient limitations restrict potential for successful revegetation. Long duration of saltcedar occupation may deplete needed microbial communities, particularly arbuscular mycorrhizae symbiotic and host-specific to native revegetation species. Results of innovative revegetation strategies at study sites on the Rio Grande and the Colorado River are discussed. Technical approaches include: soil surface and rhizosphere manipulation methods to facilitate removal of standing dead biomass, increase precipitation capture, improve soil moisture retention, and create micro-sites exhibiting lower salinity and increased protection from environmental extremes for improved seed germination; salinity remediation using HydraHume™; seeding methodologies, including use of seed coating techniques; and mycorrhizal inoculation methods.

INTRODUCTION

Executive Order 13112 (Invasive Species) mandates that federal agencies control and monitor invasive species, provide restoration of native species and desirable habitat conditions in ecosystems that have been invaded, and conduct research to develop technologies to prevent introduction and provide environmentally sound control of invasive species. Unfortunately, research is often driven by evaluation of control measure effectiveness, with secondary emphasis on ability of sites to sufficiently recover vegetatively for site stabilization and habitat value enhancement (Lair and Wynn 2002, DeLoach et al. 2000, Anderson and Ohmart 1979). On xeric, saline sites not subject to seasonal flooding, recovery of desirable vegetation may be the most limiting factor for site enhancement (Anderson 1995).

Tamarix L. (saltcedar) is a highly invasive exotic shrub that has invaded thousands of acres along many major river systems (Bureau of Reclamation 2000, McDaniel et al. 2000, Crawford et al. 1993). Throughout the western United States, saltcedar infestation has been documented to produce adverse environmental effects in riverine and lacustrine systems. These effects include increased wildfire potential resulting from high densities of fine, woody fuel materials; significant reduction in biodiversity, wildlife habitat, and riparian ecosystem function and structure; and significant reduction of surface and groundwater return flows (Zavaleta 2000a, b, California Exotic Plant Pest Council 1998, University of California 1996, Anderson 1995, Crawford et al. 1993). Saltcedar spreads by seed dispersal and vigorous sprouting from lateral roots and decumbent stems (i.e., prostrate stems with nodes in contact with the soil surface), competitively and rapidly displacing native stands of cottonwood (*Populus* L.), willow (*Salix* L.), and grasses that are more fire-resistant (Wiesenborn 1996, Lovich 1996, Anderson and Ohmart 1979, Warren and Turner 1975).

Saltcedar has been implicated in severe reduction of habitat value within the riparian corridors of major river systems (Anderson 1995, Crawford 1993, Anderson and Ohmart 1979). Minimum flow volumes within the middle Rio Grande River have recently been mandated as critical for maintenance of an endangered fish, the Rio Grande silvery minnow (*Hybognathus amarus* Girard). Saltcedar has also been suggested as a possible cause of habitat reduction along the Canadian River system for many native fish and wildlife species, including the endangered Arkansas River Shiner (*Notropis girardi* Hubbs & Ortenburger) (Eberts 2000, M. Davin personal communication). One implication of this requirement is that additional water (via surface and groundwater return flow contributions) will be needed to support improved habitat for this fish. Landscape-scale management of saltcedar could positively address this need because of saltcedar's phreatophytic growth regime, high consumptive use (evapotranspiration) rate, high stand densities, and increasing infestation extent. Similarly, adverse impacts of saltcedar infestation on habitat of the southwestern willow flycatcher (*Empidonax extimus trailii* Audubon) have been well documented (DeLoach et al. 2000, Dudley et al. 2000, Zavaleta 2000a, b, Carpenter 1998, Anderson and Ohmart 1979).

Fire prevention and management in natural areas is exacerbated in dense saltcedar stands (Zavaleta 2000a, Wiesenborn 1996, Busch 1995, Scurlock 1995, Friedman and Waisel 1966). Saltcedar is a multi-stemmed invasive (exotic) shrub, sprouting basally from the root crown and lateral roots (Carpenter 1998, DiTomaso 1996). It can produce near continuous cover, ladder fuel structure and extremely high standing biomass of fine to medium, woody fuel material (Wiesenborn 1996, Busch 1995). In dense, monotypic stands, mean canopy height can exceed 12 meters, with canopy closure (aerial cover) often approaching 100% (Lair and Wynn, unpublished data), resulting in high potential for canopy fire carry. Saltcedar stands are often characterized by dense understory and soil surface litter layers comprised of additional fine fuels consisting primarily of annual grasses (e.g., Japanese brome [*Bromus japonicus* Thunb. ex Murr.], cheatgrass (*Bromus tectorum* L.]), and saltcedar leaf litter (Lair and Eberts 2002).

BACKGROUND, RESEARCH NEEDS

Critical knowledge gaps exist regarding restoration of saltcedar infestations, for which limited research or field experience exists, especially on xeric sites. Specifically, major information needs include strategies and techniques for vegetative recovery in a) xeric, mature, monotypic saltcedar stands with no (desirable) understory; and b) sites where potential is limited for natural or artificial recovery of willow and/or cottonwood species because of unavailability of supplemental water (via seasonal flooding, shallow water table, or irrigation). Best management practices are needed that integrate multiple management tools and are capable of addressing both localized (small scale) and landscape-scale, mesic and xeric saltcedar infestations. These practices should result in implementation of control and revegetation measures that provide a) rapid initial reduction of saltcedar; b) maintenance of control over extended time periods; and c) establishment of desirable vegetation that is ecologically (successionally) sustainable, competitive, resilient to further disturbance, and provides multiple habitat, site stability and forage benefits.

Vegetative restoration of sites impacted by invasion (and subsequent control) of saltcedar presents technical and conceptual challenges, particularly within the context of biological, fire or foliar herbicide control. For example, current research funded through the Cooperative State Research, Extension and Education Service (CSREES) and Initiative for Future Agriculture and Farming Systems (IFAFS) addresses biological control of saltcedar (using *Diorhabda elongata* Brulle) as an economically sound alternative to other measures, especially in relation to reducing physical site disturbance and use of herbicides. The research places priority on evaluation of revegetation techniques in relation to anticipated results of biological control alone (i.e., as the initial or primary treatment, leaving high densities and biomass of defoliated or standing dead material), as opposed to follow-up, maintenance control subsequent to mechanical, fire or herbicidal measures.

Reducing the time for establishment of desired levels of cover, diversity, production and habitat values is also important (Lair and Wynn 2002, Anderson 1995, Pinkney 1992). Natural recovery of saltcedar infestation sites following control measures, especially in less dense stands, needs to be evaluated in light of the definition of "recovery" and an acceptable time frame for it to occur. Natural recovery scenarios (i.e., not artificially revegetated) often require 10 years or more for establishment of desirable, native vegetation, with the first 1-5 years typically dominated by ruderal weedy species. A prime objective should be to shorten or circumvent an extended ruderal and/or bare period by establishing diverse habitat characterized by predominance of early-, mid-, and late-seral perennial species. This also minimizes potential for capillary rise and salt accumulation at the soil surface following saltcedar reduction, and maintains lower wildfire hazard. Some sites may need initial establishment of earlier seral or transitional “ecobridge” species in order to cope with and adapt to harsh environmental conditions until the site stabilizes (from the standpoints of organic matter recovery, energy flow and nutrient cycling). Other sites may facilitate later seral species and accelerated successional strategies.

Development and application of revegetation strategies also need to parallel (keep pace with) recent technological developments in herbicidal and biological control of saltcedar, which holds great potential for rapid control of saltcedar on landscape scales. Valuable information can be derived from studies involving control of saltcedar by biological agents, fire or herbicide application, especially in terms of the effect of growth medium manipulation (physically, biologically, chemically) on moisture capture and retention, restoration of a functional microbial community, species adaptation, and other management inputs. Amount and density of standing biomass (live and dead) remaining after control, seedbed preparation strategies, and time frame to achieve levels of control sufficient to favor vegetation establishment and site protection/stabilization are problematic in dense, mature saltcedar stands.

Effective techniques for seedbed preparation and seeding/transplanting in standing dead or defoliated material are needed that are more cost-effective, require smaller equipment with less energy expenditure, and cause less environmental disturbance than conventional methods (e.g., root plowing and raking). Presence of dense standing dead or defoliated saltcedar biomass poses limitations in relation to seeding techniques, seed interception in aerial applications, and shading impacts. After natural or prescribed fire treatment, undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky micro-relief, nitrogen limitations, and possible livestock trampling compaction may also restrict potential for successful revegetation. Absence of arbuscular mycorrhizae specifically symbiotic to native revegetation species (especially grasses and shrubs), because of the long duration of saltcedar occupation in dense, mature stands, may also be a significant constraint.

Saltcedar reduction may yield an interaction of both positive and negative impacts resulting from biological, fire or herbicide application, requiring site-specific evaluation for restoration potential. Soil surface manipulation in the types and intensities needed for adequate soil surface manipulation (seedbed preparation) is absent following fire, biocontrol measures, and most herbicide applications (Pinkney 1992, Szaro 1989). Brief review to date of saltcedar revegetation literature, and communication with researchers and land managers experienced in saltcedar control and site restoration on xeric sites with dense, mature, monotypic infestations indicate that revegetation is difficult in the absence of soil surface manipulation (i.e. some form of seedbed preparation) (Lair and Wynn 2002, Horton et al. 1960). Different methods of achieving desirable growth medium conditions need testing through varied techniques of seedbed preparation to enhance micro-environmental conditions in the root zone of planted species, including saltcedar leaf litter dispersal or incorporation, improved contact of seed with mineral soil, salinity reduction in surface soil layers, mycorrhizal fungi inoculation, and manipulation of soil nitrogen dynamics.

Stimulation of resprouting and increases in saltcedar density from remaining live root crowns and stems may occur as a result of saltcedar biomass reduction by mechanical measures or fire (wild or prescribed). The increased proportion of young, active growth increases competition for moisture, nutrients and solar energy with planted vegetation. Use of mechanical methods or prescribed fire for biomass reduction needs sound planning and stringent controls as a viable tool, yielding an interaction of both positive and negative impacts. For example, rapid reduction of saltcedar canopy over large areas may be undesirable because of habitat sensitivity on sites occupied by endangered species such as the southwestern willow flycatcher (Wiesenborn 1996, Busch 1995). When applied on large (landscape) scales, reduction or elimination of biological control organism(s) may result, requiring reintroduction and subsequent redistribution (spread) over time of the biological agent(s) (D. Eberts, personal communication). Stimulation of resprouting from remaining live stems or root crowns resulting from mechanical or fire control measures, however, may promote higher rates of insect herbivory and increases in population size of biological agent(s) (Lair and Wynn 2002).

CURRENT RESEARCH

Objectives

The USBR is studying impacts of control measures (herbicidal, mechanical and biological) and fire on site restoration / revegetation potential on xeric saltcedar infestation sites that are not candidates for revegetation with willow and cottonwood species (i.e., arid climatic regime, rare over-bank seasonal flows, deeper water tables). Development and evaluation of revegetation and habitat enhancement techniques are being conducted in historically dominant or monotypic saltcedar stands where potential for natural recovery of desirable native vegetation following control measures is limited or negligible. The studies address saltcedar control reflecting a) simulated biological control as the primary treatment (also applicable to foliar or basal bark herbicidal treatment); and b) mechanical control or fire where biological agents would be used as continuing maintenance (follow-up) control. The studies emphasize: a) revegetation species response to mechanical techniques for saltcedar biomass reduction and seedbed preparation; b) manipulation of microbial (mycorrhizal) dynamics; and c) design and adaptation of selected species mixtures that are broadcast-applied (i.e., simulation of aerial seeding), supported by companion single species trials.

Study Locations and Experimental Treatments

Study Location

Study sites for this research are San Marcial, New Mexico (approximately 30 miles [48 kilometers] south of Socorro, New Mexico) and Cibola, Arizona (located approximately 45 miles [72 kilometers] north of Yuma, Arizona.

San Marcial, NM

The San Marcial site is situated at an elevation of approximately 4,490 feet (1,369 m) on the immediate west side of the low flow conveyance channel along the Rio Grande River. Mean annual precipitation (MAP) for the project area is 8.79 inches (22.3 cm), with 5.47 inches (13.9 cm) or 62% falling as rain during the summer monsoonal period of July through October (NOAA 2004). Soils of the project area are primarily fine sand and fine sandy loam, 0-2% mean slopes, typical of the braided channel floodplain zones adjacent to the middle Rio Grande River system (USDA-NRCS Socorro County Area Soil Survey, 1988). All soils are moderately to strongly saline (electrical conductivity [EC_e] 7-25 mmhos cm^{-1}), and may have clay loam to clay subsoil horizons with depths to bedrock typically exceeding 60 inches (152 cm). The site is now instrumented for collection of localized climate and soil environment data, utilizing a HOBO™ remote weather station (Onset Computer Corporation, Pocasset, MA)

The general study site represents two distinct age classes of monotypic saltcedar (*Tamarix ramosissima* Ledeb.) infestation (no shrub understory and negligible herbaceous understory). Younger (above-ground) saltcedar are characterized by mean stem diameters less than 3 inches (7.6 cm) and mean canopy cover less than 80%, resulting from prior prescribed burning conducted by the BLM in 1994. Older stands of saltcedar were protected from fire by means of a firebreak installed in 1993, and consists of dense, old-growth populations characterized by mean stem diameters equal to or greater than 3 inches (maximum diameters up to 16 inches [40.6 cm]), and mean canopy cover approaching 100%. Lack of historical record or on-site evidence of natural or artificial reduction of saltcedar biomass in this latter population suggests an undisturbed stand age of at least 40 years.

Cibola, AZ

The Cibola site is located at an elevation of approximately 230 feet (70 m) in the Cibola Valley along the immediate east side of the Colorado River. Mean annual precipitation for the general project area is 3.83 in (9.73 cm) (NOAA 2004). Bimodal peaks in mean monthly precipitation occur in August-September and December through February, with all precipitation occurring as rainfall. Soils of the project area are primarily deep, well-drained, silt loams (USDA-NRCS Yuma-Wellton Area, Arizona Soil Survey, 1980) common to flood plain and alluvial sites (0-1% mean slopes) along this portion of the lower Colorado River. Soils are strongly saline, with salinity levels (as indicated by EC_e measurements) extremely high (40-90 mmhos cm^{-1}) in the surface layer (top 6 inches [15 cm]), and low to moderate at 12-inch (30 cm) soil depths (5-12.5 mmhos cm^{-1}).

The Cibola study site is comprised of mixed saltcedar (*T. ramosissima* Ledeb.) and quailbush [*Atriplex lentiformis* (Torr.) S. Wats. ssp. *breweri* (S. Wats.) Hall & Clements] that was burned by wildfire on April 17, 2001. Saltcedar plants within the burn area are characterized by mean live stem diameters less than 2 inches (5 cm) and mean, post-fire canopy cover less than 25%.

Experimental Design and Statistical Analysis

Studies are replicated (4 blocks), split-plot or split-split-plot factorial designs suitable for ANOVA and multivariate analyses. These experimental designs incorporate evaluation of important response variables simultaneously within the same spatial and temporal context under a common error term. Univariate analysis was used to evaluate individual species responses, while multivariate techniques (e.g. discriminant analysis, canonical correlation, multiple linear regression) will assess treatment responses using combinations of plant community, climate, soil and applied treatment variables. Studies incorporate control plots to reflect natural revegetation potential in the absence of treatment at all plot levels and within all replicates.

Generalized Study Type and Design

Seedbed Preparation, Mycorrhizal Inoculation, Seeding Mixture

Main plot — Seedbed preparation
- Herbicide treatment only
- Herbicide / shred / roller chop
- Shred / roller chop
- Shred / roller chop / imprint

2nd Level — Mycorrhizal inoculation
- Broadcast granular
- Pelleted seed coating
- None

3rd Level — Seed mixtures
- Grass / forb / shrub mixture 1
- Grass / forb / shrub mixture 2
- Grass / forb / shrub mixture 3
- None [“natural” recovery]

Treatments emphasize seeding without supplemental moisture (e.g., seasonal flooding or irrigation) to reflect lower cost / lower maintenance vegetation establishment protocols and methodology. Specifically, treatments will emphasize: a) revegetation species response to mechanical techniques for saltcedar biomass reduction, seedbed preparation, and moisture capture/retention; b) manipulation of microbial (mycorrhizal) regimes; and c) design and adaptation of selected species mixtures (Tables 1 and 2) that are broadcast-applied (i.e., simulation of aerial seeding).

GENERAL METHODOLOGY

Project Term

Total project life is proposed for five years (2002 – 2006), involving baseline inventories, treatment applications, and post-treatment monitoring and weed management. Further, limited monitoring may continue for an additional five years following project completion, subject to research results, staff availability, and project funding. The intensive field data collection portion of the project is proposed for three years duration (2002-2004).

Baseline Inventories and Post-Treatment Monitoring

Baseline (2002) and post-treatment (2003-2006) inventories include soils (systematic core and electronic surface sampling), vegetation (fixed transects, using line intercept, line point, and systematic 1.0 m^{-2} quadrat sampling), and groundwater (monitoring wells). Post-treatment monitoring will be conducted (as a minimum) once per year in late fall to early winter (october-december). Initial, measured field variables proposed for use in conducting baseline inventories and to evaluate treatment responses include:

Soils

Using core sampling and surface electromagnetic techniques, soils are systematically sampled on an individual plot basis for the following parameters:

- Texture - surface (0-12 inches; 0-30 cm) and subsoil (12-36 inches; 30-90 cm)
- Organic matter
- Fertility (macro- and micro-nutrients; surface layer only)
- Salinity (EC/SAR; surface and subsoil)
- Reaction (pH; surface and subsoil)
- Moisture content / availability (surface and subsoil)

Groundwater

A minimum of one 2-inch (5 cm) diameter, PVC-encased monitoring well per study was installed simultaneous with baseline inventories and prior to treatment applications for monitoring of:

- Ground water depth (baseline, pre-treatment and monthly, post-treatment)
- Conductivity
- pH
- Alkalinity
- Major ions (Cl^-, $SO4^=$, Ca^{++}, Mg^{++}, Na^+, K^+)
- Trace elements/metals
- NO_3^-/NO_2^-.

Vegetation

- Age class (baseline only), plant height, plant spacing, stem densities and diameters for saltcedar
- Species frequency
- Vigor Index (function of culm and leaf height, seedhead production, and biomass)
- Basal and canopy cover (total and by species), seeded and non-seeded
- Bare ground and litter
- Species diversity (Shannon-Weiner or modified Simpson's)
- Biomass (live standing crop [LSC] + standing dead; total and by species), seeded and non-seeded species

Wildlife

- Modified Habitat Suitability Index (HSI) evaluations will be conducted on resultant small plot plant communities, with extrapolations to potential landscape-scale communities of the same character, to estimate general habitat values based on desired plant community composition and revegetation results.

HERBICIDE APPLICATION

Saltcedar was herbicidally treated at San Marcial, NM to simulate injury and defoliation from biocontrol insects, using backpack applications of triclopyr in vegetable oil as a basal bark treatment (25% v/v). Seeded species competition for moisture and nutrients, and adjustment to altered soil microbial and organic matter regimes in affected *Tamarix* communities, should be evaluated in the presence of live saltcedar root growth while undergoing above-ground defoliation over time (chronic stress leading to root reserve depletion). Ongoing control of saltcedar sprouts following fire (Cibola, AZ) or mechanical treatment (both studies) is maintained herbicidally on treated plots over the duration of the study via spot treatment using backpack sprayers, or as situations indicate following revegetation treatments, carpet roller or rope wick application (dependent upon plant densities, prevalence of non-target vegetation, and cost effectiveness). Secondary invasive species will be similarly controlled using labeled herbicides appropriate for the target species and land use type.

Mechanical Treatments

Mechanical treatments were used for saltcedar biomass reduction, seedbed preparation and mulching, salinity remediation, placement of seed, and incorporation of soil microbial (mycorrhizal) amendments. These measures include saltcedar shredding / mulching by HydroAx™ with WoodGator™ attachment, roller chopping and land imprinting. These measures will be evaluated for efficacy in a) creating soil surface micro-relief (micro-catchments) to enhance precipitation capture and retention in the rhizosphere of seeded / planted vegetation; b) reduction, redistribution, and/or dilution of salts in the upper soil profile and saltcedar leaf litter on the soil surface; c) creating more spatially uniform soil texture characteristics (in both depth and lateral extent) for improved planted vegetation adaptation; and d) proper depth placement and incorporation of mycorrhizal inoculum.

Growth Medium Amendments

Mycorrhizal inoculum (using host-specific species, as determined from baseline soil samples, current research, and pertinent literature) was obtained either commercially (e.g., RTI, Inc., Salinas, CA; Bionet LLC, Marina, CA), or was provided via Cooperative Research and Development Agreement (CRADA) as donated research materials from Bionet LLC. Inoculum was placed and incorporated into the prepared seedbed by two methods: a) as a pre-plant granular broadcast application using a manual, rotary fertilizer or seed spreader at a prescribed rate of 60 lb ac^{-1} (67 kg ha^{-1}) product; or b) raw inoculum was incorporated in commercially pelletized seed coatings (CelPril, Inc., Manteca, CA; Seed Systems, Inc., Gilroy, CA), and applied during broadcast seeding using prescribed seeding rates. Regardless of source, the inoculum contained one or more species of mycorrhizae that are host-specific to the native revegetation plant species: *Glomus mosseae, G. intraradices, G. etunicatum, G. aggregatum,* and/or *G. fasciculatus*.

Planting Methodology

Revegetation was conducted in combination with mechanical and mycorrhizal inoculation treatments using the following methods:

San Marcial, NM

- broadcast using manual (hand-held) and/or mechanized (tractor PTO-driven) rotary spreader(s).

Cibola, AZ

- broadcast using manual (hand-held) and/or mechanized (tractor PTO-driven) rotary spreader(s);
- broadcast using a mechanized Brillion-type seed drill;
- drilled using a research plot drill with leading deep-furrow openers; and

- seedling transplants, planted manually or mechanically depending upon species, container type, soil conditions, and equipment availability.

Planting was done in conjunction with selected mechanical seedbed preparation treatments using the roller chopper and/or imprinter to facilitate desired seed depth placement and juxtaposition of seed to incorporated mycorrhizal inoculum (subject to the experimental design).

Species Selection

Emphasis is placed on testing native species (in conjunction with associated seeding/planting methodology) as single species, seed mixtures, and seedling transplants that best reflect environmental site adaptation, practical field applications by agencies and private landowners, commercial availability, and cost-effectiveness. Evaluation of competition between species within designed mixtures under saltcedar control conditions is also performed. Evaluations will be made on individual species as well as resultant plant communities. General design and number of mixture applications are amenable to site-specific adjustment at other southwestern sites subject to individual site attributes.

Mixtures of native shrubs, forbs and grasses were seeded or planted following various experimental combinations of herbicide and/or mechanical treatments (San Marcial, NM: 16 species, July 15-17, 2002; Cibola, AZ: 23 species, January 30-31, 2003). Species and mixtures are detailed in Tables 1 and 2. The Cibola study also incorporates a demonstration of irrigated and non-irrigated, single species trials, utilizing both seed and seedling transplants.

Seed coating for mycorrhizal inoculation was performed in cooperation with:

- San Marcial, NM: Bionet LLC (Marina, CA) and CelPril, Inc. (Manteca, CA).Cibola, AZ: Reforestation Technologies, Inc. (Salinas, CA) and Seed Systems, Inc., (Gilroy, CA).

- Cibola, AZ: Reforestation Technologies, Inc. (Salinas, CA) and Seed Systems, Inc., (Gilroy, CA).

All species, singly or in mixtures, were selected for optimum adaptation to interactions of climate, soil, salinity, competition from existing vegetation, and planned treatments, including pre-conditioning treatments as needed (e.g., stratification and/or scarification for seed; selection for salinity tolerance and mycorrhizal inoculation potential [MIP] for transplants). Both studies incorporate "transitional" or "ecobridging" species concepts within mixtures, using regional natives that exhibit greater establishment potential in terms of germination, seedling vigor, and reproductive capability under the harsh climatic and soil conditions on saltcedar revegetation sites.

Native revegetation species were obtained through cooperation with the USDA-NRCS Plant Materials Centers (PMC) plus acquisition of local native harvest or commercial source material, depending upon individual species availability. Species were of local (endemic) or regional origin where possible. Final species and cultivar selection, for both mixture and single species applications, were determined in consultation with local / regional cooperators (e.g., Bureau of Land Management, Fish and Wildlife Service, State Fish and Game Departments, Natural Resources Conservation Service, and Bureau of Reclamation).

Table 1. Mixtures and seeding rates (PLS seedomg rate at 20 seeds/ft^2), San Marcial, NM saltcedar revegetation study.

Scientific Name	Common Name	Cultivar or Pre-Release	Mixture Rate (%)	PLS Mix Drilled[1] (lb/ac)	PLS Mix Broadcast[1] (lb/ac)
MIXTURE 1 - AGGRESSIVE					
GRASSES					
Bouteloua curtipendula	Sideoats grama	Niner	10.0	0.50	1.01
Elymus elymoides	Bottlebrush squirreltail		10.0	0.55	1.09
Elymus trachycaulus	Slender wheatgrass	Pryor	10.0	0.68	1.35
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pascopyrum smithii	Western wheatgrass	Arriba	10.0	0.87	1.74
Sporobolus giganteus	Giant dropseed		5.0	0.03	0.06
Sporobolus wrightii	Giant sacaton		5.0	0.03	0.05
FORBS					
Plantago insularis	Wooly plaintain		2.0	0.06	0.13
Sphaeralcea coccinea	Scarlet globemallow		3.0	0.06	0.13
Heliotropium curassavicum	Quailplant; salt heliotrope		2.0	0.03	0.05
Atriplex canescens	Fourwing saltbush		12.7	2.55	5.11
Forestiera neomexicana	New Mexico olive	Jemez	0.30	0.07	0.15
Atriplex lentiformis	Quailbush		10.0	0.21	0.42
Shepherdia argentea	Silver buffaloberry		5.0	1.16	2.32
		TOTAL	100.0	7.24	14.48
MIXTURE 2 - MESIC					
GRASSES					
Bothriochloa barbinodis	Cane bluestem	Grant	15.0	0.21	0.42
Elymus canadensis	Canada wildrye		9.0	0.83	1.65
Elymus lanceolatus	Streambank wheatgrass	Sodar	5.0	0.32	0.64
Pascopyrum smithii	Western wheatgrass	Arriba	15.0	1.31	2.62
Puccinellia airoides	Nuttall's alkaligrass		5.0	0.02	0.04
Sporobolus airoides	Alkali sacaton	Salado	16.0	0.10	0.21
FORBS					
Anemopsis californica	Yerba mansa		5.0	0.04	0.08
Sphaeralcea coccinea	Scarlet globemallow		5.0	0.10	0.21
SHRUBS					
Baccharis glutinosa	Seep willow		5.0	0.00	0.01
Lycium andersonii	Anderson's wolfberry		6.0	0.11	0.21
Chilopsis linearis	Desert willow		5.0	0.70	1.39
Chrysothamnus nauseosus ssp. graveolens	Rubber rabbitbrush		4.0	0.08	0.17
Sarcobatus vermiculatus	Greasewood		5.0	0.20	0.41
		TOTAL	100.0	4.03	8.06

Table 1. (Continued) Mixtures and seeding rates (PLS seeding rate at 20 seeds/ft^2), San Marcial, NM saltcedar revegetation study.

Scientific Name	Common Name	Cultivar or Pre-Release	Mixture Rate (%)	PLS Mix Drilled[1] (lb/ac)	PLS Mix Broadcast[1] (lb/ac)
MIXTURE 3 - SANDY					
Achnatherum hymenoides	Indian ricegrass	Paloma	10.0	0.57	1.14
Elymus elymoides	Bottlebrush squirreltail		10.0	0.55	1.09
Elymus lanceolatus lanceolatus	Thickspike wheatgrass	Critana	5.0	0.34	0.68
Eragrostis trichodes	Sand lovegrass	Bend	5.0	0.03	0.07
Leptochloa dubia	Green sprangletop		5.0	0.10	0.19
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pleuraphis (Hilaria) mutica	Tobosagrass		10.0	0.23	0.46
Schizachyrium scoparium	Little bluestem	Pastura	10.0	0.42	0.85
Sporobolus cryptandrus	Sand dropseed		5.0	0.01	0.02
Oenothera deltoides	Dune evening primrose		2.0	0.06	0.13
Plantago insularis	Wooly plaintain		5.0	0.16	0.32
Sphaeralcea coccinea	Scarlet globemallow		5.0	0.10	0.21
Atriplex polycarpa	Desert saltbush		3.0	0.04	0.08
Lycium torreyi / L. andersonii	Torrey / Anderson's wolfberry		4.0	0.07	0.14
Ephedra viridis	Green ephedra		4.0	2.06	4.12
Ephedra nevadensis	Nevada ephedra		2.0	1.03	2.06
		TOTAL	100.0	6.22	12.43
STANDARD MIXTURE					
GRASSES					
Bouteloua curtipendula	Sideoats grama	Niner	10.0	0.50	1.01
Elymus trachycaulus	Slender wheatgrass	Pryor	11.0	0.74	1.49
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pascopyrum smithii	Western wheatgrass	Arriba	10.0	0.87	1.74
Sporobolus airoides	Alkali sacaton	Salado	15.0	0.12	0.23
Sporobolus giganteus	Giant dropseed		5.0	0.03	0.05
FORBS AND SHRUBS					
Anemopsis californica	Yerba mansa		2.0	0.02	0.03
Plantago insularis	Wooly plaintain		2.0	0.06	0.13
Sphaeralcea coccinea	Scarlet globemallow		2.0	0.04	0.08
Atriplex canescens	Fourwing saltbush		12.0	2.41	4.83
Baccharis glutinosa	Seep willow		3.0	0.00	0.00
Atriplex lentiformis	Quailbrush		4.0	0.08	0.17
Lycium andersonii	Anderson's wolfberry		7.0	0.12	0.25
Chrysothamnus nauseosus ssp. graveolens	Rubber rabbitbrush		2.0	0.04	0.08
		TOTAL	100.0	5.48	10.96

[1] Seeding rates derived from desired number of PLS seeds ft^{-2} using mean of available literature values for number of seeds per pound (source: Hassell et al. 1996).

Table 2. Mixtures and seeding rates (PLS seeding rate at 30 seeds/ft^2), Cibola, AZ saltcedar revegetation study.

Scientific Name	Common Name	Cultivar or Pre-Release	Mixture Rate (%)	PLS Mix Drilled[1] (lb/ac)	PLS Mix Broadcast[1] (lb/ac)
MIXTURE 1 - "MESIC"					
Distichlis spicata	Inland saltgrass		10.0	0.30	0.60
Pleuraphis (Hilaria) rigida	Big galleta		5.0	0.22	0.45
Bouteloua rothrockii	Rothrock grama		5.0	0.03	0.07
Sporobolus airoides	Alkali sacaton	Salado	15.0	0.15	0.29
Camissonia brevipes	Golden evening primrose		3.0	0.03	0.07
Cassia covesii	Desert senna		3.0	0.43	0.86
Baileya multiradiata	Desert marigold		4.0	0.06	0.12
Acacia gregii	Catclaw acacia		5.0	31.36	62.73
Atriplex lentiformis	Quailbush		20.0	0.63	1.25
Ambrosia dumosa	White bursage		5.0	0.92	1.84
Chilopsis linearis	Desert willow		5.0	1.05	2.09
Lycium andersonii	Anderson wolfberry		5.0	0.13	0.26
Prosopis pubescens	Tornillo; screwbean mesquite		10.0	11.62	23.23
		TOTAL	100.0	46.93	93.87
MIXTURE 2 - "ARID"					
Bouteloua rothrockii	Rothrock grama		5.0	0.03	0.07
Pleuraphis (Hilaria) rigida	Big galleta		10.0	0.45	0.90
Pleuraphis (Hilaria) jamesii	Galletagrass	Viva	5.0	0.49	0.99
Sporobolus wrightii	Giant sacaton		10.0	0.08	0.16
Baileya multiradiata	Desert marigold		5.0	0.07	0.15
Haplopappus acradenius	Alkali goldenbush		5.0	0.10	0.20
Sphaeralcea ambigua	Desert globemallow		5.0	0.16	0.31
Atriplex canescens	Fourwing saltbush		10.0	3.02	6.03
Atriplex polycarpa	Desert (littleleaf) saltbush		5.0	0.10	0.20
Atriplex lentiformis	Quailbush		20.0	0.63	1.25
Allenrolfia occidentalis	Iodinebush; pickleweed		5.0	0.02	0.03
Lycium exsertum	Desert wolfberry		5.0	0.16	0.31
Prosopis glandulosa torreyana	Honey mesquite		10.0	11.62	23.23
		TOTAL	100.0	16.92	33.83

[1] Seeding rates derived from desired number of PLS seeds ft^{-2} using mean of available literature values for number of seeds per pound. (source: Hassell et al. 1996)

RESULTS AND DISCUSSION

Comprehensive monitoring and first-year (2003) data collection for the Cibola, AZ study were completed February 11, 2004. Results are pending current data compilation and analysis, and thus are not presented herein. Second-year (2003) response data and establishment results from the Socorro, NM study site, and first-year (2003) results from a recently installed HydraHume™ salinity remediation study, are also being currently analyzed. Therefore, San Marcial first-year (2002) results only are presented, with general observations regarding anticipated results from the 2003 monitoring year. First-year data collection addressed frequency and density variables only. Subsequent monitoring years will include canopy cover, biomass (live standing crop), plant diversity and vigor parameters.

First-year treatment response indicates promising emergence and vigor of seeded quailbush, four-wing saltbush [*Atriplex canescens* (Pursh) Nutt.], slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners], and sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.]. Anderson wolfberry (*Lycium andersonii* Gray) and giant dropseed (*Sporobolus giganteus* Nash) are also establishing in lesser quantities. Minor occurrences of native species exhibiting natural recovery (non-seeded) following saltcedar reduction include vine mesquite (*Panicum obtusum Kunth*), salt heliotrope (*Heliotropium curassavicum* L.), buffalo gourd (*Cucurbita foetidissima* Kunth), and jimson weed (*Datura stramonium* L.).

Frequency and density in 2002 of seeded plant materials were highest in plots treated with herbicide only (no mechanical treatment), achieving frequencies of 16-47% and densities of 0.25-3.0 plants m^{-2} (Figures 1 and 2). However, all plants in the herbicide-only plots were extremely stunted (less than 5 cm in height), weak and highly stressed. Although the saltcedar stands were 75% defoliated from the herbicide treatment, the remaining canopy of dense saltcedar still provided ample cover such that shading and protection from wind maintained higher humidity levels than those in plots where mechanical biomass reduction had occurred. It is hypothesized that this shading and higher humidity promoted greater initial germination of seeded materials. However, as the growing season progressed, factors of continued shading, high salinity in exposed (bare) surface soil, and undisturbed, highly saline saltcedar leaf litter duff severely inhibited growth following germination.

While mechanically treated plots exhibited less germination and emergence of the seeded species (Figures 1, 2), frequency and density ranging from 5-25% and 0.05-0.8 plants m^{-2}, respectively, indicate desirable first-year emergence of several of the key seeded species in light of site environmental constraints. Precipitation received at the site strongly reflects the southwestern regional drought status, with 7.69 inches (19.5 cm; 87% of MAP) and 5.89 inches (15.0 cm; 67% of MAP) received during the 2002-2003 study years, respectively. Of greater importance, essentially all of the emerged species exhibited greater productivity (high growth rates, vigor, and biomass production). Canopy heights ranged from 0.5-1.2 m, 0.3-0.9 m, and up to 45 cm for quailbush, fourwing saltbush, and the two dominant grasses (slender wheatgrass, sideoats grama), respectively. Many of the plants were already sexually reproductive after one growing season, particularly sideoats grama.

Observations from 2003 monitoring (data pre-analysis) indicate that essentially 100% of the species emerged under standing saltcedar (herbicide treatment only) in 2002 are dead and decomposed. In contrast, the dominant shrub species have apparently greatly increased in frequency and density, doubled in canopy height and volume, and most are sexually reproductive. It is anticipated that continued germination, emergence and establishment will occur will occur in mechanically treated plots as seed dormancy mechanisms are broken. Further observation suggests that the increased germination and emergence for the dominant species (2002-03) is a function of the roller chopping treatments, which provide depressions for increased moisture capture and retention, and salinity reduction in the depression bottoms, providing microsites for enhanced seed germination. Data analysis for the 2003 monitoring year that will address these observations will be complete by July 1, 2004.

Few differences were noted between mechanical treatments for saltcedar biomass reduction and seedbed preparation (Figures 1, 2), particularly for the seeded grasses. Herbicidal defoliation of saltcedar prior to mechanical shredding and mulching of the saltcedar, however, reduced frequency and density of the saltbushes (Figure 1), perhaps suggesting potential adverse impacts on amount and/or characteristics (chip size, amount of fine stems, recalcitrance of larger stems) of the resultant mulch material. While first-year (2002) data suggests that there are negligible differences between mechanical treatments, all such treatments resulted in saltcedar mulch material uniformly covering the soil surface. With apparent greater establishment of seeded species (based on 2003 ocular observations; data analysis pending) on mulched areas than in standing (herbicidally treated) saltcedar, potentially positive aspects of in situ, saltcedar-derived mulch cover are evident. These potential benefits include:

- weed suppression resulting from –
    - minimized soil disturbance (in comparison with traditional root plowing and root raking)
    - reduction of exposed bare soil
    - increased soil C:N ratios, providing establishment advantage to later seral (non-ruderal), perennial species
- moisture conservation
- moderation (buffering) of temperature and wind extremes
- salinity remediation through reduction of evaporation and capillary rise of salts to the soil surface
- microsite environment and protection for seedlings
- cost savings (in comparison with traditional root plowing and root raking)
- younger (aboveground) stands of saltcedar (5 cm mean stem diameter or less) amenable to biomass mulching by roller chopper alone

Sideoats grama exhibited positive response to mycorrhizal inoculation (Figure 3), with frequency and density values 2.5-4.5 times greater than under no inoculation. While reflective of first-year data only, this initial result suggests that mycorrhizal colonization and association with seeded native, mycorrhizal species can occur on highly saline / sodic sites characteristic of mature, monotypic saltcedar infestations. This capability will be critical in enabling and accelerating establishment of desirable, mycorrhizae-dependent native species on these sites, with particular importance for more rapid establishment and spread of competitive, transitional ("eco-bridging") native species that will help suppress encroachment of secondary invasive species following saltcedar control. The saltbushes and slender wheatgrass exhibited no positive response to mycorrhizal inoculation, consistent with the literature and the author's experience that these species are only mildly- to non-mycorrhizal, and thus are not dependent on mycorrhizal associations for initial establishment.

While there were no differences in sideoats grama frequency between mycorrhizal inoculation methods (Figure 3), sideoats grama density (abundance) was reduced under seed coating inoculum incorporation. This result may be reflective of the seed coating process enclosing and binding mycorrhizal spore material more tightly to the immediate floret or seed coat envelope, rather than being distributed more uniformly through the potential rhizosphere of the germinating and growing plant. This latter state is considered more desirable than mycorrhizal inoculum material being more tightly bound to the seed during early growth and establishment (Ted St. John, personal communication). Trends for inoculation efficacy will continue to be monitored in subsequent years.

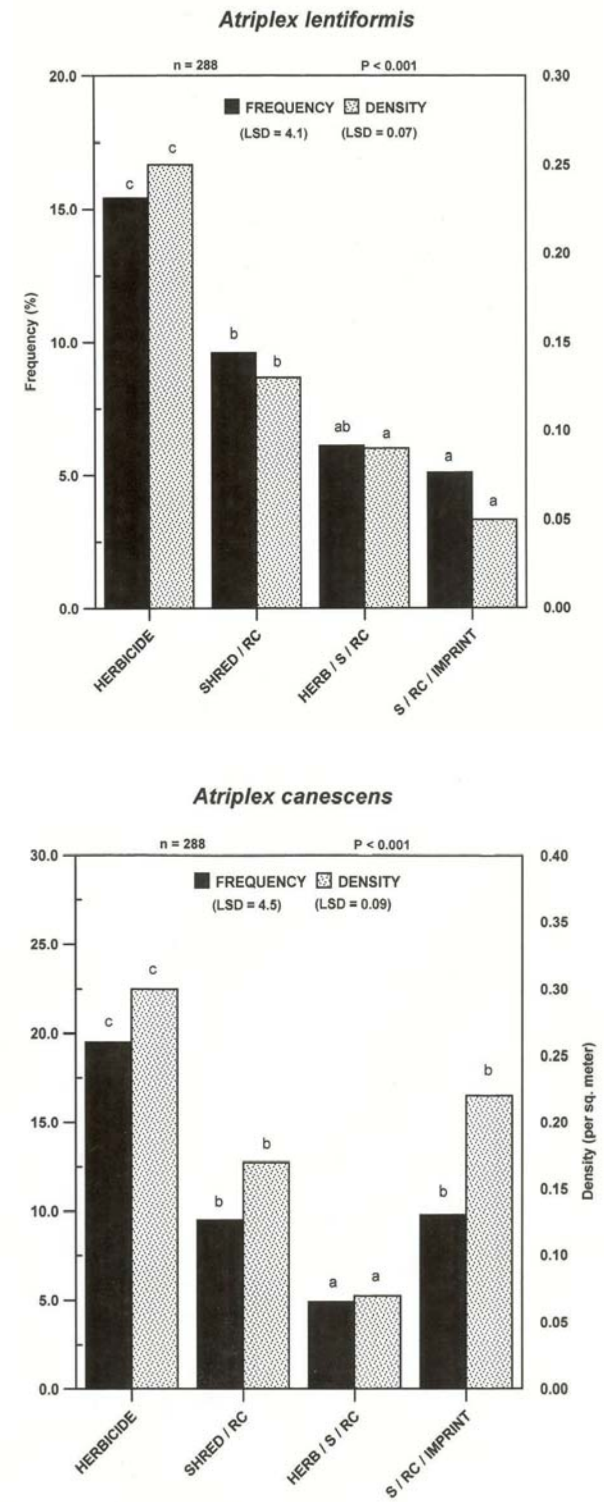

Figure 1. Response to herbicidal and mechanical treatment by *Atriplex lentiformis* and *Atriplex canescens*. First year (2002) data: San Marcial, NM saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). HERB = herbicide; SHRED or S = Woodgator shredded; RC = roller chopped. Bars within a parameter (of like color) with different letters are significantly different at P<0.001.

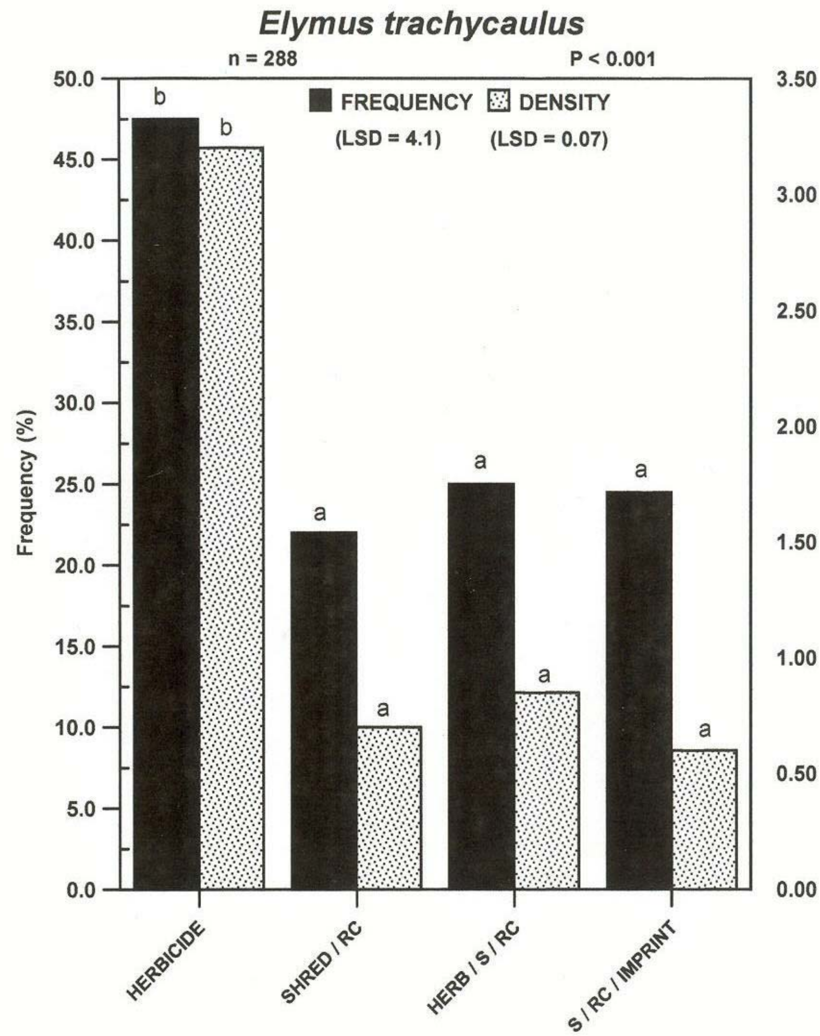

Figure 2. Response to herbicidal and mechanical treatment by *Elymus trachycaulus*. First year (2002) data: San Marcial, NM saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). HERB = herbicide; SHRED or S = Woodgator shredded; RC = roller chopped. Bars within a parameter (of like color) with different letters are significantly different at P<0.001.

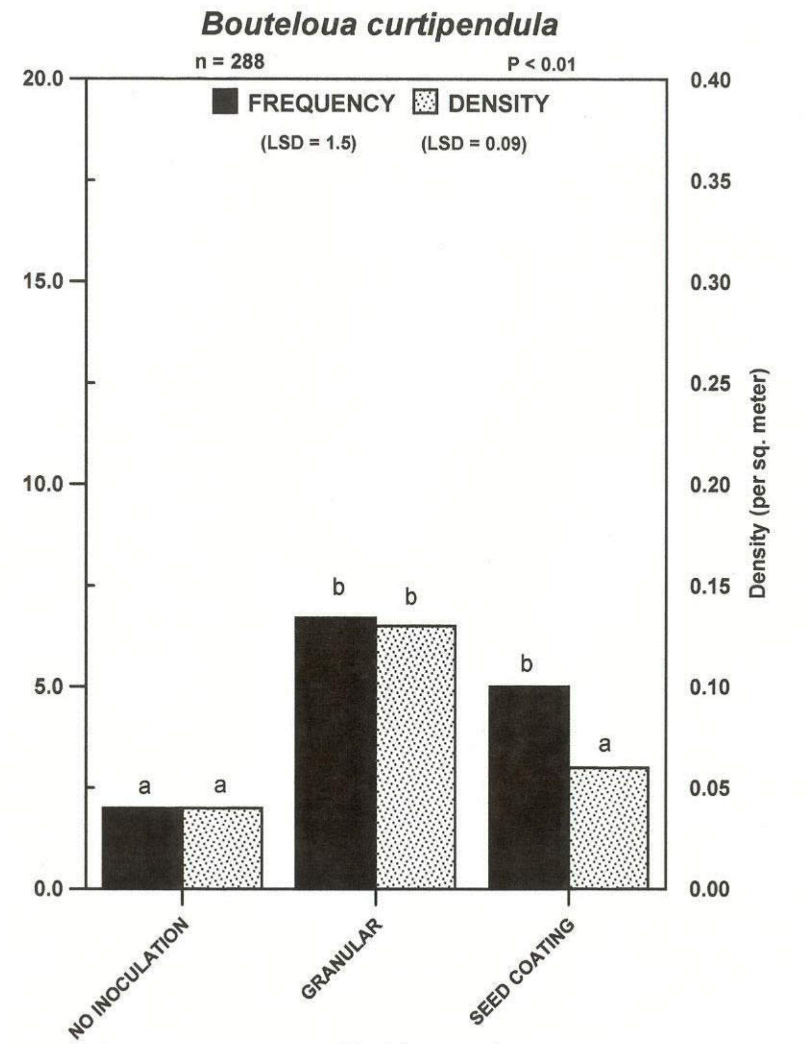

Figure 3. Response to mycorrhizal treatment by *Bouteloua curtipendula*. First year (2002) data: San Marcial, NM saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). Bars within a parameter (of like color) with different letters are significantly different at $P<0.001$.

Analysis of 2002 data indicates poor correlation ($r^2<0.10$) of dominant seeded species frequency or density with soil salinity / sodicity across plots and treatments. At the San Marcial site, soil EC_e ranges from 7-25 mmhos cm^{-1}. The majority of the dominant seeded species that have emerged in the 2002-2003 growing seasons are highly saline tolerant (by design), and thus may minimize any correlation to soil salinity because of their high tolerance levels.

SUMMARY

Formulation of revegetation strategies that provide site stabilization, resistance to further saltcedar and secondary weed infestation, and acceptable habitat values for affected wildlife species becomes particularly problematic in monotypic saltcedar stands under biological, fire and herbicidal (i.e., non-mechanical) control scenarios. Amount and density of standing biomass (live and dead) remaining after control poses limitations in relation to seeding and planting techniques, seed interception in aerial (broadcast) applications, and seedbed preparation methods. Undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky micro-relief, and nutrient limitations restrict potential for successful revegetation. Long duration of saltcedar occupation may deplete needed microbial communities, particularly arbuscular mycorrhizae symbiotic and host-specific to native revegetation species.

Technical approaches in this research include:

- species selection and mixture formulation for saline site revegetation;
- soil surface and rhizosphere manipulation methods to facilitate removal of standing dead biomass, increase precipitation capture, improve soil moisture retention, and create micro-sites exhibiting lower salinity and increased protection from environmental extremes for improved seed germination;
- salinity remediation using HydraHume™;
- seeding methodologies, including use of seed coating techniques; and
- mycorrhizal inoculation methods.

Influence of, and correlation with pre-treatment soil parameters will be summarized in subsequent reports, including surface and subsurface texture, pH, sodium adsorption ratio (SAR), electrical conductivity (ECe), and major nutrients.

Sixteen species of native shrubs, forbs and grasses were seeded in July, 2002 following various experimental combinations of simulated biocontrol treatment. First year establishment results from the Socorro, New Mexico study site indicate promising emergence and vigor of seeded quailbush, four-wing saltbush, Anderson wolfberry, slender wheatgrass, sideoats grama, and giant dropseed. Sideoats grama exhibited positive response to mycorrhizal inoculation, suggesting that mycorrhizal colonization and association with seeded native species can occur on highly saline / sodic sites characteristic of mature, monotypic saltcedar infestations.

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FIRE, LANDSCAPES AND RESTORATION – THE BENEFITS OF GETTING THE ECOLOGY RIGHT.

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ABSTRACT

Human activities have greatly impacted many western forests. In Colorado, these have included logging, grazing, and fire suppression, with mining, road building, urban development, and other activities often having large local effects. Some forests, particularly those at lower elevations, have been altered significantly from their historical condition. Ponderosa pine forests have been affected more dramatically by logging, grazing, and fire suppression than many higher elevation subalpine forests, and current ponderosa pine forests have become vulnerable to much more severe fires than occurred historically. Many ponderosa pine forests are considered to be ecologically unsustainable in their current state.

Research on historical conditions of ponderosa pine landscapes provides useful insights into restoration and fuel treatment activities that are ecologically appropriate and effective in reducing fire severity. This research shows that practicing good ecology has the dual benefits of improving ecological condition and protecting many other values at risk. Where recent severe crown fires occurred over large areas, however, ecological recovery of ponderosa pine landscapes is difficult and very slow, requiring centuries for the re-establishment of old-growth forests across the landscape. Furthermore, social and economic issues complicate fire management and fuel mitigation and restoration treatments in the wildland/urban interface. Nonetheless, significant progress is being made in restoring ponderosa pine forests through several partnerships in the Colorado Front Range and other areas across the state.

NATIONAL FIRE PLAN TO HEALTHY FOREST RESTORATION ACT, WHAT'S HAPPENING BELOW THE TREELINE

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ABSTRACT

Information, from a field manager's perspective, will be presented describing our forest health situation, the resultant wildfire problem in the Wildland Urban Interface, and how we have progressed from the National Fire Plan to the Healthy Forest Restoration Act. A brief history of the issues that demand action, both socially and ecologically, followed by an update of what is being done along the Front Range of Colorado with on-the-ground actions will be presented. Finally, the presentation will look at how we can measure success and the methods for working collaboratively with counties, communities, and interest groups to achieve common goals, and achieve more of it in a short period of time.

COMMUNITY COLLABORATION: COLORADO'S FRONT RANGE FUELS TREATMENT PARTNERSHIP

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ABSTRACT

Over the past ten years there has been an increase in the number and intensity of fires in the West. This is especially true along Colorado's Front Range threatening communities, critical watersheds as well as people's lives. Because of the devastating fires in 2000 the National Fire Plan was developed and funded, followed by a Ten Year Implementation Strategy. One of the five key elements of the plan and strategy is Community Assistance. The recent Healthy Forest Restoration Act passed in November 2003 recognizes the need for collaboration in the development of community fire protection plans.

Colorado's Front Range Fuels Treatment Partnership was formed a year ago to substantially increase fuel treatment acres in the Wildland Urban Interface across all ownerships. Its goal is to enhance community sustainability. One of the keys to success is collaboration with local government and communities in identifying and supporting fuel reduction projects which will result in protection for communities and critical watersheds. The development and implementation of a collaborative community fire protection plan is a key element in the process to meet this goal of community sustainability.

OBSERVATIONS OF HIGH ELEVATION TEMPERATURES AND PRECIPITATION IN COLORADO DURING THE PAST CENTURY

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ABSTRACT

For various reasons, climatic elements such as temperature, precipitation and winds vary across the Rocky Mountains from the West Slope to the Continental Divide and then back down to the east to the Front Range. Variations in these climatic elements will be discussed. Unfortunately, there is a very limited amount of long-term data available from high elevation sites. Recognizing that scarcity of data, some apparent recent trends, especially in temperature and precipitation, will be presented and discussed.

THE UNWELCOME ARRIVAL OF BROMUS TECTORUM TO HIGH ELEVATIONS

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ABSTRACT

Cheatgrass (*Bromus tectorum*) is an early-season, annual invasive grass that has great impacts on plant communities and ecosystems through altered fire regimes, competition with native plants and interactions with microbial communities. Cheatgrass has spread to high elevations in the western U.S. over the last 10 to 15 years, raising concerns about the negative effects it will have on the newly invaded habitats. This range expansion may be due to (1) local adaptation, (2) phenotypic plasticity of all-purpose genotypes, (3) changes in climate, (4) increased local disturbance, (5) nutrient enrichment, (6) seed dispersal, or some combination of one or more of these mechanisms. There have been climate and N deposition changes that may facilitate the success of cheatgrass at high elevations. Genetic factors may also be at work. Cheatgrass seeds from populations along an elevation gradient germinated differently over time in response to pre-chilling and light, patterns which may suggest selection for dormancy at low elevations and release from this selection at high elevations. Successional theory is being applied and the addition of carbon (to reduce N availability) and mycorrhizal inoculum (to reestablish mutualistic relationships with native plants) are being tested for restoration of cheatgrass invaded plant communities at high elevations.

INTRODUCTION

Cheatgrass or downy brome (*Bromus tectorum* L.) is a winter annual C_3 grass that is self-pollinating (McKone 1985, Allen & Meyer 2002). Cheatgrass normally germinates in the fall, but seeds germinate at other times of year as well (Mack 1981). Seedlings that emerge in the fall develop a rudimentary root and shoot system that remains quiescent during the winter. Cheatgrass begins rapidly growing in late winter and early spring with warmer night and daytime temperatures and reaches full vegetative and reproductive maturity over a period of 6 to 8 weeks (Mack & Pyke 1983, Pierson & Mack 1990). These life history traits, especially rapid growth and corresponding depletion of soil water and N, which results in lower resource availability for perennial neighbors (Gordon et al. 1989, Welker et al. 1991), have contributed to the success of cheatgrass.

Cheatgrass has large impacts on plant communities and ecosystems. It has been implicated in increasing fire frequencies and intensities (Klemmedson & Smith 1964, Stewart & Hull 1949, Knick & Rotenberry 1997), which has led to its replacement of shrubs and perennial grasses (DiTomaso 2000). It is the most ubiquitous weed in steppe vegetation in Western North America (Mack 1981). Cheatgrass is known to have negative effects on native species through competition, reducing establishment and growth of native perennial grasses (Harris 1967, Young & Evans 1985, Svejcar 1990, Rafferty and Young 2002). Cheatgrass can change N dynamics in ecosystems (Paschke et al. 2000, Evans et al. 2001) and its dominance can alter the composition of microbial communities (Belnap and Phillips 2001, Al-Qarawi 2002, Kuske et al. 2002), which can result in loss of plant species diversity (van der Heijden et al. 1998).

Land managers report that cheatgrass now occurs at elevations where it was not found in the past. Jeff Connor, Natural Resource Specialist at Rocky Mountain National Park, Colorado, reports that he has observed the advance of cheatgrass to high elevations over the past 10 to 15 years (personal communication 2003). Similar changes in distribution have been noted in Mesa Verde National Park (Bill Romme, Professor, Colorado State University, personal communication 2003), rangeland in Wyoming (Stephen Enloe, Extension Weed Specialist, University of Wyoming, personal communication 2003) and throughout the Colorado Rockies (meeting of the Colorado Weed Network, personal communications, July 16, 2003). Managers are concerned about losing valuable winter habitat for wildlife due to the invasion of cheatgrass and its ability to out-compete native perennial grasses (Harris 1967, Rafferty and Young 2002) and to increase fire frequency and intensity (Klemmendson & Smith 1964, Stewart & Hull, 1949, Knick & Rotenberry 1997).

There are many possible explanations for the expansion of cheatgrass to high elevations including (1) local adaptation (2) phenotypic plasticity of all-purpose genotypes, (3) changes in climate that create conditions at high elevations that are more favorable for cheatgrass than they were in the past, (4) increased local disturbance, e.g. extremely high grazing pressure due to over-population of elk, (5) regional nutrient enrichment, e.g. increased N deposition due to upslope air pollution (Bowman 1992), (6) seed dispersal, i.e. the seed only arrived at high elevations sites in the last 10 to 15 years, or some combination of one or more of these mechanisms. Here I begin to explore the potential roles of local adaptation, plasticity of all-purpose genotypes, N deposition and climate change in the range expansion of cheatgrass.

Genetic factors

Local adaptation is the superior performance of a genotype in its home environment compared to a new environment. Genetic differentiation may have resulted in adaptation of cheatgrass to high elevation environments, which may be a mechanism responsible for the observed expansion. Genetic differentiation that corresponds to environmental differences has been demonstrated in cheatgrass (Rice et al. 1991a, b, c, Rice et al. 1992, Meyer et al. 1997, Allen & Meyer 2002, McCarlie et al. 2003). Survival (Rice et al. 1991b, c), phenotypic plasticity (Rice et al. 1991b), growth rates (McCarlie et al. 2003) biomass allocation (Rice et al. 1991b, Rice et al. 1992), phenology (Rice et al. 1992, Rice et al. 1991a, b, c), plant size (Rice et al. 1991b) and seed production (Rice et al. 1991b, c), have all been demonstrated to be related to environments from which populations originated. Rice et al. (1992) found that populations of cheatgrass from arid steppe flowered earlier, set seed earlier and allocated less biomass to root growth than populations from mesic steppe or forest habitat. These traits correspond to adaptation to environments with short growing seasons due to limited water availability.

Previous work has shown that cheatgrass was introduced into the U.S. from multiple sources. Some of the genetic evidence for this is that there is more genetic variation within naturalized populations than native populations (Novak & Mack 2001). However, this species has reduced overall (i.e. among population) genetic variation in the naturalized range compared to native range, probably due to founder effects at the time of introduction (Novak & Mack 2001). The plant is very nearly always self-pollinating with little or no heterozygosity (Bartlett et al. 2002). Dick Mack, in his many years of working with the plant, has never found any anthers exerted from the inflorescences, thus precluding out-crossing. However, Novak & Mack (2001) reported some evidence of "novel recombinant genotypes (p 120)." The ecological significance of these patterns of genetic variability has not yet been thoroughly explored.

Nitrogen deposition

Nitrogen deposition has increased in the Rocky Mountains, most notably in areas influenced by the Colorado Front Range (Bowman and Seastedt 2001). At least half of the annual 6 kg N ha^{-1} deposition at Niwot Ridge, Colorado is anthropogenic in origin and subalpine forest, the areas most recently invaded by cheatgrass, is more influenced by air from the Colorado Front Range than the alpine tundra (Sievering 2001).

Cheatgrass may benefit from increased N deposition like that experienced by Niwot Ridge over the past several decades (1950-1996) (Welker et al. 2001). Elevated N levels can inhibit establishment of native late-successional plant species (Cherfas 1991). Increased N availability has been shown to affect successional processes in semiarid ecosystems, slowing the replacement of weedy annuals by native herbaceous perennials (McLendon & Redente 1991; Paschke et al. 2000; McLendon & Redente 1992; Trent et al. 1994). Conversely, decreased N availability has been correlated with the replacement of early-successional species by mid-successional species in a variety of systems (McLendon & Redente 1994; Paschke et al. 2000; Wedin & Tilman 1990; Tilman & Wedin 1991; McLendon & Redente 1992; Trent et al. 1994; Young et al. 1998), and competitive success of shrubs over grasses is increased by lower N availability in semiarid (Vanauken & Bush 1989) and arid ecosystems (Ettershank et al. 1978). Cheatgrass biomass and community dominance can be greatly affected through manipulation of soil N availability with sucrose amendments (McLendon & Redente 1994; McLendon & Redente 1992; Paschke et al. 2000). Given this evidence, cheatgrass may benefit much more from increased N deposition than native perennial species at high elevations.

Climate change

One possible driver of the continuing expansion of the range of cheatgrass may be climate changes that are occurring at an unprecedented rate in the western U. S. (Kittel et al. 2002). Warmer or wetter conditions in higher elevations (Kittel et al. 2002), or both, could provide new habitats for cheatgrass expansion, especially if temperatures in spring become warmer, which would facilitate early season growth, photosynthesis, and soil water extraction (Harris 1967). In addition, if snow-melt dates become earlier because of reduced snowfall and increasing spring temperatures (Kittel et al. 2002), cheatgrass may have a competitive advantage because it typically germinates in the fall and over-winters under snow. It is able to grow rapidly under the cooler temperatures of spring compared to native forbs and grasses that often reach peak growth in mid-summer. Pierson and Mack (1990) found that the growing season was too short in the forest community zones on an elevation gradient they studied for cheatgrass to be highly successful. They identified the abbreviated period suitable for cheatgrass growth as the cause for these habitats being the edge of the range for this species. With warmer and wetter climates, performance of cheatgrass in these habitats may improve.

We have initiated studies of the relationship between seed dormancy and germination response of cheatgrass populations collected from an elevation gradient that may indicate that local adaptation has occurred. We hypothesized that populations from lower elevations on the eastern plains of Colorado would be more likely to require chilling or short day lengths, indicating fall conditions, to break dormancy than populations from high elevations. The risk of premature germination may differ among habitats at different elevations, as suggested by previous work (Beckstead et al. 1996, Meyer et al. 1997). Cheatgrass that germinates in the summer on low-elevation plains, where summer precipitation is not predictable, may be less likely to reach maturity than in the mountains, where it rains most afternoons. This may exert a significant selection pressure for seed dormancy among low elevation populations.

METHODS AND RESULTS

A study investigating germination characteristics of seeds collected from 12 cheatgrass populations along an elevation gradient (1414 m – 2682 m) (Table 1) in Colorado indicates that germination response to environmental conditions differ among populations, which hints at genetic differentiation and local adaptation.

Table 1. *Bromus tectorum* populations

Location	Elevation (m)
Akron	1,414
Fort Morgan	1,385
Greeley	1,406
Loveland	1,557
Sylvandale	1,639
Drake	1,962
Crosier Mountain	2,135
Estes Park	2,350
Lower-Deer Mountain	2,460
Mid-Deer Mountain	2,581
Upper-Deer Mountain	2,670
Golden Gate Canyon	2,682

To test the hypothesis, we conducted two experiments. First, ten seeds from 11 of the 12 cheatgrass populations were planted in 15 cm diameter pots filled with commercial potting soil in a cooled greenhouse at Colorado State University in Fort Collins, Colorado in August 2003. Seed germination was monitored to evaluate differences among populations in germination percentage. Data were evaluated with analysis of variance using JMP version 5.0.1.2 (SAS Inst. Inc., Cary NC).

We expected populations from low elevations to have higher dormancy than those from high elevations. This pattern was followed in general, but the populations from the highest elevation and one of the low-elevation populations had low and high germination rates, respectively, contrary to our expectations (ANOVA $P < 0.0001$, $F_{10, 99} = 15.97$; linear regression $P = 0.0006$, df = 1,108) (Figure 1).

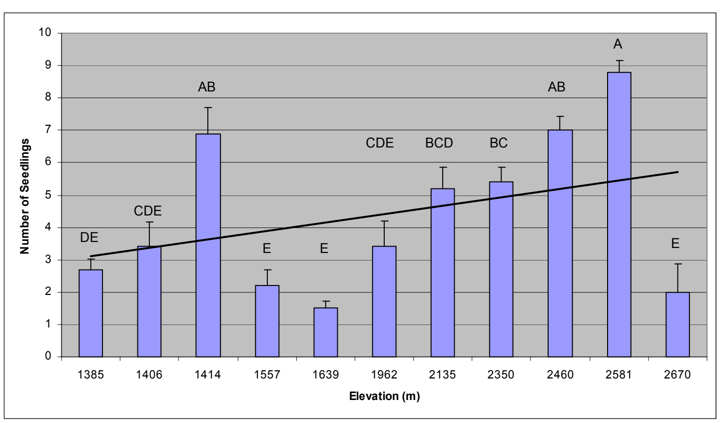

Figure 1. Number of seedlings produced from ten seeds of each of 11 cheatgrass populations along an elevation gradient. The line is the least squares linear regression. Bars are means of 10 pots ± 1 standard error of the mean. Means with different letters are significantly different aţ = 0.05 based on Tukey's HSD.

In a second experiment, seeds of four populations (1385 m, 1406 m, 2670 m and 2682 m) were placed on moist germination paper and either subjected to 10 days of 2 °C before initiation of tests (pre-chilled) or placed directly into incubation chambers (not-chilled). Chilled and not-chilled treatments were held at 25 °C and exposed either to 8 hours of light (+light) or no light (-light) during each 24-hour cycle. Data were evaluated with repeated measures analysis of variance using JMP version 5.0.1.2 (SAS Inst. Inc., Cary NC).

Populations germinated at different rates based on a significant population by time interactions ($P < 0.0001$) (Figure 2). The population from the highest elevation germinated most quickly, reaching greater than 80% germination at the fourth day of evaluation while the next highest germination rate was the population from the lowest elevation site with 60% germination.

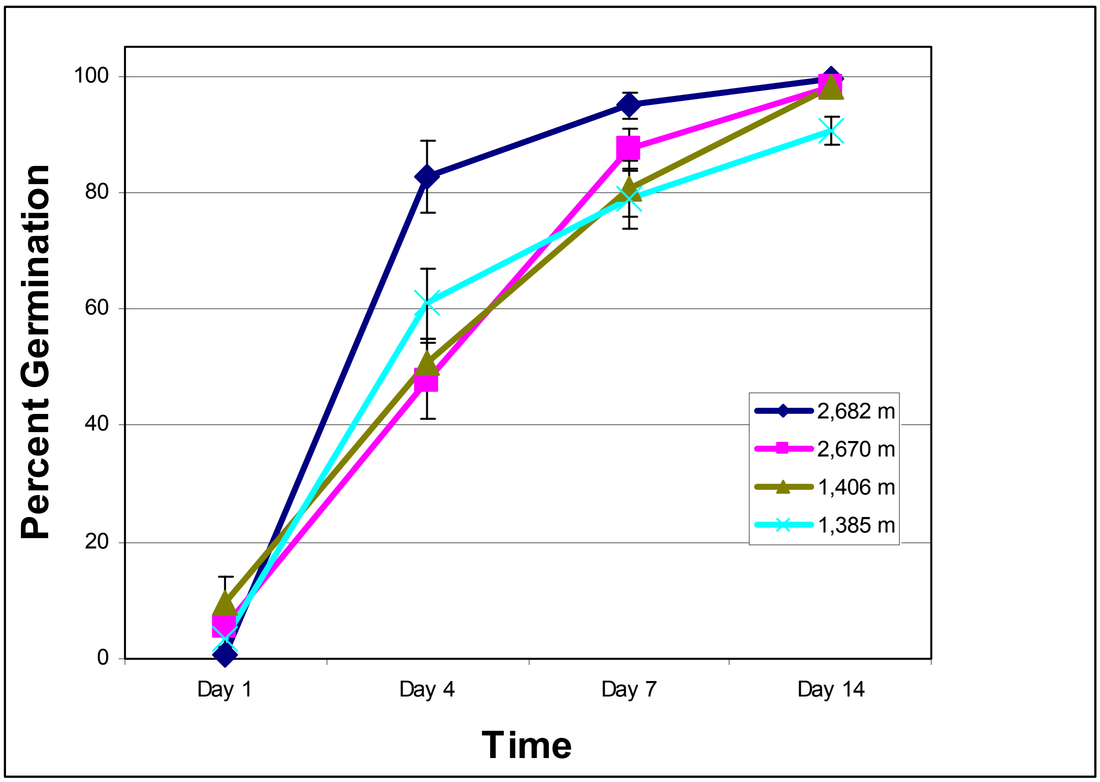

Figure 2. Percent germination over time of seeds from four populations of cheatgrass from an elevation gradient. Means of four replicates ± 1 standard error of the mean are presented.

The patterns of germination over time for the populations depended on whether or not they had been pre-chilled (time x population x chilling treatment interaction, $P < 0.0001$) (Figure 3). The germination of seeds from the 2,682 m and 1,385 m populations slowed down with chilling, while germination of seeds from the 2,670 m population occurred more rapidly with chilling.

The pattern of germination over time for the populations also depended on whether or not the seeds were exposed to light during the tests (time x population x light interaction $P = 0.02$). Light increased the speed of germination of the 2670 m and 1385 m populations, while germination rates of the 2682 m and 1406 m populations were similar with and without light (Figure 4).

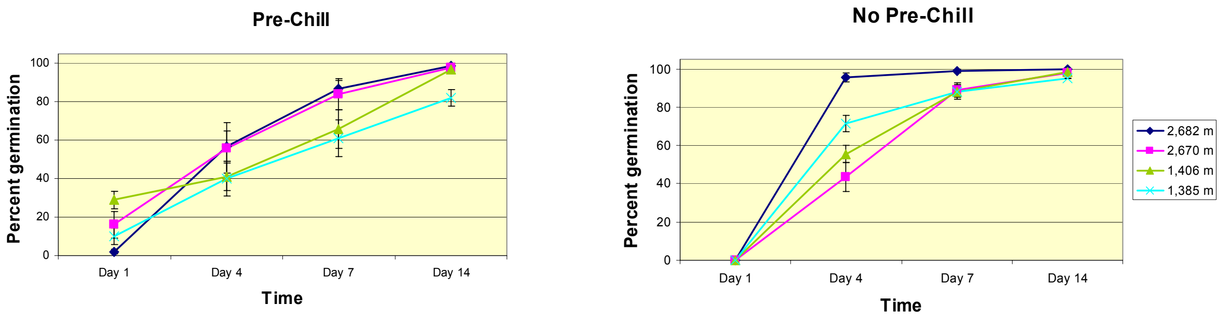

Figure 3. Percent germination over fourteen days of seeds from four populations of cheatgrass from an elevation gradient (a) with and (b) without pre-chilling. Means of four replicates ± 1 standard error of the mean are presented.

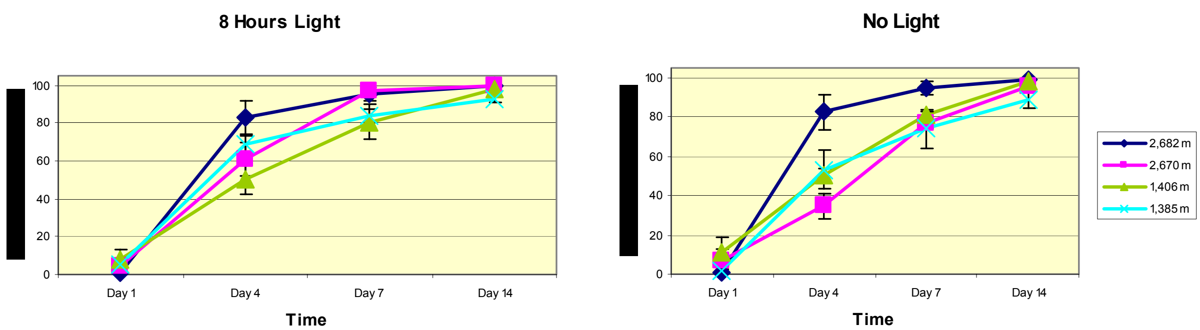

Figure 4. Percent germination over fourteen days of seeds from four populations of cheatgrass from an elevation gradient (a) with 8 hours of light and (b) without light. Means of four replicates ± 1 standard error of the mean are presented.

DISCUSSION

Potential for local adaptation

Some of the results show that patterns of cheatgrass seed dormancy correspond, on average, to seed source elevation and suggest that there may be selection for seed dormancy among low-elevation populations and release from this selection pressure at high-elevations (Figure 1). However, the patterns were not strictly followed and germination response to pre-chilling and light did not suggest that dormancy was related to seed source elevation (Figures 2, 3 and 4). Despite this, the strong differences among populations indicate potential for local adaptation. Our results are consistent with those of previous authors who found that germination responses can be of adaptive importance, but that the patterns were not always consistent (Beckstead et al. 1996, Meyer et al. 1997, Meyer & Allen 1999 a, b).

It should also be noted that the germination responses we detected may be affected by the environments in which the parent plants grew. To minimize the effects of maternal environment, tests should be conducted on seeds that come from plants grown under identical environmental conditions, which there was insufficient time to do for the experiments reported here.

Cheatgrass control and restoration of cheatgrass invaded communities

The control of cheatgrass once it has become established and restoration of plant communities that it invades continue to be major challenges for land managers. Furthermore, approaches that are most effective at high elevations may differ from those that are successful at low elevations. We have begun to test several approaches to address these problems. The use of intermediate, early-successional species as a “bridge” to ameliorate site conditions for late-successional species has been recently applied to the restoration of weed dominated landscapes (Hardy and Palazzo 2002). This research project seeks to test this “bridge” approach by applying facilitation, tolerance and inhibition models of succession (Connell and Slatyer 1977). In all models, disturbance opens a space and colonizers with early-successional traits establish on the site. The models differ in how late-successional species become established. With facilitation, early-successional species create conditions favorable for establishment of late-successional species. In the tolerance model, late-successional species establish subsequent to early species because of their life history traits but will eventually dominate due to their superior competitive abilities. The inhibition model describes conditions by which the early colonizers inhibit establishment of other species (Connell & Slatyer 1977). Integral to this “bridge” concept is that planting intermediate species will result in facilitation or tolerance models of succession. Testing whether restoration techniques can achieve these effects will allow us to evaluate the success of the methods and target modifications necessary for future applications.

We have established an experiment to test whether the facilitation, tolerance, or inhibition model of succession is supported by results from seeding techniques for cheatgrass infested sites. The study will evaluate the performance of early-succession (ES) and late-succession (LS) species mixtures grown alone, planted simultaneously (LE), or planted sequentially (LSES), with the ES seed mixture planted in the first year and the LS mixture added in the second year. In the second year, the LS mixture will also be added to plots that were not seeded in the first year (NS) to create the LSNS treatment. The following tables describe alternative hypotheses for testing the two stages of succession, establishment (Table 2) and growth (Table 3) (Connell and Slatyer 1977). The hypotheses will be tested by comparing the success of the seeded species in each of the treatments.

Table 2: Test emergence and establishment of late-successional species

Hypothesis	Interpretation	Restoration implications
LS>LE, LSNS>LSES	Inhibition	Plant LS seeds alone
LS=LE	Tolerance	Plant LS seeds with ES species or alone.
LSNS=LSES	Tolerance	Plant LS seeds alone or into established ES communities.
LS<LE	Same year facilitation	Plant LS seeds with ES species.
LSNS<LSES	Next year facilitation	Better to plant LS seeds into established ES community than into bare soil.

Table 3: Test growth in later stages of succession

Hypothesis	Interpretation	Restoration implications
LS>LE, LSNS>LSES	Inhibition	Death/damage of ES species necessary for LS establishment
LS=LE, LSNS=LSES	Tolerance	Presence of ES plants does not affect LS species
LS<LE, LSNS<LSES	Facilitation	Presence of ES plants on the site enhance LS plants.

In low nutrient environments, late-successional species with greater dependence on abuscular mycorrhizal fungi (AMF) can take advantage of mycorrhizal associations to extract scarce resources and gain a competitive edge over early-successional species (Doerr et al. 1984, Reeves 1985, Miller 1987). Sucrose addition (N-) has been an effective treatment to reduce N and other nutrient levels in soils and shift community composition from annual to perennial species (McLendon and Redente 1994, Paschke et al.

2000, McLendon and Redente 1992). Mycorrhizal fungi are ubiquitous and easily colonize sites, thus the addition of mycorrhizal inoculum is generally not required and has not been tested in combination with the sucrose treatments. However, in the case of cheatgrass, where AMF communities have been shown to be depressed (Al-Qarawi 2002), supplementation of naturally occurring AMF spores may be necessary for optimal establishment and growth of native plant species. Mycorrhizal inoculation may increase the competitive ability of highly mycorriza dependent, late-successional plants in the low nutrient environment created by sucrose addition.

An experiment is being conducted to evaluate the efficacy of carbon addition to reduce available N, and mycorrhizal inoculation to ensure important biotic mutualists to promote the establishment of native perennial vegetation. The hypotheses this experiment will test are outlined in Table 4.

Table 4: Test whether mycorrhizal inoculation (M+) in combination with sucrose (N-) has greater effect in shifting the composition of a community towards a late-successional species compared with sucrose treatments alone (N-).

Hypotheses	**Test**	**Restoration implications**
H1: AMF in cheatgrass dominated soils < AMF in desired community soils	Compare MIP[1] for cheatgrass dominated and native communities	Restore AMF for desired plant establishment
H2: High RMD[2] species establish better in M+ relative to NM	(1) Determine RMD for each species and cheatgrass. (2) Compare species biomass in M+ and NM plots.	Add AMF with high-RMD plants
H3: Cheatgrass hosts fewer/different AMF taxa, or both, relative to the desired species	(1) Inoculate cheatgrass and desired dominant species with AMF morphotypes[3]. (2) Evaluate levels of infection and plant responses with each AMF morphotype.	Need specific AMF taxa to re-establish native plants
H4: Native plants increase and cheatgrass decrease in N- relative to N	Compare establishment and biomass of seeded species in N- and N plots.	Perennial species performance > cheatgrass in N-
H5: Native plants > cheatgrass in N-M+ relative to N-NM	Compare establishment and biomass of seeded species in N-M+ and N-NM plots.	AMF increases effectiveness of N-

1 Mycorrhizal inoculation potential (MIP) is a measure of AMF infection induced in a host plant by inoculant.
2 Relative mycorrhizal dependency (RMD) is the degree of response of a plant species to mycorrhizal infection at a given nutrient level.
3 Follow established procedures (INVAM).

These experiments will provide land managers with valuable information to assist in the control of cheatgrass and restoration of plant communities at high elevations. First, the results will indicate which models of succession may be most successfully applied to restore native vegetation in high elevation habitats. Second, the results will inform us about the strength and importance of interactions between N availability and mycorrhizal symbionts for the successful establishment of native species.

The invasion of high altitude habitats by cheatgrass is relatively recent and has the potential for causing dramatic environmental change. Developing an understanding of the mechanisms underlying this range expansion will allow us to determine what approaches will be most effective at controlling its spread, reversing its effects and restoring native plant communities after its invasion.

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SNOW AND HIGH ELEVATION LANDSCAPES: RELATING ENVIRONMENTAL HETEROGENEITIES TO COVER, DECOMPOSITION, AND GOPHER ACTIVITY

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ABSTRACT

The effects of variable snow cover on ecosystem structure and function have been well-documented in cold, temperate ecosystems, especially in high-elevation treeline and alpine landscapes characterized by long, windy winters that produce dramatic variations in snow depths over short distances. Chronic and heterogeneous snow-cover patterns influence ecosystem structure (e.g., plant species distributions, soil characteristics) and function (e.g., decomposition, primary production, nutrient cycling, water balance) in systems where winters are long and most precipitation falls as snow. I sought to determine the impacts of a heterogeneous snow distribution on ecosystem properties in a 6.25 km^2 upper-treeline ecotone, called Libby Flats, in south-central Wyoming. This project involved modeling and validating landscape snow accumulation, ablation, and meltwater flow spatially coupled with observations of site and ecosystem properties (e.g., soil properties, cover, decomposition, and gopher activity). Model simulations successfully represented the general spatial patterns of snow redistribution and ablation, but field measurements indicate needed model improvements. Dominant cover types, decomposition, and gopher activity varied with site factors (e.g., snow depth, soil temperatures) and indicate that changes in snow regime and temperatures could alter high-elevation ecosystem structure and function.

INTRODUCTION

It has been well established that structural and functional properties of terrestrial ecosystems vary in response to changing environmental conditions across heterogeneous terrain. Some of the variation arises from fixed site properties such as slope aspect effects on solar radiation, elevation influence on temperature and precipitation, and soil texture relationships with plant water status. Historically, ecological studies have focused on site-specific properties to assess their effects on the subject or phenomenon of interest.

Variation also arises from the transport of matter from one area of the landscape to another. This flow of resources, while generally recognized as essential, is rarely explicitly addressed in ecosystem science (Reiners and Driese, 2001). Transport processes in environments having strong lateral movements of mass and energy can reinforce and modify topographically-derived environmental variation across terrestrial landscapes.

One environment that possesses a well-documented lateral flow of mass and energy is the treeline ecotone (Daly, 1984; Hiemstra et al., 2002). Here, resource flows are particularly important in modifying spatial patterns of ecosystem structure and function. In such environments, aeolian and fluvial transport processes are striking and ecosystem properties vary drastically over small (1–20 m) distances. Interplay among wind, topography, vegetation, and snowfall creates a heterogeneous snow distribution in treeless or semi-forested areas that have abundant snowfall coupled with relatively strong winter winds. Wind redistributes snow by eroding it from areas of high wind speeds and depositing it in areas where wind speeds are reduced by topographic features or vegetation. Where prevailing winter winds come from the same general direction, snow deposition patterns recur in the same location year after year (Billings, 1969; Daly, 1984; Figure 1). During snowmelt (mid-May through July), meltwater containing suspended and dissolved materials discharges from these drifts as directed by gravity and topographical features via sheet or channel flow into streams. All transport processes are irregularly distributed in space and time, thereby contributing to a relatively fine-grained heterogeneous array of ecosystem properties across the landscape. Snow redistribution, ablation, and meltwater flow are the predominant organizers in the treeline ecotone.

Figure 1. An aerial photograph (3 July 1998) showing snow drifts on the lee side of tree islands. The prevailing wind direction is from the west, or from left to right in this image.

Environmental conditions and ecosystem properties affected by water transport include water budget (Isard, 1986; Hartman et al., 1999), energy budget (Goodin and Isard, 1989; Liston, 1999), soil properties (Litaor et al., 2001), plant species distribution (Billings, 1988; Walker et al., 2001), growing season length (Billings and Bliss, 1959; Walker et al., 2001), net primary production (Bowman and Fisk, 2001), succession (Arseneault and Payette, 1992; Moir et al., 1999), decomposition (O'lear and Seastedt, 1994; Brooks et al., 1996), nutrient deposition (Zeller et al., 2000; Tranter and Jones, 2001; Williams et al., 2002), and animal habitat (Thorn, 1982; Aitchison, 2001).

My objective was to quantitatively understand how snow redistribution influences ecosystem structure and function. To achieve this objective, transport processes in high-elevation landscapes were simulated and related to ecosystem properties in an alpine treeline ecotone.

Study Site

Libby Flats is a gently arching ridge aligned north-south in the treeline ecotone (3100 to 3300 m elevation) of the Medicine Bow Mountains, southeastern Wyoming (Figure 2). Fifty to eighty percent of the annual precipitation arrives as snow from October to May. Because winter winds are typically westerly and strong, averaging 10 m s^{-1} (Fox et al., 1994), snow is driven transversely across the ridge.

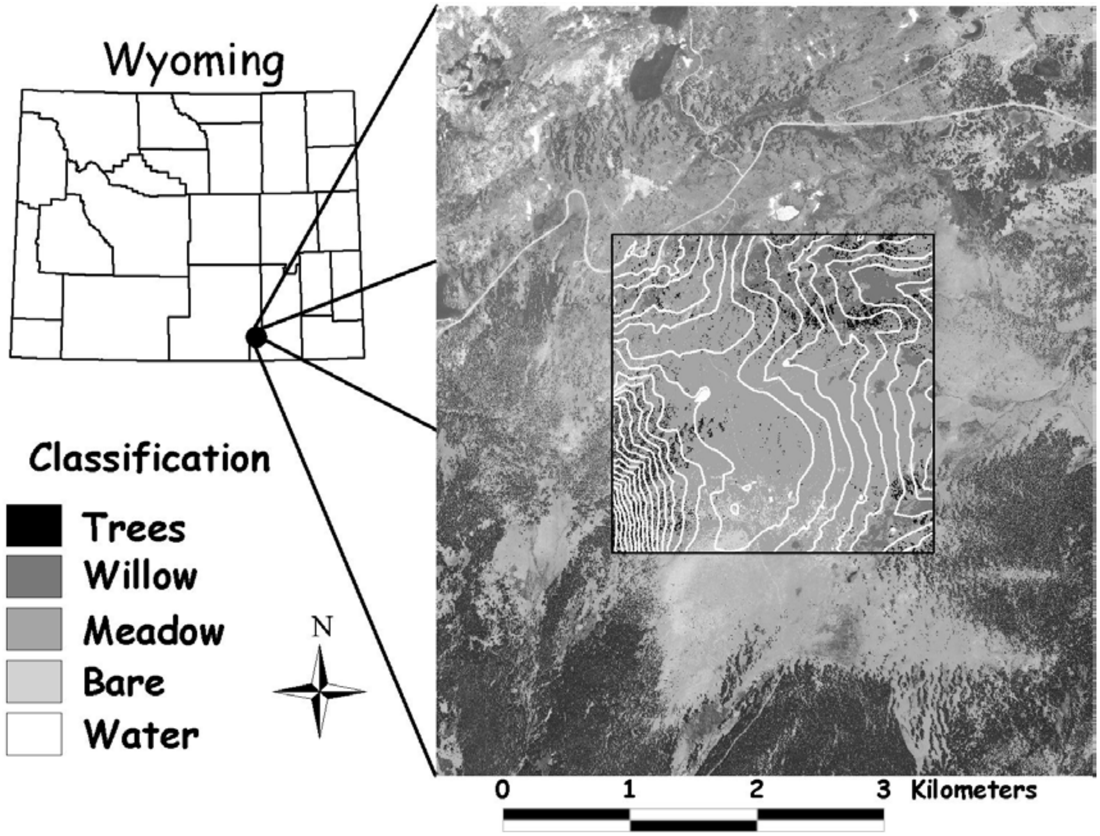

Figure 2. The study area location in Wyoming and its vegetation.

Trees (Figure 2) are embedded in a matrix of mixed subalpine and alpine meadow vegetation. They predominantly exist in two forms: krummholz patches and ribbon forests (Billings, 1969). Krummholz patches and ribbons interrupt wind flow, producing end-of-winter snow drifts as deep as 7 m on their lee sides that persist into July and August (Hiemstra, 1999). This non-uniform snow-depth distribution, and the associated spatial variations in meltwater production and fluvial drainage patterns, produce growing-season moisture gradients in the alpine meadow matrix (Isard, 1986; Walker et al., 2001). These gradients control non-tree vegetation patterns, producing a distinct mosaic of vegetation that varies from rocky fellfields to wet meadows. This mosaic of plant communities and attendant ecosystem properties is the result of complex feedback patterns among snow, wind, vegetation, and topography, as well as fluvial drainage.

METHODS

Understanding the underlying causes of heterogeneously distributed ecosystem properties in this landscape required simulation of physical processes in a spatially distributed manner, validation of these simulations, and exploration of how changes in driving variables alter patterns on this landscape.

Simulation of snow redistribution by wind, subsequent melting of the snowpack, and meltwater flow were performed for Libby Flats during three years (1997–2000). Two models were linked to estimate the physical environment of Libby Flats. SnowTran-3D (Liston and Sturm, 1998) simulated snow accumulation and redistribution processes and the Community Land Model (CLM; Bonan et al., 2002) was employed to calculate snow ablation and land-surface processes. The two models were linked together to form a “coupled model” of the water cycle on Libby Flats. The linked models produced daily, spatially-distributed estimates of snow water equivalent (SWE), soil moisture, soil temperature, and runoff. In addition to these products, an estimate of the growing-season length was developed from the daily SWE to produce a spatial estimate of snow-free-date (a surrogate for growing season length).

Snow-depth observations used for validation of model products were collected using east-west and north-south oriented transects on Libby Flats (Figure 3). These entailed measuring snow amounts during fall and winter accumulation and during spring ablation. Observed snow depths were compared with corresponding model simulations to assess model accuracy.

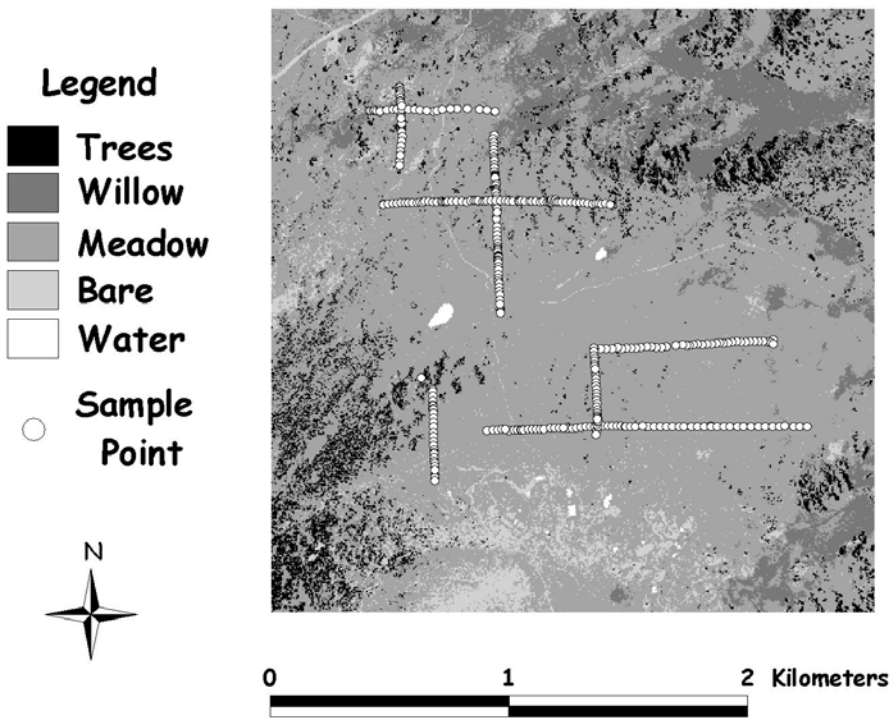

Figure 3. Snow observation transects on Libby Flats.

Ecosystem Property Observations

Cover

Plant species cover and gopher activity were measured along a series of five, 2.5 km long transects that were oriented E-W (Figure 4). During the summer of 2000, four randomly located (0 to 360 degrees and up to 10 m away from the point marker) species-cover surveys were performed at each of the 129 transect points. Individual species cover was assessed using 20 cm by 50 cm (0.10 cm^2) Daubenmire quadrats (Daubenmire, 1959), for a total of 516 cover estimates. Cover estimates were averaged for each transect point. A hierarchical cluster analysis (correlation coefficient distance, average linkage) was performed to aggregate similar point types. I used a 75% similarity cutoff to delineate 18 individual representative cover clusters.

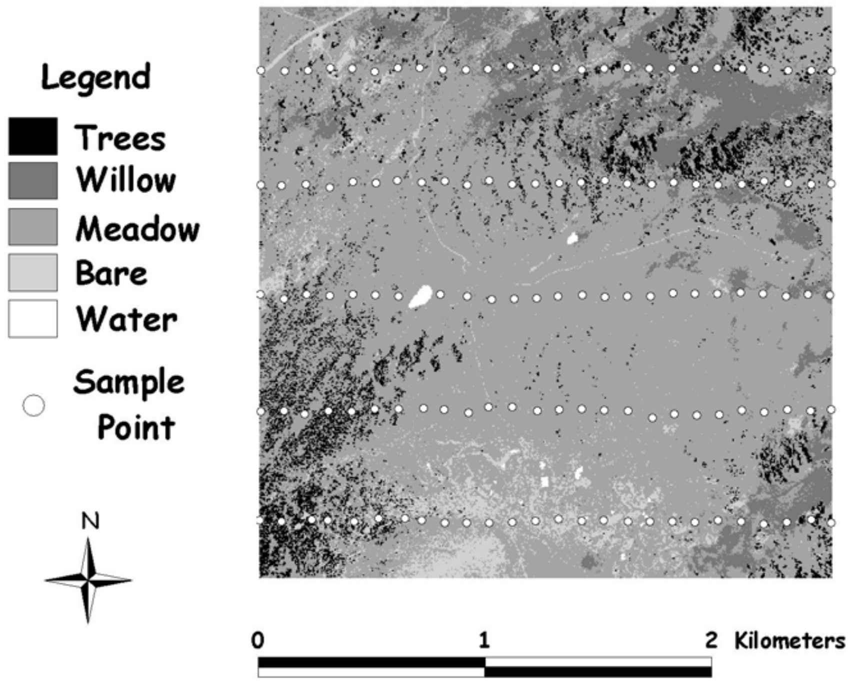

Figure 4. Transects and sample points used to measure observed ecosystem variables.

Decomposition

The litter bag technique (Edwards and Heath, 1963) was employed to measure surficial decay rates of *Deschampsia cespitosa* (graminoid), the most dominant species found on Libby Flats. Senesced litter was collected and placed into bags in the fall of 1999. Three replicates of four prevalent cover types on Libby Flats (trees, willow, snow glade, and meadow) were randomly selected to host ten *Deschampsia cespitosa* litter bags. In 2000, half of the bags were collected after a season under snow and the rest were gathered in late September. Spatial distribution of decomposition was performed using relationships identified among *Deschampsia cespitosa* decomposition rates and spatially distributed site characteristics (e.g., soil temperature and moisture, vegetation type).

Gopher Activity

Gopher activity was assessed by counting casting and mound units within a 5 m radius around each sampling point (Figure 4). Care was taken to count only the most recent year's gopher activity. A sampled population of 10 castings and 10 mounds was used to calculate a standard casting and mound unit for Libby Flats from which a surface area could be estimated. After the survey, multiple regressions were used to define the relationships of environmental factors with gopher activity. Both observed and modeled factors were regressed against gopher disturbance (surface area) to identify important factors and for interpolation of gopher activity within the modeling domain (Figure 4).

RESULTS AND DISCUSSION

Snow Simulations

Model simulations of snow redistribution paralleled temporal and spatial trends of observed snow accumulation and ablation patterns (Figure 5). As the season's snow accumulated, drifts became larger and deeper and the domain was covered by snow. As spring snowmelt occurred on Libby Flats, snow-covered area decreased over time.

Snow distribution patterns are clearly related to vegetation patterns and topographic features. Deeper snow depths are nearly always located on the lee sides of trees and in topographic concavities. In contrast, shallow snow depths were frequently located in open meadows.

How does the model perform when compared to observations? The linked model misses the exact amount of snow present (Hiemstra, 2003), but it represents the general trend of snow accumulation and spatial placement of snow drifts (Figure 5; Hiemstra et al., 2002).

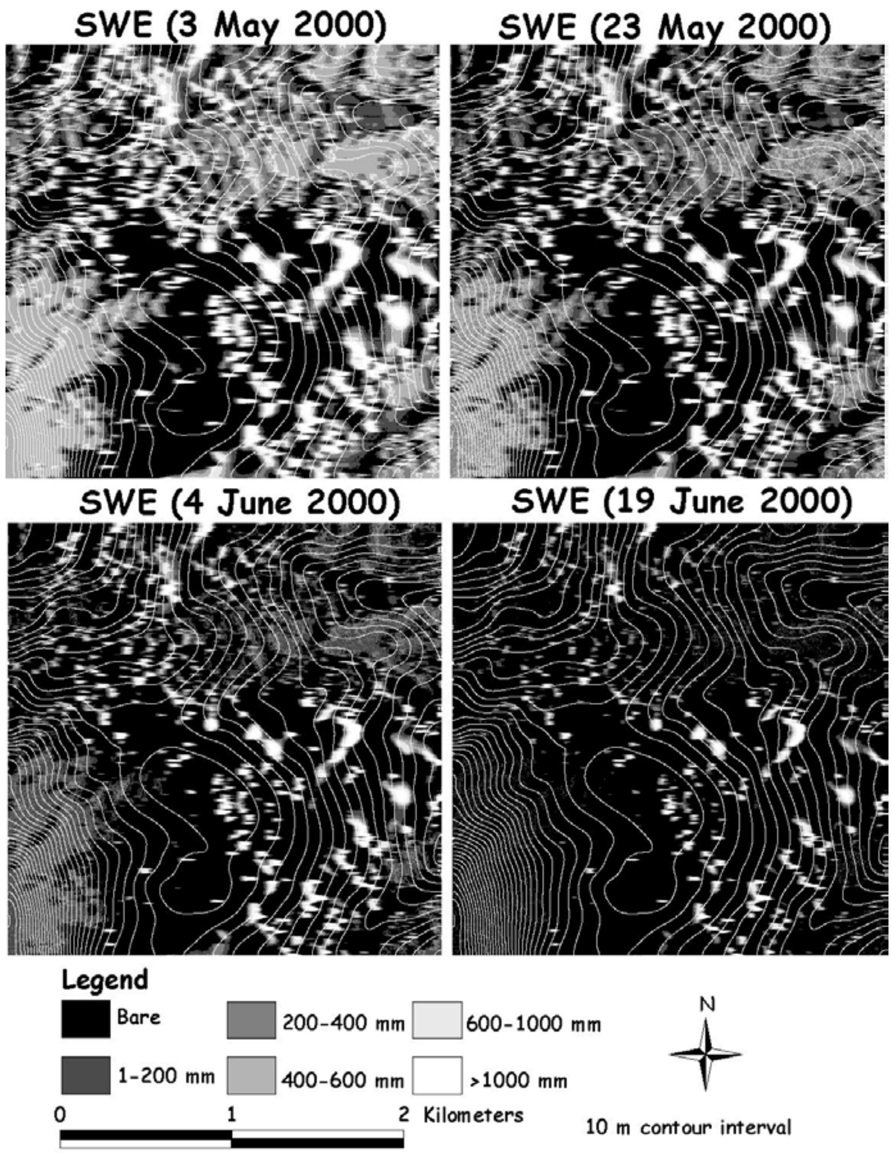

Figure 5. Model simulations showing realistic snow deposition patterns (on the lee side of trees and ridges and in topographic concavities) and snowmelt through time.

Ecosystem Properties

Cover

The 18 assemblages produced by the cluster analysis appear to be influenced by snow depth, snowmelt redistribution on the landscape, and soil temperature (Figure 6). Snow depths determine growing-season length (Johnson and Billings, 1962) and snow is the predominant source of water (Fox et al., 1994) in this system. Snow depths on Libby Flats are influenced by wind, trees, and topography (Hiemstra et al., 2002; Hiemstra, 2003) and can be divided into three general classes—low, intermediate, and high. Low snow depth is associated with exposed ridges and flat areas. Intermediate snow depths primarily exist on northern and eastern aspects away from ridges, topographic concavities, and trees. Lastly, deep snows exist in areas where trees and topography acted to reduce wind speeds, resulting in snow deposition during the winter.

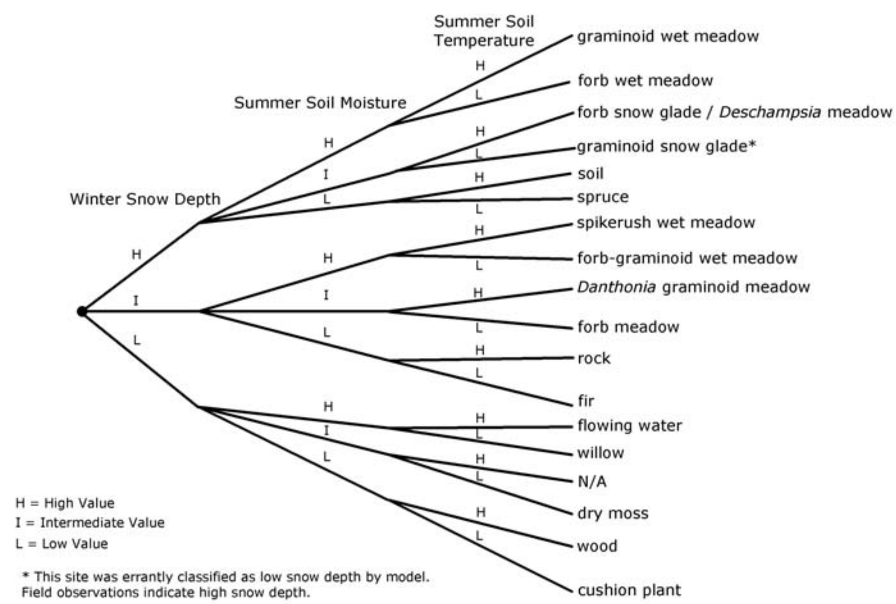

Figure 6. A simple decision tree illustrating the physical characteristics associated with the eighteen cover clusters identified on Libby Flats.

Once the snow melts on the Libby Flats landscape, the meltwater flows along slopes into swales. The factor most closely representing meltwater flow and irrigation in this landscape is soil moisture. Areas with low soil moisture enter a drought period after snowmelt since summer precipitation is usually negligible. Cover types in the low summer soil moisture regime include cushion plants, rock, *Abies* (subalpine fir), *Picea* (Engelmann spruce), and soil. Intermediate areas of soil moisture are dominated by dry moss, meadows (forb and *Danthonia* meadows), and snow glades. High soil moisture is indicative of snowmelt-irrigated terrain and this area is dominated by *Salix* (willow) patches, wet meadows, and flowing water.

Soil temperatures also change markedly among the sites after snowmelt, and this factor explained cover type distributions. Soil temperature is a function of canopy cover, aspect, soil moisture, and soil conductivity (Baver et al., 1972) and it is thought to influence plant distributions by affecting physiological processes, such as carbohydrate utilization and moisture uptake (Godfrey, 1970; Körner, 1999). On Libby Flats, cover types lacking vegetation (soil, rock, wood, and flowing water) or with a cover dominated by graminoids possess higher soil temperatures. In contrast, the cover types with lowest soil temperatures have a dense canopy: tree (*Picea* and *Abies*), *Salix*, forb, cushion plant, and dry moss.

Decomposition

Statistical models were developed on observed data and then interpolated to the domain at large (Figure 7). The resulting product is important in two ways. First, it illustrates a method by which gross decomposition can be predicted in areas of the landscape not directly sampled. Second, it allows for prediction of decomposition given alterations in statistical model factors (e.g., soil temperature, snow water equivalent, vegetation).

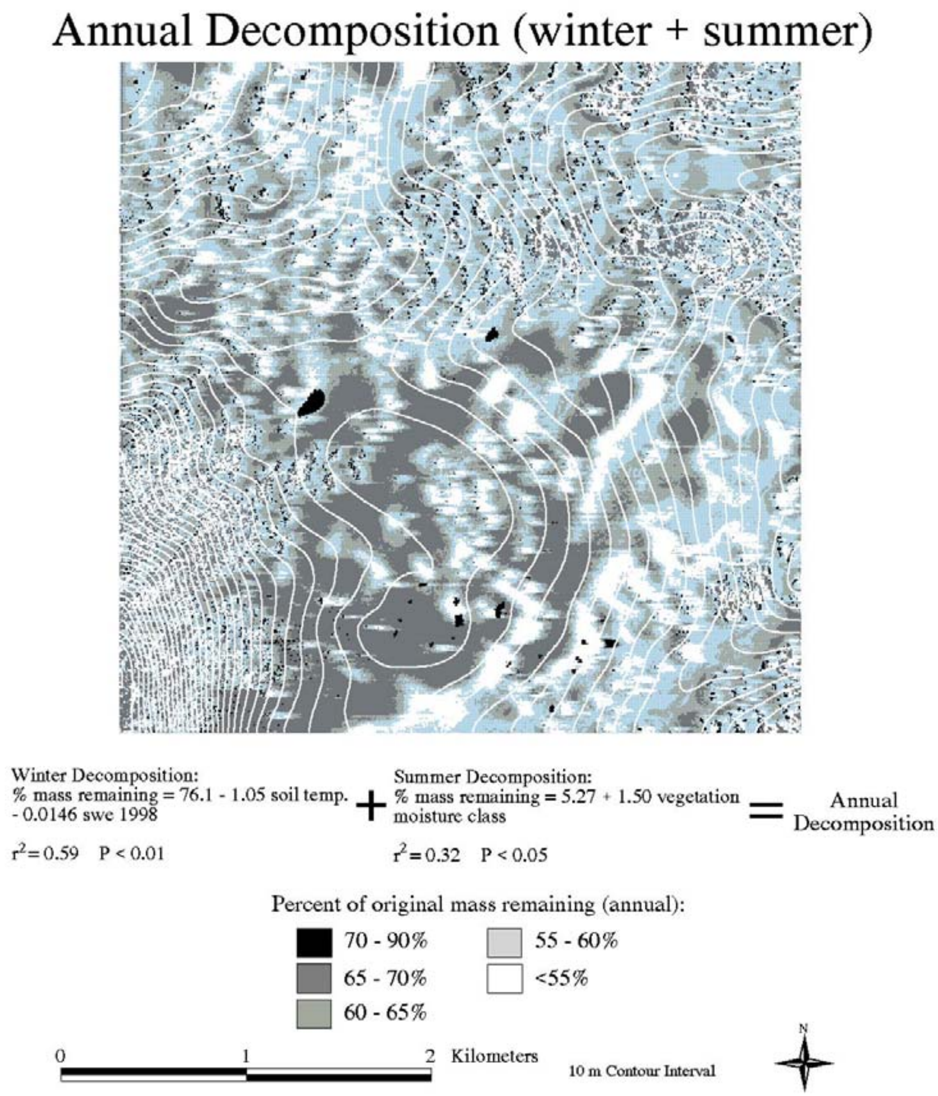

Figure 7. Interpolated decomposition of *Deschampsia cespitosa* on Libby Flats derived from statistical regressions of winter (under snow) and summer (snow free) decomposition losses.

Spatial distribution of decomposition is of interest to those finding ways to address how decomposition varies across landscapes. My approach involved a statistically derived empirical model of decomposition spatially distributed across the domain. However, this model has not been validated with observed data and it was constructed with only one year of observations. Nevertheless, the patterns produced by the model appear to be realistic in light of snow patterns in this landscape (Hiemstra et al., 2002) and predominant vegetation (Figure 2).

The model allows for prediction of change in decomposition rates with alterations in model conditions. Such simulations suggest how changes in factors influence decomposition.

Gopher Activity

Gopher activity was interpolated over the full (6.25 km^2) study area using relationships gleaned from field observations in 2000 (Figure 8). The interpolation can be used to spatially realize the statistical relationships developed from the regression analyses and visualize landscape differences in gopher activity.

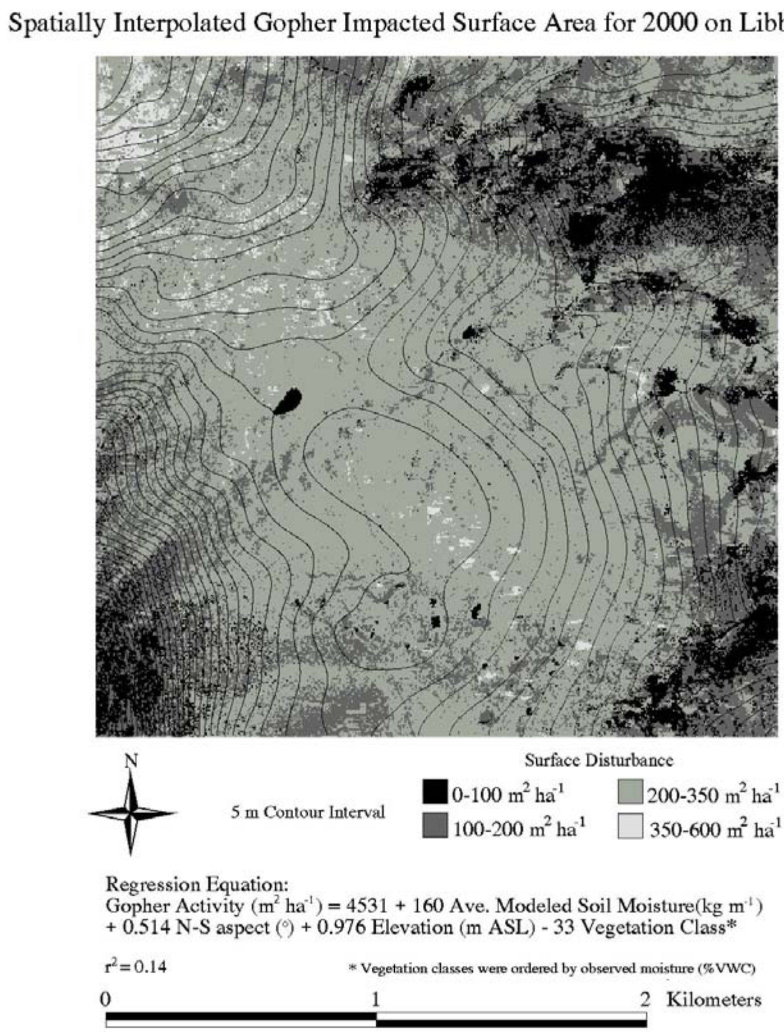

Figure 8. Interpolated gopher activity on Libby Flats derived from statistical relationships among gopher activity and soil moisture, aspect, elevation, and vegetation.

Since the components in the interpolation equation were model (snow water equivalent and soil moisture) and vegetation derived, the differences between the years simulated must have been related to snow, its effects on water distribution, and vegetation patterns. Tree and willow patches (Figure 2), along with bare areas, were essentially devoid of gopher activity. The highest gopher activity was in the open meadows. While the statistical relationship of the regression is significant, this simple model fails to account for much variation as evidenced by the low r^2 value ($r^2 = 0.14$). Therefore, the distributed product should be interpreted with appropriate caution.

CONCLUDING REMARKS

Libby Flats is a complex, spatially heterogeneous landscape where extremes in snow depth and water transport are separated by meters of space. The spatial pattern associated with this landscape is clearly influenced by water redistribution processes, and I have attempted to quantify and distribute the processes that account for observed spatial differences in cover, decomposition, and animal activity on Libby Flats. With anticipated model improvements and work being done in other landscapes, advances are being made that will allow us to address the consequences of potential climate change.

ACKNOWLEDGEMENTS

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RIPARIAN VEGETATION OF COLORADO: USE OF ECOLOGICAL CLASSIFICATION IN RESTORATION

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ABSTRACT

A classification of riparian plant associations for Colorado was developed to understand riparian vegetation biodiversity and functionality. The nine-year project designed a comprehensive, field-based, classification of riparian wetlands. This classification provides information at multiple scales useful for restoration. As part of the classification, an Ecological System is a group of associations that are driven by similar ecological processes and occur together on the landscape. Ecological Systems define the wetland on a broad-scale, and can include several small-scale associations that occur in a mosaic, like on broad floodplains. Systems range from Subalpine Forested Wetlands to Playa Lakes. Given the physical setting of a site, Ecological Systems can be used to determine what associations are expected. At a finer scale, the plant association provides details on species composition, driving ecological processes, and physical setting such as hydrologic position. Across Colorado, 150 native riparian plant associations were described and placed within Ecological Systems. In addition, criteria for inventory and monitoring were developed. These data include attributes for mapping wetlands and assessing their quality based on size, condition, and landscape context. These same criteria can serve as restoration and monitoring goals, and can determine the level of success of a restoration project. Lastly, this multiscale approach can be used to prioritize restoration needs.

INTRODUCTION

A standard classification of riparian and wetland plant associations and ecological systems provides context and can be used to set priorities and provide minimum standards for restoration. The classification can identify what is, or what ought to be, at a site. It may be far more valuable biologically and consequentially less expensive to restore a riparian area with rare or imperiled plant associations than to create a common wetland type with less biodiversity value. Understanding a wetland's degree of functionality, or its level of ecological integrity, is also important. Criteria defining thresholds of ecological integrity (high, medium, and minimum) are available for some wetland types. Minimum ecological integrity criteria state the overall size, site condition, and surrounding landscape context needed for a wetland to function properly, on its own, in perpetuity.

In this paper we will discuss the classification of riparian and isolated wetland plant associations for the state of Colorado. We will also cover the concept of ecological systems, another unit of the classification, and how these are used for mapping and conservation planning. We will discuss how this type of existing information can be used to set priorities for restoration and set goals and monitoring criteria for restored wetlands. In addition, we will discuss NatureServe and the Heritage Program Network's role in maintaining the International Vegetation Classification and present standards for the development of ecological data. In addition, some examples of standards for mapping and setting Ecological Integrity ranks will be illustrated and how these data can be translated into restoration and monitoring goals.

RIPARIAN PLANT ASSOCIATION CLASSIFICATION

Project Goal and Methods

From 1991 – 1999 field work was conducted by The Nature Conservancy and the Colorado Natural Heritage Program to describe the native and natural riparian plant associations across Colorado, and to find high quality occurrences that may merit protection (Kittel et al. 1999). We used a stratified random site selection method. We used USGS delineated perennial streams at the 1:100,000 scale. The state was stratified by elevation (4500 - >10,000 ft, in 1000 foot segments) and stream order (Stahler 1952). The number of streams per cell type (elevation x stream order) was weighted by that cell's abundance. For example if 20% of the stream miles occurred above 10,000 feet elevation on first order streams, then 20% of all the samples taken would be in that type.

We sampled only high quality, relatively undisturbed riparian areas. We did not sample areas heavily dominated by non-native plants such as tamarisk. We measured percent canopy cover of all vascular woody and herbaceous species using 50 m line-intercept transect and 15-20 20 x 50 cm micro-plots, located on alternate sides of the transect. We took several physical site parameters including width of the valley floor, stream gradient, channel width to depth ratio, and categorized the steam segment according to Rosgen's (1985) Steam Classification System. Other parameters included a brief soil description and the size, condition and landscape context of the entire riparian area sampled.

Results

Over 1880 quantitative plots were collected. These encompassed 1266 plant taxa, or about 40.9% of all Colorado plant taxa was found within the riparian areas sampled. One hundred fifty plant associations were described. We estimate this covers about 80-90% of the riparian biodiversity in the State. A plant association is the smallest unit in the International Vegetation Classification. A plant association is defined as stands of similar dominant and subdominant association species occurring on similar environmental setting. In other words, stands of vegetation with the same overstory and understory species composition that repeat across the landscape.

A plant association then, gives the fine details of species composition and environmental setting and distribution. Some example results of this study:

- we found that *Salix drummondiana* is more likely to be found along steep streams than its very similar looking counterpart, *Salix geyeriana*. *Salix geyeriana* often occurs on broad, flat shrublands with high water tables along meandering, low gradient streams.
- The cottonwood associations along the South Platte River have entirely different understory shrubs and herbaceous species than those found along the Arkansas River.

We also determined that not all riparian areas are equal. We applied the NatureServe / Natural Heritage Program Rarity Ranking to each of the 150 plant associations. Rarity Ranks are scaled 1-5; 1 being known from less than 5 locations or populations worldwide, to 5, secure, with many known occurrences or populations (>100). Of the riparian associations described in this study, 45 (29%) were G1 and G2—Rare and Critically imperiled to imperiled (between 1-20 known occurrences worldwide); 49 (32%) G3—Vulnerable (20-100 known occurrences or more but declining); and 58 (38%) G4 and G5—demonstrably secure globally (common, 100's of occurrences, many of them in high quality condition).

Additional Wetland Research

Since the completion of the Riparian Classification in 1999, further wetland research has been conducted by the Colorado Natural Heritage Program, in cooperation with other wetland researchers in Colorado. These studies focused primarily on isolated wetlands. An additional 2600 quantitative plots have been added to the Colorado Wetland and Riparian Classification. The total number of plots to date included in this effort is 4527, and 232 plant associations are recognized. Each association has been placed into a Hydrogeomorphic class and subclass. This describes or attempts to categorize the relationship between geomorphology, wetland vegetation and wetland functions. There are four hydrogeomorphic (HGM) classes in Colorado: riverine, slope, depression and mineral soil flats. Within a geographic region, HGM classes are further subdivided into subclasses. A subclass includes all those wetlands that have similar characteristics and perform similar functions. Riparian areas, loosely defined as streamside vegetation communities, may include depressional, slope or mineral flats associations, as well as riverine associations. Position on the landscape and source of the water supporting the wetland are the critical factors distinguishing the four types (Carsey et al. 2003, Cooper 1998).

This classification has been published in "Field Guide to the Wetland and Riparian Plant Associations of Colorado" (Carsey et al. 2003). One hundred eighty-four types are described, along with photographs, elevational range, the HGM subclass, distribution maps, and species composition tables, with percent constancy and cover (Figure 1). It is available on the web or in hard copy.

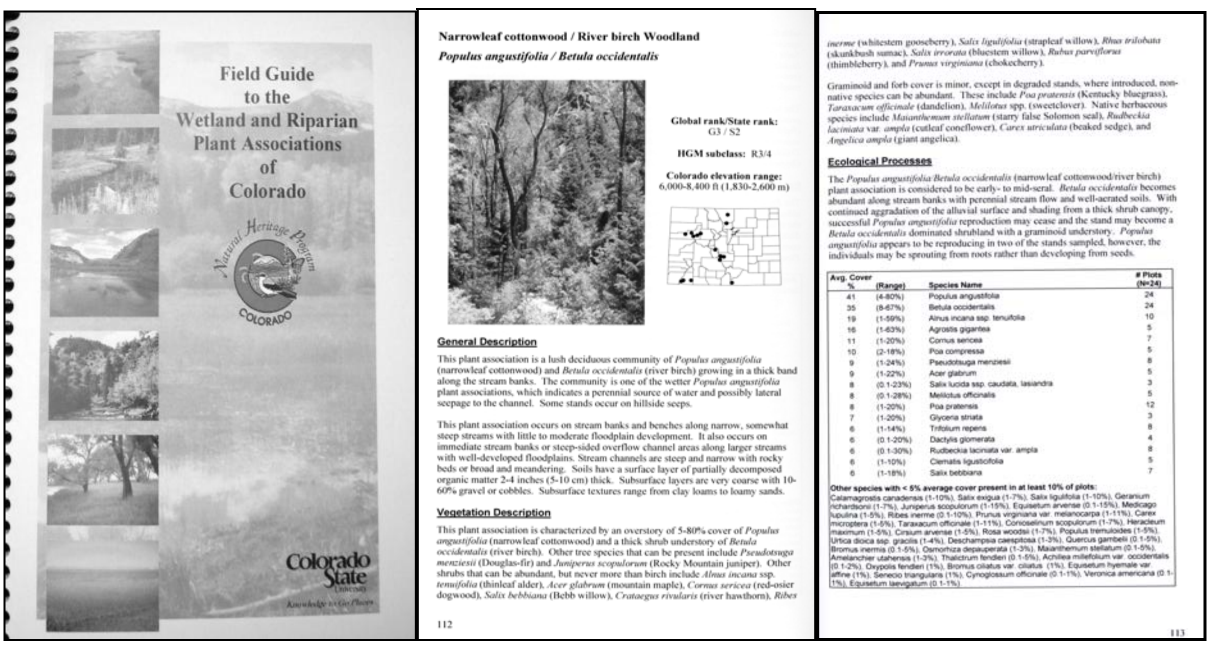

Figure 1. Field Guide cover and examples of descriptions for Riparian Plant Associations. (Go to www.cnhp.colostate.edu, click on "Classification of Riparian Wetland Plant Associations in Colorado", a PDF file can be downloaded. Bound, printed copies (5x7 inch, spiral bound, durable paper) are available for a $25 donation to the Colorado Riparian Association, 2400 Spruce St., Suite 201, Boulder, CO 80302.)

One limitation to plant associations, especially riparian and wetland plant associations, is they naturally cover very small areas, and mapping them is problematic at any sort of reasonable management scale. Ecological Systems can be used at broader scales.

ECOLOGICAL SYSTEMS

While plant associations provide detail about site specific biodiversity and environmental setting, they are small in area and difficult to map. There is another classification underway to define Ecological Systems across North America (Comer et al. 2003). An Ecological System is an aggregation of plant associations that can occur together on the landscape and share environment/driving ecological processes. This is a ground up classification of plant associations that may occur together on the landscape and are driven by the same ecological processes.

All of the Colorado Riparian associations have been placed into 11 Ecological Systems. Their component associations Heritage Rarity ranks are summarized as: Common = G5 or G4, Vulnerable = G3, and rare = G1 or G2. These systems include:

- Subalpine / Upper Montane Riparian Forest System (23 associations: 11 common , 9 vulnerable, 4 rare) (Figure 2).
- Subalpine Riparian Shrubland System (11 associations: 7 common, 4 vulnerable) (Figure3).
- Subalpine Riparian Meadow System (7 associations: 5 common, 1 vulnerable, 1 unranked) (Figure 4).


Figure 2.


Figure 3.


Figure 4.

- Montane Riparian Meadow System (9 associations: 8 common, 1 rare) (Figure 5).
- Montane Riparian Shrubland System (30 associations: 9 common, 21 vulnerable) (Figure 6).
- Lower Montane Riparian Woodland System (24 associations: 5 common, 7 vulnerable, 11 rare, 1 unranked) (Figure 7).


Figure 5.


Figure 6.


Figure 7.

- Foothills Riparian Shrubland System (13 associations: 5 common, 3 vulnerable, 4 rare, 1 unranked) (Figure 8).

- Plains Riparian Woodland and Shrubland System (15 associations: 2 common, 12 rare, 1 unranked) (Figure 9).
- Plains Riparian Meadow System (11 associations: 2 common, 4 vulnerable, 3 rare, 2 unranked) (Figure 10).

Figure 8.

Figure 9.

Figure 10.

- Playa Lake System (2 associations: 2 common) (Figure 11).
- Riparian Freshwater Marsh System (5 associations: 3 common, 2 vulnerable) (Figure 12).

Figure 11.

Figure 12.

NATURESERVE

The classification of riparian and wetland plant associations and ecological systems for Colorado is not being developed in a vacuum. NatureServe is the national organization of the Natural Heritage Programs. We are a network of Conservation Data Centers, Natural Diversity Databases, and Natural Heritage Programs. There are member programs in every US state, every Canadian province, in Mexico, and in many South American countries.

NatureServe provides the standards, methods, data, and expertise for conservation of plants, animals, natural communities (plant associations) and ecological systems for the western hemisphere. Our mission is to develop, manage, and distribute authoritative information critical to the conservation of the world's biodiversity.

NatureServe maintains the International Vegetation Classification (NatureServe 2003). The classification is developed in conjunction with the Ecological Society of America (ESA) Vegetation Committee, The Nature Conservancy and The Federal Data Geographic Committee. Go to http://www.esa.org/vegweb/ to read more about the standards and development of the National Vegetation Classification. This work is built upon work by The Nature Conservancy and the structure of the classification as 1998 (see Grossman et al. 1998). This can be downloaded from the web at http://natureserve.org/library/vol1.pdf.

The ESA Panel on Vegetation Classification (of which NatureServe is a member) provides impartial scientific expertise to public, professional and private partners in support of the development and use of a scientifically credible National Vegetation Classification System.

The Panel's goals are to:

1. Advance the standardization of the national vegetation classification;
2. Advance quality assurance of the data in the national vegetation classification;
3. Support the application of the national vegetation classification to management and conservation objectives;
4. Foster and coordinate research in vegetation classification; and
5. Promote understanding of North American vegetation classification information and its importance to the national and international community.

NatureServe's website http://www.natureserve.org/Explorer/ has detailed information on the status and distribution of rare, imperiled or endangered plant and animal species as well as natural communities (plant associations). It can be searched by scientific or common names, and filtered by taxa, location, or federal land ownership. Various status and descriptive reports as well as state by state distribution maps are available.

ECOLOGICAL SYSTEM CLASSIFICATION

Conservation of the Earth's diversity of life requires a sound understanding of the distribution and condition of the components of that diversity. Efforts to understand our natural world are directed at a variety of biological and ecological scales—from genes and species, to natural communities, local ecosystems, and landscapes. While scientists have made considerable progress classifying fine-grained ecological communities on the one hand, and coarse-grained ecoregions on the other, land managers have identified a critical need for practical, mid-scale ecological units to inform conservation and resource management decisions. Comer et al. (2003) describes an outline to the conceptual basis for such a mid-scale classification unit-—*ecological systems*.

Ecological systems represent recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding. They are intended to provide a classification unit that is readily mappable, often from remote imagery, and readily identifiable by conservation and resource managers in the field.

NatureServe and its natural heritage program members, with funding from The Nature Conservancy, have completed a working classification of terrestrial ecological systems in the coterminous United States, southern Alaska, and adjacent portions of Mexico and Canada. Comer et al. (2003) summarizes the nearly 600 ecological systems that currently are classified and described. About 240 are Wetland Ecological Systems. This report discusses applications of these ecological systems for conservation assessment, ecological inventory, mapping, land management, ecological monitoring, and species habitat modeling. This report is available at http://natureserve.org/library/usEcologicalsystems.pdf

Terrestrial ecological systems are specifically defined as a group of plant community types (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. A given system will typically manifest itself in a landscape at intermediate geographic scales of tens to thousands of hectares and will persist for 50 or more years. This temporal scale allows typical successional dynamics to be integrated into the concept of each unit. With these temporal and spatial scales bounding the concept of ecological systems, we then integrate multiple ecological factors—or *diagnostic classifiers*—to define each classification unit. The multiple ecological factors are evaluated and combined in different ways to explain the spatial co-occurrence of plant associations.

Terrestrial ecological system units represent practical, systematically defined groupings of plant associations that provide the basis for mapping terrestrial communities and ecosystems at multiple scales of spatial and thematic resolution. The systems approach complements the U.S. National Vegetation Classification, whose finer-scale units provide a basis for interpreting larger-scale ecological system patterns and concepts. The working classification will serve as the basis for NatureServe to facilitate the ongoing development and refinement of the U.S. component of an International Terrestrial Ecological Systems Classification.

We use a standard nomenclature for each Ecological System. Names include:

1) Name of the Ecological Divisions or nested Provinces that describe the distribution of the type,
2) Characteristic vegetative composition and physiognomy, and
3) Environmental modifiers.

Examples include:

- Atlantic Coastal Plain Southern Tidal Wooded Swamp,
- Laurentian-Acadian Alkaline Swamp, Willamette Valley Wet Prairie, and
- Southern Rocky Mountain Foothills Riparian Woodland and Shrubland.

WHY USE STANDARD ECOLOGICAL CLASSIFICATIONS IN ASSESSMENT, RESTORATION AND MONITORING?

Plant associations and ecological systems, within the standard framework of the International Vegetation Classification (NatureServe 2003) provides information about ecological function. Each ecological system is useful as:

- They encompass <u>interactions among species</u> and characteristic ecological processes.
- They can readily link observable <u>ecological pattern with dynamic processes</u>.
- They provide an explicit framework to <u>characterize condition and trend in land/waterscapes</u>

Data from the Classification include:

- Minimum criteria for recognizing an occurrence (specific locations)
- Guidance in defining populations (species) so that viability can be assessed for population units
- Guidance in determining if two or more source features are part of the same occurrence (= same population or metapopulation for most species)

In addition, NatureServe can

- Provide an estimate of ecological integrity (communities and systems) or population viability (species)
- Help prioritize sites for conservation attention (management, monitoring, or restoration)
- Highlight indicators for monitoring

ECOLOGICAL INTEGRITY RANKING CRITERIA

The NatureServe / Heritage Methodology involves a Viability or Ecological Integrity Rank for any element of biodiversity: Viability Ranks for a plant or animal population, and Ecological Integrity Ranks for natural communities (plant associations). This is a simple scale of A-D (Figure 13). Stands of vegetation beyond (below) the D rank are not viable and in general cannot be identified as a particular plant association.

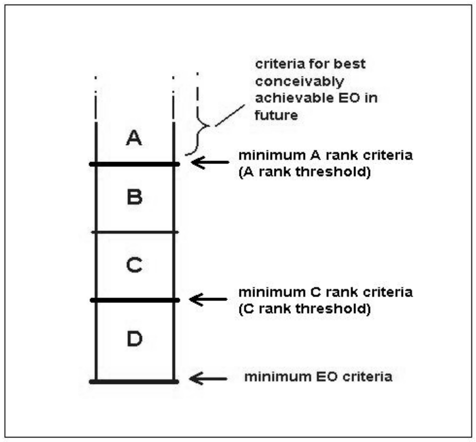

Figure 13. EO stands for Element (species or natural community) Occurrence (specific location).

Rank criteria involves three basic categories: Size, Condition and Landscape Context (Figure 14). These categories can be weighted depending on the system in question. For example forested ecosystems are more dependent on size to be able to respond to natural disturbances such as fire, and many species may depend on being un-affected by forest/ non-forest edge effects. Other systems, like wetlands, naturally cover small areas, so size is less important, than condition, and the surrounding landscape can have large influence on the ability for the ecosystem to function. The degree to which the above stream hydrology had been altered and the degree of fragmentation in the surrounding immediate watershed are important factors to the well-being and functionality of a small wetland. Indicators are very specific and need to be developed for each association and for each rank.

EO RANK	ATTRIBUTE CATEGORIES	KEY ECOLOGICAL ATTRIBUTES	INDICATORS
	Condition	Stand Development / Maturity	?
		Biotic Composition	?
		Ecological Processes	?
		Abiotic Physical/Chemical Attributes and variability	?
	Size	Area supporting patch dynamics	?
	Landscape Context	Landscape Structure	?
		Landscape Dynamics	?

Figure 14. Rank criteria categories.

It is critical to define the threshold to achieve an A ranked occurrence (excellent Integrity from somewhat compromised Integrity) and the threshold to achieve the minimum condition to be a functioning, viable ecosystems (the C level threshold). The threshold tells us the status and trend of the area and indicates the degree to which a change in management or restoration is needed, assuming the management goal is to achieve the highest possible ecological integrity.

In order to define thresholds we need to know the acceptable range of variation that comprises an functioning ecosystem (Figure 15). Outside the range of accepted variation, the ecosystem is not functioning, and will not continue to exist without major, and often expensive, intervention. In Figure 15, the term "restorable" refers to ecosystems where a change in management is all that is required. A change in grazing use, recreational use, or change in the hydrological regime. Many of you in the audience today deal mainly with sites that are in the "non-viable" category, i.e. hard core restoration is required to bring the site back to some level of ecological integrity (wetland functionality). Criteria outlined here can be used as goals for restoration projects. Will the plan bring the site to a C-level, or B-level of Integrity? Any restoration work should strive to bring ecosystems up to a C-level as a minimum. A C-level is the minimum size, condition and landscape features required for the ecosystem to function without continued assistance or intervention.

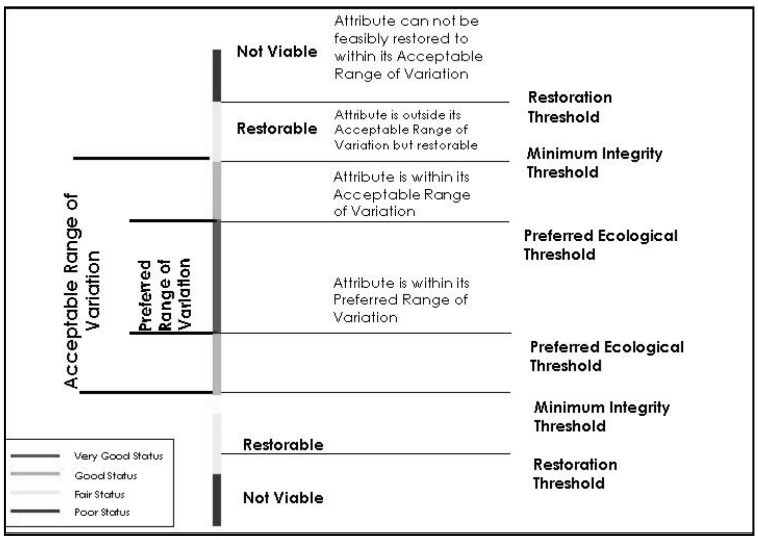

Figure 15. Acceptable range of variation in ecosystems.

Reference Conditions and Reference Sites

Reference Conditions are the ecological integrity criteria that define a Reference Site. Reference sites are well within the range acceptable ecosystem functionality, and (hopefully) are the best example of high ecological integrity. Reference Conditions:

- Determine Expected Ranges of Variation and Thresholds between A, B, C, & D
- Characterize multiple, apparently undisturbed/healthy examples
- Examine specific impact of human-induced alterations in existing occurrences
- Come from a review of literature and historical records
- Can be tested through the Development and testing of simulation models

MAPPING CRITERIA

In addition to ranking the Ecological Integrity of a site, we need to understand its pattern of variation on the ground. We need to set criteria for how ecosystems are mapped. This becomes critical when trying to determine how abundant a type is, or whether the genetics can interact between populations when considering species level viability. Plant associations, especially riparian and wetlands, are difficult to map at convenient scales. As we can see from the map (Figure 16), there are several polygons within the willow map unit. The map unit represents several plant associations or one ecological system, in this case, a Southern Rocky Mountain Foothill Riparian Shrubland. Because all of the polygons occur on one stream, in total they are considered one occurrence.

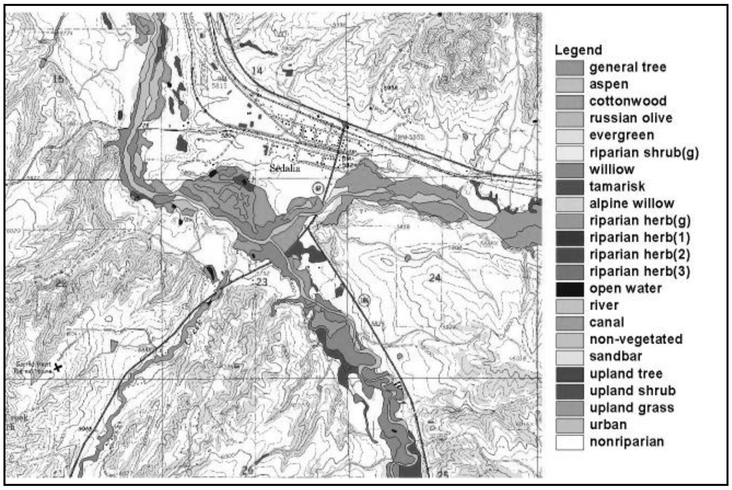

Figure 16. Example of a riparian plant association map showing a Southern Rocky Mountain Riparian Shrubland.

The reason these many polygons are not counted individually is that the primary criterion for their mapping is the reaction to natural flooding. A separation distance of intervening natural or semi-natural communities assumes dynamic movements due to natural flooding regimes. In other words, if the polygons can interact as they respond to flooding, they are considered part of the same occurrence.

Mapping criteria for a So. Rocky Mountain Foothill Riparian Woodlands and Shrubland Ecosystem are:

- Descriptive: Scale and Range**:** Linear And Widespread
- Minimum Size: 0.5 mile by 30 feet.
- Separation Distances:
  1. Substantial barriers… > ¼ mile long, major highways, urban development, large bodies of water,
  2. Different natural riparian system longer than 1 mile,
  3. Major break in topography, soils, geology, etc., especially one resulting in a hydrologic break.

ECOLOGICAL INTEGRITY RANKING AND RESTORATION

The following series of photographs illustrate, by example, different points on the Ecological Integrity Rank Scale. The ends of the scale, the best and the worst are pretty straight forward (Figure 17). An A-rank occurrence of a foothills riparian area is large (>1/4 mile long, > 30 meters wide), very few weeds/non-native species, the surrounding landscape is not fragmented. There are no bridges or roads that either cross the creek upstream or run parallel to the creek and constrict it. At the opposite end of the scale, the photo on the right (Figure 17), is not a functioning riparian ecosystem. It is highly damaged, the flow of water and sediment movement are impeded, the banks are armored, and there is no riparian vegetation to speak of. Clearly this site has low ecological integrity as an example of a foothills riparian ecosystem.

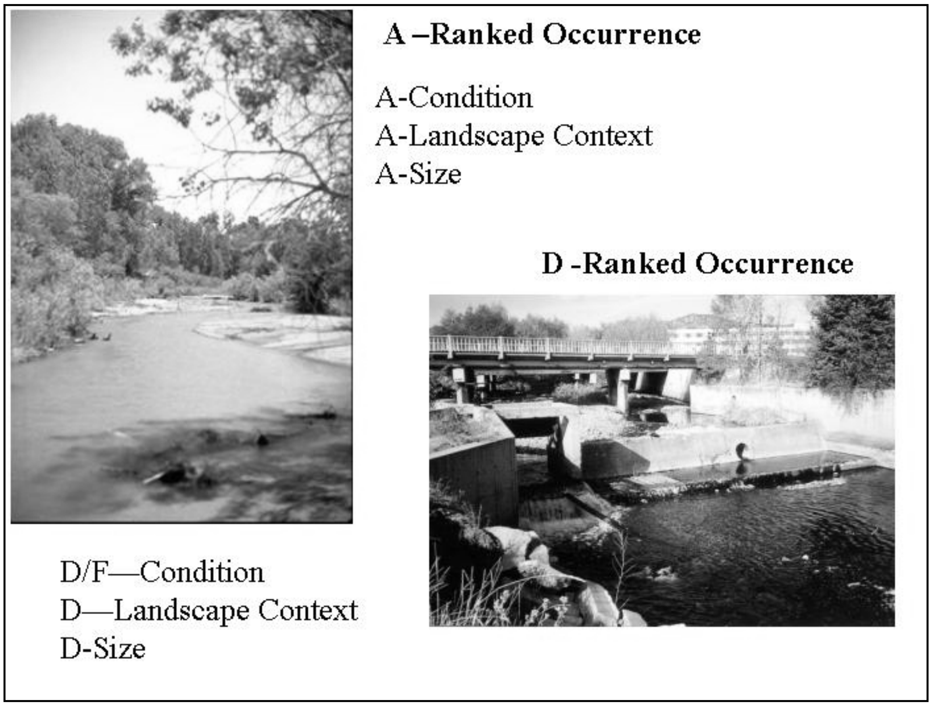

Figure 17.Example of ranges of Ecological Integrity Rank Scale for a foothills riparian ecosystem.

The differences between an A and a B ranked occurrence, and between a C and D ranked occurrences can be more subtle. In the following series of photographs, these differences are illustrated, and at the same time, we can discuss how ecological integrity ranking criteria can be used as restoration goals.

Remember that Ecological Integrity criteria has three categories: Size, Condition and Landscape Context. The next three example illustrate the Condition criteria. Condition consists of local site specific criteria, such as the abundance of non-native weeds, the amount of soil compaction or erosion, amount and type of vegetative cover, and species composition. Part of the definition of A through D rank criteria, is defining the threshold of a A–ranked site and that of a C-rank site. Thresholds indicate when is a site condition moves fully into the A criteria, and when a site condition moves from non-functioning wetland (D-rank) to a site with "just enough" ecological integrity to function as a wetland (C-rank).

MITIGATION: RESTORATION OR CREATION?

Each series of photographs below show before and after of a restoration effort. By determining where on the Integrity ranking scale a site currently lies, we can document what amount of restoration is needed. Any restoration undertaken needs to improve a site to a least C-Integrity rank. A C-rank is the minimum criteria to be considered a functioning riparian or wetland area. For mitigation, there may be places where restoration of an existing damaged riparian or wetland will have far greater biological value than a more expensive creation of another cattail wetland. Using the International Vegetation Classification can help prioritize the relative importance of the biodiversity of a site, and may point to greater biodiversity conservation through restoration of that site. For example, a mitigation choice may be between 1) restoration of a rare G2 ranked riparian wetland, and preventing its loss, or 2) the creation of a very common G5 wetland that may not contain all of the biodiversity of a natural occurrence of the same type of G5 wetland.

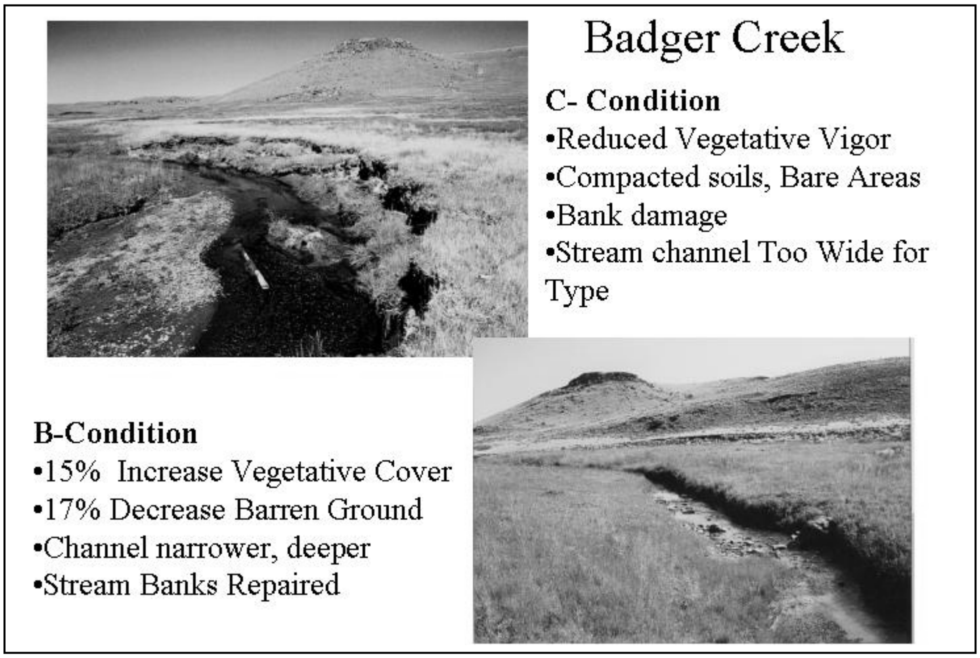

Figure 18. Changes in vegetation condition at Badger Creek.

At Badger Creek, we can see the damage from over grazing (upper left, Figure 18). The stream is much wider than expected for high mountain stream on fine clay soils, the stream bank is damaged, and the vegetation is trampled, soils compacted, there are areas of bare soil exposed. This represents a C-ranked Condition of a riparian ecosystem. After a 4-year rest, grazing management was changed to intensive early spring grazing with high numbers of cattle for short periods of time. Improvement is evident. There is increased vegetative cover, reduced soil compaction and the stream channel has improved by becoming narrow and more stable. This restored state is an example of a B-ranked occurrence. There are still many exotic species in site, preventing an A-rank.

Ford Creek is an example where a little bit of management change at the right time goes a long way. The stream is running from left to right, just out of the frame. Summer long grazing had deteriorated the stream and stream banks. There are compacted soils and bare ground. The site is ripe for invasive species problem. Changes in grazing management had increased the vegetative cover, filled in the bare areas, and reduced the potential for weed invasion. The site was improved from a B-condition to an A-condition.

At Boulder Creek, a lot of money was spent on to improve this urban corridor creek. While the aquatic habitat and the stream's ability to move water and sediment has been greatly improved, the overall riparian ecosystem has not been restored above a D-rank. There still lacks vegetation along the stream banks. It may have been impossible to take this site any further with limitation of the surrounding urban lands, but we still cannot give the restored site better than low C / D rank (Figure 20).

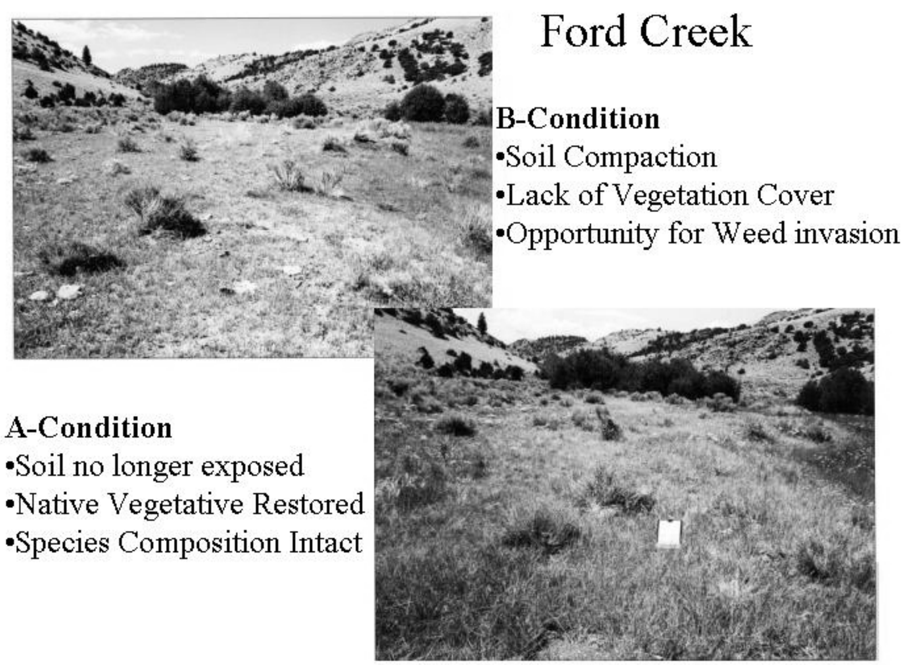

Figure 19. Vegetation changes at Ford Creek.

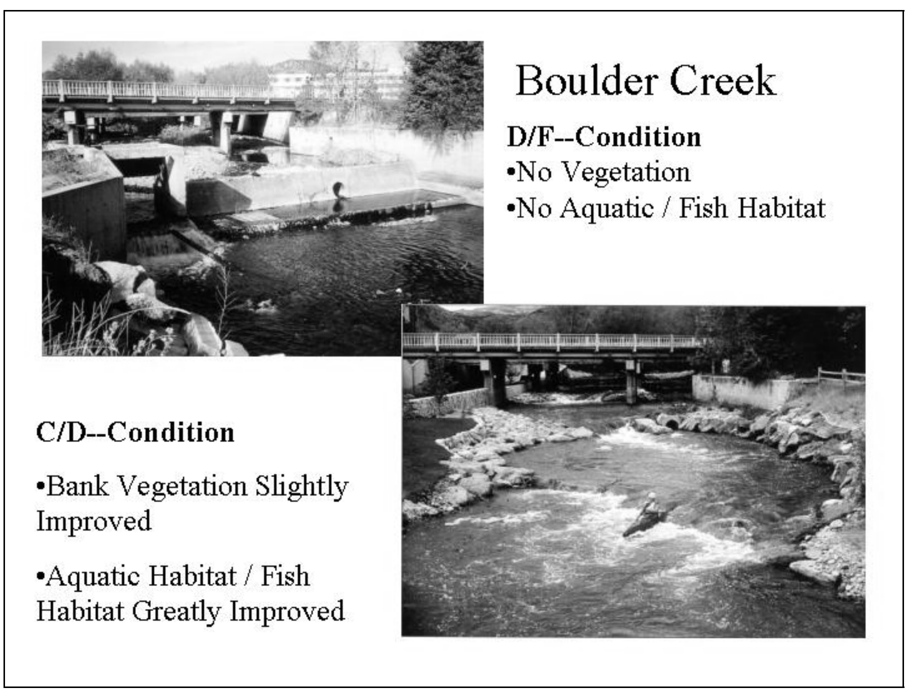

Figure 20. Stream changes in an urban corridor along Boulder Creek.

Included in the Integrity Rank is the Landscape Context of the site. Beyond the boundaries of the occurrence, what is the watershed setting, the surrounding uplands, and the upstream and downstream environments. How fragmented are the lands surrounding the wetland? Are there constrictions to the natural meandering pattern of the alluvial channel? The landscape setting can help define the potential success of a restoration project, as in the Boulder Creek example above. In Figure 21, we can see that the riparian area in the upper left runs through a fragmented landscape. One may want to spend time restoring a portion of the stream bank, but this may be in vain if the entire reach, the landscape setting is not taken into consideration. The riparian area on the lower right (Figure 21) gets an A-rank for landscape context. There are no clear cuts to cause erosion in the immediate uplands, there are no roads constricting the width of the riparian area on the valley floor.

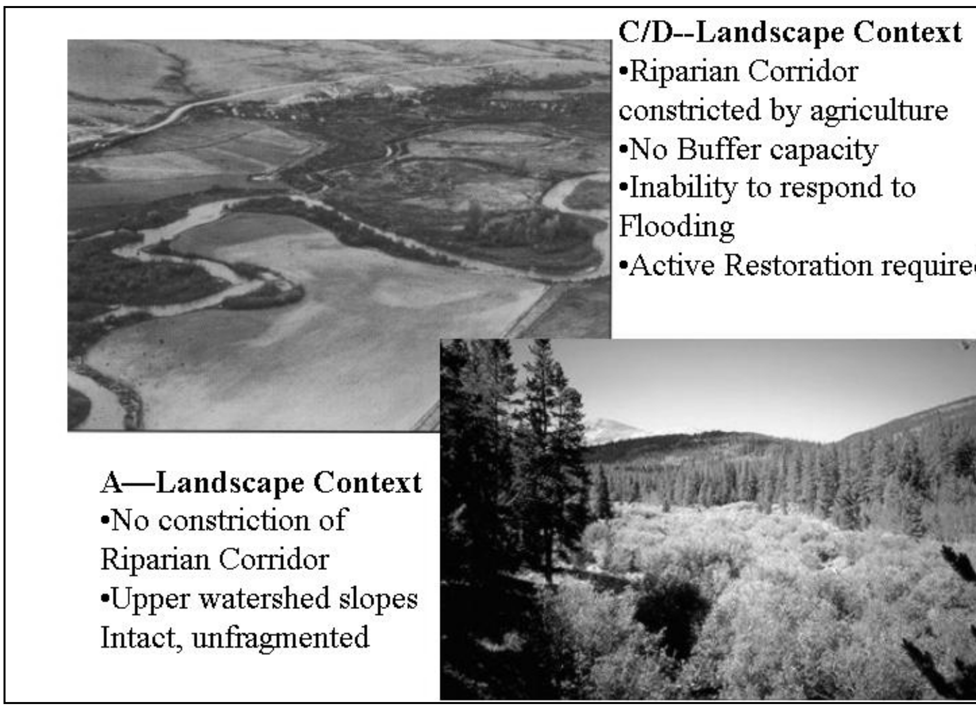

Figure 21. Example of how Landscape Context influences Integrity Ranking.

NatureServe / Heritage Program Integrity Ranks define the reference conditions, and can be the frame work for restoration goals. The International Vegetation Classification gives the context of the biodiversity of an area, and the Integrity ranking criteria is the standard to which compare a restored wetland.

SUMMARY

In Colorado, over 230 riparian and wetland plant associations were described with quantitative data. One hundred eighty-four wetland descriptions are available in a published field guide, complete with vegetative key to types and descriptions. This classification is part of the International Vegetation Classification (IVC), maintained by NatureServe and with the assistance of the Ecological Society of America Vegetation Panel and the Federal Geographic Standards Committee on the U.S. part.

In addition to the IVC, all plant associations have been placed into Ecological Systems. Ecological Systems are groups of associations that occur together on the landscape within the same environmental and/or disturbance regime. Systems are convenient for mapping and other management issues, and can be a closer link to a sites landscape/watershed context and the physical processes needed for long term persistence. The plant associations have more detailed, site specific information, such as species composition.

Mapping and Ecological Integrity Ranking Criteria has been developed for many associations and systems. Ecological Integrity Rank criteria are written specific to each Ecological System or Plant Association. Ranks are set on a simple A-D scale, and are based on three categories of criteria: Size, Condition, and Landscape Context. Ecological indicators need to be developed for each criterion, for each system. A-rank occurrences are the healthy, viable and resilient. C-ranked occurrences are damaged but functional with limited buffering capacity from further degradation. D-rank occurrences will not continue (have no ecological integrity) without intensive intervention. The criteria defining each rank can be used as restoration goals (bring a site from a D-rank up to a B-rank) which can also be applied as monitoring goals (measure the same parameters to ensure management / land use is maintaining a B-rank). In addition, standard ranking criteria are used for defining Reference Sites. A standard Ecological Integrity ranking will make it possible to compare restored wetlands to reference sites.

Any restoration undertaken needs to improve a site to a least C level Integrity rank. A C-rank is the minimum criteria to be considered a functioning riparian or wetland area. For mitigation, there may be places where restoration of an existing damaged riparian or wetland will have far greater benefits to biodiversity conservation/restoration than a more expensive creation of another cattail wetland.

A standard Classification of riparian and wetland plant associations and ecological systems provides context, can help set priorities and provide minimum standards for restoration. While the classification is developed and available, and individual Ecological Integrity ranking criteria has been developed for about 30 Ecological Systems. Ecological Integrity ranking criteria for many more systems from throughout the country need to be developed. NatureServe and your local Heritage Programs has the expertise in place to develop this data. By working together we can provide standardized data needed for restoration and monitoring.

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VEGETATION ESTABLISHMENT ON COPPER SMELTER ALTERED SOILS NEAR ANACONDA, MONTANA

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ABSTRACT

Copper smelting operations near Anaconda, Montana between 1884 and 1980 produced an abundance of sulfur dioxide which killed much of the vegetation in the vicinity of the smelter. Long term exposure to sulfur dioxide lowered the pH of the soil surface and upper portions of the soil profile. Fugitive metals and metalloid particulates (arsenic, cadmium, copper, lead and zinc) from the smelter stacks were distributed across the landscape and caused an enrichment of these elements in the upper soil profiles. The areas around the former smelter are included within the boundaries of the Anaconda Smelter Superfund Site. The selected approach for remediation of smelter related impacts is land reclamation, which consists of a variety of approaches including tilling and amending disturbed soils.

As part of on-going site remediation and development of disturbed lands remediation designs, a field scale demonstration study was conducted to evaluate the effectiveness of two different tilling approaches and different rates of lime amendments on an upland site. Field sampling between 1999 and 2003 has consisted of site characterization (vegetation and soils) prior to remediation and then following implementation of the various treatments. This paper presents the results of soil treatments and discusses vegetation development on the treated areas.

INTRODUCTION

Remediation of smelter impacted upland areas in the vicinity of the former copper smelters near Anaconda will include a variety of techniques including tilling and amending sites that currently have limited vegetation development. In order to obtain insight into the effectiveness of tilling approaches, a demonstration project was initiated on Stucky Ridge in 1999 (just north of the smelters that operated between 1884 and 1903 and approximately 2.5 miles northwest of the Washoe Smelter which operated between 1903 and 1980). The purpose of this project was to evaluate different tilling depths and liming rates which can be used to remediate sites impacted by past smelting activities. Specifically, the study was designed to evaluate the effectiveness of six or twelve inch tilling, and to evaluate revegetation success on sites not treated with lime and sites treated with lime at rates based on an acid-base accounting (ABA) equation and rates based on the ABA equation plus an additional 25 percent of the lime rate.

While it is possible to compare the results of the different approaches among themselves, inherent differences in the pre-treatment vegetation within the demonstration study area make it difficult to adequately rank the effectiveness of the different treatments. An alternative approach is to compare the demonstration plot results with proposed performance standards that have been put forth by the EPA and their contractors (CDM Federal and the Montana State University Reclamation Research Unit 1999).

This paper presents information about the demonstration study plots prior to treatment (1999) and describes the changes in vegetation and soil resulting from implementation of the various treatments. The post treatment vegetation data are from 2001 and 2003 which were the first and third full growing seasons, respectively, following establishment of seedlings.

PROJECT DESIGN

Location

The project site is located in west-central Montana near the town of Anaconda (Figure 1). Specifically, the site is located on Stucky Ridge in an area where tilling was selected as the remediation technique (Figure 2). The total area is approximately 60 acres with each of the demonstration plots being approximately 10 acres in extent. The site was selected based on its relative consistency of topography, accessibility and land ownership. The south side of the demonstration area is adjacent to a dismantled flue and stack that were part of the Old Works Smelter that operated between 1884 and 1903. Because of the proximity to the old stack, the soil concentrations of arsenic, copper and zinc tend to be higher on the south side of the demonstration area (Plots 4, 5 and 6) than they are on the north part of the site (Plots 1, 2 and 3).

Figure 1. Location of Project site in Montana, USA.

Treatments

The treatments consisted of two tilling depths [tilling to 6 inches (T6) and tilling to 12 inches (T12)] and three liming evaluations (no lime, lime applied at a rate based on the ABA equation and lime applied at the ABA rate plus 25 percent).

All of the plots were initially tilled to loosen the existing surfaces. Lime (in the form of lime kiln dust) was then applied at the specified rates. After lime application, the plots were then tilled to either 6 or 12 inches using a Rhome disc pulled by an agricultural tractor. Two, more or less perpendicular passes were used to till the plots. While the project design was to restrict the tilling to either 6 or 12 inches, the actual depth of tilling varied in response to rock content,

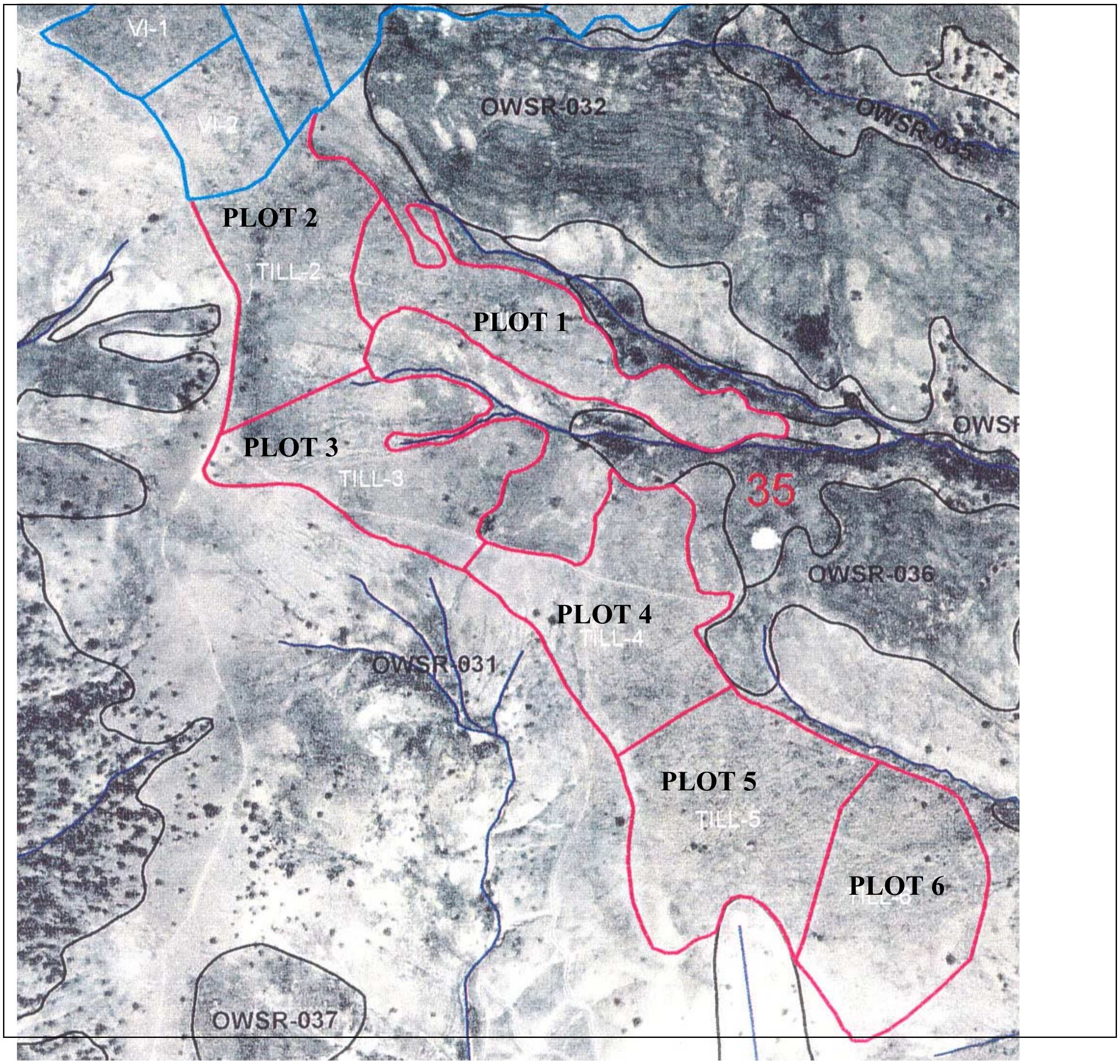

Figure 2. Map showing location of the six tilling plots on Stucky Ridge.

topography and other soil textural attributes. Regardless of these problems, the two tilling approaches were fair representations of what may be expected to occur when these techniques (T6 and T12) are implemented at full scale levels during site remediation.

The lime rates were determined based on pre-treatment soil data (Atlantic Richfield 2000) using the following acid base accounting equation:

ABA Equation

Lime Rate in tons/6 inch layer =
(%HNO_3-Sulfur + %Residual Sulfur) X 31.25 +
(%HCL-Sulfur) X 23.44 +
SMP Buffer

A more detailed description of the determination of liming rates is presented in Atlantic Richfield (2000). Plot 1 (T12) and Plot 2 (T6) were limed based on rates determined by the ABA equation. Plot 3 (T12) and Plot 4 (T6) were limed on the rates determined by the ABA equation plus an additional 25 percent of the lime rate. Plot 5 (T12) and Plot 6 (T6) were not limed. Tilling and liming of the plots was completed in October 1999. The plots were drilled seeded and fertilized in April 2000.

Seed Mix

The seed mix for the project is presented in the following table:

Table 1. Seed mix used in the tilling demonstration study on Stucky Ridge.

Scientific Name	Common Name	Variety	Pounds of pure live seed/acre
Agropyron trachycaulum	Slender Wheatgrass	Pryor	3.5
Agropyron smithii	Western Wheatgrass	Rosana	3.5
Agropyron dasystachyum	Thickspike Wheatgrass	Bannock	2.5
Agropyron spicatum	Bluebunch Wheatgrass	Goldar	3.5
Elymus cinereus	Great Basin Wildrye	Magnar	2.5
Poa ampla	Big Bluegrass	Sherman	2.5
Festuca ovina	Sheep Fescue		2.5
Oryzopsis hymenoides	Indian Ricegrass	Nezpar	2.5
Penstemon strictus	Rocky Mountain Penstemon	Bandera	1.0
Linum lewisii	Common Blue Flax		1.0
		Total	25.0

The seed mix consists primarily of native perennial grasses that at one time occurred as components of the original grasslands or are species that have colonized the disturbed areas. Seed for these species is commercially readily available. Broadleaved species were included to only a limited extent, because of the anticipated need for herbicide control of broad leaved weeds after the sites had been seeded.

METHODS

Soil Data

Prior to treatment, soil samples were collected from four locations in each of the six plots. Samples were collected from 0-2 inch, 2-6 inch, 6-12 inch, 12-18 inch and 0-6 soil layers. To the extent possible, the pre-treatment soil sampling locations were re-sampled following treatment. Complete analyses for these samples and a more complete description of sampling approaches are presented in Atlantic Richfield (2000). For this paper, pre- and post treatment for pH, and total concentrations for arsenic, copper and zinc are included.

Vegetation Data

Vegetation cover data were obtained using a point sampling method. With this method, vegetation cover data are obtained by making observations using an optical sighting device mounted on a tripod. Observations of what is encountered in the cross hairs of the sighting device are made along a transect. For this study, transects were 25 meters long, and observations were made at one-meter intervals along each side of the transect (a total of 50 points per transect). Ten transects were sampled in each demonstration plot in September 1999 prior to treatment. These same general locations were sampled in September 2001 at the end of the first full growing season following seedling establishment. The data were summarized by computing mean cover values for each species and for total vegetation cover, cover by litter, cover by rock and cover by bare soil. In the summary tables, the species were grouped based on the following categories:

Species Group	Description
Seeded Species	Species included in the seed mix
Remnants of the Original Vegetation	Species that were present prior to smelting that have persisted on impacted sites.
Native Colonizers	Native species that have become established on disturbed sites.
Other Perennial Species	Non-native perennial species that have become established on disturbed sites (mostly grasses).
Native Trees and Shrubs	Native trees and shrubs are either remnants of the original vegetation or have become established on disturbed sites.
Undesirable Weedy Species	Non-native annual and perennial grasses and forbs that are generally considered to be weeds or undesirable species in native rangelands or reclaimed lands.

Grouping the species in this manner provided a means for assessing the changes in the vegetation resulting from implementation of the various treatments.

RESULTS

Plot 1

Treatment Summary

The treatment implemented in Plot 1 is summarized in the following table.

Plot 1 Treatment Summary
(T12 Base ABA Lime Rate)

Action	Date	Procedure
Tilling	October 1999	Prior to lime application the plot was tilled (one pass) to a depth of 12 inches. Following lime application, two additional tilling passes were made using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 12 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment	October 1999	Lime was applied at the rate determined by the ABA equation (15 tons/acre). The lime rate was based on the soil samples collected within Plot 1.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 1 consisted of a sparse grassland dominated by red top *(Agrostis alba)* which accounted for 69 percent of the cover present in the plot. Mean total vegetation cover was 18 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for most of the remainder of the cover. Shrubs had a mean cover of one percent. Approximately 50 percent of the area was either rock (17 percent) or bare soil (33 percent). Cover by plant litter amounted to 32 percent. In all, 23 species were observed along the sample transects (Table 2).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 4.02 and 5.28 with a mean of 4.63. Values in the 0-6 inch layer ranged between 4.00 and 5.53 with a mean of 4.81, and values in the 6-12 inch layer ranged between 4.45 and 7.47 with a mean of 5.81. In the 12-18 inch layer, all pH values were greater than 7.0 with a mean value of 7.76 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 224 and 479 mg/kg with a mean of 384 mg/kg prior to treatment. Arsenic values decreased substantially with depth (Table 3). The mean arsenic concentration was 162 mg/kg in the 2-6 inch soil layer; 40.6 mg/kg in the 6-12 inch layer and 14.2 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 775 mg/kg to 1620 mg/kg with a mean value of 1103 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth (Table 3). In the 2-6 inch soil layer, the mean total soil copper concentration was 764 mg/kg; in the 6-12 inch layer it was 276 mg/kg and in the 12-18 inch layer the mean copper concentration was 67 mg/kg. Total zinc ranged between 233 and 358 mg/kg in the 0-2 inch layer with a mean of 299 mg/kg (Table 3). Concentrations in the top 12 inches were quite consistent with the mean zinc concentration

Table 2. Mean cover values for each of the demonstration plots. Based on a sample size of 10 transects for each plot for each year of sampling.

Mean Values Based on Transect Data	**Plot 1 T12, ABA Lime Rate**			**Plot 2 T6, ABA Lime Rate**			**Plot 3 T12, ABA Lime Rate + 25%**			**Plot 4 T6, ABA Lime Rate + 25%**			**Plot 5 T12, No Lime Added**			**Plot 6 T6, No Lime Added**		
	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003
Total Vegetation Cover	18.0	43.4	39.2	26.6	45.6	40.8	21.4	43.2	40.0	11.8	35.8	40.4	18.8	37.0	34.6	18.2	45.6	31.4
Bare Soil	32.6	41.4	12.6	26.2	30.6	10.8	31.8	41.8	8.4	34.0	42.0	11.2	30.2	39.6	20.0	30.0	29.8	11.0
Litter and Rock Combined	49.4	15.2	43.8	47.2	23.8	48.4	46.8	15.0	51.6	54.2	22.2	48.4	51.0	23.4	45.4	51.8	24.6	57.6
Total Ground Cover	67.4	58.6	83.0	73.8	69.4	89.2	68.2	58.2	91.6	66.0	58.0	88.8	69.8	60.4	80.0	70.0	70.2	89.0
Litter	32.4	6.6	41.4	31.4	13.4	43.2	31.2	4.4	48.6	36.2	7.2	43.4	25.8	7.2	37.6	23.6	11.6	46.4
Rock	17.0	8.6	2.4	15.8	10.4	5.2	15.6	10.6	3.0	18.0	15.0	5.0	25.2	16.2	7.8	28.2	13.0	11.2
Seeded Species																		
Agropyron dasystachyum	<0.1	8.6	4.4	<0.1	4.2	4.6		15.8	10.0		4.2	6.6	0.2	1.6	1.2	0.4	3.4	3.6
Agropyron smithii		1.2	1.2		1.2	1.2		1.2	1.6		0.8	1.0	0.2	<0.1	0.4	<0.1	<0.1	0.6
Agropyron spicatum		0.2	2.0		0.6	1.2		0.4	2.2		0.8	2.6	<0.1	0.2	2.4	<0.1	0.6	1.6
Agropyron trachycaulum	<0.1	2.6	3.4	<0.1	4.0	5.4	<0.1	3.8	9.0	<0.1	4.2	6.2	0.2	1.6	3.2	<0.1	2.8	3.6
Elymus cinereus	0.2	0.2	2.0	0.2	<0.1	1.2	0.4	0.4	2.4	3.0	1.2	2.8	2.2	0.2	1.6	1.6	0.6	3.0
Festuca ovina		2.8	2.4		1.0	1.2		2.2	1.0		2.2	1.8	<0.1	1.4	1.2	0.2	1.0	0.4
Linum lewisii		0.4	1.0		<0.1	<0.1		<0.1			<0.1	<0.1		<0.1	<0.1		0.6	0.4
Oryzopsis hymenoides		0.2	3.0	0.2	<0.1	1.4		<0.1	0.4		<0.1	0.4	<0.1	<0.1	0.2	0.6	<0.1	0.4
Penstemon strictus		<0.1													<0.1			<0.1
Poa ampla		1.8	4.4		2.8	9.0		2.6	6.6		4.4	8.2		2.0	4.0		2.4	3.2
Sub-total	0.2	18.0	23.8	0.4	13.8	25.2	0.4	26.4	33.2	3.0	17.8	29.6	2.8	7.0	14.2	2.8	11.4	16.8
Remnants of Original Vegetation																		
Allium cernuum										<0.1			<0.1			<0.1	<0.1	<0.1
Carex douglasii	<0.1		<0.1	0.4			<0.1			0.2			<0.1			0.4		
Comandra umbellata	<0.1	<0.1		<0.1	<0.1		0.2	<0.1		<0.1			0.2			<0.1		
Lygodesmia juncea																		<0.1
Sphaeralcea coccinea	<0.1						<0.1	<0.1			<0.1							
Sub-total	0.0	0.0		0.4	0.0		0.2	0.0		0.2	0.0		0.2	0.0		0.4	0.0	
Native Colonizers																		
Artemisia ludoviciana	<0.1			<0.1	<0.1		<0.1											
Aster adscendens	<0.1	<0.1	<0.1	<0.1			<0.1									<0.1	<0.1	<0.1
Aster falcatus	0.2						<0.1											
Cirsium undulatum																<0.1		
Elymus canadensis						<0.1												
Epilobium angustifolium				<0.1														
Grindelia squarrosa														0.2				
Gutierrezia sarothrae																<0.1		<0.1
Hordeum jubatum	<0.1	0.2	0.2	1.0	0.6	1.4	0.2	1.0	1.2	0.8	2.0	2.4	0.4	0.8	<0.1	0.8	2.8	0.8
Koeleria macrantha									<0.1									
Lithospermum ruderale	<0.1			<0.1			0.2									<0.1		
Lupinus argenteus		<0.1		<0.1	<0.1													<0.1
Mentzelia laevicaulis		1.2	<0.1		0.4			<0.1		1.0	1.0		1.0	1.2		1.0	4.6	
Mosses	<0.1						<0.1			<0.1								
Phacelia hastata	<0.1	<0.1												<0.1	<0.1	<0.1	<0.1	0.2
Poa interior						<0.1			<0.1	0.4		0.4	0.2			0.2		<0.1
Poa secunda										<0.1			<0.1			<0.1		
Sitanion longifolium				0.2						0.2		<0.1	<0.1			0.4		

Table 2. (Continued) Mean cover values for each of the demonstration plots. Based on a sample size of 10 transects for each plot for each year of sampling.

Mean Values Based on Transect Data	**Plot 1 T12, ABA Lime Rate**			**Plot 2 T6, ABA Lime Rate**			**Plot 3 T12, ABA Lime Rate + 25%**			**Plot 4 T6, ABA Lime Rate + 25%**			**Plot 5 T12, No Lime Added**			**Plot 6 T6, No Lime Added**		
	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003	1999	2001	2003
Solidago missouriensis	<0.1																	
Stipa comata				<0.1	<0.1	0.2								<0.1	<0.1	<0.1	<0.1	<0.1
Stipa viridula				<0.1														
Sub-total	0.2	1.4	0.2	1.2	1.0	1.6	0.4	1.0	1.2	2.4	3.0	2.8	1.6	2.2		2.4	7.4	1.0
Other Perennial Species																		
Agropyron cristatum					<0.1													<0.1
Agropyron elongatum					<0.1											<0.1		
Agropyron intermedium					<0.1			<0.1	0.2		<0.1	<0.1						
Agrostis alba	12.4	11.8	12.6	21.2	20.0	13.2	18.0	11.8	4.6	4.6	8.8	6.2	11.0	22.4	18.2	8.0	22.8	11.4
Bromus inermis		<0.1	<0.1		<0.1	<0.1		<0.1	<0.1		<0.1	0.2		<0.1	<0.1		<0.1	<0.1
Dactylis glomerata		0.2	<0.1								<0.1							
Elymus junceus						<1			<0.1			0.2			<0.1			
Poa compressa						<1												
Poa pratensis	<0.1	<0.1	0.2	0.2	<0.1	<1	0.6	0.4	0.6	0.2	<0.1	<0.1			<0.1		<0.1	<0.1
Sub-total	12.4	12.0	12.8	21.4	20.0	13.2	18.6	12.2	5.4	4.8	8.8	6.6	11.0	22.4	18.2	8.0	22.8	11.4
Native Trees and Shrubs																		
Ceratoides lanata													0.6					
Chrysothamnus nauseosus				<0.1			0.6			0.2						0.6	<0.1	0.2
Pinus flexilis	<0.1															<0.1		
Prunus virginiana	0.2	<0.1	<0.1															
Pseudotsuga menziesii			<0.1															
Rosa woodsii				<0.1	0.4		<0.1	<0.1	<0.1							<0.1	<0.1	<0.1
Symphoricarpos albus							<0.1											
Tetradymia canescens	0.8	<0.1	<0.1	0.6		<1	<0.1			<0.1			<0.1			0.2		
Sub-total	1.0			0.6	0.4		0.6			0.2	0.0		0.6	0.0		0.8	0.0	0.2
Undesirable Weedy Species																		
Avena sativa								<0.1										
Bromus japonicus								<0.1										
Bromus tectorum		<0.1	<0.1	0.2	<0.1	0.6		<0.1			0.6	<0.1	<0.1	0.2			<0.1	<0.1
Cardaria draba	0.2	4.8	1.4	2.2	7.6	0.2	<0.1	2.0	<0.1	0.2	0.2	<0.1	<0.1	0.2	0.2			0.2
Centaurea maculosa	1.4	2.4	0.2	<0.1	<0.1	<0.1	0.6	0.2	<0.1	0.4	0.2	<0.1	1.6	3.0	1.8	2.8	2.0	1.0
Cirsium arvense	2.4	4.4	0.4	0.2	2.2	<0.1	0.6	1.0	<0.1	0.6	1.0	<0.1	1.0	1.6	0.2	1.0	1.0	0.8
Conringia orientalis					<0.1													
Euphorbia esula		<0.1	<0.1													<0.1	<0.1	<0.1
Helianthus annuus											<0.1			<0.1				
Kochia scoparia		0.2	0.4		0.6			0.4	0.2		4.2	1.4		0.4	<0.1	<0.1	1.0	<0.1
Melilotus officinalis														<0.1				
Rumex crispus										<0.1								
Sisymbrium altissimum		0.2			<0.1			<0.1			<0.1							
Tragopogon dubius	0.2		<0.1							<0.1					<0.1			
Triticum aestivum										<0.1			<0.1					
Sub-total	4.2	12.0	2.4	2.6	10.4	0.8	1.2	3.6	0.2	1.2	6.2	1.4	2.6	5.4	2.2	3.8	4.0	2.0
Total Cover by Acceptable Species	13.8	31.4	36.8	24.0	35.2	40.0	20.2	39.6	39.8	10.6	29.6	39.0	16.2	31.6	32.4	14.4	41.6	29.4
Total Cover by Weedy Species	4.2	12.0	2.4	2.6	10.4	0.8	1.2	3.6	0.2	1.2	6.2	1.4	2.6	5.4	2.2	3.8	4.0	2.0
Total Cover by All Species	18.0	43.4	39.2	26.6	45.6	40.8	21.4	43.2	40.0	11.8	35.8	40.4	18.8	37.0	34.6	18.2	45.6	31.4

Table 3. Soil analytical results for each of the demonstration plots before and after implementation of treatments. Means based on four samples. NA=Not Analyzed.

PLOT and Sample Depth	pH (standard units)						ARSENIC (mg/kg dw)					
	Minimum		Maximum		Mean		Minimum		Maximum		Mean	
	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After
Plot 1 0-2”	4.02	NA	5.28	NA	4.63	NA	224	164	479	275	384	214
Plot 1 2-6”	NA	NA	NA	NA	NA	NA	112	100	233	300	162	223
Plot 1 0-6”	4.00	6.61	5.53	7.74	4.81	7.20	NA	NA	NA	NA	NA	NA
Plot 1 6-12”	4.45	6.90	7.47	8.28	5.81	7.64	13	90	78	244	41	178
Plot 1 12-18”	7.47	NA	7.94	NA	7.76	NA	8	NA	18	NA	14	NA
Plot 2 0-2”	4.20	NA	7.63	NA	5.20	NA	266	209	733	422	389	272
Plot 2 2-6”	NA	NA	NA	NA	NA	NA	140	176	355	333	244	247
Plot 2 0-6”	4.68	7.44	7.35	7.70	5.30	7.58	NA	NA	NA	NA	NA	NA
Plot 2 6-12”	4.43	5.39	8.02	8.03	6.12	7.12	40	32	123	72	90	48
Plot 2 12-18”	6.15	NA	8.32	NA	7.60	NA	12	NA	26	NA	21	NA
Plot 3 0-2”	4.14	NA	5.05	NA	4.46	NA	203	55	578	195	390	130
Plot 3 2-6”	NA	NA	NA	NA	NA	NA	66	93	248	246	150	155
Plot 3 0-6”	4.12	7.55	5.47	8.38	4.66	8.06	NA	NA	NA	NA	NA	NA
Plot 3 6-12”	4.82	6.08	6.92	7.43	5.79	6.65	20	34	62	226	35	90
Plot 3 12-18”	6.58	NA	8.20	NA	7.60	NA	8	NA	48	NA	24	NA
Plot 4 0-2”	5.54	NA	7.75	NA	6.77	NA	255	191	495	746	397	358
Plot 4 2-6”	NA	NA	NA	NA	NA	NA	161	159	373	768	223	338
Plot 4 0-6”	4.75	6.77	7.60	8.40	6.54	7.66	NA	NA	NA	NA	NA	NA
Plot 4 6-12”	7.62	5.13	7.93	7.76	7.74	6.98	38	70	143	426	84	204
Plot 4 12-18”	7.61	NA	7.82	NA	7.72	NA	16	NA	108	NA	41	NA
Plot 5 0-2”	4.05	NA	7.61	NA	5.79	NA	348	127	857	405	484	259
Plot 5 2-6”	NA	NA	NA	NA	NA	NA	78	158	304	548	197	332
Plot 5 0-6”	4.36	6.74	7.40	7.58	6.39	7.34	NA	NA	NA	NA	NA	NA
Plot 5 6-12”	7.62	6.12	7.88	7.46	7.74	6.99	25	76	61	492	36	294
Plot 5 12-18”	6.12	NA	7.46	NA	6.99	NA	6	NA	41	NA	22	NA
Plot 6 0-2”	5.96	NA	8.05	NA	7.26	NA	146	113	563	403	290	196
Plot 6 2-6”	NA	NA	NA	NA	NA	NA	81	134	576	280	272	180
Plot 6 0-6”	5.65	6.08	8.00	7.59	6.68	7.13	NA	NA	NA	NA	NA	NA
Plot 6 6-12”	7.67	6.88	7.94	7.76	7.88	7.36	29	22	345	368	112	132
Plot 6 12-18”	7.82	NA	7.97	NA	7.88	NA	14	NA	133	NA	49	NA

Table 3. (Continued) Soil analytical results for each of the demonstration plots before and after implementation of treatments. Means based on four samples. NA=Not Analyzed.

PLOT and Sample Depth	COPPPER (mg/kg dw)						ZINC (mg/kg dw)					
	Minimum		Maximum		Mean		Minimum		Maximum		Mean	
	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After	1999 Before	2000 After
Plot 1 0-2”	775	448	1620	892	1103	758	233	201	358	257	299	224
Plot 1 2-6”	589	235	944	993	764	706	168	171	255	227	204	208
Plot 1 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 1 6-12”	143	216	615	933	276	608	110	145	261	255	182	211
Plot 1 12-18”	49	NA	80	NA	67	NA	67	NA	116	NA	87	NA
Plot 2 0-2”	667	545	1850	1390	1237	1018	200	183	431	275	302	239
Plot 2 2-6”	374	479	1480	1180	785	866	142	190	208	252	184	220
Plot 2 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 2 6-12”	71	89	451	227	196	140	58	54	260	209	144	128
Plot 2 12-18”	49	NA	70	NA	57	NA	46	NA	81	NA	68	NA
Plot 3 0-2”	736	184	1340	817	1016	533	187	182	328	252	247	222
Plot 3 2-6”	436	339	902	825	590	562	149	175	309	248	226	202
Plot 3 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 3 6-12”	84	134	179	902	124	328	123	106	197	256	161	162
Plot 3 12-18”	43	NA	92	NA	62	NA	86	NA	106	NA	97	NA
Plot 4 0-2”	1540	953	2120	2120	1840	1521	319	313	850	394	476	350
Plot 4 2-6”	565	790	1290	2230	944	1290	223	266	343	356	295	302
Plot 4 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 4 6-12”	95	136	204	1860	143	690	61	65	189	297	104	160
Plot 4 12-18”	54	NA	101	NA	78	NA	29	NA	59	NA	48	NA
Plot 5 0-2”	1030	490	3660	1420	1865	1022	263	198	628	319	379	272
Plot 5 2-6”	781	550	2060	1790	1253	1140	205	215	337	329	269	278
Plot 5 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 5 6-12”	142	273	1420	1640	482	1136	131	149	325	356	205	286
Plot 5 12-18”	43	NA	233	NA	95	NA	46	NA	113	NA	65	NA
Plot 6 0-2”	1510	838	3460	2320	2055	1320	285	268	869	547	465	358
Plot 6 2-6”	702	934	2230	1620	1586	1254	229	271	547	490	380	343
Plot 6 0-6”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Plot 6 6-12”	75	349	1450	1470	539	704	55	138	410	392	218	243
Plot 6 12-18”	55	NA	528	NA	194	NA	47	NA	352	NA	138	NA

value of 204 mg/kg in the 2-6 inch layer and 182 mg/kg in the 6-12 inch layer. The mean value in the 12-18 inch layer was 87 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

After the second growing season (2001), the dominant species in Plot 1 (Table 2) included red top, thickspike wheatgrass *(Agropyron dasystachyum)* white top *(Cardaria draba)* and Canada thistle *(Cirsium arvense)*. During 2002 and 2003 herbicides were applied to control weeds. By the latter part of the fourth growing season, the dominant species in the plot included red top, thickspike wheatgrass, big bluegrass *(Poa ampla)* and slender wheatgrass *(Agropyron trachycaulum)*. Total vegetation cover increased from 18 to 43 percent following treatment and decreased to 39 percent in 2003. However, the overall cover by desirable species increased from 31 percent in 2001 to 37 percent in 2003. The decrease in total vegetation cover occurred primarily as a result of the decrease in cover by weedy species which declined from 12 percent in 2001 to 2 percent in 2003. Following treatment, bare soil increased from 33 to 41 percent, but decreased from 41 percent in 2001 to 13 percent in 2003. This decrease was related to changes in plant litter cover which increased from 7 percent in 2001 to 41 percent in 2003.

Most of the change in vegetation cover occurred as a result of the establishment of the seeded species which have increased from less than one percent prior to treatment to 24 percent by the fourth growing season. The tilling approach is a relatively severe treatment that essentially destroys all of the existing vegetation on the site. Plants with deep root or rhizome systems (some shrubs, for example) resprouted following tilling, however cover values are mostly less than what they were prior to treatment. Even though red top was not included in the seed mix, the abundance of seed present in the soil prior to tilling served as an adequate seed source for the establishment of this species. The 2003 cover values for red top were comparable to what they were prior to treatment.

The addition of lime and the 12 inch tilling altered the soil pH and the concentration of arsenic, copper and zinc in Plot 1. Mean 0-6 inch soil pH increased from 4.81 to 7.2 and pH in the 6-12 inch soil layer increased from 5.81 to 7.64 (Table 3). Mean arsenic concentrations in the 0-2 inch soil layer decreased from 384 to 214 mg/kg as a result of tilling. Mean arsenic concentrations in the 2-6 and 6-12 inch layers increased as a result of tilling. The mean arsenic concentrations for all sampled layers in the 0-12 inch treatment zone were below 300 mg/kg following treatment. Results for copper (Table 3) were similar to those obtained for arsenic. Concentrations in the 0-2 inch layer were decreased and concentrations in the 6-12 inch zone were increased. The concentrations in the 2-6 inch layer showed a slight decrease. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 800 mg/kg. The tilling dilution results for zinc were comparable to those obtained for copper. Concentrations in the 0-2 inch layer were reduced; values in the 2-6 inch layer were about the same; and concentrations in the 6-12 inch layer increased (Table 3). All mean zinc concentrations in the various samples in the 0-12 inch layer were less than 250 mg/kg.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 1 were successful in achieving remediation goals. Total vegetation cover by acceptable species increased from 14 percent prior to treatment to 37 percent following treatment. After four growing seasons, there were 10 species with mean cover values greater than one percent. Post remediation soil pH was greater than 7.0 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer. Surface rock coverage was reduced as a result of tilling. It is likely that the vegetation will continue to develop over the next several growing seasons. Before (1999) and after (2003) photographs of Plot 1 are shown in Photos 1 and 2.

Photo 1. Plot 1 prior to tilling. September 1999.

Photo 2. Plot 1 after treatment. August 2003.

Plot 2

Treatment Summary

The treatment implemented in Plot 2 is summarized in the following table.

Plot 2 Treatment Summary
(T6 Base ABA Lime Rate)

Action	Date	Procedure
Tilling	October 1999	Prior to lime application the plot was tilled (one pass) to a depth of 6 inches. Following lime application, two additional tilling passes were made using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 6 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment	October 1999	Lime was applied at the rate determined by the ABA equation (12 tons/acre). The lime rate was based on the soil samples collected within Plot 2.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 2 consisted of a grassland dominated by red top which accounted for 80 percent of the cover present in the plot. Mean total vegetation cover was 26.6 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for approximately 10 percent of the total vegetation cover. Shrubs had a mean cover of less than one percent. Approximately 42 percent of the area was either rock (16 percent) or bare soil (26 percent). Cover by plant litter amounted to 31 percent. In all, 24 species were observed along the sample transects (Table 2).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 4.20 and 7.63 with a mean of 5.20. Values in the 0-6 inch layer ranged between 4.06 and 7.35 with a mean of 5.30, and values in the 6-12 inch layer ranged between 4.43 and 8.02 with a mean of 6.12. In the 12-18 inch layer, the pH values ranged between 6.15 and 8.32 with a mean value of 7.70 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 266 and 733 mg/kg with a mean of 389 mg/kg prior to treatment. Arsenic values decreased substantially with depth (Table 3). The mean arsenic concentration was 244 mg/kg in the 2-6 inch soil layer; 90.2 mg/kg in the 6-12 inch layer and 21.3 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 667 mg/kg to 1850 mg/kg with a mean value of 1237 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth (Table 3). In the 2-6 inch soil layer, the mean total soil copper concentration was 785 mg/kg; in the 6-12 inch layer it was 196 mg/kg and in the 12-18 inch layer the mean copper concentration was 57 mg/kg. Total zinc ranged between 200 and 431 mg/kg in the 0-2 inch layer with a mean of 302 mg/kg (Table 3). Concentrations in the top 12 inches were quite consistent with the mean zinc concentration value of 183 mg/kg in the 2-6 inch layer and 144 mg/kg in the 6-12 inch layer. The mean value in the 12-18 inch layer was 68 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

The dominant species in Plot 2 following treatment (Table 2) included red top, big bluegrass, slender wheatgrass, and thickspike wheatgrass. Total vegetation cover increased from 27 percent in 1999 to 46 percent in 2001 following treatment and decreased to 41 percent in 2003. Most of this decrease in total cover was attributable to a decrease in weedy species cover which decreased from 10 percent to less than one percent following herbicide applications in 2002 and 2003. Cover by non-weedy, acceptable or desirable species increased from 24 percent in 1999 to 35 percent in 2001 and 40 percent in 2003. Rock cover which was 16 percent prior to treatment decreased 5 percent during the fourth growing season. Following treatment, bare soil increased from 26 to 31 percent in 2001 and decreased to 11 percent in 2003. As a result of tilling, plant litter cover decreased from 31 to 13 percent, but then increased to 43 percent by the end of the fourth growing season. Most of the change in vegetation cover occurred as a result of the establishment of the seeded species (Table 2). Small amounts of the species included in the seed mix were present in the plot prior to tilling. Cover by this group increased from less than one percent to 14 percent in 2001 and 25 percent in 2003. Even though red top was not included in the seed mix, the abundance of seed present in the soil prior to tilling served as an adequate seed source for the establishment of this species, such that even after tilling, red top occurred as the most abundant species in the plot. A small group of species that represent remnants of the original vegetation were only occasionally noted in the plot after tilling, but were not encountered in the cover sampling. The other group of species that increased in cover after treatment included weedy species like Canada thistle, spotted knapweed *(Centaurea maculosa)* and white top, however herbicide applications have been very successful in reducing the amounts of these species.

The addition of lime and the 6 inch tilling altered the soil pH and the concentration of arsenic, copper and zinc in Plot 2. Mean 0-6 inch soil pH increased from 5.30 to 7.58 and pH in the 6-12 inch soil layer increased from 6.12 to 7.12. Mean arsenic concentrations in the 0-2 inch soil layer decreased from 389 to 272 mg/kg as a result of tilling. Mean arsenic concentrations in the 2-6 and 6-12 inch layers increased as a result of tilling. The mean arsenic concentrations for all sampled layers in the 0-12 inch treatment zone were below 400 mg/kg following treatment. Results for copper were similar to those obtained for arsenic. Concentrations in the 0-2 inch layer were decreased and concentrations in the 6-12 inch zone were increased. The concentrations in the 2-6 inch layer showed a slight increase. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 1020 mg/kg. The tilling dilution results for zinc were similar to those obtained for copper. Concentrations in the 0-2 inch layer were reduced; values in the 2-6 inch layer increased slightly; and concentrations in the 6-12 inch layer remained about the same. All mean zinc concentrations in the various samples in the 0-12 inch layer were less than 250 mg/kg. Before and after treatment soil concentrations for Plot 2 are presented in Table 3.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 2 were successful in achieving remediation goals. After four growing seasons, total vegetation cover was increased to over 40 percent with nearly all of the cover being attributable to desirable species. Several species occur as major components of the vegetation, and ten acceptable or desirable species have mean cover values greater than one percent. Post remediation mean soil pH was greater than 7.0 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer, however these reductions were not as great as those observed in the adjacent 12 inch tilling plot. Surface rock coverage was reduced as a result of tilling. Before and after photographs of Plot 2 are shown in Photos 3 and 4.


Photo 3. Plot 2 prior to tilling. September 1999.


Photo 4. Plot 2 after treatment. August 2003.

Plot 3

Treatment Summary

The treatment implemented in Plot 3 is summarized in the following table.

Plot 3 Treatment Summary
(T12 Base ABA Lime Rate + 25%)

Action	Date	Procedure
Tilling	October 1999	Prior to lime application the plot was tilled (one pass) to a depth of 12 inches. Following lime application, two additional tilling passes were made using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 12 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment	October 1999	Lime was applied at the rate determined by the ABA equation plus an additional 25% of the lime rate (24 tons/acre). The lime rate was based on the soil samples collected within Plot 3.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 3 consisted of a sparse grassland dominated by red top which accounted for 84 percent of the cover present in the plot. Mean total vegetation cover was 21.4 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for approximately 6 percent of the total vegetation cover. Shrubs had a mean cover of less than one percent. Approximately 48 percent of the area was either rock (16 percent) or bare soil (32 percent). Cover by plant litter amounted to 31 percent. In all, 20 species were observed along the sample transects (Table 1).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 4.14 and 5.05 with a mean of 4.46. Values in the 0-6 inch layer ranged between 4.12 and 5.47 with a mean of 4.66, and values in the 6-12 inch layer ranged between 4.82 and 6.92 with a mean of 5.79. In the 12-18 inch layer, the pH values ranged between 6.58 and 8.20 with a mean value of 7.60 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 203 and 578 mg/kg with a mean of 390 mg/kg prior to treatment. Arsenic values decreased substantially with depth (Table 3). The mean arsenic concentration was 150 mg/kg in the 2-6 inch soil layer; 34.7 mg/kg in the 6-12 inch layer and 24.5 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 736 mg/kg to 1340 mg/kg with a mean value of 1016 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth. In the 2-6 inch soil layer, the mean total soil copper concentration was 590 mg/kg; in the 6-12 inch layer it was 124 mg/kg and in the 12-18 inch layer the mean copper concentration was 61.7 mg/kg. Total zinc ranged between 187 and 328 mg/kg in the 0-2 inch layer with a mean of 247 mg/kg (Table 3). Concentrations in the top 12 inches were quite consistent with the mean zinc concentration value of 226 mg/kg in the 2-6 inch layer and 161 mg/kg in the 6-12 inch layer. The mean value in the 12-18 inch layer was 97.1 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

The dominant species in Plot 3 following treatment (Table 2) included thickspike wheatgrass, slender wheatgrass, big bluegrass, and red top. Total vegetation cover increased from 21 to 43 percent following treatment in the second growing season and then decreased to 40 percent in the fourth growing season. Most of the decrease in total cover resulted from reduced weed cover resulting from herbicide treatments. Cover by non-weedy, acceptable or desirable species increased from 20 percent to 40 percent following treatment. Rock cover decreased from 16 to 3 percent following treatment. Bare soil increased from 32 to 42 percent in the second growing season following tilling, but decreased to 8 percent after four growing seasons. As a result of tilling, plant litter cover decreased from 31 to 4 percent in the second growing season but increased to 49 percent by the fourth growing season.

Most of the change in vegetation cover occurred as a result of the establishment of the seeded species (Table 2). Small amounts (0.4 percent cover) of the species included in the seed mix were present in the plot prior to tilling. Cover by this group increased from less than one percent to 26 percent in the second growing season and 33 percent in the fourth growing season. Cover by red top decreased from 12 percent in the second growing season to 5 percent in the fourth growing season. A small group of species that represent remnants of the original vegetation were only occasionally noted in the plot after tilling and were not encountered in the cover sampling.

The addition of lime and the 12 inch tilling altered the soil pH and the concentration of arsenic, copper and zinc in Plot 3. Mean 0-6 inch soil pH increased from 4.66 to 8.06 and pH in the 6-12 inch soil layer increased from 5.79 to 6.65 (Table 3). Mean arsenic concentrations in the 0-2 inch soil layer decreased from 390 to 130 mg/kg as a result of tilling. Mean arsenic concentrations in the 2-6 and 6-12 inch layers increased as a result of tilling. The mean arsenic concentrations for all sampled layers in the 0-12 inch soil layer were below 200 mg/kg following treatment. Results for copper (Table 3) were similar to those obtained for arsenic. Concentrations in the 0-2 inch and 2-6 inch layers were decreased and concentrations in the 6-12 inch zone were increased. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 600 mg/kg. The tilling dilution results for zinc were similar to those obtained for copper. Concentrations in the 0-2 inch and 2-6 inch layers were reduced and concentrations in the 6-12 inch layer remained about the same. After remediation, all mean zinc concentrations in the various samples in the 0-12 inch layer were less than 250 mg/kg. Before and after treatment soil concentrations for Plot 3 are presented in Table 3.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 3 were successful in achieving remediation goals. Total vegetation cover was increased to 40 percent with cover by desirable species being more than 39 percent. Several species occur as major components of the vegetation, and nine acceptable or desirable species have mean cover values greater than one percent. Post remediation mean soil pH was greater than 6.5 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer. Surface rock coverage was reduced as a result of tilling. It is likely that the vegetation will continue to develop over the next several growing seasons. Before and after photographs of Plot 3 are shown in Photos 5 and 6.


Photo 5. Plot 3 prior to tilling. September 1999.


Photo 6. Plot 3 after treatment. August 2003.

Plot 4

Treatment Summary

The treatment implemented in Plot 4 is summarized in the following table.

Plot 4 Treatment Summary
(T6 Base ABA Lime Rate + 25%)

Action	Date	Procedure
Tilling	October 1999	Prior to lime application the plot was tilled (one pass) to a depth of 6 inches. Following lime application, two additional tilling passes were made using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 6 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment	October 1999	Lime was applied at the rate determined by the ABA equation plus an additional 25% of the lime rate (9 tons/acre). The lime rate was based on the soil samples collected within Plot 4.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 4 consisted of a sparse grassland dominated by red top and Great Basin wildrye. These two species accounted for 64 percent of the cover present in the plot. Mean total vegetation cover was 11.8 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for approximately 10 percent of the total vegetation cover. Shrubs had a mean cover of less than one percent. Approximately 52 percent of the area was either rock (18 percent) or bare soil (34 percent). Cover by plant litter amounted to 36 percent. In all, 21 species were observed along the sample transects (Table 2).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 5.54 and 7.75 with a mean of 6.77. Values in the 0-6 inch layer ranged between 4.75 and 7.60 with a mean of 6.54, and values in the 6-12 inch layer ranged between 7.62 and 7.93 with a mean of 7.74. In the 12-18 inch layer, the pH values ranged between 7.61 and 7.82 with a mean value of 7.72 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 255 and 495 mg/kg with a mean of 397 mg/kg prior to treatment. Arsenic values decreased substantially with depth (Table 3). The mean arsenic concentration was 223 mg/kg in the 2-6 inch soil layer; 83.7 mg/kg in the 6-12 inch layer and 41.2 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 1540 mg/kg to 2120 mg/kg with a mean value of 1840 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth (Table 3). In the 2-6 inch soil layer, the mean total soil copper concentration was 944 mg/kg; in the 6-12 inch layer it was 143 mg/kg and in the 12-18 inch layer the mean copper concentration was 77.6

mg/kg. Total zinc ranged between 319 and 850 mg/kg in the 0-2 inch layer with a mean of 476 mg/kg (Table 3). Concentrations decreased with depth in the top 18 inches with the mean zinc concentration value of 295 mg/kg in the 2-6 inch layer and 104 mg/kg in the 6-12 inch layer. The mean value in the 12-18 inch layer was 47.6 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

The dominant species in Plot 4 following treatment (Table 2) included big bluegrass, thickspike wheatgrass, slender wheatgrass and red top. Total vegetation cover increased from 12 to 36 percent in the second growing season following treatment and increased to 40 percent by the end of the fourth growing season. Cover by non-weedy, acceptable or desirable species increased from 11 to 40 percent. Weedy species increased from one to six percent and then decreased to 1.4 percent by the end of the fourth growing season (Table 2). Rock cover decreased from 18 to 5 percent after four growing seasons. Bare soil increased from 34 to 42 percent after tilling but then decreased to 11 percent as plant litter has accumulated. Plant litter cover decreased from 36 to 7 percent after tilling, but has increased to 43 percent after four growing seasons.

Most of the change in vegetation cover has occurred as a result of the establishment of the seeded species (Table 2). Small amounts of the species included in the seed mix were present in the plot prior to tilling. Cover by this group has increased from 3 percent to 30 percent.

The addition of lime and the 6 inch tilling altered the soil pH and the concentration of arsenic, copper and zinc in Plot 4. Mean 0-6 inch soil pH increased from 6.54 to 7.66 and pH in the 6-12 inch soil layer decreased from 7.74 to 6.98. Mean arsenic concentrations in the 0-2 inch soil layer decreased from 397 to 358 mg/kg as a result of tilling. Mean arsenic concentrations in the 2-6 and 6-12 inch layers increased as a result of tilling. The mean arsenic concentrations for all sampled layers in the 0-12 inch soil layer were below 400 mg/kg following treatment. Results for copper were similar to those obtained for arsenic. Concentrations in the 0-2 inch were decreased and concentrations in the 2-6 inch and the 6-12 inch layers were increased. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 1525 mg/kg. The tilling dilution results for zinc were similar to those obtained for copper. Concentrations in the 0-2 inch were reduced and concentrations in the 2-6 inch and in the 6-12 inch layers increased. After remediation, all mean zinc concentrations in the various samples in the 0-12 inch layer were less than 350 mg/kg. Before and after treatment soil concentrations for Plot 4 are presented in Table 3.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 4 were successful in achieving remediation goals. Total vegetation cover was increased to over 40 percent with cover by desirable species being 39 percent. Several species occur as major components of the vegetation, and nine acceptable or desirable species have mean cover values greater than one percent. Post remediation mean soil pH was greater than 6.5 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer. Surface rock coverage was reduced as a result of tilling. The above results were obtained after four growing seasons Before and after photographs of Plot 4 are shown in Photos 7 and 8.

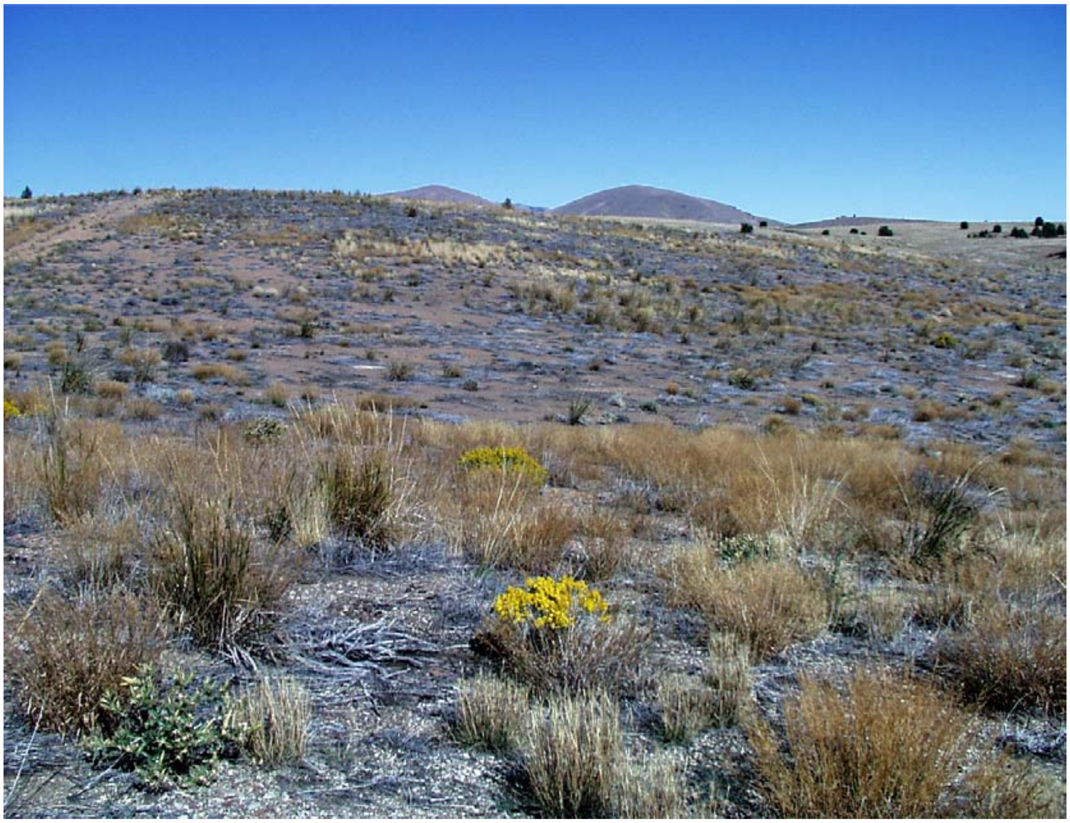
Photo 7. Plot 4 prior to tilling. September 1999.


Photo 8. Plot 4 after treatment. August 2003.

Plot 5

Treatment Summary

The treatment implemented in Plot 5 is summarized in the following table.

Plot 5 Treatment Summary
(T12 No Lime Added)

Action	Date	Procedure
Tilling	October 1999	An initial pass at a depth of 12 inches was made to loosen the soil. This was followed with two additional tilling passes using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 12 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment		No lime was added.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 5 consisted of a sparse grassland dominated by red top and Great Basin wildrye. These two species accounted for 70 percent of the cover present in the plot. Mean total vegetation cover was 18.8 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for approximately 14 percent of the total vegetation cover. Shrubs had a mean cover of less than one percent. Approximately 55 percent of the area was either rock (25 percent) or bare soil (30 percent). Cover by plant litter amounted to 26 percent. In all, 23 species were observed along the sample transects (Table 2).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 4.05 and 6.95 with a mean of 5.79. Values in the 0-6 inch layer ranged between 4.36 and 7.40 with a mean of 6.39, and values in the 6-12 inch layer ranged between 7.62 and 7.88 with a mean of 7.74. In the 12-18 inch layer, the pH values ranged between 7.61 and 7.81 with a mean value of 7.68 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 348 and 857 mg/kg with a mean of 483 mg/kg prior to treatment. Arsenic values decreased substantially with depth (Table 3). The mean arsenic concentration was 197 mg/kg in the 2-6 inch soil layer; 35.8 mg/kg in the 6-12 inch layer and 22.1 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 1030 mg/kg to 3660 mg/kg with a mean value of 1865 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth (Table 3). In the 2-6 inch soil layer, the mean total soil copper concentration was 1253 mg/kg; in the 6-12 inch layer it was 482 mg/kg and in the 12-18 inch layer the mean copper concentration was 95.3 mg/kg. Total zinc ranged between 263 and 628 mg/kg in the 0-2 inch layer with a mean of 379 mg/kg (Table 3). Concentrations decreased with depth in the top 18 inches with the mean zinc concentration value of 269 mg/kg in the 2-6 inch layer and 205 mg/kg in the 6-12 inch layer. The mean value in the 12-

18 inch layer was 65.4 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

The dominant species in Plot 5 following treatment (Table 2) included red top, big bluegrass, slender wheatgrass, and bluebunch wheatgrass *(Agropyron spicatum)*. Total vegetation cover increased from 19 to 35 percent following treatment. Cover by non-weedy, acceptable or desirable species increased from 16 to 32 percent, and weedy species increased from 2.6 to 5.4 percent and then decreased to two percent following herbicide applications in 2002 and 2003. Rock cover decreased from 25 to 8 percent. Bare soil increased from 30 to 40 percent and then decreased to 20 percent after four growing seasons.. As a result of tilling, plant litter cover decreased from 26 to 7 percent, but has increased to 38 percent as the vegetation in this plot has continued to develop.

Most of the change in vegetation cover occurred as a result of an increase in seeded species and in other perennial species (primarily red top) (Table 2). Small amounts of the species included in the seed mix were present in the plot prior to tilling. Cover by this group increased from 3 percent to 14 percent after four growing seasons. Even though red top was not included in the seed mix, the abundance of seed present in the soil prior to tilling served as an adequate seed source for the establishment of this species, such that even after tilling, red top occurred as the most prevalent species in the plot.

Since no lime was added to this plot, changes in pH were related to the effects of tilling to 12 inches. Mean 0-6 inch soil pH increased from 6.39 to 7.34 and pH in the 6-12 inch soil layer decreased from 7.74 to 6.99. Mean arsenic concentrations in the 0-2 inch soil layer decreased from 483 to 259 mg/kg as a result of tilling. Mean arsenic concentrations in the 2-6 and 6-12 inch layers increased as a result of tilling. The mean arsenic concentrations for all sampled layers in the 0-12 inch soil layer were below 335 mg/kg following treatment. Results for copper were similar to those obtained for arsenic. Concentrations in the 0-2 inch and 2-6 inch layers were decreased and concentrations in the 6-12 inch layers were increased. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 1140 mg/kg. The tilling dilution results for zinc were similar to those obtained for copper. Concentrations in the 0-2 inch layer were reduced and concentrations in the 2-6 inch and in the 6-12 inch layers increased. After remediation, all mean zinc concentrations in the various samples in the 0-12 inch layer were less than 300 mg/kg. Before and after treatment soil concentrations for Plot 5 are presented in Table 3.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 5 were successful in achieving remediation goals. Total vegetation cover was increased to 35 percent with cover by desirable species being approximately 32 percent. Several species occur as major components of the vegetation, and seven acceptable or desirable species have mean cover values greater than one percent (Table 2). Post remediation mean soil pH was greater than 6.5 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer. Surface rock coverage was reduced as a result of tilling. The above results were obtained after four growing seasons. While not clearly shown by the data, the vegetation in Plot 5 is less uniform than the vegetation in the limed plots. Even though the goal of 30 percent cover by acceptable species was attained, there are more sparsely vegetated areas in Plot 5 compared to the limed plots (Plots 1-4). This observation is reflected in the higher bare soil values in Plot 5 compared with the limed plots. Before and after photographs of Plot 5 are shown in Photos 9 and 10.


Photo 9. Plot 5 prior to tilling. September 1999.

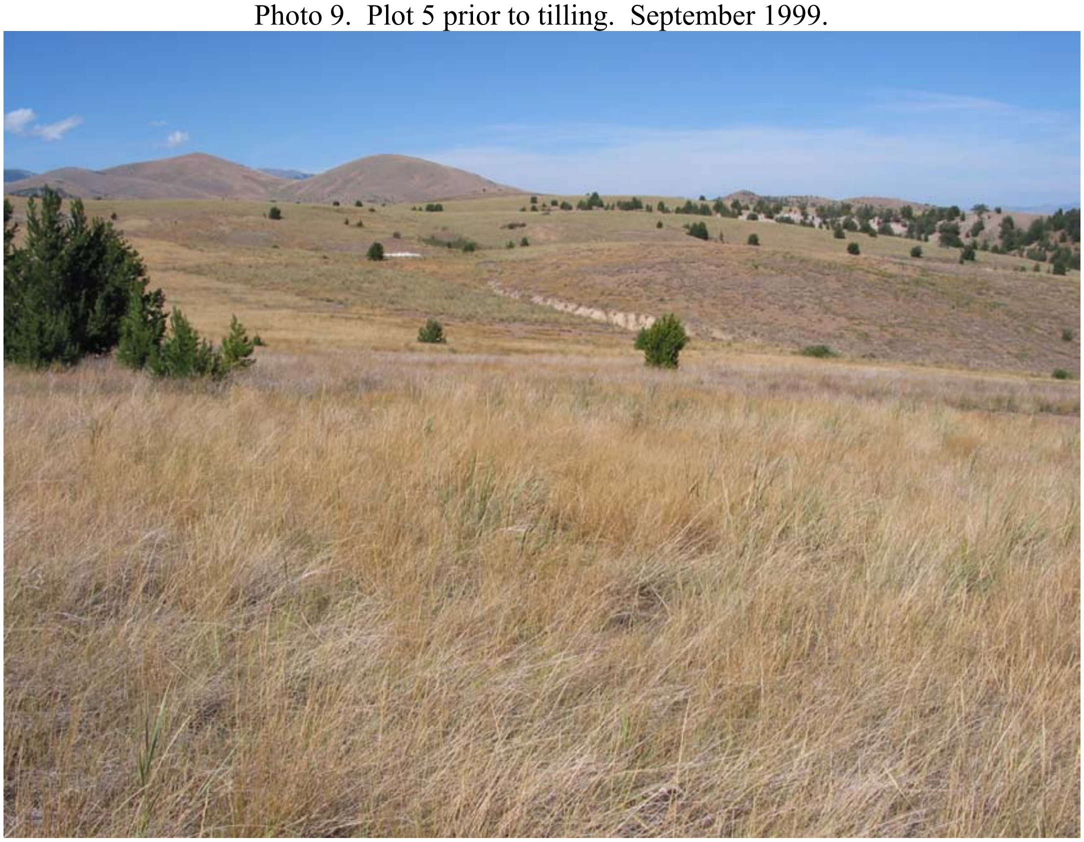
Photo 10. Plot 5 after treatment. August 2003.

Plot 6

Treatment Summary

The treatment implemented in Plot 6 is summarized in the following table.

Plot 6 Treatment Summary
(T6 No Lime Added)

Action	Date	Procedure
Tilling	October 1999	An initial pass at a depth of 6 inches was made to loosen the soil. This was followed with two additional tilling passes using a Rhome disc. These passes were perpendicular to each other as allowed by topography. The design tilling depth was 6 inches, however the actual depth may have varied in response to topography, rock content and other soil factors.
Lime Amendment		No lime was added.
Seeding	April 2000	The plot was drill seeded using the seed mix shown in Table 1.
Fertilization	April 2000	Applied at the time of seeding at a rate of 500 lbs/acre. Fertilizer consisted of 12% nitrogen, 16% P_2O_5 and 30% K_2O.
Mulch		The site was not mulched
Organic Matter		No organic matter was added.

Pre-treatment Vegetation

Prior to treatment, the vegetation in Plot 6 consisted of a sparse grassland dominated by red top and Great Basin wildrye. These two species accounted for 53 percent of the cover present in the plot. Mean total vegetation cover was 18.2 percent. Undesirable weedy species including Canada thistle and spotted knapweed accounted for approximately 21 percent of the total vegetation cover. Shrubs had a mean cover of less than one percent. Approximately 58 percent of the area was either rock (28 percent) or bare soil (30 percent). Cover by plant litter amounted to 24 percent. In all, 31 species were observed along the sample transects (Table 2).

Pre-treatment Soil Conditions

Prior to tilling, the pH of the 0-2 inch soil layer ranged between 5.96 and 8.05 with a mean of 7.26. Values in the 0-6 inch layer ranged between 5.65 and 8.00 with a mean of 6.68, and all values in the 6-12 inch and 12 -18 inch layers were greater than 7.00 (Table 3).

Arsenic values in the 0-2 inch soil layer ranged between 146 and 563 mg/kg with a mean of 290 mg/kg prior to treatment. Mean arsenic values in the 2-6 inch layer were similar to those in the 0-2 inch layer (mean arsenic of 272 mg/kg, and a range from 81-576). Values in the lower soil layers were substantially less (Table 3). The mean arsenic concentration was 112 mg/kg in the 6-12 inch layer and 48.9 mg/kg in the 12-18 inch layer. Copper values in the 0-2 inch soil layer ranged from 1400 mg/kg to 3460 mg/kg with a mean value of 2055 mg/kg. As with arsenic, the total soil copper concentrations decreased with depth (Table 3). In the 2-6 inch soil layer, the mean total soil copper concentration was 1586 mg/kg; in the 6-12 inch layer it was 539 mg/kg and in the 12-18 inch layer the mean copper concentration was 194 mg/kg. Total zinc ranged between 285 and 869 mg/kg in the 0-2 inch layer with a mean of 465 mg/kg (Table 3). Concentrations decreased with depth in the top 18 inches with the mean zinc concentration value of 380 mg/kg in the 2-6 inch layer and 218 mg/kg in the 6-12 inch layer. The mean value in the 12-

18 inch layer was 138 mg/kg. All metals and arsenic showed a consistent pattern of the highest total concentrations occurring in the 0-2 inch layer with reducing concentrations as the soil depths increased.

Post-Treatment Results

After four growing seasons, the dominant species in Plot 6 (Table 2) included red top, thickspike wheatgrass, slender wheatgrass, big bluegrass and Great Basin wildrye. Yellow evening star *(Mentzelia laevicaulis)*, a native biennial forb, increased in abundance following tilling (4.6 percent cover in 2001) but was mostly absent after four growing seasons. Total vegetation cover increased from 18 percent in 1999 to 46 percent following treatment in 2001 and then decreased to 31 percent in 2003. Most of this difference was related to a change in red top which decreased from 23 percent in 2001 to 11 percent in 2003. Cover by non-weedy, acceptable or desirable species increased from 14 percent prior to tilling to 29 percent after tilling. Weedy species increased from 3.8 to 4 percent and then decreased to two percent following herbicide applications. Rock cover decreased from 28 to 11 percent and bare soil decreased form 30 percent to 11 percent (Table 2). Plant litter cover decreased from 24 to 12 percent following treatment, but has increased to 46 percent as the vegetation has continued to develop.

Most of the change in vegetation cover occurred as a result of the establishment of the seeded species (an increase from three percent to 17 percent) and an increase in other perennial species (8 percent to 11 percent).

Even without the addition of lime, the 6 inch tilling altered the soil pH and the concentration of arsenic, copper and zinc in Plot 6. Mean 0-6 inch soil pH increased from 6.68 to 7.13 and pH in the 6-12 inch soil layer decreased from 7.88 to 7.36. Mean arsenic concentrations in the 0-2 inch soil layer decreased from 290 to 196 mg/kg as a result of tilling. Mean arsenic concentrations in the 6-12 inch layer increased as a result of tilling, and the mean arsenic in the 2-6 inch layer decreased. The mean arsenic concentrations for all sampled layers in the 0-12 inch soil layer were below 300 mg/kg following treatment. Results for copper were similar to those obtained for arsenic. Concentrations in the 0-2 inch and 2-6 inch layer were decreased and concentrations in the 6-12 inch layer were increased. Following treatment, the mean copper concentrations in the 0-12 inch layer were less than 1325 mg/kg. The tilling dilution results for zinc were similar to those obtained for copper. Concentrations in the 0-2 inch were reduced and concentrations in the 2-6 inch and in the 6-12 inch layers increased. After remediation, all mean zinc concentrations in the various samples in the 0-12 inch layer were less than 360 mg/kg. Before and after treatment soil concentrations for Plot 6 are presented in Table 3.

Evaluation of Remediation Approach

The reclamation techniques used in Plot 6 were successful in achieving remediation goals. Total vegetation cover was increased to over 30 percent with cover by desirable species being approximately 29 percent. Several species occur as major components of the vegetation, and six acceptable or desirable species have mean cover values greater than one percent. Post remediation mean soil pH was greater than 7.0 in the 0-12 inch soil layer. Arsenic, copper and zinc values were reduced in the 0-2 inch soil layer. Surface rock coverage was reduced as a result of tilling. The above results were obtained after four growing seasons. It is likely that the vegetation will continue to develop over the next several growing seasons. Before and after photographs of Plot 6 are shown in Photos 11 and 12.


Photo 11. Plot 6 prior to tilling. September 1999.

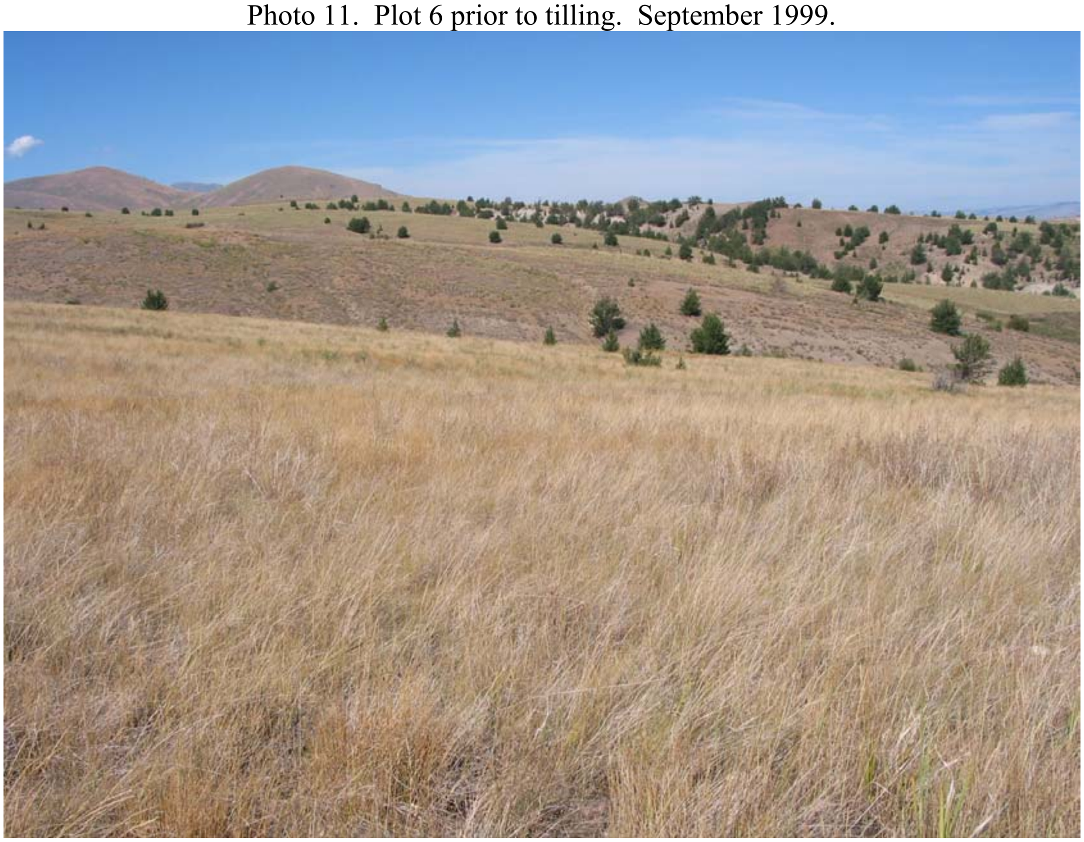
Photo 12. Plot 6 after treatment. August 2003.

DISCUSSION

Soil Changes

pH

In all treatments, the pH of the 0-6 inch soil layer increased (including plots where no lime was added), suggesting that simply mixing the substrate altered the pH. The 0-6 inch increase in pH in non-limed plots (approximately 10 percent) was less than the increases measured in the plots where lime was added (46 percent). In plots limed at the basic ABA rate, the percent increase in pH (46 percent) was essentially the same as that in plots limed at the ABA rate plus 25% (45 percent). In all but one of the treatments where lime was incorporated into the 0-6 or 0-12 inch soil layer, the pH of the soil increased. In Plot 4 (ABA + 25%) the 6-12 inch pH decreased slightly. One of the goals of remediation is to improve (raise) the surface and near surface pH of the soil as a means of enhancing vegetation cover. All of the tested tilling approaches accomplished this; however the overall increases were greater in limed plots. There was no observable difference between plots limed with the basic ABA rate and those limed at the ABA rate plus 25 percent.

Arsenic, Copper and Zinc

The following table summarizes the percent changes in total soil concentrations for arsenic, copper and zinc. The values are means based on three plots each for T6 (Plots 2, 4 and 6) and T12 (Plots 1, 3 and 5).

Treatment and Soil Depth		**Arsenic**	**Copper**	**Zinc**	**Comments**
T6	0-2”	24% Decrease	24% Decrease	23% Decrease	All results showed decreases in the 0-2” layer.
	2-6”	6% Increase	9% Increase	4% Increase	Results mixed with both increases and decreases.
	6-12”	38% Increase	128% Increase	18% Increase	Results mixed with both increases and decreases
T12	0-2”	52% Decrease	41% Decrease	21% Decrease	All results showed decreases in the 0-2” layer
	2-6”	37% Increase	7% Decrease	2% Decrease	Results mixed with both increases and decreases
	6-12”	406% Increase	140% Increase	19% Increase	All results showed increases in the 6-12” layer.

Several trends relative to mixing and dilution can be seen in the results. In all cases, whether the treatment was 6 or 12 inch tilling, the concentrations of arsenic, copper and zinc were all reduced in the 0-2 inch layer. The dilutions for arsenic and copper were greater when the plots were tilled to 12 inches. In all cases, the concentrations in the 6-12 inch layer increased as a result of tilling. The increases associated with the 0-6 inch tilling most likely occur as a result of imprecision in the tilling technique. Field observations at the time of tilling suggest that in some places the plots were tilled deeper than 6 inches. On plots tilled to 12 inches, the percent increase in arsenic and copper in the lower soil layers can be substantial, because the initial concentrations were quite low. Percent changes for zinc tended to be less than for arsenic in copper. This is likely related to lower initial values and more consistent concentrations in the soil profile.

The mixing results are mostly consistent with what would be expected using these tilling depths. To the extent that one of the overall goals of remediation is to reduce surface and near surface arsenic and metals concentrations, the 12 inch tilling constitutes a more effective treatment.

Vegetation Changes

Vegetation Cover

All of the treatments accomplished the goal of increasing the vegetation cover of desirable, perennial species. In all cases, the tilled soils appeared to be adequate for the establishment of the species included in the seed mix. While some of these species occurred on the site prior to treatment, the overall amount of this group of species increased dramatically from what was present prior to tilling. All of the seeded species were encountered as part of the field sampling; however some of the species were more prevalent than others. Great Basin wildrye was observed throughout the demonstration plots, but contributed only a small amount to the total vegetation cover. Most of the individuals of this species are still small and will require several more growing seasons to develop into mature plants. Most of the other seeded grasses have developed to the extent that many flowering stems were noted.

Native colonizers and native trees and shrubs were substantially reduced as a result of tilling. In all cases, the native colonizers constituted a minor component of the vegetation prior to tilling. Shrubs [mostly horsebrush *(Tetradymia canescens)*] were common in the demonstration plots prior to tilling. Most of shrubs were destroyed by tilling, however some have resprouted from surviving root systems and new individuals may become established from seed present in the soil.

In most of the plots, implementation of the treatments resulted in an increase in weedy species, most notably Canada thistle, spotted knapweed and white top. All of these species were common on the demonstration study site prior to tilling. Tilling served to increase these species by spreading seeds, fragmenting and spreading rhizomes and by providing bare open surfaces where the weedy species can become established (windblown seed from adjacent areas). Undesirable weedy species increased in all the plots following tilling. Weed control with herbicide applications in 2002 and 2003 served to greatly reduce the cover and abundance of the weed species.

In all plots, the amount of rock cover on the surface and the amount of litter was reduced as a result of tilling. The reduction in litter constituted a short term change since plant litter has increased as the vegetation has continued to develop. As litter cover increases, the amount of bare soil will decrease.

While all of the treatments resulted in attaining cover values of 30 percent for desirable or acceptable species, some vegetation differences among the treatments can be seen in the field. As the before and after photographs show, some bare or sparsely vegetated areas remain in the plots. Bare patches tend to be more prevalent in Plots 5 and 6 (plots with no lime addition). Some of the bare areas are very rocky. It is possible that some of the bare areas may ultimately be colonized by perennial species. Field observations of seedlings in the bare areas suggest that over time, perennial grasses may become established.

Species Diversity

A second objective of site remediation is to enhance the overall species diversity of the upland areas. Prior to implementation of the treatments, most of the plots were dominated by only one or two species. All of the treatments were successful in increasing the species diversity, especially with regard to increasing the total number of species that had mean cover values greater than one percent. A complete list of all species encountered along the sampled transects in the demonstration plots before and after treatment is presented in Table 2.

CONCLUSIONS

- All of the tilling approaches achieved proposed performance standards of 30 percent cover by acceptable species.

- All of the species included in the seed mix were observed in the demonstration plots, suggesting that these species are capable of germination, establishment and growth under the conditions of the impacted uplands on Stucky Ridge.

- All of the tilling approaches improved the diversity of perennial grasses, especially with regard to the number of species with more than one percent cover.

- While total vegetation cover was not always a reflection of the treatment intensity, cover data and field observations suggest that plots in which lime was added tended to have better vegetation development.

- Field observations and vegetation cover data suggest that no measurable or noticeable improvement occurred as a result of increasing the ABA lime rate by 25%.

- In nearly all of the tilling plots, the post treatment vegetation had a higher component of weeds than occurred prior to tilling. The weed populations were successfully reduced through the application of herbicides

- Both 6 inch and 12 inch tilling reduced the surface concentrations of arsenic, copper and zinc, however the reductions with 12 inch tilling tended to be greater than reductions noted with 6 inch tilling.

- Since the upland areas tend to be heterogeneous relative to soil pH values, it can be anticipated that tilling and lime amendment approaches based on available soil data will produce variable results relative to predicted changes in pH. This variability, however, does not appear to seriously affect vegetation development on treated sites, as long as pH values approach 7.0.

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CDM Federal and Reclamation Research Unit. 1999. Land reclamation design specifications, performance standards and performance targets (Draft). Report prepared for US Environmental Protection Agency. Doc. Control No. 3280-001-RT-OTHR-04209. 16p + tables.

THE ECOLOGICAL BALANCE OF RESTORED AREA PLANT COVER AND DIVERSITY: IMPLICATIONS FOR MINED LAND BOND RELEASE

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ABSTRACT

With the passage of over twenty-five years since the federal Surface Mine Control and Reclamation Act (SMCRA, Pub. Law 95-87) and related state laws, the need to pronounce final judgement on revegetated areas associated with coal extraction and reclamation has come to the front. Observations of the results of revegetation efforts over this time period facilitated a greater understanding of the dynamics of both "restored" and un-mined vegetation. The technological know-how required to elicit high plant cover and production through use of introduced (domesticated) plant species had largely been established by the beginning of post-SMCRA reclamation. However, the attempt to simultaneously achieve goals for cover and production as well as woody plant density and species diversity was going to be made in unknown territory. Early reclamation results clearly demonstrated the need for moderated levels of grass competition to allow woody plant and forbs the opportunity to establish and persist. Case studies are reviewed that demonstrate the inexorable advance of grass growth on sites where required moderate slopes and agriculturally suitable soils comprise the "grass vision of heaven". Among the solutions to making reclamation performance standards more achievable (simultaneously) have been reduction in soil depth, omission of soils, inclusion of steep slopes, use of coarse growth medium, and omission of cool season grasses.

On older reclamation, however, the favored / required balance of cover/production/woody plants/species diversity is out of reach until stresses to the dominant grasses allow the establishment of forbs and significant shrub / tree cover. The time-frame in which this is likely to occur is probably much longer than the ten-year liability period or even the 25+ years that some revegetation has already been in place. Over the long term, conditions of climate and human management, among other variables, will change, perhaps disadvantaging the "ruling" grasses. It is speculated that the species composition / balance of pre-mining plant communities to a large degree reflects the accumulated effects ("scars") of stresses and readjustments between plant lifeforms and species. Evaluation of the adequacy of many older revegetation efforts will necessitate development of alternative views of woody plant density and forb abundance. Among these alternative views may be some that, in conjunction with realistic understanding of ecological dynamics, may reasonably point to the potential of the older sites for development of more shrubby and species–diverse vegetation in the longer term.

INTRODUCTION

Rules and regulations developed pursuant to the federal Surface Mine Control and Reclamation Act (SMCRA, Pub Law 95-87) of 1977 along with state laws that preceded it (e.g. Wyoming Open Cut Mine Act of 1973) established for the first time well-defined and quantitative standards for revegetation of recontoured mine excavations. Although the opportunity has existed to test lands against these standards as early as years 9 and 10 after planting, for the most part these tests have not been made, and large acreages of reclamation subject to bond release testing have accumulated at many mines. Some areas subject to the provisions of SMCRA are nearly 25 years old.

STANDARDS!

The standards for the many mines that have formally designated post-mining land uses of rangeland and wildlife habitat, are typically four in number: 1) percent ground cover by live plants (and in some cases by plants plus litter plus rock), 2) livestock-useable forage production, 3) the number of woody plants present per unit area, and 4) species diversity (or richness or composition). Each of the four standards listed can be envisioned as addressing a particular "focus" concern. Percent ground cover addresses erosion and site stability questions, forage production addresses ranching utility concerns, woody plant density is/was thought to address landscape suitability as wildlife habitat, and species diversity addresses concerns that would most recently be termed "biodiversity."

Over the twenty-five plus years since the passage of SMCRA, a substantial body of practical knowledge has accumulated related to reaching these goals. As of the 1970's, the technology needed to address each of the standards was at least basically known. Technologies of plantings to stabilize soils were known through USDA Soil Conservation Service (SCS, now NRCS) plant materials programs and soil conservation programs. Livestock forage production enhancement had long been the focus of range science and agricultural technology. Woody plant propagation for the purpose of post-logging or post-fire reforestation and for wildlife habitat improvement was also a well-traveled path. Establishment of botanically diverse large-scale landscapes was not well known, but certainly the concept and accomplishment of placing many (even native) species together in cultivation in a common garden environment was known. What was not known, and had not even attempted, was how to achieve all these things simultaneously at huge scale.

THE LEARNING CURVE

Inasmuch as most of the readily available technology, equipment and plant material was agricultural in nature, reclamation in the early post-law years resembled establishment of improved pasture. Most of the earliest post-law attempts included domesticated forage plants, especially grasses along with such native species as could be found commercially available. The results of these plantings consistently saw the slow to rapid demise of native species, especially forbs and shrubs, in the face of extremely strong competition from the domesticated species. As time went on, the recognized need to incorporate surviving diverse species (as opposed to planted diverse species) was met with a realization that the domesticated super plants, especially smooth brome (*Bromus inermis*)and crested wheatgrass (*Agropyron desertorum*) had to be restrained.

For example, the progressive stand composition illustrated in Figures 1 and 2 documents the original presence of native grasses, forbs and shrubs, and the progressive diminishment of those species in the face of a rhizomatous introduced brome (meadow brome (*Bromus riparius*), in these cases).

GRASSES – THE SUBVERSIVE LIFEFORM

When the evident ability of grasses to dominate landscapes suited to their growth characteristics is truly appreciated it can fairly be said, at least from the forb and shrub viewpoint, that this plant group is capable of overthrow and ruin of the prospects for any competing types of plant (and thus, grasses are "subversive"). What growth characteristics of grasses are particularly important in this competitive advantage? First and foremost it is the capacity to root shallowly and extremely densely, forming, in soils of suitably homogeneous texture, an effective, broadly unblemished "skin" that other lifeforms must pierce to access moisture and nutrients. It is a strategy of landscape dominance that is vastly under-appreciated. The other great strategy for dominance among terrestrial plants, that of the woody lifeforms can be described as "might-makes–right" or "size trumps all." The grass approach is, by comparison, an innovation that directly controls the most limiting resource of semi-arid landscapes --- moisture. In

Figure 1. Vegetation Cover, 1983 to 2000, at Permanent Transect V1, Rosebud Co., MT

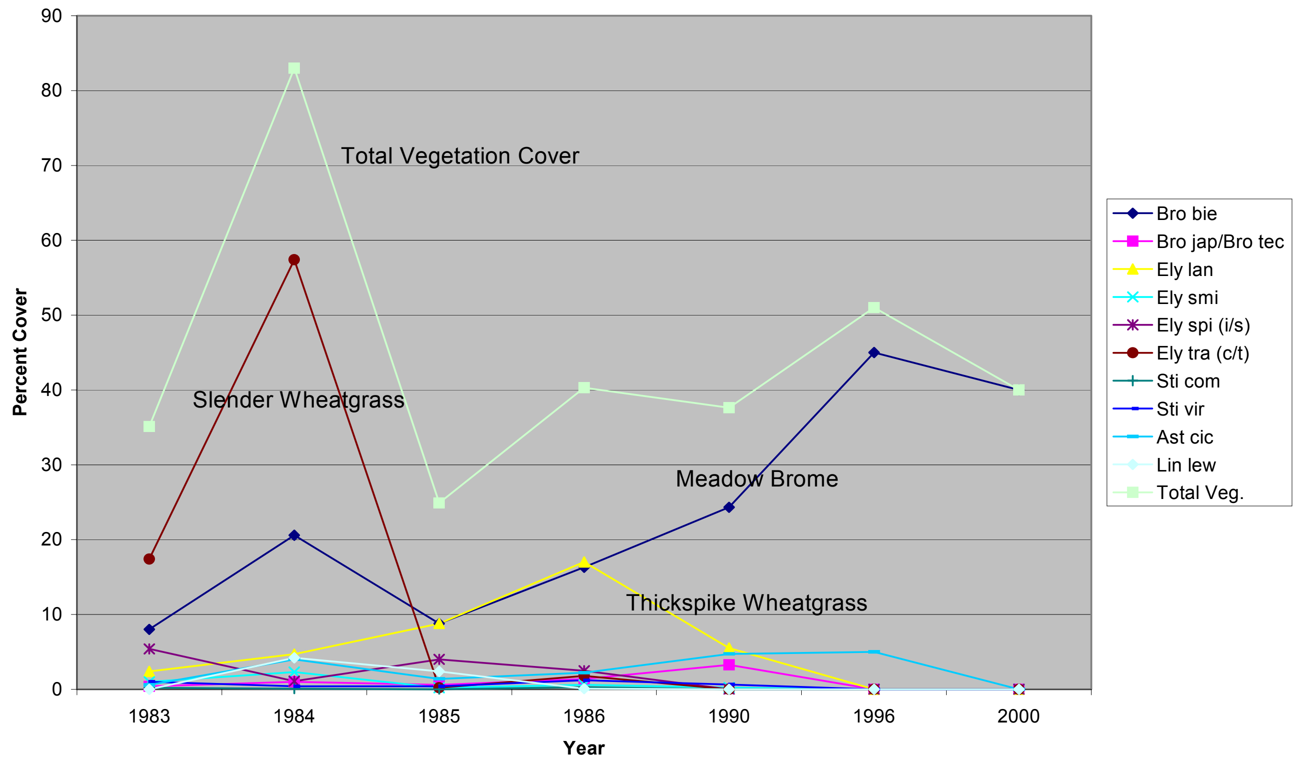
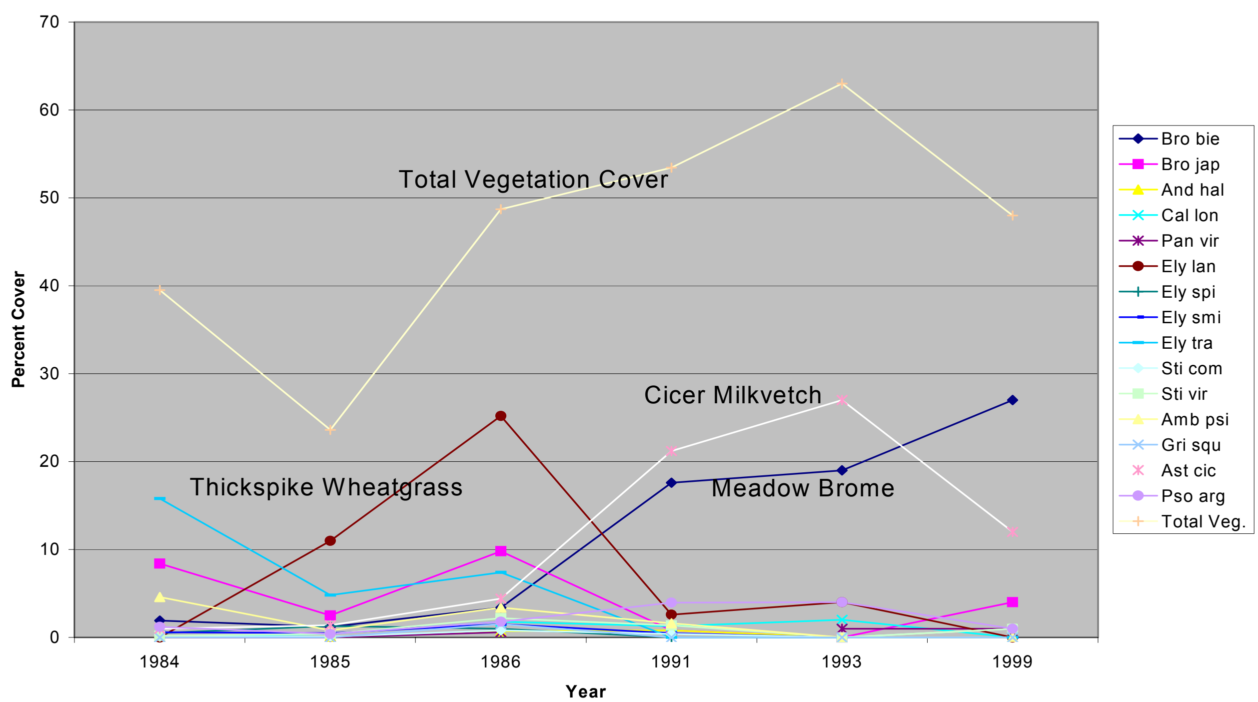


Figure 2. Vegetation Cover, 1984 to 1999, at Permanent Transect BB, Rosebud Co., MT



addition, of course, as is well appreciated, the grass lifeform with its renewal buds kept at or below ground level is also well adapted to recurrent fire and grazing. However, the importance of the competitive root zone mantle is, I believe, of greater overall importance in accounting for the success of the lifeform in the grasslands of North America.

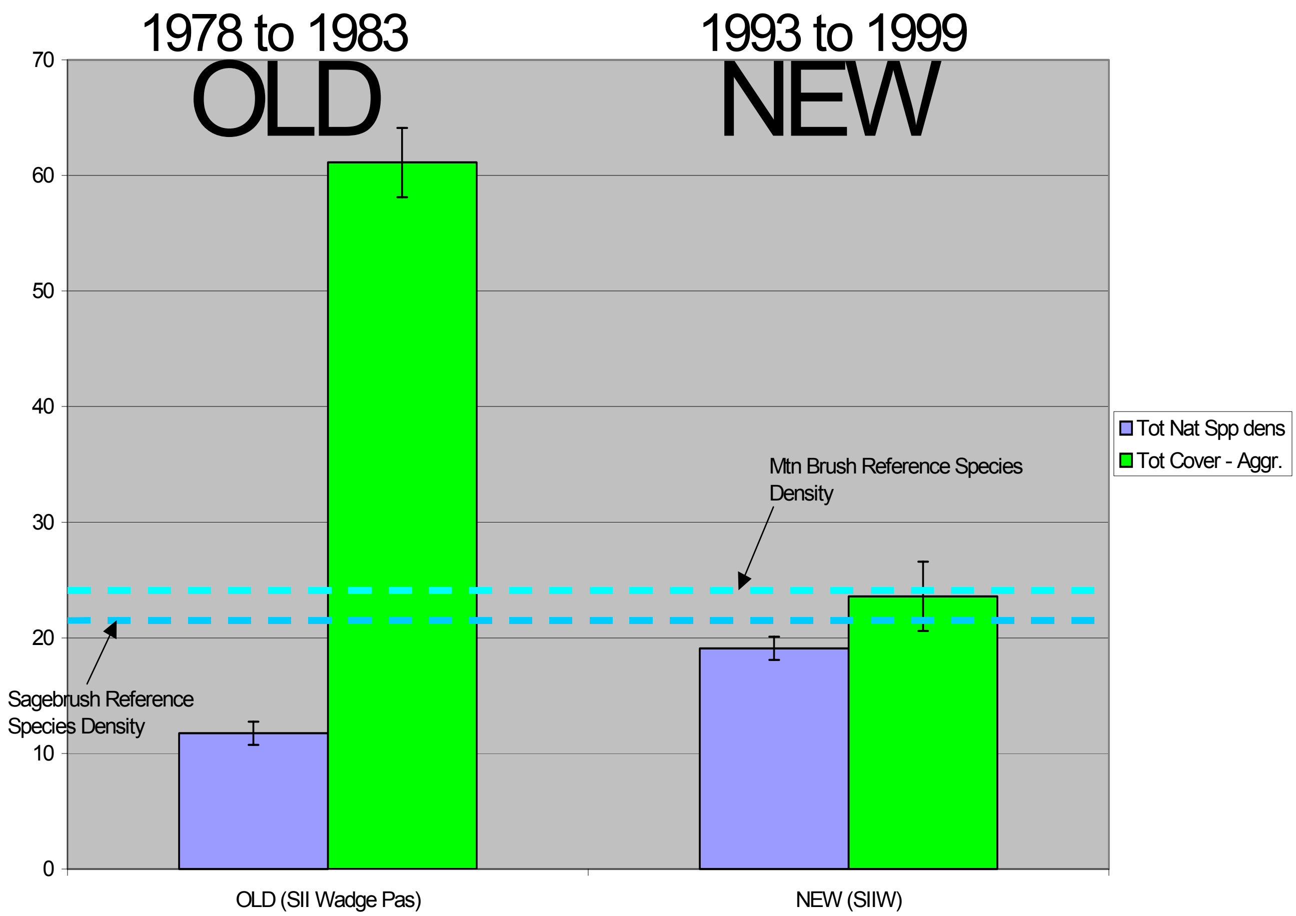
One may reasonably ask, "what are the limitations to the advantage the grass lifeform has in moisture competition"? Perhaps the main restriction is that, in the absence of limiting moisture, the dense root system cannot out-compete the roots of woody plants and forbs because there is no, or insignificant, shortage of water. Hence, as one moves east from the Rocky Mountains across the prairies to a climate zone with 35 or more inches of annual precipitation, trees and shrubs rapidly become more abundant, until, in short order, one reaches comparatively well-wetted landscapes that are dominated by woody plants, mainly the larger forms, trees. A second main restriction on the effectiveness of grass root systems in landscape dominance is that, even where moisture is limiting, the dominant grass root system blanket cannot develop unless unconsolidated relatively fine-textured substrate (i.e medium sand and finer) exists in unbroken expanse. Where alluvial/colluvial deposits of coarse or uneven texture, or relatively unweathered bedrock, occupies the surface, the opportunity to thoroughly dominate the landscape escapes the grasses. Where moisture is extremely limiting, there may be only occasionally sufficient moisture to sustain a consolidated grass cover. Hence in desert environments, grasslands are, over the long term, ephemeral, succumbing with relative ease and rapidity to stresses such as overgrazing and, of course, drought.

THE GRASS VISION OF HEAVEN

Given the nature of grass, the SMCRA-mandated landscapes at coal reclamation sites, i.e. smooth contours without break and with deep layers of agriculturally suitable soils, comprise what can only be termed the Grass Vision of Heaven. Here, the grass root system is free to proliferate and form large expanses of continuous barrier (or at least serious restriction) to the presence of forbs and woody plants.

So, given the mining permit-prescribed need to have forbs and woody plants in post-mining plant communities, what approaches have been made to allow their presence? Various mines have been allowed to try to abridge the strangling limitations of grasses on species diversity by a) reducing soil depth or in some cases eliminating soil entirely, b) using growth media coarser and more irregular than grasses can thoroughly permeate, c) incorporating steep slopes that allow certain more weakly competitive plants to prosper, and d) omitting highly competitive cool season grasses. Regarding the latter, it was quickly realized that inclusion of cool season domesticated grasses, especially smooth brome and crested wheatgrass, was an invitation to plenty of cover and forage production with no real prospects of woody plant or forb presence. Though less competitive, even some of the native cool season grasses have proven themselves deleterious to woody plants and forbs. Given this problem, there have been successful efforts to keep the cool season grasses, whose importance in cover/erosion control and forage production is hard to deny, separated in time or space from forb and woody plant development. This separation may take the form of an initial seeding / planting of warm season grasses (also generally weak competitors), forbs, shrubs and trees that is followed by at least a growing season with a cool-season interseeding. Or, the separation may be spatial with, for example, only intermittent drill furrows being provided with cool season grass seed flow. Spatial separation of large strips of shrub-only planting has been undertaken at some sites.

Figure 3. Comparison of Native Species Density in Old and New Reclamation Approaches



As can be seen in Figure 3, in "Old" reclamation in Routt Co, CO at the Seneca II Mine, native species density over a 17 year continuous record averaged about 11 species per 100 sq.m., while the reference (un-mined) area values were from 22 to 24 species per 100 sq.m. The older reclamation was accompanied by an average of over 60 percent cover by perennial grasses and introduced forbs (mostly alfalfa (*Medicago sativa*) and cicer milkvetch (*Astragalus cicer*)). In newer reclamation at the nearby Seneca II-W Mine, cover by these competitive grasses and introduced forbs was reduced to an average of about 24 percent, and native species density averages over 19 species per 100 sq.m., very close to the reference area values.

WHENCE NATIVE GRASSLAND PLANT COMMUNITY DIVERSITY?

Although outside the purview of this paper, the question of the origin and maintenance of plant species diversity in native grassland (and shrub-steppe) plant communities inevitably arises. The presence of diverse species of forbs and shrubs (and other life forms) necessitates the presence of literal and figurative "openings" in the highly competitive mantle that grass can develop in order to allow forb and woody plant diversity to develop and persist. It is speculated (and observed in long term native area sampling also conducted at many mines) that such openings are provided as stresses such as sustained droughts, other forms of severe weather, overgrazing, grasshoppers (or perhaps in former times locusts), and disease occur and contribute to periodic lapses in grass hegemony. In this context, the long-term presence of non-grass lifeforms in climatic and geologic circumstances favorable to grasses constitute "scars", or at least lingering marks, on the grass skin.

FAIR AND EFFECTIVE EVALUATION OF PLANT SPECIES DIVERSITY ON OLDER RECLAIMED LANDS

While care to provide highly stable slope configurations and large amounts of agriculturally favorable soil on recontoured coal mine sites has resulted in generally favorable erosion control and high livestock forage production, the indirect consequence of depression of species diversity and the development of woody plants leaves the performance standards for these two parameters largely unmet. Despite this, the longer term prospects of these sites may nonetheless include the development of substantial woody plant abundance and overall species diversity. The signs of the potential for this to happen may be present now. One of the reasonable precursors to eventual diversity may simply be the number of species present without regard to their abundance. If the accumulation of species diversity is a slow process, as seems often to be the case, the mere presence of the plant in reclamation may be the most positive indicator of progress toward pre-mining diversity. Such an evaluation essentially assesses to what degree the "shelves" of the ecological "warehouse" are stocked and ready to supply the appropriate species as circumstances change. Given the sustained availability of adapted native species, the new landscape has multiple possible destinations, the particular destination depending on a large number of variables that have in the past and will in the future have facilitated the presence of greater or lesser amounts of particular plant species.

Another often observed pattern is that, even in the brief window of observation that we have been provided, the distribution of species density by lifeform within reclaimed and native comparison sites is at least as similar as the similarity in the abundance distribution of lifeforms between individual samples of a native comparison area. Numerical / statistical tests of the potential of restored lands to eventually support the pre-disturbance species / lifeform diversity are being developed for use in bond-release testing.

REFERENCES

Annual Reports including Revegetation Monitoring Data for the Big Sky Mine, Rosebud Co, MT submitted to Montana Department of Environmental Quality on a yearly basis.

Annual Reports including Revegetation Monitoring Data for the Seneca II and Seneca II-W Mines, Routt Co, CO submitted to Colorado Department of Natural Resources, Division of Minerals and Geology on a yearly basis.

CAN MOUNTAIN RESORTS SURVIVE PROSPERITY?

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ABSTRACT

Thomas Jefferson, Ben Franklin, John Adams and Alexander Hamilton, the intellectual leaders of the new republic, all believed the creation of a property owning middle class was vital to sustaining the new Republic. Their ideal, a middle class free from the corrupt domination of government and big business, was carried through the Northwest Ordinance, the Homestead Act and federal mortgage financing tools. Not long ago, resort mountain towns could be fairly characterized as predominantly middle class entities characterized by local ownership, fierce independence, a largely indigenous work force and an egalitarian sense of community.

Three interrelated economic and public policy forces have served to transform mountain resort communities into an urban model closely resembling the "commuter culture" from which many mountain residents fled. The forces identified are changes in tax policy, concentration of wealth and the aging of the baby boomers. Formerly thriving "inner" cities are now "hollowing out" and struggling to retain the vitality that put them on the map as "must visit" locales.

The social, geographic and economic stratification of formerly coherent communities has created a need for urban services such as transit, subsidized housing, human service agencies and regional government. The adverse environmental impacts are obvious.

Particular emphasis is placed upon the data and experiences of Aspen and Pitkin County in meeting these challenges.

INTRODUCTION

The geniuses behind the formation of the American republic believed the virtue and liberty of the new government depended on empowering a middle class of independent workers. They feared concentration of wealth, power, and government authority. They observed that power derived from wealth, wealth derived from land and therefore property ownership should be widely disbursed to avoid the evils and decadence of Old Europe. The second home real estate boom in Colorado resort communities has some aspects of the Old Europe they deplored and is partly a consequence of the current American trend toward concentration of wealth feared by the founders together with tax policies they probably would not have approved. The same resort development also has aspects they would likely have applauded and is, in any event, likely to continue as it has in recent years.

PROPERTY OWNERSHIP

The founding Fathers (or brothers in the current coinage) were advocates of property ownership. There was almost universal support among the big names (John Adams, Thomas Jefferson, Alexander Hamilton, James Madison) for universal property ownership as a path to prosperity and "liberal" government. But they were not property 'rights" advocates in the modern sense. Property ownership for them was a means to prevent the concentration of power in the hands of a landed aristocracy.

Property ownership was as an instrument for protecting the liberty and virtue of the new Republic, to prevent it from becoming like the corrupt European states with whom the Brothers proposed a clean break. Property ownership was the ticket to entry into politics, not a "castle" whereby public responsibility could be evaded. More property owners meant more stakeholders, more incipient Ralph Naders fighting for "virtuous" government.

Wrote Adams: "Harrington has Shewn that Power always follows Property. This I believe to be as infallible a Maxim, in Politicks, as, that Action and Re-action are equal, is in Mechanicks. Nay I believe We may advance one Step farther and affirm that the Ballance of Power in a Society, accompanies the Ballance of Property in Land. The only possible Way then of preserving the Ballance of Power on the side of equal Liberty and public Virtue, is to make the Acquisition of Land easy to every Member of Society: to make a Division of the Land into Small Quantities, So that the Multitude may be possessed of landed Estates. If the Multitude is possessed of the Ballance of real Estate, the Multitude will have the Ballance of Power, and in that Case the Multitude will take Care of the Liberty, Virtue, and Interest of the Multitude in all Acts of Government." Letter to James Sullivan May 26 1776

Hamilton, of course, believed the rise of an aristocracy was inevitable, why not just accept that and create something like the House of Lords. Jefferson's views were more aggressively egalitarian, at least for whites: he sought to include in Virginia's constitution a provision granting each citizen 50 acres of land as a matter of right. Jefferson's draft constitution for Virginia states: "Every person of full age neither owning nor having owned [50] acres of land, shall be entitled to an appropriation of [50] acres or to so much as shall make up what he owns or has owned [50] acres in full and absolute dominion." (The Avalon Project, www.edu/lawweb/avalon/jeffcons.htm.) More radical ideas were floated on the subject of property. The Pennsylvania constitutional assembly considered and narrowly defeated the following provision: “"An enormous Proportion of Property vested in a few Individuals is dangerous to the Rights, and destructive of the Common Happiness of Mankind; and therefore any free State hath a Right by its Laws to discourage the Possession of such Property." Ben Franklin, the most celebrated resident of the Keystone state, said, “…"that no man ought to own more property than needed for his livelihood; the rest, by right, belonged to the state." (www.tompaine.com/feature2.cfm/ID/7082).

In a day and age of missing chads and the disputes over the value of touch screen voting and its possible malfunctions – "Too err is human, to really screw up takes a computer." – it's difficult to recollect that in Jefferson's day voting was done orally. One walked in to a polling place and announced for whom you were voting and a clerk wrote down the result. This is how we know Abraham Lincoln's choices in his first trip to the polls. The so called the "Australian" or secret ballot didn't come along until 1848 and Jefferson and others were acutely aware of the ability of poll watchers to record a voter's preferences and report them to the voter's employer or commanding officer.

Though they advocated property ownership, they did not share the "takings" mentality that has done so much to promote sprawl and poor planning. "Regulatory" taking was a concept that came a century later: the concern in Vermont was for actual physical occupation of the land by government or by authority of government. None of the original 13 states adopted a "Takings Clause" in their constitutions and the notion of just compensation was largely a reaction to the actions of the royal government in issuing New York titles to Vermont land speculators. Vermont was too far remote from New York and Vermont farmers had no ability to effectively contest the granting of incorrect land titles by New York through the ordinary political process. The Vermont Constitution states, "That private property ought to be subservient to public uses, when necessity requires it; nevertheless, whenever any particular man's property is taken for the use of the public, the owner ought to receive an equivalent in money." (www.usconstitution.net/veconst.htm#Article2).

A similar provision was included in the Northwest Ordinance, quite possibly in response to military seizures of property for government purposes on the frontier. Landowners were simply too far from the seat of government to contest the appropriations of property. Other explanations include the possibility that the Ohio Land Company was afraid the local legislature would not recognize the company's very favorable terms of acquisition of 1.5 million acres in the new territory (Treanor 1995).

"While property rights advocates sometimes argue as if the founders believed that the Takings Clause was the central feature of the Constitution (or at least the Bill of Rights), the historical reality is almost the exact opposite. The state ratifying conventions that considered the Constitution proposed almost two hundred constitutional amendments. Not one, however, proposed a takings clause. The clause is part of the Constitution, not because there was a national demand for it, but because James Madison, the author of the Bill of Rights, unilaterally included it among the amendments he proposed in 1789. Madison did not explain what the clause meant when he presented it to Congress, and no debate in Congress about its meaning -- if there was any debate -- has been preserved. The language of Madison's proposal shows that he was concerned only with physical seizures: 'No person shall be...obliged to relinquish his property, where it may be necessary for public use, without just compensation.'" The Original Understanding of the Takings Clause, Environmental Policy Project Georgetown University Law Center, www.law.georgetown.edu/gelpi/papers/ptreanr.htm.

The Founding Relatives (Siblings? Parents?) were acutely aware of what they viewed as the pernicious influence of concentrated wealth. Greed was one of the Seven Deadly Sins, a villain, not a "good" or creed to live by. One tool for concentration of power was the corporation or syndicate. The East India Company, at one point, collected taxes equal to almost half the taxes collected by Britain, at the time the world's greatest economic power. In America, corporations were proliferating and by 1795 more than 150 had been chartered. www.prorev.com/corpsandus.htm.

Jefferson was one of those who proposed balancing the scales in favor of the "… small landowners (who) are the most precious part of the state," by means of progressive taxation. Jefferson wrote Madison in 1785: "Another means of silently lessening the inequality of property is to exempt all from taxation below a certain point and to tax in the higher portions of property in geometrical progression as they rise." In The Rights of Man, Part II, Jefferson analyzed the British taxation system at length and faulted it for imposing consumption rather than property taxes. He argued that taxes such as the Beer tax fell more heavily on working people while estate holders could manufacture or import brew product without taxes. The famous quote about taxation cited above comes from his letter to James Madison written from Europe on October 28, 1785. Excerpted here is a portion: "I am conscious that an equal division of property is impracticable. But the consequences of this enormous inequality producing so much misery to the bulk of mankind, legislators cannot invent too many devices for subdividing property, only taking care to let their subdivisions go hand in hand with the natural affections of the human mind. The descent of property of every kind therefore to all the children, or to all the brothers and sisters, or other relations in equal degree is a politic measure, and a practicable one. Another means of silently lessening the inequality of property is to exempt all from taxation below a certain point, and to tax the higher portions of property in geometrical progression as they rise. Whenever there is in any country, uncultivated lf lands and unemployed poor, it is clear that the laws of property have been so far extended as to violate natural right."

Silent means may have been one of the few avenues available given the acknowledged ability of the few to obtain title to immense swaths of property through the political process. Land speculation at the end of the Revolution was rampant; George Washington had been a player realizing the possibilities during the French and Indian Wars. After the conclusion of the revolution, speculators successfully sought federal contracts to purchase land at a discount using the unredeemed military warrants issued by the Continental Congress (hence the old saying, "Not worth a Continental").

Many of the Founding Siblings, including Robert Morris, Goveneur Morris and Patrick Henry were engaged in the practice of buying military warrants and state currency for as little as 10 cents on the dollar and using those to purchase government land at the face value of the currency, sometimes for pennies an acre. Although Congress (and Jefferson) had intended the sale of the Northwest Territories (Ohio, Indiana, Illinois etc.) to be sold exclusively to individuals and communities, the companies were able to persuade the cash starved congress to sell that land cheaply and in quantity, contrary to Jefferson's vision for the subdivision of the land into small parcels. Perhaps the greatest land scam ever was the purchase of most of Alabama and Mississippi, some 40 million acres, for $500,000 from the state of Georgia. James Madison was later appointed a special master to investigate the sale and reported that all but one member of the Georgia legislature was either a stockholder in the deal or was bribed. A territorial governor, court judges and state and federal legislators all benefited. The sale was nonetheless upheld (Linklater 2003).

MODERN DAY COLORADO RESORTS

The issues at play at the inception of the republic remain with us today and are amply illustrated by the land use policies and development patterns in Colorado today. This paper identifies the three major forces affecting land ownership and development patterns in resort communities, changing demographics, concentration of wealth and regressive taxation policies. The result is a trend toward land ownership and development pattern that is much closer to the Old European model of aristocracy feared and loathed by the republic's founders.

The most salient economic fact of life in resort communities is that second home services and construction rank as the biggest (or a close second) economic driver in resort counties such as Pitkin (home to Aspen), Eagle (home to Vail and Beaver Creek), Grand (Winter Park) and Summit County (Breckenridge). For example, in Eagle County, Lloyd Levy Consulting with Hammer Siler George Associate's preliminary findings for the Northwest Colorado Council of Governments (NWCCOG) released on February 27, 2004, found that 33% of the economic activity in the county could be attributed to second home spending and construction compared to 31% of the activity being attributed to winter recreation. Similar findings were made for the other resort counties in NWCCOG. In Pitkin County, 29% of the economic activity was attributed to second homes and 35% to winter recreation. In reaching those conclusions, Levy relied on the Colorado demography Section base industry job estimates and studies of homeowners conducted by NWCCOG in recent years. In addition, Levy used United States Forest Service, Park Service and 2000 census data. In addition, a national study of second homeowners published by American Demographics in June of 2003 delineated the spending patterns of second homeowners as well as their demographic characteristics.

As a result of the immense buying power of the second homeowners and the pressure on real estate prices, resort communities such as Aspen, Vail and Breckenridge are experiencing stable or declining populations, stagnant sales tax revenue and a rapidly aging population as younger, middle class residents are unable to compete for real property ownership with the retired and semi retired second home owners.

Aspen lost population in virtually every age group between 20 and 45 (Figure 1) in spite of a vigorous affordable housing program that added approximately 1,000 units of deed restricted housing to the local inventory. Aspen and Pitkin County have a joint housing authority that creates deed restricted rental and ownership housing aimed at keeping housing costs at about 28% of household income, the same standard used in the federal definition of affordability. The housing stock is evenly split between rental and purchase units with virtually all purchase units priced below $200,000 and a large number under $100,000.

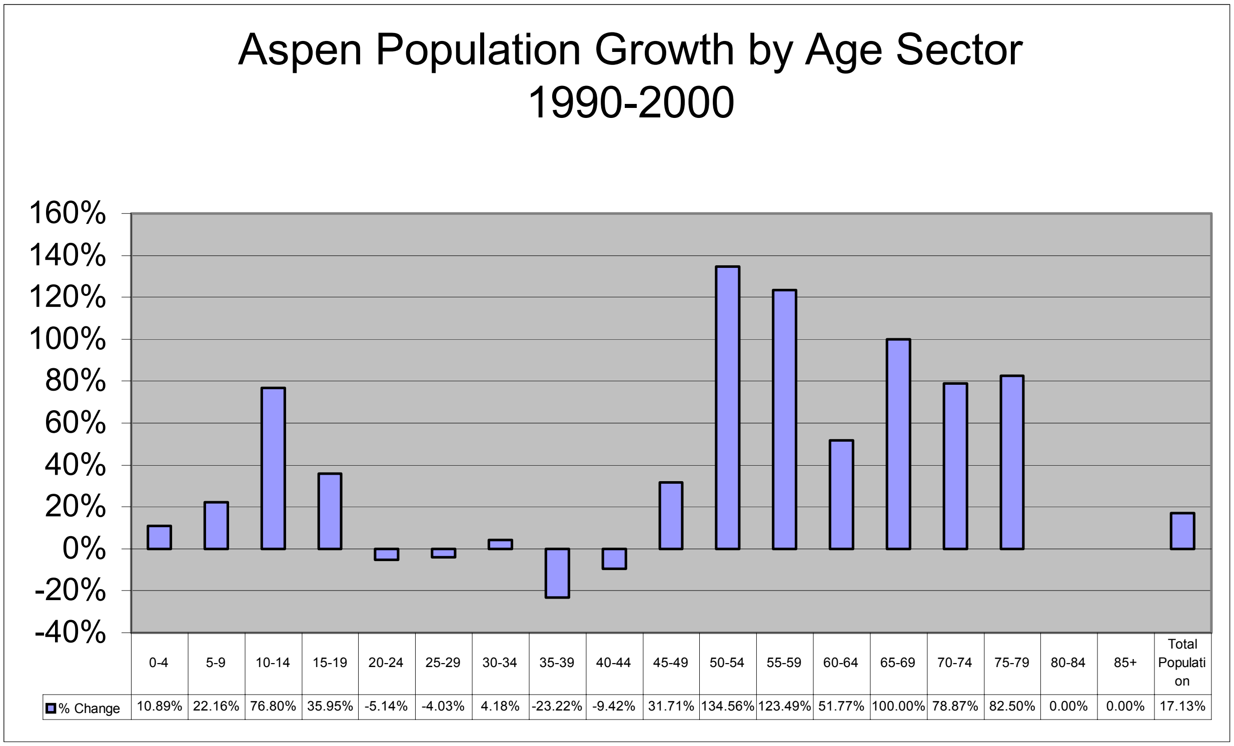


Figure 1. Aspen population growth by age sector between 1990 and 2000. Based on census data for 1990 and 2000.

A similar pattern can be seen in data for Winter Park, Snowmass Village, Vail and Breckenridge: weak or negative growth in the 20-45 groups, explosive growth in the 55 and older age brackets. Winter Park, for example, saw a 28% decline in population aged 25 to 29 and a 14% loss for ages 20-24. The age group 45-49 grew by 150% in the same period in Winter Park. While younger people have been disappearing, the incoming second homeowners are typically at or near retirement age. According to the NWCCOG survey, 67% of the region's second homeowners were aged 55 and above.

In Aspen, the author's own study in late 2003 of property records on the West End of Aspen found 54% of the homes were owned by out of county residents (Figure 2). As in the NWCCOG study, the address for mailing of the tax notice was used to identify "foreign" or "local" ownership. This was cross-checked against the survey results asking owners where they had their primary residence. The median value in the property tax records for the 145 properties studied by the author was approximately $2,000,000. The median age of the owners was 64, and 75% of all local owners were aged 60 and above. About 42% of all properties "local" or "foreign" owned were owned by corporate entities such as trusts and Limited Liability Companies.

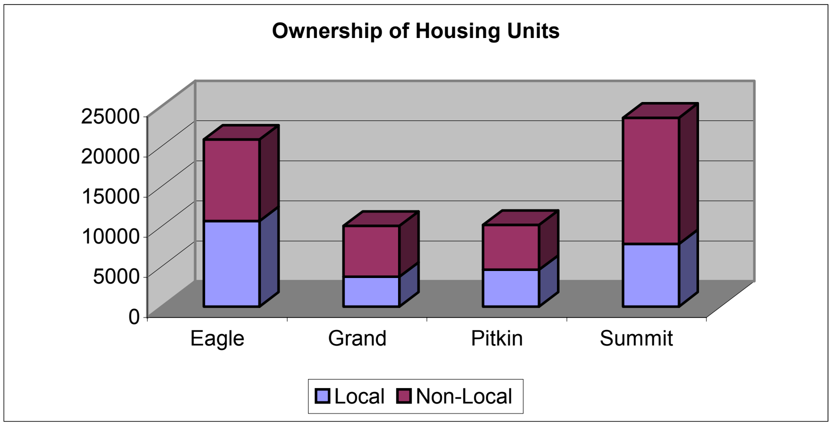


Figure 2. Ownership of Housing Units in Eagle, Grand, Pitkin and Summit Counties, Colorado.

Based on a NWCCOG survey, the median income for second home owners in Pitkin County was found to be approximately $250,000. This survey was conducted in 2003 by Linda Ventroni and included a review of 64,000 property records (to determine values and ownership residence) and a survey of 4,342 homeowners of whom 1,346 responded. The Pitkin and Eagle second home results were based on 112 and 123 responses from second homeowners, respectively. For Eagle County, the median was higher. Both counties reported more than a quarter of their second home owners had incomes in excess of $500,000 per year. The comparable figure for the state of Colorado in 2000 to 2002 was $49,617 based on a moving three year average (www.census.gov/hhes/income/income02/statemhi.html).

The Census doesn't offer tables for the percentage of households with in excess of $250,000 since there are no boxes to check for high incomes other than "above $250,000."

While real estate values have been soaring, real wages for entry level resort workers have been falling. In January of 1979, the author of this paper was offered three jobs through the job service center: dish washing, bus driving and lift operations. Each offered $4.75 an hour. Adjusted for inflation using CPI-U all Urban Consumers, all items (the most common index), those positions would be paying $12.50 per hour today. Neither dish washers nor lift operators start at anything close to $12.50 – most of those positions offer about $9 per hour. The anecdotal evidence for resort communities is reflected in numerous national studies. For example, the Congressional Budget Office reported in 2000 that the twenty previous years had seen 84% growth in income for the top 1% of households, 44.6% for the top 10% and losses for the bottom 60%. The gains at the very top have been more impressive.

HOW TAX POLICY AND WEALTH CONCENTRATION DRIVE RESORT GROWTH

Whatever one thinks of income distribution and wealth concentration as an abstract issue, the important fact of life for resorts is that their prime real estate clients have been experiencing significant jumps in income over the past two decades. By any reasonably objective measure, the top of the income pyramid has done very well during the past two decades, relative to inflation and relative to the rest of the nation's household. Perhaps not coincidentally, the Colorado state tax scheme, taken as a whole, is very regressive, the reverse of the Jeffersonian scheme described above. Taking into account sales, property and income taxes, Coloradoans in the bottom 20% (income of less than $17,000) pay about 9.9% of their income to the State of Colorado and local government through taxes while those in the top 1% (incomes exceeding $692,000, average of $1,185,000) pay 4.4% to state and local taxes (Institute on Taxation and Economic Policy 2003).

The top one percent – the "typical" second homebuyer in Eagle and Pitkin counties – saw its share of the income pie approximately double during the period 1979 to 1997. That top one percent receives about 16% of all income, twice the 8% of two decades ago and equal to the entire earnings reported by the bottom 40% of the pyramid. Krugman (2002) notes that the wealthiest 13,000 families have almost as much income as the poorest 20 million and four times as large a share (3%) of the total pie than they did in 1970. Krugman attributes this redistribution of wealth to an unraveling of social norms, a replacement of politically established norms of equality with an "ethos of 'anything goes'."Concentrated wealth means more millionaires (and billionaires) needing a place to park some of that wealth. The sheer number of households with incomes and assets sufficient to warrant an additional home rose as real income rose at the top of the pyramid.

Tax policy changes accelerate the second home boom

Competition for elite resort properties in Aspen began in earnest in about 1986. Prior to 1986, Aspen real estate sales showed a relatively stable price pattern with median single family household prices running at about $450,000 in constant dollars. The Tax Reform Act (TRA) of 1986, together with the tax cuts of the early 1980s, increased real income for the chief beneficiaries. The top marginal rate on the wealthiest taxpayers was reduced from 50% to 28%, a drop of 44% for some families at the top. Perhaps more importantly, 1986 TRA made significant changes in tax policies regulating investment and allowable deductions. Tax policies that favored commercial real estate shelters and other investments were repealed. In simple terms, prior to 1986 taxpayers could use "non recourse" loans as the basis for depreciation deductions even if the were not "at risk" for repaying those events in the event of a failure to make payments. This meant that residential real estate became more attractive as an investment alternative since there were fewer tax driven reasons to invest in commercial real estate ventures. Citizens for Tax Justice, a group vehemently opposed to the latest tax cuts, favored this bill while Newt Gingrich and Donald Trump, presumptive beneficiaries of the rate cuts, were opponents.

Figure 4 illustrates the dramatic changes in Aspen real estate in 1986 and 1987. In constant dollars, single family housing approximately doubled in price from around $450,000 to more than $1 million. Of 38 sales reported in late 1986, 36 were for cash, breaking the typical mortgage pattern that had previously prevailed. Aspen experienced a rapid loss of its workforce at the same time. Prior to 1987, Aspen had housed about 60% to 65% of its workforce in town. By 1990, that proportion had slipped under 40%. Other communities have reported similar changes in work force housing patterns but the author has not found any resort that had an ongoing housing survey that documented the changes.

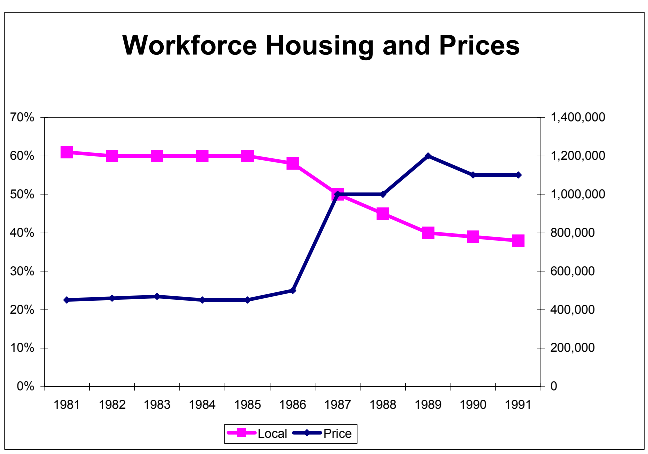


Figure 4. Workforce housing and prices for Aspen, Colorado.

IS ANOTHER BOOM COMING?

Formerly self sufficient resorts have been transformed into commuter cultures by the forces described above. On July 4 of 2004, Aspen experienced a record 30,000 plus vehicle trips crossing the bridge into the West End of Town, a level that is akin to a busy day at the Eisenhower Tunnel. Pitkin, Eagle and Garfield counties are host to the state's first and only (so far) rural Regional Transportation Authority (Roaring Fork Transit Agency) serving about 1.5 million rides annually and costing about $12 million for operations and maintenance. Eagle and Summit County also have local transit agencies.

Effects of Tax Cuts

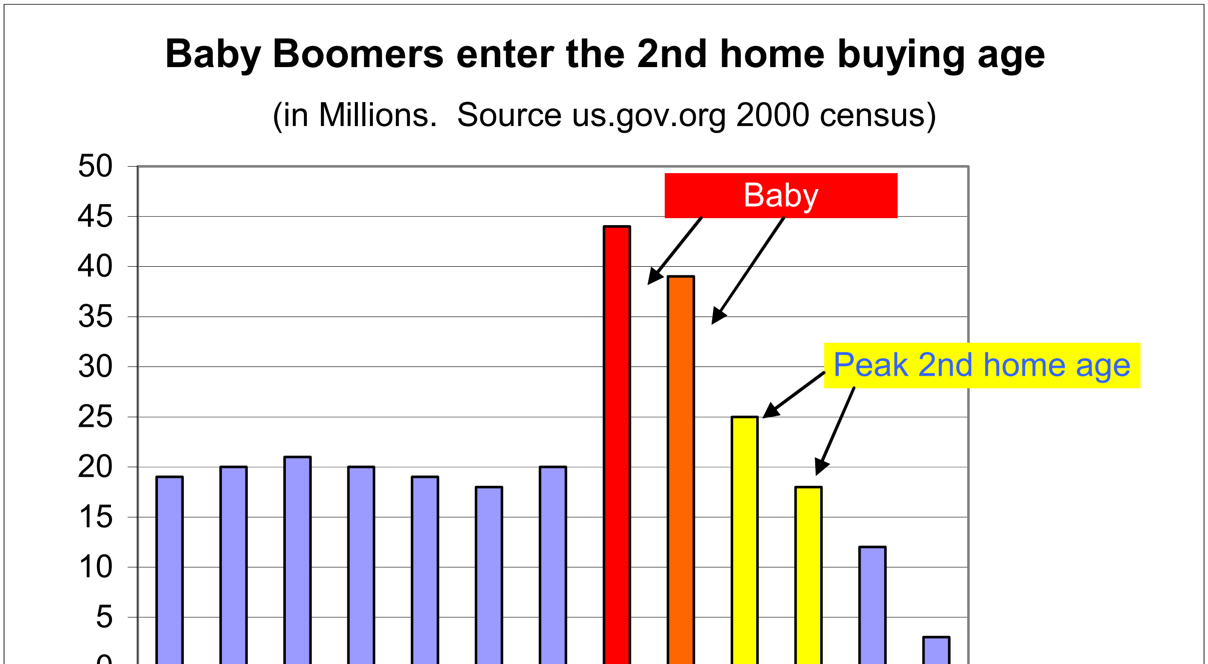
The newly adopted tax cuts and the campaign to make such cuts permanent may infuse more capital into the second home market. Ironically, while rising interest rates and a slowing economy generally dampen real estate sales, the second home market may be relatively attractive to high end purchasers if alternative investments become less attractive, as happened in the late 1970s when capital shifted out of commercial investments and into residential real estate in response to inflation.

The latest tax cuts are significant in scope, estimated at $1 trillion or more and targeted tightly on the taxpayers most likely to buy another home. The NWCCOG survey cited earlier, notes that almost 40% of second homeowners in the four county region report having three or more homes. Citizens for Tax Justice, supporters of the 1986 tax cuts, strongly opposed the current and proposed tax cuts, noting the typical taxpayer in the top 1% (incomes of $350,000 per year and up) will see a 17% reduction in taxes and will be paying taxes at about the same rate as a single person making $123,000 per year. Professor Joel Sermon of the University of Michigan asked the IRS to publish data on the 400 wealthiest taxpayers for the period 1992 to 2000. The IRS found that this elite group (the lowest income, 400 on the list, was about $86 million) had doubled its share of income to 1% of the total nationwide and had actually experienced declining tax rates. Under the Bush plan, taxes will decline another 17% for this group, about $8 million per year (Johnston 2003)

The Role of Baby Boomers

Perhaps the most decisive trend driving future second home sales is the aging of the baby boomer generation. Baby boomers are more likely to buy second homes than their parents and, at least at the top, they have more resources to devote to the task. According to an article in American Demographics, Life on Easy Street, April 1997: "If Baby Boomers continue to buy vacation homes at the 7% rate their parents did, (demographer) Hirsch predicts that the market could jump more than 40% in the next decade…" The article goes on to note the "'average' very rich" are likely to own three or more homes, per the NWCCOG survey where about 40% of the respondents said they own three or more residences.

It is worth noting that the huge wave of baby boomers entering the second home peak buying years may be larger than it appears in Figure 5 because they are more likely to but second homes than their predecessors. Fueled by the tax cuts at the top and the wealth concentration trend, this much larger generation of second home buyers are likely to drive resort real estate further into the stratosphere.



	Under 5	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 44	45 to 54	55 to 64	65 to 74	75 to 84	85 +
Pop. 2000	19	20	21	20	19	18	20	44	39	25	18	12	3

Figure 5. Number of Baby Boomers entering the Second Home Buying Age.

Yeomen Second Homeowners?

Would Jefferson and his friends/allies/rivals pass judgment on our resort lifestyle and development pattern as the recreation of the European society that so revolted them? This is not at all clear although the driving force of wealth concentration was certainly something they disdained. On the other hand, property ownership is certainly more widely distributed than in revolutionary times although a good many local residents remain disenfranchised.

The Founding Relatives were hobgoblin free when it came to small-minded consistency. Most notoriously, authors who penned such noble works as the Rights of Man Part II, The Declaration of Independence, the Federalist papers were able to reconcile themselves with the ongoing institution of slavery as a necessary evil tolerated to create the Union. Benjamin Franklin accepted the presidency of the Pennsylvania Society for Promoting the Abolition of Slavery, finally abandoning his previous rationale that it was impractical to precipitously free approximately 700,000 slaves (Isaacson 2003).

Given the inherent practicality of their views on the moral question of the day, it is hard to take issue with their inconsistency on the economic forces at issue in allowing rampant land speculation while trying to promote widespread ownership. Neither communism nor capitalism were defined ideologies or even terms accepted in common usage. Socialism as a solution was rejected out of hand – individuals would never be equal in economic productivity – but there was considerable support for restraint on accumulated wealth and for progressive taxes

SUMMARY

Today's resort communities would probably produce the same mix of reactions and conflicting responses that the exposure to Europe engendered in Jefferson, Franklin and Adams. Jefferson would surely recognize the regressive nature of the local tax scheme with its dependence on excise taxes very similar to the British Beer tax he criticized in the Rights of Man II. Adams, who lived a frugal life style, and Franklin, who nurtured the self improvement movement even to the point of setting forth Rules to Live By for himself at an early age (Isaacson calls it the Moral Perfectionist project) – would probably be aghast at the heated driveways, 15,000 square foot homes and personal aircraft that are the accoutrements of high end living in resorts. The lifestyles of the rich and famous may be popular television but it certainly doesn't further the goal of creating a virtuous republic stocked by independent yeomen laboring for themselves.

The notion that there is a fundamental constitutional right to build wherever, whatever and whenever a property owner sees fit would probably leave them wondering what happened to the constitution they drafted. State governments were, in those early years, constantly meddling with property rights, outlawing undesirable uses through zoning, taking over private roads for public use, regulating the sale prices of commodities, confiscating loyalist property and requiring it to be sold in small tracts and generally intervening for the "public good" without recognizing a duty to compensate. Every state except Massachusetts allowed undeveloped land to be taken for roads without compensation (Treanor 1995). In Virginia, if the state needed your property, it would be taken and your compensation limited to the value of the undeveloped land. Needless to say, such policies kept taxes low by (unfairly) imposing the costs of public improvements on the hapless landowner who had the land that the state needed. The states also effected income redistribution from creditors to debtors by forcing creditors to accept devalued currency in full payment of debt.

On the other hand, they might well be pleased by the various state and local efforts to create ownership housing for workers through grants, loans, exactions and real estate transfer taxes. And they would surely find comfort in the fact that whatever faults are the result of public policy, the secret ballot is still available to rectify them.

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SPEAKING WESTERN: HONEST CONVERSATIONS IN THE NEW WEST

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> *The frontiers have been explored and crossed. It is probably time we settled down. It is probably time we looked around us instead of looking ahead. We have no business, any longer, in being impatient with history. We need to know our history in much greater depth...Plunging into the future through a landscape that had no history, we did both the country and ourselves some harm along with some good. Neither the country nor the society we built out of it can be healthy until we stop raiding and running, and learn to be quiet part of the time, and acquire the sense not of ownership but of belonging.* (Stegner 1992:205-206).

ABSTRACT

The American West is quite different from what it was even 20 years ago. In a nutshell, today's West is better defined as a "playscape" than as a "workscape." Today's New Westerner moves here to "ranch the view" rather than work the land. Today the highest and best use of the West that is in private ownership is residential and commercial development. The highest and best use of the West that is in the public domain is outdoor recreation. Perhaps not surprisingly, these uses are among the top five threats to federally threatened and endangered species. Westerners have always needed reminding of Aldo Leopold's "land ethic," though perhaps today what we are more in need of is a "consumption ethic" for Westerners are not so much of the land as they are of the "mall."

THE NEW-OLD WEST

The American West is a new place; increasingly comprised of individuals who have just arrived and who came from somewhere else. Indeed, the concept of the "floating baseline" ensures our region will continue to fill up with people from somewhere else. Because the quality of life is so much better here than it is elsewhere, people will continue to leave where they live and move to the West where the cost of living, traffic congestion, crime rate, and pollution are less than where they are from. Not surprisingly, nine of the ten fastest growing states are in the West; as are the fastest growing counties and the "most desirable places to live, work, retire,..."

The upshot of this is we live in a New West, a quite different place than what it was just a short time ago. This New West is presently going through a transition from what might be called a "workscape" where people dress in canvas and denim to a "playscape' where they are more likely to be seen in fleece and lycra. Historically, the main economies of the intermountain West were extractive in origin. Today, we see the industries of logging, mining, water development, and ranching being replaced by the newer amenity-based economies related to technology and service jobs (Knight 1997).

The most important generalization that emerges from this phenomenal shift in demographics is that of land-use change, on both private and public lands. And these changes are emphasized because land ownership in our region is blended; half public and half private. In the not too distance past private lands beyond city limits were allocated to utilitarian uses, today their emerging best use is increasingly residential and commercial development. Whereas the public lands were historically devoted to extractive uses, today their highest and best uses has been decreed to be outdoor recreation in all its myriad forms; from passive to mechanized to motorized.

Let me hasten to say that I am speaking of transitions; not of absolutes that have already taken place everywhere across our region. True, there are still sectors of public and private lands in the West where ranching or logging or energy development are still the principle uses. What I speak of are trends that we are in the middle of, though increasingly, these conversions in land use have already occurred. For example, in Colorado, annually over 270,000 acres of private land are converted from farming and ranching to residential and commercial development. On the public lands, we see less logging, mining, and grazing every year as recreationists descend on our state and federal lands, fully motorized and looking for a week or weekend of happiness away from our region's increasingly congested and stressful cities.

If you agree with me that we are living during a period of rapid land-use change, that affects equally our public and private landscapes, then let me suggest that we are as much in need of a land ethic as at any other time in our history. And, critically, we are also in desperate need of a consumption ethic, for our region's unbridled growth and expansion is partially a byproduct of unprecedented consumption, sanctioned by a remarkably complacent attitude of denial that we can continue to grow this New West without limits.

First, let us examine whether the economies of the New West are benign, or equally as damaging to our region's natural heritage as the traditional extractive uses that so defined the Old West

RECREATION AND RESIDENTIAL DEVELOPMENT: EXTRACTIVE USES UNDER DIFFERENT NAMES?

First, the public lands. Outdoor recreation, it turns out, has the same potential, albeit in different ways, to affect biodiversity as the traditional land uses of logging, mining, water development, and livestock grazing (Knight and Gutzwiller 1995). On public lands, outdoor recreation is second only to water development as the chief culprit for the decline of federally threatened and endangered species (Losos et al. 1995). On all lands, public and private, outdoor recreation is the fourth leading cause for the decline of federally listed species (Czech and Krausman 2000).

Let me be quick to point out, for those of us who recreate passively while hiking, rocking climbing, or dry fly fishing, that a further breakdown of which recreation activities harm native species, that we are all at fault, whether we mountain bike or dirt bike across our region's public lands (Knight and Cole 1995, Losos et al. 1995). So, although we may call outdoor recreation an amenity use, it is as culpable as logging or dam building in its ability to affect populations of species that help define our region's natural diversity.

What about residential and commercial development on private lands? Do these activities alter our natural heritage as, belatedly, we are discovering outdoor recreation does? Yes, and then some. Exurban development is the second leading cause across America, subservient only to invasive species, for the decline in federally threatened and endangered species (Czech and Krausman 2000). Perhaps this is not too surprising. After all, if we transplanted a typical city suburb from town to country, might we not expect to see more robins, starlings, raccoons and skunks, and fewer (if any!) bobcats, badgers, orange-crowned warblers and lark buntings? Research on species that thrive near rural ranchettes and species that decline, suggest that residential development away from city limits results in increases in generalist or human-adapted species and the displacement of specialist or human-sensitive species (Odell and Knight 2001). As we convert the once formally-rural parts of the West in private ownership to ranchette developments as vast as the former ranches that once occurred, we will see a landscape increasingly populated with generalist species, of little conservation concern other than their weedy capacity to displace more sensitive species whose evolutionary history does not allow them to successfully compete with the newcomers.

A quick aside for those of you who may think we can sacrifice our rural private lands yet still protect our region's natural heritage just on its public lands. Our public lands are the least productive, have the most harsh climates and the least fertile soils. The private lands of the West are where we find the highest primary productivity, as they occur at the lowest elevations with the richest soils (Scott et. al 2001). The early settlers weren't fools.

One further note for those of you who wonder why NGOs are working with ranchers across the West to keep their ranches vital economic units and out of development. In an ongoing study with the Natural Resources Conservation Service we are examining bird, plant, and mammal communities across the three principle land uses of the New West other than cities and metropolitan areas: protected areas, ranches, and ranchette developments. Perhaps not too surprisingly, we are finding that private-land ranches support a biodiversity quite similar to that found on protected areas. Ranchette landscapes, however, have a quite different collection of fauna and flora, more closely approximating what would be found in town than in country (Knight 2002).

ETHICS OF LAND AND CONSUMPTION

If these results surprise you, please know that you are not alone. My sense is that many individuals and organizations have worked long and hard to either eliminate or modify the traditional extractive uses in the West. Their primary motivation, I suspect, was if we have less utilitarian uses in our region, we would have a more pristine and natural landscape in which to live, work, and recreate. I can imagine the disappointment among those who believe this when they discover that the uses we have replaced them with also come with great ecological costs. When one devotes their career to stopping rampant logging, inappropriate grazing, water development, and mining, one should expect to see the place where they live better off.

This thinking, however, is far too simplistic. In reality, as we replace the Old West with a New West, we run a great risk of continuing to live here in a nonsustainable fashion, and with our region's natural heritage to be in jeopardy (Knight and Landres 1998). This is where we finally confront the need for a land ethic, a consumption ethic, and honest conversations.

Aldo Leopold gave us the land ethic. Along with a vast amount of published and unpublished writing, what he had in mind can be captured in a variety of excerpts from his written legacy (Meine and Knight 1999). These include:

> "a universal symbiosis with land, economic and aesthetic, public and private"
> "a protest against destructive land use that seeks to preserve both the utility and beauty of the landscape"
> "a harmony between men and land"
>
> And my favorite:
> *We end, I think, at what might be called the standard paradox of the twentieth century: our tools are better than we are, and grow better faster than we do. They suffice to crack the atom, to command the tides. But they do not suffice for the oldest task in human history: to live on a piece of land without spoiling it.*

What Leopold, of course, was asking is for us to acknowledge our responsibilities to ensure land health. This entails stewardship and placing our obligations to sustainable uses of natural resources ahead of our individual rights to treat natural resources however we may wish to. This is a tall order indeed, for the words "property" and "rights" are emblazoned across our Constitution, while the words "land" and "responsibilities" cannot be found within this august document.

You can easily see how Leopold's philosophy of ethical responsibilities to land is captured today in the concept of ecosystem management (Knight 1996). Within ecosystem management is the acknowledgment that land uses, both extractive and recreational, are welcome, but only if they are done in a sustainable way. The heart of Leopold's land ethic insists that we have ethical obligations to ensure that land remains capable of supporting both healthy natural and human communities.

What about a consumption ethic? Are we living within our ecological footprint? Across the New West we inhabit, are we consuming resources and producing wastes in keeping with the amount of productive land and water required to generate the resources and assimilate the wastes?

I sense not. Since 1970, the size of U.S. families has declined by 16%, yet house size has increased by 48%. From 1965 to 1999, annual paper consumption increased by 120% and annual per capita consumption of paper increased from 468 to 750 pounds. And, not surprisingly, this is occurring at the same time that forest products on our public lands have plummeted. Between 1987 and 1997, federal timber harvest dropped 70%, from about 13 billion board feet to 4 billion board feet annually (MacCleery 2000).

As we speak America, including parts of the American West, is involved in a national dialogue about producing more energy to match our rapacious consumption levels. The concept of conservation and living within our limits was initially discarded by the present administration as a matter of personal virtue. In a more thoughtful country, the concept of conservation would have dovetailed nicely within a party of conservatives.

I don't mean to take cheap shots at partisan politics but the present energy "crisis" is a good example of the need for a consumption ethic to balance a land ethic. After all, if wood products, food, energy and minerals don't come from within our country, they must come from elsewhere. Indeed, there is increasingly across our region and nation serious conversations about off-shore production of all of these natural resources. That the best and highest use of our public lands is for play and of our private lands is for homes. From where I stand, this seems both unfair and hypocritical.

Ask yourself this question next time you are faced with choices of resource consumption, whether at the mall or at the thermostat. Should the resources you use come from where you live, or from somewhere afar, where not only are environmental regulations more lax, but also not as well enforced?

So, in contrasting a land ethic and a consumption ethic, allow me to make these observations. In 1930, nearly half of all Americans lived on farms. Today fewer than 2% of us are farmers, foresters, and ranchers. Which, therefore, is easier, a land ethic or a consumption ethic? Leopold wrote that: "A farmer who clears the woods off a 75% slope, turns his cows into the clearing, and dumps its rainfall, rocks, and soil into the community creek, is still a respected member of society," and he lamented the fact that we were still so far from a land ethic (Meine and Knight 1999). If you will indulge me, I might paraphrase Leopold and say, "A ranchette dweller who lives in a 4,000 square foot home, owns three cars, commutes to work alone is still a respected member of society." Should either be respected members of society? Times are more complicated today than when Leopold was struggling with how to get across the need of ethical relations between human and natural communities. Today we need not only a land ethic but also a consumption ethic for we are increasingly not of the land, but of the mall.

THE TIME FOR HONEST CONVERSATIONS

Wallace Stegner once wrote that "We are the unfinished product of a long beginning." (Stegner and Stegner 1981). Our region is not the same place it was only a decade ago. It is filling up and the traditional cultures, dating back to the First Americans, are changing as rapidly as at any time in our history. There is a dire need to begin honest conversations. For too long we have been dishonest in our dealings with each other and those from outside our region. We have arrived at a point in Western history where conversations about Western lands and land health, private and public, are entwined and cannot be separated. They must be dealt with simultaneously when discussing the future of the New West. The science needs to be accurate, not value driven, and the conversations about culture and natural histories need to be honest, not mythologized. Science is important in these discussions, but to be useful, the science must be done carefully so that the answers are the best we can get. All of us need to look better and listen more carefully as we struggle to match Stegner's challenge for us to make a society that matches the scenery (Knight and Bates 1995).

There are those among us who actively champion the far ends of the political spectrum. Some Westerners want the public and private lands free of manure, cows, clearcuts and pumpjacks because they want these places for their own uses, such as mountain biking and river rafting. They want ranchers, loggers, and miners off the Western ranges and forests because they believe what others have told them, that cows sandblast land and that loggers and miners denude hillsides and leave it to wash away into our waterways.

What about the far right? The New Federalists who are obsessed with spreading their private-property rights hysteria? They are as intolerant of collaborative conservation efforts in the New West that bring ranchers, scientists, and environmentalists together as the Far Left. These powerful players in the West throw out incendiary remarks about wildland protection and government land grabs as easily as their counterparts reflexively oppose appropriate grazing and logging. Thank goodness for those in the radical center who strive to build connections across landscapes, that run through human and natural communities, and across socio-political chasms. Perhaps the wing nuts at either ends of this human spectrum stir up dissent because they find it easier and more profitable to simplify, divide, demean, and demonize.

Perhaps it all comes down to values--of the rancher, the urban environmentalist, the scientist, and the government employee. Each of us is in love with the West, its punctuated geography, its rich cultures, its wildlife, and its heart-rending beauty that stretches sometimes further than our imaginings. All of us will have to change in order to make this a place where we live have vibrant human and natural communities. We can do that, one only needs to look at the history of natural resources management, a continuing evolution which increasingly shows concern for all of our natural heritage. Other than those of us with extremely narrow ideologies, the far right and far left, the rest of us should, perhaps, meet half-way, or nearly so. The need of the moment is to find common ground on which to work for a common good. Good-faith efforts, and a retreat from demonization and demagoguery, are what we need today.

If it makes what I have written any more palatable, let me admit where my values come from. My wife and I live in a valley along the northern end of the Colorado Front Range. Our neighbors and friends are ranching families and those who live on ranchettes. Over the years we have come together to dance, eat, neighbor, and chart a common ground. Whether working together in our weed cooperative, developing a place-based education program in the valley school, fencing out overgrazed riparian areas, we are working together to be known more as a place where people cooperate, collaborate, and show communitarian tendencies, than as a place where they engage in ferocious combat, litigation, and confrontation. We are home, we have our hands in the soil, and our eyes on the hills that comfort us. In our imperfect lives, we work together to build a community that will sustain us and our children, for we understand that we belong to the land far more than we will ever own it. We strive together in a cooperative enterprise, to steward our lands for all of God's children and all of God's creatures. Perhaps that it why I write as I do.

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U.S. HIGHWAY 40, BERTHOUD PASS, COLORADO-EFFECTIVE PRESERVATION AND RESTORATION

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ABSTRACT

Highway US 40 over Berthoud Pass is located in North Central Colorado approximately 80 kilometers (50 miles) west of Denver in Clear Creek and Grand Counties. The project also lies within the Arapaho National Forest. The primary focus of the projects is east of the Berthoud Pass Summit over the Continental Divide to the Berthoud Falls, a distance of 10 kilometers (6.2 miles) and approximately 10 kilometers west of the pass towards Winter Park.

Safety, mobility and resolving roadway deficiencies associated with snow storage, eroded and unstable slopes surface icing and water quality problems became the main project goals. Tight switchbacks, steep slopes, eroded and unstable slopes, glacial till, avalanche paths and landslides required civil engineering, geotechnical and environmental solutions. Several restoration methods were developed on the west side of the pass to stabilize existing eroded 1:1 slopes. Erosion control was achieved by incremental seeding and mulching surfaces during construction. Wetland Mitigation involved transplanting existing on site plant material. Landscape planting included collected and nursery grown trees and shrubs.

INTRODUCTION

Project improvements to the template have been a concern for over 30 years. The Colorado Department of Transportation (CDOT) initiated engineering studies in 1971 and the Environmental Assessment (EA) was initiated in 1983. The goal was to widen the template, however funding constraints prevented completion of a 3 lane and 4-lane widening presented in the EA.

The EA was updated in 1987 and stated the following purpose " to construct a feasible improvement which will increase the operation efficiency of U.S 40 on Berthoud Pass". A tunnel was even considered by local citizens but to date private funding has not been secured.

Since 1987, the need for safety and traffic-flow improvements have become urgent. Hence, a new EA was created for the present day construction of the corridor. The key environmental study issues are as follows:

- Water Quality and Erosion Control
- Slope Stability and Plant Establishment
- Wetlands
- Threatened and Endangered Species
- Avoidance of the Alpine Forest
- Visual Resources & Impacts
- Cultural & Historic Impacts

Constraints and Opportunities

Is the preferred alternative to the assessment a compromise? The answer is “YES”. Each agency worked with environmental study objectives and project goals to shape a project suitable for the environment and the traveling public. The chosen alternative is an example of what the National Environmental Policy Act (NEPA) process can achieve. CDOT managers where sensitive to the needs defined in the Environmental Document. A pure roadway engineering preference would have been the 4 lane alternative. This widening in glacial till would have greatly altered the landscape with minimal capacity to contain sediment. On the other hand, the no build alternative would have addressed safety and environmental concerns. The preferred alternative consists of three travel lines, shoulder and snow storage with barrier and retaining walls. The result is an engineering solution for environment and transportation.

Site conditions presented many challenges. Approaches to these constraints are discussed further in the booklet by the specialties involved in the development of the project.

US 40 over Berthoud Pass is also a very scenic corridor with views of the Colorado Mountains. The corridor crosses the Continental Divide National Scenic Trail and is a primary route to the Winter Park Ski Area and National Forest recreation access. As stated the project lies completely in alpine forest of the Arapaho National Forest CDOT was committed to minimizing aesthetic impacts.

A key component of the project is retaining walls. Retaining walls avoid forest impacts, stabilize slopes, improve aesthetic of the corridor and reduce the risk of rock fall. Retaining walls in combination with barrier, snow storage and a third climbing lane are the key environmental mitigation measures used in the alternative chosen in construction.

Furthermore, the collaborative EA process involved the formation of an Environmental Interdisciplinary Team and a Value Engineering Team. Together these teams addressed the concerns and choose the 3-lane alternative. The Commitments were defined and followed through the entire development process including construction. Each discipline worked together to achieve the projects goal. CDOT construction personnel made those goals a reality.

Water

A challenge to each area of expertise in the project development process was the presence of water. Hydrologic issues drove the major revisions during construction. Higher measured water elevations posed many challenges during construction. A primary objective of the project was to store most of the 400 plus inches per annual snowfall. Avoiding construction in the aquatic environments and minimizing construction and permanent sedimentation were also project objectives.

Each design specialty worked with the hydrology of this 10,000-ft elevation mountain environment. Water quality and quantity drove the project. Even the long-term maintenance of the template and drainage system was addressed in the NEPA process. Drainage issues were also a key factor in construction revisions with culverts being added or moved.

The project engineer coordinated the water issues of the project from wetlands to ground water drains throughout construction. The contractor had to work with water in several of the wall designs. Water levels where anticipated to be lower during the design phase. Consequently, designers, construction engineers and the Contractor redesigned walls, added underdrains and made changes to the drainage system to compensate for the ever-changing mountain hydrology. The project started during a wet summer with several additional inches of rain (e.g. 1999 8.79 inches for August was wettest on record;

compare with regional mean values - Table 1). Despite the new challenges for the project the result was an improved design to drain the water.

Table 1. Average Annual Precipitation 1971-2000, Western Regional Climate Center.

Month	**Average Total Precipitation (inches)**
January	3.70
February	3.23
March	4.36
April	4.68
May	4.32
June	2.02
July	2.29
August	2.50
September	1.83
October	2.28
November	3.39
December	3.84
TOTAL	38.44

Environment and Engineering

The project costs for the East Side of the pass may approach 80 million dollars. To work and be successful in the alpine environments one requires adequate resources to retain the mountain slopes, protect and preserve the forests and create a safe mountain corridor. One also requires teamwork, technical expertise and a will to create a successful project for the public and the environment.

INTER AGENCY COOPERATION

An EA was completed in Nov 1997 in order to comply with the requirements of the National Environmental Policy Act (NEPA). CDOT and the FHWA are the lead agencies for this project and the US Fish and Wildlife Service (USFS) is a cooperating agency. The entire length of the project lies on USFS managed lands. The environmental process started with public and agency scoping meetings, which were held in order to identify issues and alternatives. In order to achieve a high quality and safe roadway shared decision-making is essential. The FHWA and CDOT policy on decision-making is to actively involve the public and agencies in a process that is open, cooperative and collaborative.

Federal agencies with jurisdiction on the project include the US Army Corps of Engineers (COE), the USFWS. The Colorado Division of Wildlife (CDOW) also provided input. Numerous meetings and field trips were held with all of the involved agencies. Early coordination reduced the likelihood of the controversy and delay regarding mitigation and other permitting issues. The COE issued a 404 permit for the entire length of the project. The purpose of the 404 program is to insure that the biological and chemical quality of waterways is protected from irresponsible and unregulated discharges of dredged or fill material that could permanently alter or destroy valuable resources. The project required a 404 permit because we could not avoid placing fill material in waterways or wetlands. Fill material includes widening of the roadway where portions of the construction are in waters or wetland and protection devices such as riprap and other bank stabilization. In order to obtain the permit CDOT had to show that we had taken steps to avoid wetland impacts where practicable, 2) minimized potential impacts to wetlands and 3) provided compensation for any remaining unavoidable impacts through activities to restore or create wetlands. The permit will be amended as design moves forward along the corridor. The

COE placed many conditions on the permit, some of which require monitoring of wetland restoration and creation success and the submission of yearly status reports.

The USFS was involved in the project because they administer the Endangered Species Act (ESA). The lynx was listed as a threatened species and is protected by the ESA. Refer to the T&E section for information on habitat issues.

REGIONAL GEOLOGY

The effects of alpine glaciation dominate the geomorphology of the Berthoud Pass area. Glaciation occurred from the Pleistocene Epoch (1.8 million to 70,000 years ago) to the Holocene Epoch (fewer than 10,000 years ago). Recent episodes include the Bull Lake Glaciation that began about (150,000) years ago and the Pinedale Glaciation that probably remained at full glaciation until (15,000 to 20,000) years ago. Depths of glacial materials through most of the study area are estimated to be less than five to over 30 feet thick. Some of the test holes indicate nearly 100 feet of till and colluvial deposits at the transition area from the Phase 2 project to the Phase 3 portion. This material is a medial moraine deposit from the glacier that flowed and subsequently receded, down the Hoop Creek tributary basin.

Bedrock in the area consists of Precambrian Silver Plume Granite and related igneous and metamorphic rocks. Some areas have interlayered granite and biotite gneiss along with migmatite. The primary minerals in these rocks are quartz, feldspars, hornblende, and biotite. There are also numerous accessory minerals, particularly in altered zones. Some of the gneissic rocks show pronounced foliation from millimeters to several inches in scale. In other areas, such as the upper portion of the pass, foliation is not apparent.

Faults have altered much of the bedrock in the area and cross the roadway at several locations. Rock within the fault zones is shattered and/or highly altered with clay gouge and infilling in most of the joints. Evidence of fault-altered bedrock was more apparent along the lower portions of the pass. At times the rock recovered in the core samples was so decomposed that it could be crushed by hand, while the rock fabric was still visible (saprolite). Occasionally secondary mineralization such as calcite and iron staining is also present.

Small faults are visible in some of the rock cuts. Offset, if detectable, is small on these features. Fault gouge was also encountered in several of the drill holes, and may be in excess of 30 feet thick in some areas. The fault gouge in this area generally consists of a very stiff, yellow to gray silty sand with clay and angular gravel- and cobble-sized rock fragments.

Groundwater

Groundwater conditions along the pass vary considerably throughout the year. Many groundwater seeps and springs exist alongside the roadway and some of these are present year-round. Other hydrologic features appear to have less flow during the dry season for this area: late summer and fall.

There may be multiple groundwater tables present along the pass. For example, there may be a natural water table below the depth of bedrock as well as a perched groundwater table that rests on the bedrock surface or somewhere within the overlying materials. Fracture flow within the bedrock is probable and complicates the interpretation of the groundwater surface.

CIVIL DESIGN OBJECTIVES

The use of US 40 between Winter Park and I 70 has increased dramatically in the past 40 years. The original 2-lane roadway template has been altered over the years to allow for the short stretches of passing lanes on the east side of Berthoud Pass between Berthoud Falls and the top of the pass and continuous 3-lane on the rest of it.

This increased traffic demand and numerous safety issues instigated the process to fill the gaps and make the entire road a 3-lane road on the east side. CDOT approach to this project was to widen the road with a least impact to the surrounding environment. Final roadway template for this project includes three 12-foot lanes, 8-foot shoulders and 5- to 11-foot wide snow storage areas.

Early design of the west side of the pass pioneered many designs used throughout the corridor. The design of the west side consisted of barrier and paved ditches. This feature provided toe of slope stability and access for maintenance.

To minimize the impact to the forest, large retaining walls where build on both fills and cut slopes. Soil nail or tieback design of cut side retaining walls provided for stabilization of the highly erodable and unstable slopes. Massive landslide within project limits was stabilized using tieback anchors and extensive system of horizontal and vertical drains. Cut side retaining walls were designed to be tiered if maximum facing height exceeded 14 feet. This allowed top to bottom construction and minimized room required building these walls. As a result, it allowed for a more efficient traffic management during construction. It also produced a more pleasing aesthetic appearance and ability to better landscape the resulting terraces. In addition to being a nice landscaping feature, these terraces are intended to function as additional snow storage areas. The height of the fill side retaining walls varies between 15 to 40 feet. Therefore, a Mechanically Stabilized Earth (MSE) wall system was selected as a more cost effective for this application.

The bids documents contained only partial design for both cut and fill slope wall systems. CDOT analyzed global stability of the proposed walls and requested that final design of the wall system including internal stability to be a responsibility of the contractor. This resulted in a modified design-built concept of this portion of bid documents. The intent was to involve contractor's ingenuity to come up with a most cost efficient wall system.

Design Evolution

The design goals resulting from the EA for Berthoud Pass East were to enhance the national forest setting by addressing existing roadside scars, and to minimize contrast of project elements and activities. In order to achieve these goals, all attempts were made to provide for aesthetic treatment of walls, grading and landscape treatment that provide visual continuity with surrounding elements by repetition of compatible colors, textures, lines and forms of the characteristic landscape.

Landscape Treatment

A primary goal for the Berthoud Pass East project was to establish plantings that would result in a sustainable landscape and that will provide for vegetative cover, aesthetic enhancement, and partial screening of walls. To be sustainable, landscape treatment must first respond to the environmental conditions of the setting, including:

- Elevation and climate
- Suitable vegetation
- Slope orientation or aspect
- Soil and geologic conditions
- Plant Palate
- Slopes and terraces

During the design and construction of the Berthoud Pass landscape planting plan several innovative planting requirements where incorporated to enhance plant establishment. Firstly, the design allowed for field layout of the planting material (native trees and shrubs). The contractor and the field landscape architect located plants to best fit site conditions. Planting the wall terraces were a concern of the contractor. Wall plantings favored deciduous trees and shrubs that could tolerate snow storage. Evergreen trees where reduced in areas where snow storage could impact the plantings. Methods of snow removal will also be evaluated over time and the effect removal has on plant material.

Secondly, trees were collected within 1000 ft of elevation to increase adaptation of the alpine environment. Lastly, a plant establishment incentive (Table 2) was included in the project budget and specifications. If the survival rate of trees and shrubs is achieved the contractor will be awarded the incentive after the two year period. During this period the contractor is responsible for plant survival and maintenance.

Table 2. Species and type of planting stock included in the incentive.

Englemann spruce	2-6 ft ht balled and burlaped (collected)
Lodgepole pine	2-6 ft ht balled and burlaped (collected)
Aspen	1.5 inch caliper (collected)
Common Juniper	5 gallon container
Squaw current, Woods rose, Mountain lover Alpine prickly currant	5 gallon container

Plants were installed during the 4.5-year construction period. The landscape contractor was paid to water the material during construction. During the two-year warranty period all provisions required to establish the material is provided and paid for by the contractor.

Erosion Control

Native grass seeding along the corridor stabilized earthwork disturbance during construction and restored grasses on existing slopes. The native seed mix included the following species:

- Slender wheatgrass
- Streambank wheatgrass
- Mountain brome
- Canada bluegrass
- Alpine blue grass
- Sheep fescue
- Timothy
- Showy Goldeneye
- Rocky Mountain Penstemon

Rates varied between 50 to 55 kgs per hectare. Seeding application consisted of a mixture of organic fertilizers and water hydro seeded over soil. Seeded areas were covered with weed free mulch and organic mulch tackifier. Multiply seedings were applied.

Implementation & Lessons Learned

An objective of the EA and the project was to utilize the lower bench for snow storage. This resulted in damage to vegetation from these maintenance activities and accumulation of sand. To resolve this issue hardier plant species and modified maintenance procedures will be implemented to allow the plants to succeed. In the EA and design process, much consideration was given to the appropriate width of the terraces, to address the proportions of the walls to terraces, and to allow for planting on these terraces. However due to the difficulty of construction in the unconsolidated glacial till stabilization was difficult and terraces widths were diminished. This narrowed template has also been detrimental to plant survivability. To address this issue, on future construction phases the number of trees on terraces will be reduced and the number of shrubs will be increase.

Slopes / Grading and Selective Clearing

Another goal for the Berthoud Pass East project was to emulate natural topography by undulating cut lines to emphasize ridges and draws, and transitioning cut and fill slopes into the natural grade thereby avoiding harsh cuts and fills. All cut and fill slopes were blended with the surrounding terrain through slope rounding, layback and warping techniques. Slope rounding occurred at the top of all cuts, except in rock. Slope warping was used in order to attain a more natural-appearing transition between two unlike surfaces. Slope warping is a further refinement of slope blending and works to vary the pitch of the cut slopes. This involved slope rounding in both vertical and horizontal forms as a more natural extension of landform surface configurations. Additionally, boulders encountered while excavating slopes were either left in place or transported to alternate locations to assist with slope stability as well as add visual interest.

Prior to planting any new vegetation, selective thinning and clearing was implemented to emphasize natural vegetative patterns and avoid vertical vegetation wall or “tunnel effect”. Re-planted areas (cut and fill slopes, terraces between retaining walls) were also planted to emphasize natural vegetation patterns.

Wetland Design

Early in the EA process wetlands were delineated as required by the US Army Corps of Engineers guidelines. Wetlands were mapped utilizing color infrared aerial photos and field surveys. They were identified by type as required by FHWA. The total wetland area within the project corridor (800-meter width) was calculated by type. Wetland delineations were coordinated with appropriate State and Federal Agencies. Early coordination with the U.S. Army Corps of Engineers, EPA, U.S. Fish and Wildlife Service as well as the Colorado Division of Wildlife was essential to identify any agency concern well in advance and determine the least damaging alternative to the numerous water-related resources associated with this high mountain corridor.

Once the wetland maps were complete they were given to the design engineers to incorporate into their alternative analysis process. Biologists worked with design engineers and agency representatives during the alternative analysis phase to identify high value wetlands and avoid them during the development of the various alternatives.

After alternative selection, biologists, landscape architects, engineers and agency personnel worked together to further avoid and minimize impacts to wetlands associated with the preferred alternative as the site specific design progressed, always keeping in mind that if a wetland could be avoided then wetland replacement would not be required; a strong incentive in an area where the majority of land was not flat. Everyone knew that wetland mitigation at this elevation would be a formidable task. High elevations, extreme winter temperatures and a greatly reduced growing season would make successful creation or restoration difficult at best. The wetland mapping must be incorporated into the design/bid plans early on to facilitate this process.

CDOT/FHWA had committed to replacing all wetlands on a 1:1 basis in the EA. Given the topography of the project area, replacement of all impacted wetlands on-site was not going to be easy. Colorado also has very strict water rights that limit where wetland mitigation can occur. During the EA/404 processes several potential wetland creation and restoration sites were identified in coordination with State and Federal Agencies. Sites were identified both within the project corridor and for some distance downstream of the confluence of Hoop Creek and the West Fork of Clear Creek.

During final design, engineers, landscape architects, and biologists worked together to determine the final wetland impacts (Table 3). In cooperation with State and Federal Agencies they then developed the wetland mitigation plans for inclusion in the bid plans. Flexibility was essential as this process progressed. Design changes, resulting in less wetland impacts in some cases and more impacts in others, resulted in three amendments to the 404 individual permit that was obtained at the end of the final design process, over a period of several years. The water right issue made it impractical for CDOT to create or restore more wetlands than were impacted during construction. Also if ways to avoid or reduce impacts to wetlands during construction could be found they were rewarded by a reduction in the amount required to be replaced.

Table 3. Approximate Wetland Impacts and Mitigation for Phases I, II and III. Values in acres.

Construction Phase	Permanent Impacts	Temporary Impacts	Mitigation
I & II completed in 2002	0.612	0.182	0.648 (0.1 preservation credit)
III	0.604	0.010	0.55
Total	1.2	0.192	1.2

Wetland Construction Phases I & II

Creativity is an important factor in identifying wetland replacement sites. Sometimes it is important to “think outside the box’ in order to find a suitable wetland mitigation site. If a potential wetland mitigation site requires some excavation, and it generates topsoil and the project needs topsoil; that results in the decreased cost of the wetland and a source of cheap topsoil for the project. In the case of Berthoud Pass, a portion of Hoop Creek ran right at the toe of the roadway fill at one location and was being negatively impacted by sediment and salt ladened run-off. The solution was to move the creek away from the road, which also gave us the opportunity to mitigate for riparian wetlands lost at other locales.

A landscape architect in the field closely supervised construction of wetland mitigation, stormwater management and erosion control, and restoration plantings with coordination from other environmental specialists and the project engineering staff. It was essential to make sure that construction was not left to those familiar only with roadway construction. Notes and plans that look perfectly understandable to a biologist or landscape architect may not be recognizable when constructed by someone whose margin for error may be measured in feet and not in inches so critical to wetland hydrology.

The Berthoud Pass completed wetland mitigation sites are being monitored yearly in accordance with the 404 permit conditions. It is anticipated because of the high altitude and extremely short growing season, full success will take several years. After 2 years, progress is slow, but moving forward. Colorado's current drought situation was useful to Construction for erosion control purposes, but did not benefit the wetland mitigation sites.

Because this project is being built in phases, there is opportunity to tinker with any wetland mitigation site that needs help, under the next phase. The ability to come back and correct a grade elevation, stabilize a slope or replace dead plant material is extremely important to the success and rate of success of these wetland mitigation sites.

WATER QUALITY

The Hoop Creek basin is a high elevation, subalpine basin that encompasses a relatively small drainage area of approximately 2.5 square miles. It ranges in elevation from over 13,000 feet to 9,600 feet. Hoop Creek begins just above the Summit of Berthoud Pass and continues down though the basin, bisecting the alignment of SH 40 in several locations. The stream confluence's with the West Fork of Clear Creek, approximately five miles west of the town of Empire, CO. Hoop Creek and its tributaries are the primary surface waters in the vicinity of SH 40 and throughout the east side of Berthoud Pass.

These are high gradient streams, with the mainstem of Hoop Creek having an average channel slope of approximately 21 percent. Streamflow is seasonal with peak flows that occur during the spring snowmelt-runoff period from May to June. Increases in streamflow also result from summer thunderstorm events. Streamflow has been observed at the mouth of Hoop Creek to vary from less than 1 cubic feet per second (cfs) up to 73 cfs. Currently, there are no fish populations existing in Hoop Creek or any of its tributaries.

The Hoop Creek basin is located within the Upper Clear Creek Watershed. Protection of surface waters within the Upper Clear Creek Watershed is of prime importance to the many stakeholders that have an interest in maintaining and improving the water quality in the area. The Watershed supplies drinking water to approximately 300,000 people in the Denver-metro area and is also utilized for a variety of industrial and agricultural purposes. Numerous efforts have been made in recent years by the stakeholders to address nonpoint and point sources from past mining activities, hazardous material spills, treatment plant discharges, sediment loading, and other land uses. CDOT is a stakeholder in the watershed and is committed to addressing highway-related water quality issues from past and current activities.

In keeping with this approach, CDOT undertook a data collection effort beginning in 1997 to obtain baseline data in anticipation of future construction activities along the SH 40 corridor. It was determined at the time that a long-term monitoring program would be needed to assess basin-wide water quality conditions. The monitoring program has been beneficial in assessing potential impacts to surface waters during construction activities and will ultimately be used to assess the overall effectiveness of the permanent Best Management Practices (BMPs) being implemented along the corridor.

The event-based water-monitoring program that has been implemented includes stream flow data and seasonal sampling at strategic locations along U.S. 40 using automated monitoring equipment to analyze storm event and snowmelt water runoff. Other sites along the highway are monitored on an as-needed or diagnostic observational, basis. These diagnostic sites are very useful in stormwater monitoring efforts, especially at highway outfalls. Water quality parameters include (or have included) conductivity, flow, temperature, turbidity, bedload sediment sampling, totals suspended solids, phosphorus, sodium, chloride and heavy metals. The data are being collected and utilized for the following purposes:

- Fulfill mitigation monitoring requirements in the Environmental Assessment
- Assess potential sedimentation impacts to the West Fork of Clear Creek and to downstream water users
- Distinguish between sedimentation from highway-related sand/salt runoff and other sources
- Provide hydrologic monitoring of the Horseshoe Bend Fen area
- Assess the overall effectiveness of erosion control MBPS during construction
- Assess the long-term effectiveness of permanent erosion and sediment control BMP's

Project Drainage Goals and Maintenance Practices

A primary object of the environmental studies was to address impacts from highway runoff and sanding operations. The constructed highway template was designed to contain 50-60 % of the traction sand, provide snow storage and collect traction sand via sediment basins. Furthermore, under drains and cross culverts prevented clean off site drainage from mixing with highway surface drainage. CDOT was committed to protecting water quality during and after construction.

Winter maintenance of SH 40 includes snow removal and a sand/salt mixture used for safety purposes. Annual snow accumulation on Berthoud Pass can range from 130 inches to 600 inches in a given winter season. Approximately 3,000 – 4,000 tons of traction sand material are typically placed on the roadway to provide adequate traction for the traveling public. The sand mixture contains approximately a 5% salt content.

The combination of continuous erosion from exposed slopes and traction sand have been identified as contributing to the sediment loading of Hoop Creek and the West Fork of Clear Creek. It is anticipated that as a result of the roadway improvements, sediment loading from the highway corridor will be significantly reduced. Along with sediment and erosion control BMP's, maintenance BMP's are also being implemented along the corridor to ensure the effectiveness of the permanent BMP's. The maintenance MBPs include:

- Specific snow storage zones
- Paved ditches
- Knee walls along cut slopes
- Routine sweeping operations
- Regular inspection and maintenance of culverts, rundowns and sediment basins
- Routine maintenance of roadside vegetation and slope erosion
- Training for maintenance personnel
- Maintenance BMP Manual
- Annual meeting of maintenance and environmental personnel

The amount of sediment material being collected and removed from the sediment control structures and the roadway corridor is being tracked and will be monitored over time. These efforts will be correlated with the water quality monitoring data to evaluate the overall efficiency of the BMP program and ensure the long-term protection of the Hoop Creek basin.

If you can achieve your project goals and not remove a tree or disturb the ground, drainage or stream then you can lessen environmental impacts. The avoidance and minimization principal was applied in the design and construction process prior to considering mitigation of impacts.

When it was determined that altering the environment was required, then mitigation design was implemented. The project team determined it would be beneficial for the roadway and the stream to move a 300-ft reach of the Hoop Creek tributary. The result was a new reach cut into the forest with minimal impact to the terrain and forest.

During the construction of wetland mitigation at Floral Park, the project team determined that fewer check structures where needed for grade control in Hoop Creek and several large Engelmann spruce trees should be protected. The result was less on site mitigation, 0.6 acres to 0.41 acres of mitigation, but preservation of forest and existing riparian was increased. The additional required mitigation was moved down stream on future projects.

THE CHALLENGES OF BRINGING NATIVE PLANT MATERIALS INTO THE MARKETPLACE

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ABSTRACT

In this report various challenges are presented concerning the difficulties of bringing native plant materials into the commercial marketplace. These challenges include (I) Unfamiliarity within the Marketplace with Native Plants; (II) Financial Constraints; (III) Biological Constraints; (IV) Policy Constraints; and (V) The Difficulty of Strong Expectations within the Ecological Community for Production of Site-Specific Materials Contrasted with an Economic Environment Only Willing to Compensate to the Lowest Economic Denominator Achievable by the Marketplace. Various explanations and solutions are explored for each of the five challenges. Finally, applicable areas of research are suggested to further the science of reclamation and market acceptance of the use of native plants.

INTRODUCTION

The use of native plants for reclamation is as old as the story of human efforts to improve and stabilize their environmental surroundings. In the United States, the use of native plant materials for reclamation had its greatest boost in 1933 with the creation of the Soil Conservation Corps, then under the control of the US Department of the Interior. In 1938 when the Soil Conservation Service was transferred to the USDA under its first Chief, Hugh Hammond Bennett, its earliest attempts to restore order within the great dustbowl of the Midwest was with native plant materials. Soon thereafter, however, there was deviation from this concept through the importation of potential reclamation materials by efforts such as the USDA Agricultural Research Service Plant Introduction Program.

In the late 1950's and early 1960's the Soil Conservation Service reinitiated its native plant program in earnest through its establishment of various Plant Materials Centers. In addition to these programs, the US Forest Service began its tree improvement program through the selection of superior provenances from which to reclaim various logging efforts. Simultaneous to these federal efforts, various native wetland seed and plant providers, such as Kessler's Nursery, were established in the Great Lakes Area. By the mid-1970's, the first of these containerized nurseries to move west was begun in Utah by Native Plants, Inc. (NPI). Soon after, other containerized efforts were started including Bitterroot Restoration, Inc. in Montana. Today there are several such efforts throughout the Rocky Mountain Region including Bitterroot Restoration in Montana as well as Aquatic and Wetlands Company and Rocky Mountain Native Plants Company in Colorado.

For the purpose of this talk, the term "native" shall refer to those materials that have been endemic to a given locality since the ingress of European Colonists.

CHALLENGE I: UNFAMILIARITY WITHIN THE MARKETPLACE WITH NATIVE PLANTS

One of the greatest initial challenges with making containerized native plants available for reclamation is unfamiliarity in the marketplace with these materials. While familiarity with these materials is relatively easy to address through marketing and public awareness, it is essential to get in front of reclamation specialists with the traits, timing strategies, overall usage, and limitations of native plants. There must be adequate field trials and collective experience to allow a widespread knowledge base to be built in order to understand the abilities and limitations of these materials. Poor knowledge of plant materials and their limitations can lead to disappointment and unfulfilled expectations which can result in eventual resistance within the marketplace.

This reality is complicated by the variability of traits that is typical of genetically diverse populations, such as those that are inherent to wildland ecotypes. There are often as many differences between populations of the same species as there are between different species. This variability can be exacerbated by environmental interactions resulting in non-predictable outcomes and diverse pheneological expression. One such example is *Penstemon whippleanus* (Whipple's penstemon), which grows leggy and violet to white at lower elevations rather than short, stocky and almost black in its endemic environments. The challenge of site variability includes elevation, aspect, soil type and characteristic, competitive relationships, and adjacency to water.

CHALLENGE II: FINANCIAL CONSTRAINTS

It takes major amounts of money to initiate a native plant business. Making the situation more challenging is that there are huge opportunity costs for both land and money. Further complicating these facts is that there are distinct and very expensive expectations for entrepreneurial capital in terms of quick timing and rate of return (often over 21% interest). Furthermore, one can not really "Ma and Pa" their approach due to strong competitive pressures in the marketplace in terms of pricing, inventory availability, and species diversity. The bottom-line is that native plant nurseries are very capital and labor intensive endeavors.

Plant diversity is essential. Given the gamut of differences between populations and the slowness of some of the inventory to be ready for market, it is difficult to grow and maintain stock at a commercial level. In addition, labor is very expensive being up to $15 to $20 per hour in some areas. This labor is essential for propagation, transplanting, maintenance, and cultivation as well as installation if those services are offered. Nursery endeavors are often competing with jobs with better pay and easier workloads.

As mentioned, land is very expensive. However, many individuals believe that it represents poor planning to invest a great deal of capital improvement on leased land. Often the best land for use as well as that which is adjacent to desirable marketplaces has some of the greatest initial purchase and opportunity costs.

Obtaining adequate water, especially in the arid west, is also very expensive. Water availability includes quantity, quality, duration, and reliability constraints. It also includes cost of delivery as well as treatment facilities and equipment.

Proper facilities are also costly. These facilities include proper propagation houses, greenhouses, transitional facilities (for field conditioning – essential in the Rocky Mountain Region), seed storage and stratification facilities, and chemical and pesticide facilities that are both OSHA and EPA compliant, as well as water storage, delivery, and irrigation mechanisms.

If installation services are offered, these can also be very expensive. Trained labor and all of its expenses is essential to ensure that the utilized plants are properly placed and installed within the correct hydrologic situation or under sufficient irrigation of the proper intensity and duration. In addition to the challenges of procuring and keeping trained labor in a competitive marketplace, installation services can be very expensive to maintain. The required labor includes that which is capable of providing the correct design criteria and landscape architecture and that which can blend aesthetic appeal with ecological integrity and longevity. Earth moving and shaping equipment may be required. This labor also includes both hourly workers and trained supervisors. Off-facility projects require out-of-town housing plus meals and incidentals as well transportation for people, plants, and equipment. Extended warranties under uncertain field, weather, and irrigation conditions are normally required. Even with these bases covered, there are still the additional uncertainties of unforeseen drought, weed invasion, predation, trespass, and other variables.

CHALLENGE III: BIOLOGICAL CONSTRAINTS

As mentioned earlier, native plants are characterized by a great deal of variability between populations as well as between members of a given population (genealogical variation). In addition, a given population interacts with its surrounding environment (pheneological variation). This can result in variation within a given native species for drought and/or saturation tolerance, as well as tolerance to other factors such as soil condition, sun and/or shade, temperature, elevation, and the ability to reproduce sexually or asexually.

Biological constraints also influence the ability to obtain the proper propagules for increase. Predation, weather, seed shatter and seed indeterminacy all influence the ability to obtain the necessary amount of germplasm to create the requisite stock. It is often necessary to obtain the required seed before all, or even most of it, is completely ready. Biological factors such as whether or not the seed after-ripens or has a shelf-life must be determined. Most members of the Rosaceae and Fabaceae after-ripen, which is essential for species such as *Purshia tridentata* (antelope bitterbrush) that are largely carried off by burrowing rodents for winter food reserves. Examples of species with little shelf-life include all members of the citrus family as well as the genus *Quercus* (oak). Species indeterminacy has lead to lead cultivar development such as 'Rimrock' *Acnatherum hymenoides* (Indian ricegrass) for traits such as a more narrow caryopsis bract angle to better retain seed and retard field loss.

Germinability and survival can vary from wild populations to those under cultivation. These traits can vary by population, growth technique, and the means of seed harvest and/or seed preparation. For example with many "berry-forming" species, if the berries are allowed to fully dry out, they can become more dormant and, thus, be much more difficult to propagate. Case-and-point, *Lonicera involucrata* (twinberry honeysuckle) is much more difficult to propagate if the berries are allowed to dehydrate, resulting in the initiation of a double dormancy requiring both a warm period and a cool period to overcome. Ironically, if these berries are passed through the gut of an animal and subjected to its digestive system, the internal acids will counteract this dormancy.

Biological traits can also vary by cultivation technique...part of the difficulty utilizing propagation through common gardens. Higher elevation materials may be recalcitrant at lower elevations. Examples of this phenomena include *Caltha leptosepala* (true marsh marigold), higher elevation *Salicacea* (willows), or higher elevation *Juncaceae* (rush). Certain wetland plants, such as various *Carices* (sedges), are more apt to form seed under dryer conditions versus more wet ones, leading to utilized practices such as "drawdown" in their cultivation. Soil pH and texture variability can have huge effects. There is an inherent danger in unforeseen variables, underscoring the importance of uniform media attributes.

Germination protocols are poorly understood for many native species. This represents a broad area of need for future study. We applaud efforts such as the Propagation Database and other efforts to publish freely-accessible germination information on the web.

The bottom-line is that it is essential to better understand the reproductive biology of our native species. One can not make sound decisions concerning population and/or reproductive strategies without better understanding the underlying population biology of our natives.

CHALLENGE IV: POLICY CONSTRAINTS

Having come from a federal background, there is a surprising degree of challenges with native seed collection on public land when one is in the private sector. There is much inconsistency with the administration of native seed collection on public lands. Native seed policy appears to be arbitrarily administered within a given agency. This policy varies considerably from office to office within a given agency. When these challenges were raised to the regional level within the US Forest Service, we were informed that native seed collection was a "locally administered program" and that it was up to the individual office to make a decision concerning its permissibility. This being said, it is important for us within the private sector to recognize the challenges of agency staffing in light of changing budget priorities. We need to understand the difficulties of increasing workload and program responsibilities with stagnant or decreasing budgets. Still, some of the same National Forest Districts that requested site-specific collections were unwilling to grant collection permits because of policy, personnel, and/or time constraints. The end-result is that site-specific, or at least watershed-specific, plant materials collected from populations of known attribute and relevant local adaptability are in the best interest of reclamation and the greater public good. It is ironic that in some forest districts that it is easier to receive a timber harvest permit than one for seed harvest, given their relative environmental impact.

The result of difficulties with permitting is that many native seed collections take place either illegally or only on private land. Complicating this is the reality that there is very little private land over 10,000 feet in elevation, preventing certain species from being available in the necessary quantities within the marketplace. An example of this challenge is the near-complete absence of *Phleum alpinum* (true alpine timothy) versus mislabeled *Phleum pratense* (European timothy). This results in a lack of availability and unrealistic pricing, causing reclamation to miss a portion of importance species suites, and/or to use common class seed of unknown origin and purity, or named varieties that are utilized over too broad of a range in applicability.

There is also more than a little bit of misrepresented seed, in terms of both species and origin, in the marketplace. Not only is this unethical, but it can also result in poor establishment and long-term stabilization, discouraging the proper use of native plant materials for reclamation. "One size fits all" may not be the best approach to reclamation, although named varieties of known attribute certainly have their time and place. It is essential that the reclamation industry self-regulates in its representation of genetic origin. It is important that, as a whole, the reclamation industry utilizes its "dollar votes" to support those companies with plant materials of known origin who are willing to stand behind their products with documentation and warranties. To this end, we support the concept of permitting native plant collections as first suggested by Utah State University Cooperative Extension Service and the US Forest Service Shrub lab close to 15-years ago.

CHALLENGE V: THE DIFFICULTY OF STRONG EXPECTATIONS WITHIN THE ECOLOGICAL COMMUNITY FOR PRODUCTION OF SITE-SPECIFIC MATERIALS CONTRASTED WITH AN ECONOMIC ENVIRONMENT ONLY WILLING TO COMPENSATE TO THE LOWEST ECONOMIC DENOMINATOR ACHIEVABLE BY THE MARKETPLACE

The reclamation marketplace requests, or in some cases, demands the production of site-specific materials of known origin and genealogy, but is often only willing to pay for common class stock and the least expensive size and/or source available. This can result in the use of plant materials that are too small for the stresses that typify their site of applicability. For example, the use of 3 cubic inch plugs rather than 10 cubic inch plugs despite the proven superiority and more rapid establishment of the larger materials. In one extreme case, an unmentionable company used propagation-sized starter materials rather than adequately sized plugs for an un-namable local highway project with questionable hydrology. In our experience with container stock, the greater the degree of stress, typically the greater the size of material that is required to establish and stabilize the site. However, this trend appears reversed with Balled and Burlapped stock, with smaller B & B stock showing better field survival than with larger stock. These pressures can also result in the use of seed for areas where containerized stock would be clearly superior for zones of highest impact and/or potential erosion loss through erosion (e.g., fire reclamation in water courses with seed). It often also results in the use of common class materials or cultivars over too broad of an area for their proper applicability (e.g., southern ecotypes of *Atriplex canescens* – fourwing saltbush – in more northern reclamation projects). This can be especially problematic with species that show a great deal of variability over their zone of occurrence (e.g., *Deschampsia caespitosa* – tufted hairgrass). It is more cost-effective to do the job right the first time. One needs to remember that the most expensive commodity for most projects is the combination of labor and time.

This problem is compounded by inexperienced or irresponsible companies that are more concerned with winning a bid through the generation of false expectations, followed by adjustment through change orders and/or arbitration, rather than helping the bid reflect true production and labor costs in the first place. Again this leads to faulty expectations and a tainting of the reclamation industry towards native versus introduced materials. It is important to remember that the least expensive bid may often not be the best, although it is difficult to allow for this flexibility by either a government entity or within a competitive bid environment.

It is important for project designers to recognize that it is expensive to propagate and maintain multiple collections (accessions) for a single species without having those accessions outcross and "pollute" one-another's genetic integrity. The degree to which this problem manifests depends upon the management objective for a given project as well as the reproductive biology and outcrossing potential for a given species. Whether a species is apomictic, cleistogamous, partially cleistogamous, facultively cleistogamous, wind pollinated, or insect pollinated will determine its field requirements and the degree of separation required between adjacent field of the same or closely related species in order to maintain genetic integrity.

This underlines the need for additional research into the difference in establishment and site closure times for different classes of reclamation materials: (1) Seed versus plants; (2) Smaller plants versus larger plants; and (3) Bare-root plants versus containerized plants. It also underlines the need for additional research concerning the difference in establishment and closure times for different spacings of the same size class of materials or either a mix of size class or a mix of containerized plant and seed. Additional cultural studies are one of the greatest means for the public sector and plant research community to assist the native plant industry in successfully bringing endemic materials into the marketplace.

SEED-SOURCE SELECTION IN WESTERN REVEGETATION

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ABSTRACT

The natural-resource challenges of the U.S. West emphasize the need for native-plant materials choices that effectively sustain basic ecosystem functions and processes. However, seed-source selections for revegetation projects are increasingly influenced by fear, fad, fashion, or folklore and are often ecologically unhealthy and economically unwise. The issues include using local types versus seed from cultivars or common seed from non-local areas. Whether working with native cultivars or common native sources, we recognize species within ecoregions are not genetically uniform. They are stratified into north-south latitudinal or high to low elevation gradients. However, only limited information is available on regions of adaptation. Regions of adaptation need to be known and understood. Resources must become available for developing this knowledge. Simply mandating "local" plant materials use on a mileage or political boundary basis is not acceptable. Arguments for preferring local seed sources over cultivars, or over other less expensive sources within a region of adaptation, are not defensible in the face of history, evolution, genetics or the past 50+ years revegetation experience. We advocate exercising science and intellect over natural randomness. We recommend revegetation seed mixtures include proven, certified cultivars where possible. Otherwise, use the best local or regionally adapted and reasonably priced seed available.

NATIVE ROADSIDE VEGETATION CENTER: THE IOWA MODEL

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ABSTRACT

The Native Roadside Vegetation (NRV) Center was established at the University of Northern Iowa (UNI) in 1999. Through partnerships with federal, state and local agencies, the NRV Center provides research, techniques, education and source identified seed for restoration and preservation of native vegetation systems in rights-of-way and other lands. The Center includes the Roadside Program, the Iowa Ecotype Project and the Prairie. The Prairie Institute is a long-term program at UNI involving prairie reconstruction, restoration, management and advocacy. In 1988, based upon this prairie experience a Roadside Program was established to assist Iowa counties in implementing Integrated Roadside Vegetation Management (IRVM) programs. Prairie vegetation is a key component of Midwest IRVM programs since native prairie plants form stable and diverse communities that effectively compete against weeds. To provide an alternative to native cultivars in roadside plantings, the Iowa Ecotype Project (IEP) was initiated in 1990 to produce and increase regionally adapted Iowa-origin source identified foundation seed for commercial producers, and to promote commercial availability and affordability of this seed. To account for north to south variation in species, the state was divided into three "ecotype regions." Native seed growers purchase the right to grow the IEP regional ecotypes and are provided seed for increase and marketing.

INTRODUCTION

The Native Roadside Vegetation (NRV) Center was established at the University of Northern Iowa (UNI) in 1999 with funding from the Transportation Equity Act for the Twenty-First Century (TEA 21). The Center is located on the UNI campus in a recently renovated building adjacent to 35 acres of land used for foundation seed production plots. The mission of the NRV Center is to provide research, techniques, education and source identified seed for restoration and preservation of native vegetation systems in rights-of-way and other lands.

The NRV Center continues UNI's long term commitment to prairie preservation, restoration, management, interpretation and education through the Prairie Institute and merges the Institute with two successful offspring, the UNI Roadside Program and the Iowa Ecotype Project (IEP). When fully operational, the NRV Center will play a vital role in native plant initiatives, particularly in the Midwest, but also nationally.

HISTORICAL PERSPECTIVE

The Iowa landscape prior to beginning of Euro-American settlement in 1833 consisted of vast stretches of tallgrass prairie interspersed with savannas and wetlands. Woodlands were limited primarily to river and stream valleys in the eastern and southern part of the state. The rich black soil created by the extensive root systems of the prairie plants proved to be a valuable resource for agriculture. Within one lifetime, almost all of the 28 million acres of tallgrass prairie was rapidly converted to cropland. Consequently, the exact composition of Iowa's original prairies is not known because many plant and animal species were gone before their presence was recorded. Both the drastic reduction in total prairie area and the break-up of the original contiguous prairie have resulted in lower biological diversity on the remaining prairies, reduced genetic diversity of remaining plant species, and fewer prairie animal species (especially forms that had co-evolved with rare prairie plants). Shimek (1931) documented 265 plant species as comprising most of Iowa's prairie flora, although it is estimated that the total of original prairie species was probably closer to 400 (Bultena, et.al. 1996). Very early in the 19th century Mueller (1904) observed, "At the present time the homes of most of our native flowers are limited to the highways and timbered areas on account of the cultivation and pasturage of the land." Very little native prairie remained when prairie preservation efforts were initiated more than a century after settlement. Today, the prairie preserves and remaining unprotected prairie remnants constitute less than 0.1% of the original Iowa prairie and are widely scattered across an agricultural landscape. Those isolated remnants have been, and continue to be, impacted by human activities.

Iowa's natural landscape has been modified more extensively than any other state in the U. S. (Bultena, et.al. 1996). Although agricultural conversion is considered the main cause of loss of natural habitat, other human activities such as urban and commercial development also contributed to the decline. Iowa's blacksoil prairies were the hardest hit, but the remainder of the prairie ecosystem as well as the savanna, wetland and forest ecosystems was also heavily impacted. Plant and animal species disappeared with the demise of native habitat, as they were an integral part of the natural ecosystems. The Iowa Natural Areas Inventory (1984) list of rare and endangered plant species included 100 endangered species, 52 threatened species, 61 species presumed extirpated, and 25 rare species of undetermined status.

Ecosystem restoration and recovery in Iowa presents some very unique challenges. Restoring damaged ecosystems as described by Jamie Sayen (1989) is desirable, "The goal of restoration must be natural recovery. Remove the destructive forces, attempt to restore in an ecologically appropriate manner as many species, community functions and structures as possible, taking a holistic view of the ecosystem. Proceed in accordance with natural succession. Vigilantly monitor and guard against further human abuses and let nature run her course." In Iowa, that approach may not be possible, as the critical mass of native remnants is not sufficient to let nature take its course. Our prairie remnants are islands scattered across an agricultural sea, small areas with large exposed perimeters, stressed from encroachment by non-native and undesirable species. These remnants need to be managed just to maintain their natural integrity. As they are widely scattered, there is little opportunity to expand them and create a contiguous system that would support ecosystem recovery.

Iowa's prairie ecosystem provided suitable habitats for a diverse collection of plants and animals, and helped build and maintain the productivity of the soils. Currently, prairie vegetation is being used in roadside sides to control weeds. Prairie plantings in roadsides contribute to natural corridors in the agricultural landscape. These corridors may aid gene flow in both plants and animals.

INTEGRATED ROADSIDE VEGETATION MANAGEMENT

Most of the roadsides in Iowa as well as other Midwestern states are not natural; they have been modified and smooth brome, fescue and other exotics have replaced the native prairie vegetation. Iowa counties are responsible for weed control on secondary roadsides. By the mid 1980s, it was becoming apparent to most counties that both mowing and extensive herbicide spraying were not only ineffective, but increasingly costly methods of weed control. In addition, annual broadcast spraying was keeping the roadside vegetation in a perpetual state of disturbance and damaging the environment. A more appropriate, cost efficient means of roadside vegetation management was needed. A grassroots solution to weed control emerged as a few counties initiated Integrated Roadside Vegetation Management (IRVM) programs. As more counties considered initiating IRVM programs, the demand for information increased. Because of its expertise in prairie establishment and management and its outreach capabilities, UNI was asked to form a Roadside Management Program to assist Iowa counties in implementing IRVM.

As indicated, IRVM provided a viable alternative for agencies seeking a cost effective, environmentally sound means of roadside weed control (Smith 1995). The groundwork for IRVM had been laid earlier by Landers and Kowalski (1968) and Christiansen and Lyons (1975). IRVM programs utilized a variety of techniques in applying ecological principles to roadside management. Ecological theory indicates that the most stable and diverse plant communities occur on sites which are least disturbed (Odum 1971). These undisturbed native communities have naturally adapted to the area over an extended period of time. As noted, the Iowa landscape at the time of settlement was dominated by tall grass prairie. Establishment of native prairie vegetation in Iowa's roadsides replicates the plant community best adapted to the landscape and is a major component of the IRVM program. Stable, diverse native prairie communities tend to maintain themselves under adverse conditions and resist weedy invasion. Weed control with native vegetation reduces the need for mowing and permits more selective chemical weed control. The extensive root systems of the native vegetation provide the most effective means of holding soil and preventing erosion. The grasses and other wildflowers add a rich aesthetic quality by providing motorists with a wide variety of forms, texture, colors and hues that change with the seasons. Starbuck (1925) was well ahead of his time when he proposed the use of native wildflowers to beautify roadsides. The more diverse prairie communities not only aid in preserving native flora and fauna, but also provide more improved habitat for wildlife.

The IRVM program incorporates and combines a variety of techniques and activities in roadside management. Mowing can be greatly reduced resulting in savings in equipment maintenance and personnel. Herbicides are used more selectively and with greater safety. Specific problem species or locations are targeted and sprayed by trained staff. Prairie remnants that remain on the roadside are managed to enhance their diversity and size. New prairie plantings can incorporate a diverse mixture of species. As with prairie management, the use of fire is an important part of an IRVM program (Henderson 1991, 1993). Prairie vegetation is fire adapted so prescribed burning can be used to enhance prairie remnants by suppressing woody species and non-native species. In addition, fire often increases the vigor and diversity of the prairie vegetation and reduces the incidence of disease in prairie plants. Many Iowa counties readily adopted this management tool, however, the Iowa DOT is more reluctant to do so. Roadside managers can work with adjacent landowners to reduce disturbance in the roadside by cautioning against over-spraying and encroaching into the right-of-way and encouraging reduction of soil erosion from cropland into ditches. More selectivity can be used in woody vegetation removal. Ultimately consideration can be given to revegetating with natives to replace exotics. Reconstructing natural prairie roadsides entails more than just planting prairie species. The most successful reconstructions replicate as nearly as possible the well-adapted, diverse prairie community that existed prior to settlement.

When the UNI Roadside program was started in 1988, six counties had IRVM programs. The increase in number of counties implementing IRVM programs was very rapid in the early years, almost doubling annually. Today, 39 counties have active IRVM programs with a Roadside Manager, 14 have active IRVM programs without a Roadside Manager, and 29 counties have developed IRVM plans. Two-thirds of Iowa's counties have received technical assistance, educational programs, and seed or management assistance from the UNI Roadside Program. From 1998-2003 the Roadside Program obtained more than $2 million in Transportation Enhancement grants to purchase and distribute native seed to 66 counties for roadside plantings. During the 1990's, the UNI Roadside Program became an unofficial resource center for information and assistance in native vegetation initiatives. The UNI Roadside Program has developed a variety of educational and technology transfer programs, conferences, and a newsletter with readership in forty states and Canada. Packets of information are routinely shipped to states seeking to emulate the Iowa model for IRVM.

Changing public perception of what constitutes an attractive roadside is part of the ongoing IRVM education effort. Many people have little understanding of what should be the composition of a natural roadside. Increased awareness of native prairie has helped gain support for natural landscapes. This awareness has resulted in an acceptance of native prairie in roadsides rather than the manicured-lawn look requiring high-maintenance roadside management.

Iowa is committed to using native vegetation in roadsides. In 1999, the Iowa Legislature developed legislation for IRVM, established funding for the UNI Roadside Office and initiated a Living Roadway Trust Fund (LRTF) administered by the Iowa DOT. The LRTF has provided approximately $600,000 annually to support state, county and city projects involving roadside vegetation. The State Transportation Commission in 2000 committed to establishing prairie in all state managed roadsides and designated $5-7 million annually to achieve that goal.

Iowa roadsides occupy approximately 720,000 acres. Converting all or most of that acreage to native prairie is an awe-inspiring project. Not only would it create a marvelous statewide network of natural habitat, it would be a giant step toward returning the tallgrass prairie to Iowa.

IOWA ECOTYPE PROJECT

The demand for native seed increased as more counties established IRVM programs and began to plant prairie roadsides. It soon became apparent that roadside managers were faced with the same problem that had plagued those engaged in prairie reconstruction. It was difficult to obtain sufficient quantities of viable seed at a reasonable price.

During the 1960s and 1970s, increasing interest in prairie reconstruction and restoration had stimulated a need for quantities of native prairie seed. Commercial producers of native prairie grass seed in Nebraska and Kansas were positioned to meet this demand. They had been providing seed for range restoration and were a ready source of large quantities of prairie grass seed. The seed they provided was cultivated varieties (cultivars) of native prairie grasses developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) Plant Materials Centers (PMCs) to increase grazing productivity of rangeland. In developing these cultivars, plants were selected for characteristics common to forage plants such as vigorous growth, high germination rate and an extended vegetative state. The cultivars were often moved two hundred miles north of their origin to extend grazing time. Frequently, the cultivars exhibited more vigorous growth than local species and flowered after the local plants had set seed.

The availability of large quantities of inexpensive, viable cultivar prairie seed was attractive to prairie reconstructionists as locally collected seed was expensive and often exhibited low viability (Smith 1994). However, very quickly a concern arose in the eastern tallgrass prairie region regarding the importation of the cultivars or “western ecotypes” as they were called. Since the plants had been selected and developed for specific traits, a more appropriate term would have been “western cultivars.” Although western cultivars are the same species as the local plants, the selection process has affected their genetic make-up. Some prairie restorationists felt that the more vigorous western cultivars would “swamp out” or overwhelm the local ecotypes and then die out as they weren’t locally adapted (Schwarzmeier 1973).

Ecotypes are defined as genetically differentiated strains of a population restricted to specific habitats. “Western ecotypes” proved to be an unfortunate designation. This shifted the focus of the concern from “cultivars vs. local species” to “nonlocal vs. local ecotypes.” This debate persisted for almost thirty years in the absence of definitive genetic information regarding the variability of ecotypes. Some took the position that sources of seed for reconstruction and restoration should be limited to within 10-15 miles of the site. Others maintained that Iowa has been modified so greatly by agriculture (i.e. less than 0.1% of presettlement tallgrass prairie remaining) that we should just plant native prairie species and not worry about whether they were cultivars. However, regardless of their position in this debate, almost all prairie restoration proponents in the eastern tallgrass prairie region agree that it is inappropriate to use western cultivars in prairie reconstruction and roadside prairie plantings.

When county IRVM programs began to expand across the state in 1988, prairie reconstruction and restoration consisted primarily of small private projects. Iowa-origin seed was not readily available, as there were only a couple of small native seed suppliers operating in the state. Most of their product was hand collected from local remnants and quite expensive.

In spite of the wide spread opinion that western cultivars were not desirable, roadside managers faced with tight budgets felt compelled to limit costs and buy the less expensive western cultivar seed. Interactions with roadside managers through the UNI Roadside Program increased awareness of a need for a cost-effective alternative to the western cultivars to provide for more ecologically sound roadside management programs.

I initiated the Iowa Ecotype Project (IEP) in 1990 with the goal of providing adequate quantities of regional ecotype seed of Iowa-origin at an economically competitive price. Funding has been provided by Iowa DOT's Living Roadway Trust Fund and UNI. Cooperating groups and agencies include the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Iowa office in Des Moines, the USDA NRCS Plant Materials Center (PMC) in Elsberry, Missouri, Iowa Crop Improvement Association, the UNI Biology Department and Iowa counties with IRVM Programs. During the first decade of the project we relied heavily on the Elsberry PMC for seed increase and cleaning. The NRV Center now has more campus land for production plots and seed cleaning equipment and does most of the seed increases and cleaning.

To allow for perceived latitudinal differences in native plant populations, the state was divided into three zones, northern, central and southern. The IEP was designed to provide a basic roadside planting mixture from each of the three designated northern, central and southern regions within the state. Some growers resisted the concept of three regions because they felt that one ecotype for the entire state would be more economically viable. On the other hand, proponents of local ecotypes felt that 99 regions (one for each county) were more appropriate. Moderates favored nine regions, but agreed with the general consensus that the native seed market would not support more than three regional ecotypes. From a practical perspective, harvesting problems created by differences in times of flowering and seed set for plants from different latitudes are sufficient justification for three zones. As plants are quite variable, we may eventually determine that one region is sufficient for some species and three regions better for others. However, until more definite genetic information is available, we will continue the more conservative approach of three regions per species.

Prairie species that are widely distributed and successful competitors are selected for the project. Seed is collected from at least 20 prairie remnant sites in each region. Seedlings are started in conetainers in the greenhouse and transplanted into production plots. Fifty to one hundred plants from each collection site comprise a production plot for that region. Cross-pollination can occur within each production plot, but production plots for each region are isolated from the other regions. Seed harvested from these plots is cleaned and stored until sufficient quantities are available for release to growers. There may be some inadvertent loss of genetic variability as a result of collecting, planting and harvesting, but there is no intentional selection for particular traits. Genetic material of the remnants should be retained and possibly enhanced with new material created by mixing seed from isolated populations. Growers and the public are informed when sufficient seed of an ecotype is available for release. Native seed growers purchase the right to increase and market IEP regional ecotypes. They are supplied with a specific quantity of seed of the species being released.

The source-identified seed program (yellow tag) of the Association of Official Seed Certifying Agencies initiated in 1994 by the Iowa Crop Improvement Association was a logical and timely fit with IEP. The seed is not selected for any traits and the source is guaranteed. The "yellow tag" program provided a meaningful designation for IEP seed and made it a value added product.

Acceptance of the IEP was slow as we attempted to persuade agencies, native seed growers and prairie proponents of the benefits of Iowa-origin seed. The regional approach remained a concern for some time. Seed of two IEP species were first released on a trial basis to growers in 1994. The beginning was not good, one grower didn't get his allocation planted and lost the foundation seed in a fire, and another failed to get his field certified. Some felt that their source-identified seed would be more marketable than that of the IEP. Only two actually had their IEP increase fields certified. However, we continued to produce seed for release and developed a release agreement with more precise detail regarding the responsibilities of the IEP and the grower. Gradually the growers began to buy into the program; one of the major growers became a strong supporter. The biggest boost for the yellow tag program was provided through federal transportation enhancement funds. Beginning in 1978, Kirk Henderson, Roadside Program Manager, obtained seven consecutive grants to annually purchase $300,000 -$500,000 of native seed for roadside planting by 66 counties. Through the statewide bidding process, he developed a system of preference and premiums for Iowa source-identified seed. In addition, for the past two years, the Iowa DOT has indicated a preference for Iowa-origin seed in their bid letting.

Native seed growers seem quite willing to grow native grasses, but they have been reluctant to become heavily involved in forb production due to the variability of a more limited market and problems in propagation of some species. Initially the growers were more interested in the IEP grass releases than the forbs. However, the success of the IEP in producing forb foundation seed coupled with agency purchases of roadside mixtures containing a high forb component has allayed marketing concerns of growers. The bulk of the current demand is still skewed toward the warm season grasses. However, the number of species of forbs being requested in Iowa DOT bids has increased, it is anticipated that growers will respond by producing greater quantities of forb seed. At one time we thought the NRV Center might have to produce and market species the growers didn't want to bother with because they were difficult to grow or the demand was low. However, it now appears that if someone wants to buy seed, someone will grow and sell it.

The price of source-identified seed fluctuates with supply and demand, as does all native seed. However, in the past 3-4 years, the price of Iowa-origin seed has declined from the hand collected highs of the past to levels that are competitive with cultivars. It appears that we have attained the original goal of providing an adequate supply of Iowa-origin seed at an economically competitive price for roadside plantings and reconstruction projects.

Due to the expressed preferences for IEP seed in bid letting, we have received requests form native seed growers in other states to purchase IEP foundation seed. To reinforce the ecological premises of the program, we do not widely distribute IEP seed. We maintain that Iowa regional ecotypes should be confined to Iowa and immediately adjacent portions of neighboring states (i.e. Northern Zone Ecotype could be used in southern Minnesota and Southern Zone Ecotype could be used in northern Missouri). In addition, by agreement IEP production is limited to the region inspected by the Iowa Crop Improvement Association.

The IEP Model has widespread application and can be adapted throughout the United States and Canada. It is a proven model program for developing a regional source-identified seed with native seed growers. Some states have recognized the merits of the model and are beginning to emulate it. We are willing to assist states in developing and initiating source-identified seed programs based upon the IEP Model. The growers can then increase and market the seed to agencies and individuals involved in roadside prairie reconstruction or restoration. With source identified native seed from an IEP type model, states can have more natural roadsides and stimulate development of value added agriculture (Houseal and Smith 2000).

There is still much to be learned about the population genetics of native species. A part of our applied research program involves analysis of population genetics and assessment of establishment success of species included in the IEP. Currently, we are conducting common garden studies in conjunction with an analysis of the genetic make up of IEP northern and southern ecotypes of switchgrass and prairie coreopsis.

In conclusion, the logic and practicality of native plants for all kinds of landscaping is not a new idea. It is an idea whose time has arrived and is rapidly gaining acceptance. Native plants are adapted to local growing conditions and therefore require limited input of fertilizer, herbicides, irrigation or mowing. The natural beauty of native plants captures an image of our past and enhances understanding of our biological heritage. Native prairie along our roadsides is not popular nostalgia or a passing fad; it is an awakening. Prairie plants have been around for thousands of years and possess valuable lessons of co-existence and survival. Increasing understanding and appreciation of the original landscape and our natural heritage are encouraging signs that we are maturing as a society and coming to know and love this land.

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DESIGNING SUSTAINABLE COVERS FOR URANIUM MILL TAILINGS

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ABSTRACT

The U.S. Department of Energy in Grand Junction, Colorado, combines three tools to design and evaluate the performance of engineered covers for uranium mill tailings: field monitoring, modeling, and natural analog studies. This paper presents lessons learned from monitoring existing low-permeability covers, tests of alternative covers intended to accommodate long-term environmental change, and the use of natural analog studies in combination with monitoring and modeling to project the long-term performance of both low-permeability covers and alternative covers. The saturated hydraulic conductivity of conventional, low-permeability covers can be one to several orders of magnitude greater than designed because of biological intrusion and soil development in compacted soil layers. Lysimeter studies show that alternative cover designs that rely on the water storage capacity of a thick soil sponge to retain precipitation while plants are dormant, and evapotranspiration to dry the sponge during the growing season, can limit infiltration of tailings. Clues about possible long-term changes in the environmental setting of engineered covers can be gleaned from evaluations of past changes in analogous settings. Data from natural analog sites can be input to probabilistic models to estimate reasonable ranges of future performance.

INTRODUCTION

The U.S. Department of Energy (DOE) Office of Legacy Management is responsible for long-term stewardship of former uranium ore processing and mill tailings sites in all regions of the country (www.gjo.doe.gov/programs/ltsm/). Final remedies at most sites include engineered cover systems designed to contain tailings contaminants and limit human health and ecological risks for 200 to 1000 years (U.S. Environmental Protection Agency, 1983)—an unprecedented engineering challenge. Notwithstanding this longevity requirement, existing cover design and performance evaluation guidelines (U.S. Environmental Protection Agency, 1989; U.S. Department of Energy, 1989) are prescriptive in nature and fail to consider influences of inevitable changes in the environmental setting.

In contrast, the DOE Environmental Sciences Laboratory in Grand Junction, Colorado, combines three tools to design and project the long-term performance of engineered covers for uranium mill tailings: field monitoring, modeling, and natural analog studies. This paper presents examples and lessons learned from (1) monitoring existing covers, (2) designing alternative covers that accommodate long-term environmental change, and (3) using natural analog studies in combination with monitoring and modeling to project the long-term performance of both existing and alternative covers.

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MONITORING EXISTING COVERS

Many DOE Office of Legacy Management sites have disposal cells designed and constructed under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The design philosophy for UMTRCA covers evolved in response to regulatory changes and applications of lessons learned (Waugh et al., 2001). Before groundwater quality standards for UMTRCA sites were promulgated, the design process focused on radon attenuation and a 1,000-year longevity standard. The early designs consisted basically of three layers (U.S. Department of Energy, 1989a): (1) a compacted soil layer (CSL) or radon barrier overlying the tailings, (2) a surface layer of rock for erosion protection, and (3) sandwiched in between, a lateral drainage layer consisting of coarse sand and gravel. The CSLs in these designs were later advocated as low-permeability barriers to water movement into the tailings (U.S. Department of Energy, 1989a).

Plants began growing on the rock covers within a few years after construction (U.S. Department of Energy, 1992). Emergence of vegetation should have been anticipated. Surface layers of rock reduce evaporation (Groenevelt et al., 1989), increase soil water storage (Kemper et al., 1994), and consequently create habitat for deep-rooted plants.

A key issue is whether deep-rooted plants will increase or decrease the likelihood of contaminant discharge from the disposal cell. This issue can be argued two ways. Decaying plant roots may create conduits through which water and gases readily pass, thus potentially increasing permeability and downward flux. Conversely, extraction of soil water from the cover by plants (transpiration) may significantly decrease flux. Even in humid climates, where precipitation exceeds potential evapotranspiration, water extraction by plants may account for more than half the soil water loss from disposal cell covers (Melchior et al., 1994). Woody vegetation has also been shown to improve the stability of riprap-armored slopes, although the complexity of vegetation and rock-slope interactions has hampered quatification (Morgan and Rickson, 1995).

Problems with deep-rooted plants may counteract the potential benefits. Plants can root through soil covers into underlying waste material, disseminating contaminants in aboveground tissues. Plants rooted in uranium mill tailings may contain elevated levels of U, Mo, Se, 226Ra, 230Th, and 210Po (Clulow et al., 1991; Dreesen and Williams, 1982; Hosner et al., 1992; Lapham et al., 1989; Markose et al., 1993). Radon-222 can be transported into the atmosphere as plant roots extract water from tailings (Lewis and MacDonell, 1990; Morris and Fraley, 1989). Roots may also alter waste chemistry, potentially mobilizing contaminants (Cataldo et al., 1987).

Root intrusion can also physically degrade covers. Evidence has increased suggesting that covers with compacted soil layers are vulnerable to desiccation and cracking from wet-dry cycles, freeze-thaw cycles, and biointrusion (Melchior et al., 1994, Kim and Daniel, 1992). Macropores left by decomposing plant roots can act as channels for water and gases to rapidly bypass the soil mass in compacted soil layers. Plant roots also tend to concentrate in and extract water from compacted clay layers, causing desiccation and cracking. This can occur even when overlying soils are nearly saturated (Hakonson, 1986), indicating that the rate of water extraction by plants may exceed the rehydration rate of the compacted clay. In addition, roots may clog lateral drainage layers (U.S Department of Energy, 1992), potentially increasing rates of infiltration through the underlying compacted soil.

Results of performance evaluations of early, rock-armored, low-permeability covers at an arid site, Shiprock, New Mexico, and a humid site, Burrell, Pennsylvania, are summarized below.

Shiprock, New Mexico

The Shiprock, New Mexico, disposal cell was constructed in 1986 before the U.S. Environmental Protection Agency (EPA) proposed ground water quality standards for uranium mill tailings sites. The cover design used at Shiprock consists of three layers (Figure 1): a 198-cm silt loam CSL to control radon releases, a 15-cm sand drainage/bedding layer overlying the CSL, and a 30-cm rock armor layer sized to prevent erosion. On the basis of laboratory tests, the Shiprock CSL was thought to have a saturated hydraulic conductivity (Ksat) between 6.4 x 10-8 and 2.3 x 10-6 cm /s (U.S. Department of Energy, 1989b). DOE became concerned in the years after construction that vegetation observed growing on the cover could compromise the low permeability of the CSL. Potentially deep-rooted species included tamarisk, rubber rabbitbrush, gray horsebrush, and Russian thistle.

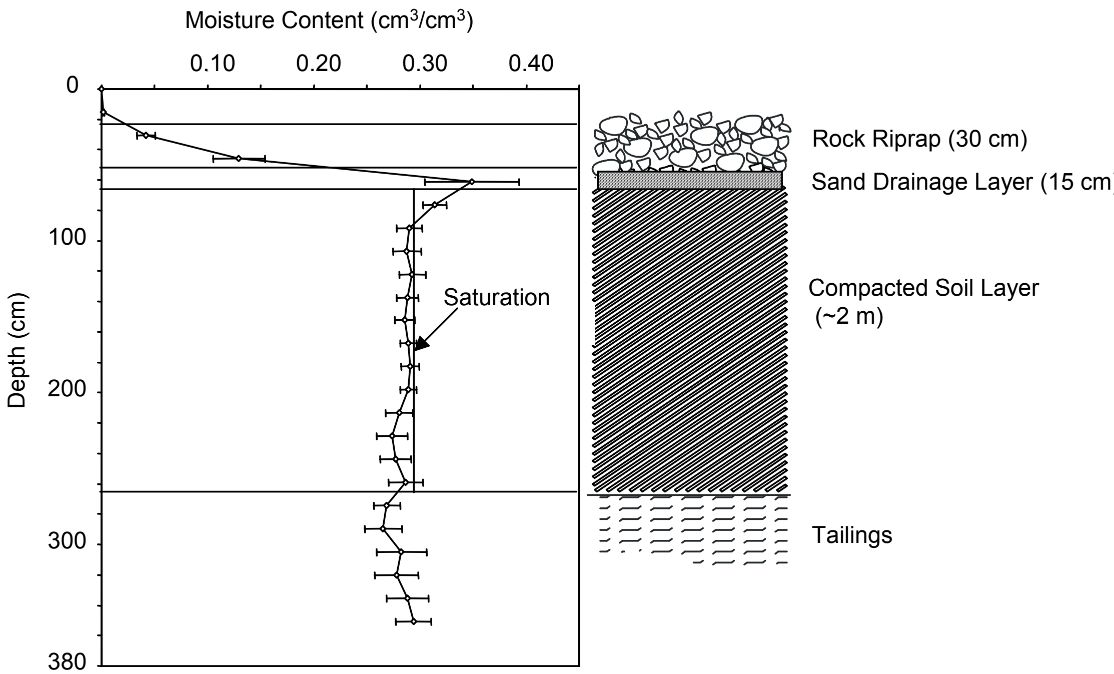

Figure 1. Cover design for the Shiprock, New Mexico, uranium mill tailings disposal cell, mean (± 2SEM) volumetric soil moisture profile monitored monthly from June 1999 to September 2000, and volumetric moisture content of the compacted soil layer at saturation.

Results of soil moisture monitoring and in situ measurements of Ksat indicate that the cover may not be performing as anticipated (Glenn and Waugh, 2001). Soil moisture profiles through the CSL and into underlying tailings were measured monthly between June 1999 and September 2000 using a neutron hydroprobe (Gardner, 1986) at four locations in the cover. The moisture content of the CSL (mean = 28.8 percent by volume, SEM = 0.6) and the porosity of the CSL (27.1 percent, SEM = 1.7) were statistically the same; the CSL was essentially 100-percent saturated (Figure 1).

The in situ Ksat of the CSL was measured at six locations in 1998 using air-entry permeameters designed and manufactured by Daniel B. Stephens and Associates, Inc. (Stephens et al. 1988). The AEP, based on a design by Bouwer (1966), consists of a round, 30-cm-deep permeameter ring, air-tight cover, standpipe, graduated water reservoir, and vacuum gauge. The vacuum gauge measurement is used to calculate the air-entry or bubbling pressure of the soil. Three AEP measurements were made in pits excavated where tamarisk, rubber rabbitbrush, and Russian thistle rooted into the CSL, and in adjacent pits where plant root intrusion was not observed. Results were highly variable with a mean = 4.4 x 10-5 cm/s that was significantly greater than the laboratory test mean. CSL Ksat values were actually lower in locations where roots penetrated the CSL than in locations with no observed root intrusion.

If the CSL remains continuously saturated, as neutron hydroprobe data indicate, then the passage of water through the CSL and into the tailings would be greatly influenced by the Ksat. Under saturated conditions, the hydraulic gradient is approximately 1 and water flux through the cover can be estimated using Darcy's law. Given near-saturation of the CSL and tailings, and the high values for the CSL Ksat, it would be prudent to further evaluate water flux through the disposal cell to assure that the source of groundwater contamination is contained.

Burrell, Pennsylvania

The effects of root intrusion on the performance of the uranium mill tailings disposal cell at Burrell, Pennsylvania, were also evaluated (Waugh and Smith, 1997). As with Shiprock, the intended design life is 200 to 1,000 years. Annual precipitation at Burrell averages greater than 100 cm/yr.

From the bottom up, the Burrell cover consists of a 90-cm CSL overlying residual radioactive materials (RMM), a 30-cm sand and gravel drainage layer, and a 30-cm rock riprap layer. (See Waugh et al. [1999] for soil physical and hydraulic property data.) Within 3 years after construction, a diverse community of woody plants had established on the rock cover of the disposal cell, including sycamore, box elder, black locust, tree-of-heaven, and Japanese knotweed, an exotic perennial with a woody base. Within 10 years Japanese knotweed had rooted through the rock layer and the underlying CSL.

Air-entry permeameters (Stephens et al. 1988) were also used at Burrell to measure the in situ Ksat of the CSL. The Ksat averaged 3.0 x 10–5 cm/s at locations where Japanese knotweed roots penetrated the CSL compared to 2.9 x 10–7 cm/s at locations where there were no plants. The weighted-average Ksat for the 6-acre cover, calculated using the community leaf area index (LAI) for Japanese knotweed, was 4.4 x 10–6 cm/s. Plant community LAI was estimated with an LAI-2000 Plant Canopy Analyzer (Wells and Norman, 1991; LI-COR, Inc., 1992). At a nearby site with a subsoil consisting of the same type of material as used for the CSL, the Ksat averaged 1.3 x 10–4 cm/s. Earthworm holes, root channels, and soil structural planes all contributed to macropore flow of water in the subsoil. This nearby site was considered to be a reasonable analog of the long-term condition of the Burrell disposal cell cover.

ALTERNATIVE COVER DESIGN

Lessons learned from monitoring early UMTRCA covers contributed to design improvements. The low-permeability covers attempt to resist natural processes, rather than work with them, and will likely require increasing levels of maintenance or retrofitting in the future (Clarke et al. in press). DOE and the U.S. Environmental Protection Agency (EPA), Region 8, collaborated on an alternative design for a uranium mill tailings disposal cell at the Monticello, Utah, Superfund Site (Berwick et al., 2000). The goal at Monticello was to design an engineered cover system that enhances beneficial natural processes to help make long-term containment possible (Waugh and Richardson, 1997).

At semiarid sites such as Monticello, relatively low precipitation (P), high potential evapotranspiration (PET), and thick unsaturated soils seem to favor long-term hydrologic isolation of buried waste (Winograd, 1981; Reith and Thompson, 1992). But simple P/PET relationships inadequately predict recharge that can approach 60% of precipitation in arid regions where coarse-textured soils have been denuded of vegetation (Gee and Tyler, 1994). At arid and semiarid sites, recharge can be minimized if disposal cells are covered with thick, fine-textured soil layers that store precipitation in the root zone where evapotranspiration (ET) seasonally removes it (Anderson et al., 1993; Link et al., 1994; Ward and

Gee, 1997). Capillary barriers consisting of coarse-textured sand and gravel placed below this soil "sponge" layer can enhance water storage and limit unsaturated flow (Stormont and Anderson, 1998; Khire et al. 2000). To be accepted by regulators, end users must demonstrate that the water balance of these alternative ET cover designs is at least equivalent to conventional designs (U.S. Environmental Protection Agency, 2003).

Monticello Cover Design

The Monticello alternative cover design (Figure 2) is fundamentally an ET cover with a capillary barrier. The design relies on the water-storage capacity of a 163-cm fine-textured soil sponge layer overlying a 38-cm sand capillary barrier layer to retain precipitation until it is seasonally removed by vegetation. Drainage should occur only if water accumulation at the sponge/sand layer interface approaches saturation and tensions decrease sufficiently for water to enter the larger pores of the sand layer. Hydraulic performance can be evaluated as the probability that, over time, ET is sufficient to prevent water accumulation in the soil sponge from exceeding the storage capacity.

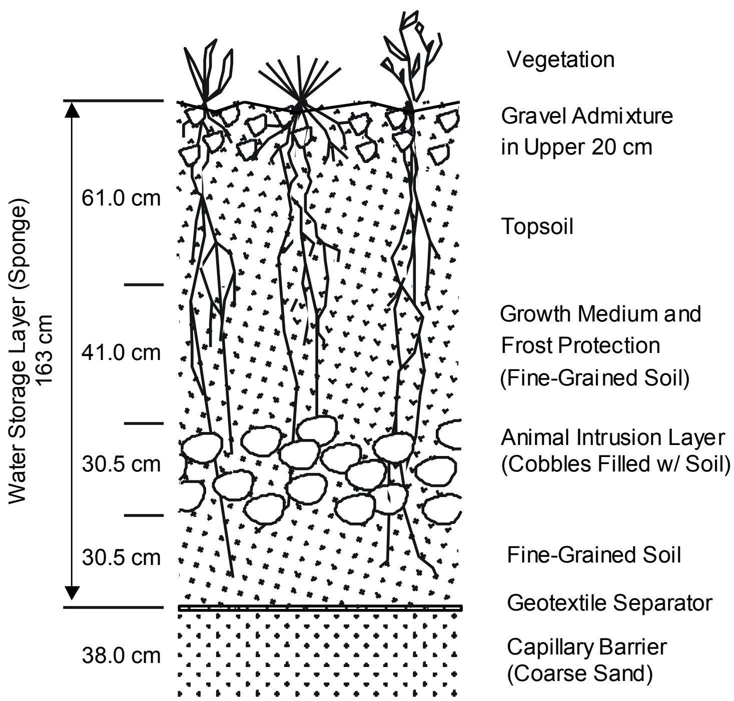

Figure 2. Alternative cover design tested in caisson lysimeters and constructed on a uranium mill tailings disposal cell at the Monticello Superfund Site.

Other components of the Monticello design either facilitated construction or were included to enhance long-term performance. A geotextile fabric maintains the fine-grained soil/coarse sand layer discontinuity during construction and until soil aggregation occurs by natural pedogenic processes (Bjornstad and Teel, 1993). The combination of vegetation and gravel admixture controls erosion. Vegetation and organic litter disperse raindrop energy, shield underlying fine soils, increase infiltration, reduce water flow and surface wind velocity, bind soil particles, and filter sediment from runoff (Wischmeier and Smith, 1978). Gravel mixed into the surface helps control erosion when vegetation is sparse (following construction, fires, drought, etc.), mimicking conditions that lead to the formation of gravel pavements. The gravel admixture can control both wind and water erosion (Ligotke, 1994; Finely et al., 1985) and, functioning as a mulch, can enhance seedling emergence and plant growth (Waugh et al. 1994).

The Monticello design includes deterrents for biointrusion and other attributes for plant growth. The soil sponge thickness is the primary biointrusion deterrent. Water retention in the soil sponge creates habitat for relatively shallow-rooted plants, and the thickness of the sponge exceeds the depth of most burrowing vertebrates in the Monticello area. A layer of cobble-size rock 30.5 cm above the capillary barrier is an added deterrent should deeper burrowers, such as prairie dogs, move into the area in response to climate change. Fine-textured sponge soil fills the interstices of the rock layer, preventing it from behaving like a second capillary barrier. The topsoil layer, obtained from the root zone of the borrow area, has physical and hydraulic properties similar to the rest of the soil sponge, but also contains available nutrients, propagules, and microorganisms (e.g., mycorrhizae) needed for the establishment of a sustainable plant community.

Caisson Lysimeter Installation

Weighing and drainage lysimeters offer the most direct and reliable means for evaluating soil-water balance of alternative cover designs (Gee and Hillel, 1988). Lysimeters have been used for several years to test the hydrologic performance of waste landfill cover designs (Nyhan et al., 1990; Sachschewsky et al., 1995; Roesler et al., 2002). Two large drainage lysimeters were installed to evaluate the range of as-built conditions in the actual Monticello alternative cover (Waugh et al., 2004) (Figure 3).

Lysimeter 1 closely matches the materials and compaction as built during the latter stages of construction. Lysimeter 2 mimics less desirable materials and compaction as built during the early stages of construction. The sponge layer consists of loam topsoil compacted to 1.45 g/cm2 in Lysimeter 1, and of clay loam subsoil compacted to 1.65 g/cm2 in Lysimeter 2. Lysimeters were installed by excavating a pit using a track hoe. Corrugated steel culverts, 3.05 m in diameter by 2.75 m in depth, form the walls of the lysimeters. Access to instrumentation is through an adjacent caisson, 1.52 m in diameter by 3.66 m in depth. Culverts were lined with 40-mil high-density polyethylene (HDPE), filled with water, covered with plastic, and leak tested using a manometer. HDPE tubes, welded to drainage holes cut into the lower end of the HDPE floor liner, were inserted through ports into the access caisson. Soil layers were installed by marking soil lift heights on the interior walls, hauling and dumping stockpiled materials into the lysimeters, spreading and wetting lift materials, and then tamping lifts to achieve soil bulk-density specifications. Bulk density was measured with a nuclear density gauge (Troxler Inc.).

Plant Establishment

Revegetation goals for ET covers include plants that (1) are well-adapted to the engineered soil habitat, (2) are capable of high transpiration rates, (3) limit soil erosion, and (4) are structurally and functionally resilient (Waugh and VanReyper, 2002). Diverse mixtures of native and naturalized plants are thought to maximize water removal and remain more resilient given variable and unpredictable changes in the environment resulting from pathogen and pest outbreaks, disturbances (overgrazing, fire, etc.), and climatic fluctuations. In contrast, the exotic grass plantings common on engineered covers are genetically and structurally rigid, are more vulnerable to disturbance or eradication by single factors, and will require continual maintenance.

Revegetation of the Monticello lysimeters matched the specifications and methods used for the adjacent tailings disposal cell (Kastens and Waugh, 2002). Lysimeters were seeded in September 2000 with a mixture of grasses, forbs, and shrubs in an attempt to mimic the potential natural vegetation of the borrow soils and local climate (Table 1).

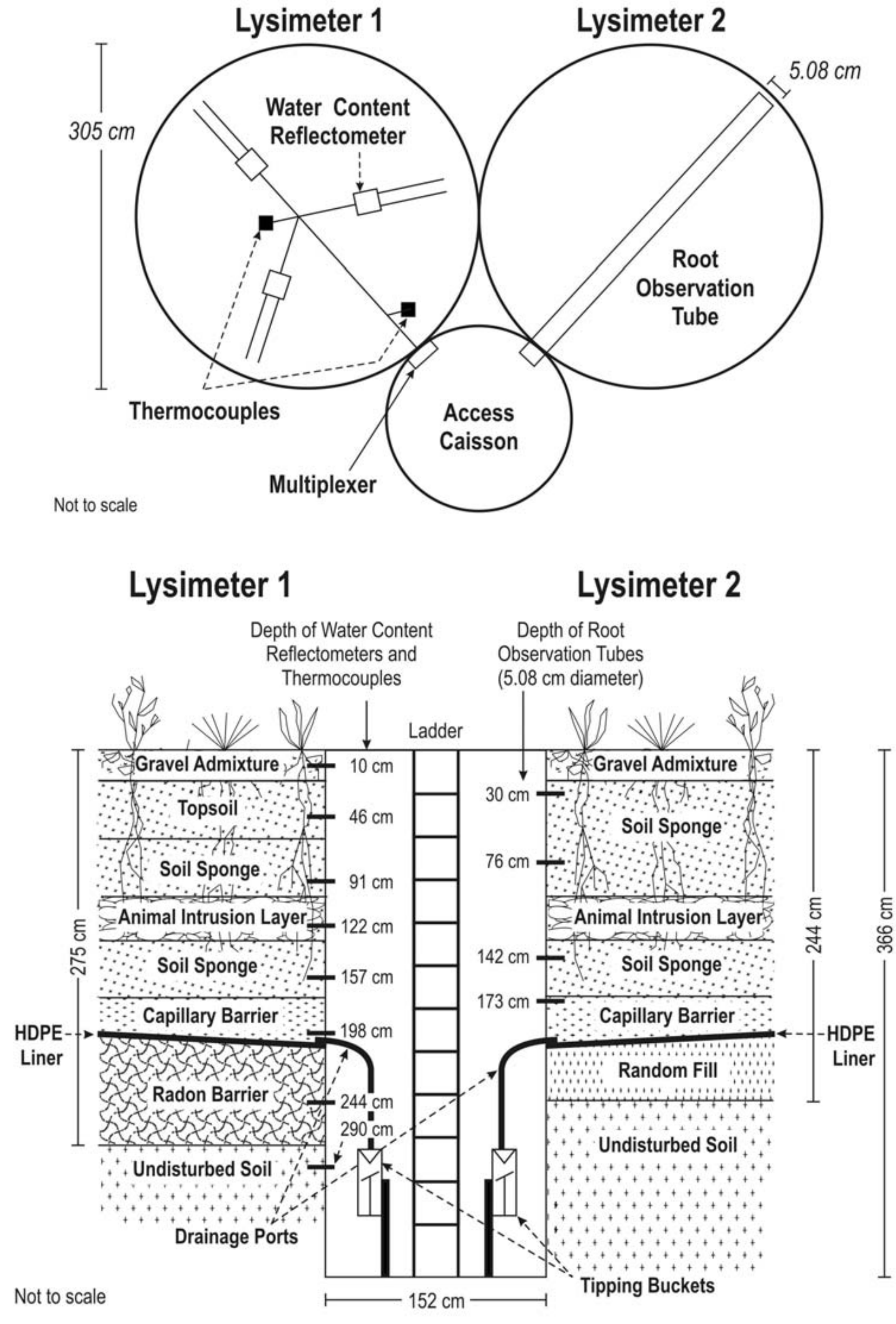

Figure 3. Plan view (top) and cross section (bottom) of instrumentation in the lysimeter and access caissons. Water Content Reflectometers, thermocouples, and root observations tubes, shown separately for purposes of illustrating layouts and depths, were all installed in both lysimeters.

Table 1. Species and seeding rates as planted on the Monticello cover.

Scientific Name	Common Name	PLS/Acre[a]
SHRUBS		
Ericameria nauseosa	Rubber rabbitbrush	1.5
Purshia tridentata	Antelope bitterbrush	1.0
Artemisia tridentata var. vaseyana	Mountain big sagebrushb	0.5
Artemisia tridentata var tridentata	Basin big sagebrush	0.1
Artemisia tridentata var. wyomingensis	Wyoming big sagebrush	0.05
FORBS		
Linum perenne	Blue flax[b]	2.0
Astragalus cicer	Cicer milkvetch[e]	1.6
Sphaeralcea coccinea	Scarlet globemallow[d]	0.5
Sphaeralcea grossulariifolia	Gooseberryleaf	0.5
Erigeron speciosus	Aspen fleabane	0.15
Achillea millefolium	Common yarrow	0.12
Machaeranthera tanacetifolia	Tanseyleaf tansyaster	0.05
GRASSES		
Bromus marginatus	Mountain brome[b]	4.0
Elymus lanceolatus	Streambank wheatgrass	3.0
Pascopyrum smithii	Western wheatgrass[b]	3.0
Stipa comata	Needle-and-thread grass	2.0
Achnatherum hymenoides	Indian ricegrass	2.0
Bouteloua gracilis	Blue grama[d]	1.0
Pleuraphis jamesii	Galleta	1.0

[a]PLS/acre = pure live seed per acre.
[b]Plants seeded and transplanted onto small lysimeters.
[c]Annual or biennial.
[d]Warm season (C4) species.
[e]Not native.

Monitoring Methods, Results, and Discussion

Evaluating the performance of the Monticello cover required a careful analysis of climate, soil hydrology, and plant ecology. Lysimeters enable us to evaluate performance of the cover as a system—an integrated whole—over diurnal, seasonal, and yearly time scales. Our monitoring instrumentation and methods focused on the components of the soil-water balance (precipitation, changes in water storage, drainage, and evapotranspiration) and on plant community composition and relative abundance.

Soil Water Balance

The caisson lysimeter soil surfaces are isolated from runoff and runon, thus ET was estimated using a simplified water balance equation:

$$ET = P - D - \Delta S,$$

where ET, P (precipitation), and ΔS (soil water storage changes) are recorded as mm of water. Precipitation, drainage, and water storage changes were monitored, and actual ET was estimated by difference.

Total annual precipitation, measured with a CSI weather station (Campbell Scientific, Inc., Logan, Utah) has been less than the 30-yr average (39 cm) since the lysimeters were planted in 2000. The 2002 growing season was particularly dry, with winter and spring precipitation about 50% and 15% of normal, respectively. Precipitation was only 57% of normal between November 2000 and June 2002, the critical period for plant establishment.

Soil moisture and water storage were monitored with CS-615 water content reflectometers (WCRs) manufactured by CSI. Drainage was monitored with tipping bucket rain gauges. Drainage did not exceed 0.1 mm/yr, well below the EPA target of <3.0 mm/yr. The only drainage occurred in spring 2000. The lysimeters were not planted until 2000 to allow water storage to build to the maximum limit for each soil type. No measurable drainage occurred during the dry years while vegetation was maturing.

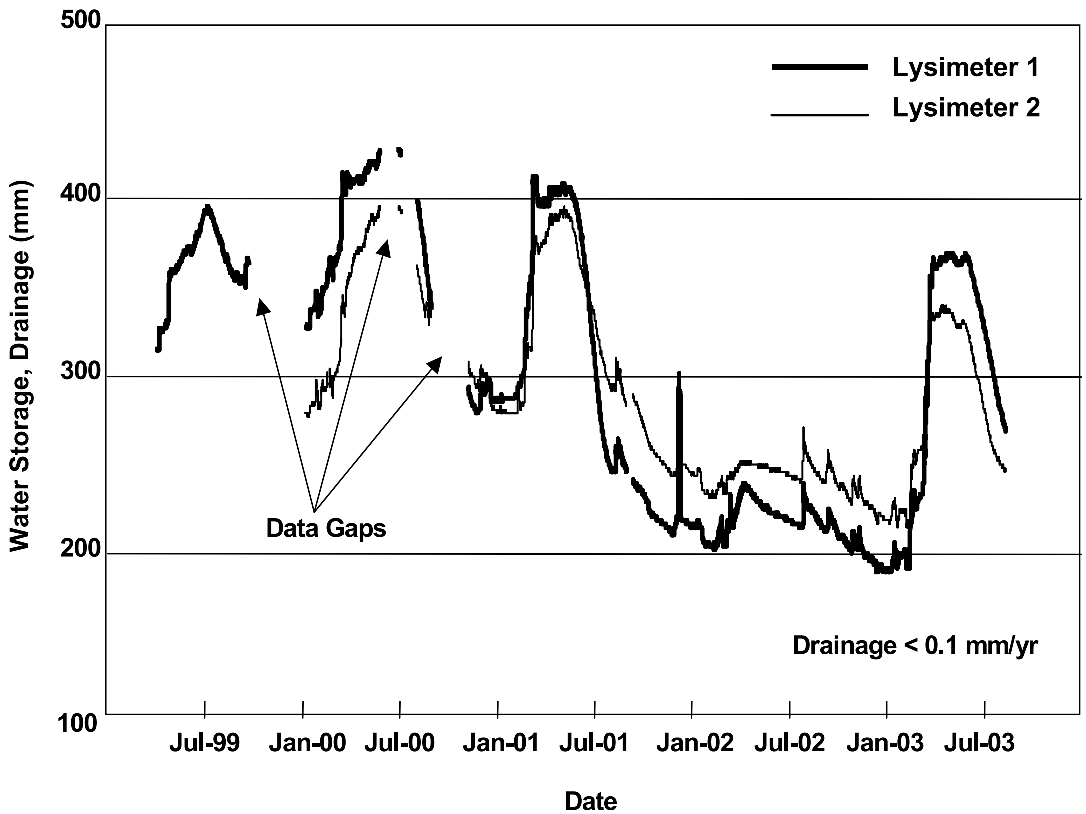

Figure 4. Soil-water storage time series in Lysimeter 1 (less compacted loam soil sponge) and Lysimeter 2 (more compacted clay loam soil sponge) between July 1999 and August 2003.

Time series of water storage changes show conspicuous seasonal variability and an overall drying trend (Figure 4). In both lysimeters, seasonal high and low water storage occurred in mid-to-late spring and mid-to-late fall, respectively, depending on the amount and seasonality of precipitation, the soil type and compaction, and the maturity of vegetation. The maximum storage in both lysimeters occurred in spring 2000 before plants became established. Because drainage also occurred at that time, water storage may have reached the maximum limit for each soil type: about 440 mm in Lysimeter 1 and 400 mm in

Lysimeter 2. The lower maximum storage limit for Lysimeter 2 as compared with Lysimeter 1 may be attributable to a lower porosity in the more compacted clay loam than in the less compacted loam. Once vegetation established during the dry years, the seasonal peak storage did not approach the limit in either lysimeter and no drainage occurred.

Seasonal low water-storage levels also differed between the two lysimeters. The difference is most likely attributable to differences in ET. During the 2000 growing season, before plants established, the seasonal low remained at about 280 mm; only about a 5-mm difference was observed between lysimeters. After plants became established, water storage in the less compacted loam (Lysimeter 1) dropped below 200 mm, about 30 mm below water storage in the compacted clay loam (Lysimeter 2). The water storage capacity of a soil layer can be calculated as the difference between the maximum storage limit and the lowest measured water storage level after the plant water potential reaches the wilting point. If this definition is used, the water storage capacity for the less compacted loam soil in Lysimeter 1 (about 250 mm) is more than 40% greater than the more compacted clay loam in Lysimeter 2 (about 175 mm).

Plant Abundance

The hydrologic performance of the Monticello cover relies, in part, on the establishment and resilience of a diverse plant community. Species composition, leaf area index (LAI), productivity, and percent cover were measured on the caisson lysimeters near the end of the 2002 and 2003 growing seasons. Species composition and percent cover were measured over the entire 7.3-m2 lysimeter surface. The lysimeter surface was divided into 50- by 100-cm quadrats delineated with string. A quadrat is an area of ground surface delimited for plant measurement. All plant species in each quadrat were recorded. We used an ocular point-intercept sampling method (Floyd and Anderson, 1982) to measure percent cover in each quadrat. LAI and productivity of green vegetation (current year's growth) were sampled in half of the quadrats by harvesting green leaf material and running the leaves through a Licor, Inc. LI-3100 Area Meter (www.licor.com). Green leaf material was harvested by hand or cut with shears, placed in paper bags, and processed soon after returning to the laboratory. Sagebrush green leaves were not removed because defoliation can stress or kill the plants.

Total percent cover for all plants growing in lysimeters, when averaged over years and lysimeters (37.1%, S.E.=0.6%, n = 4), was close to the minimum 40% cover criterion (Kastens and Waugh, 2002). However, as much as 20.6% cover or 56% relative cover consisted of species either not listed as a permissible or listed as noxious and non-noxious weeds (Table 2). Only about 16.5% of the cover consisted of permissible species, well below the requirement.

Total plant cover remained consistent between lysimeters and years (Figure 5). Green LAI, a better measure of the transpiration potential than percent cover, was significantly greater in 2002 on the less compacted loam (Lysimeter 1) than on the overly compacted clay loam (Lysimeter 2). Greater transpiration loss may partially explain the seasonally lower water storage values and consistently greater water storage capacity of the less compacted loam. As an apparent anomaly, productivity was highest on Lysimeter 2 in 2003, possibly attributable to the combination of a wet late summer, different species composition, and a later sampling date in 2003. Much of the high 2003 biomass on Lysimeter 2 is thick-stemmed alfalfa that re-greened following late summer rains.

OVERVIEW OF NATURAL ANALOGS OF LONG-TERM COVER PERFORMANCE

The performance of engineered covers will change in the long term as environmental conditions inevitably evolve in response to natural processes. Understanding how environmental conditions may change is crucial to designing, constructing, and maintaining long-term cover systems (Clarke et al., in press). Effective modeling and performance assessment requires scenarios based on both current and

Table 2. Plant species composition and percent cover.

Scientific Name[a]	Common Name[a]	% Cover
Permissible Species[b]		16.5
Grasses		15.1
Bromus inermis	Smooth brome	2.2
Pascopyrum smithii	Western wheatgrass	10.0
Thinopyrum intermedium	Intermediate wheatgrass	2.9
Forbs		1.4
Astragalus spp	Milk vetch	0.4
Sphaeralcea spp	Globemallow	*
Shrubs		1.0
Artemisia tridentata	Big sagebrush	0.7
Ericameria nauseosa	Rubber rabbitbrush	0.3
Non-Noxious Weed Species[b]		0.5
Kochia scoparia	Mexican fireweed	*
Salsola kali	Russian thistle	0.5
Not Listed as Permissible or Not Permissible[b]		20.1
Grasses		16.0
Achnatherum hymenoides	Indian ricegrass	0.3
Agropyron cristatum	Crested wheatgrass	1.1
Bromus tectorum	Cheatgrass	0.5
Elymus lanceolatus	Streambank wheatgrass	0.7
Elymus trachycaulus	Slender wheatgrass	2.8
Pseudoroegneria spicata	Bluebunch wheatgrass	3.1
Hesperostipa comata	Needle and thread	0.3
Unidentifiable perennial grasses		7.2
Forbs		4.1
Achillea millefolium	Common yarrow	*
Amaranthus blitoides	Mat amaranth	*
Chenopodium album	Lambsquarters	*
Linum perenne	Blue flax	2.6
Medicago sativa	Alfalfa	1.5
Taraxacum officinale	Common dandelion	*
Ground Surface		68.3
Soil		30.8
Rock		10.4
Litter		27.1

[a]Scientific and common names are consistent with the USDA Plants National Database.
[b]Plant categories are from revegetation acceptance criteria for the Monticello cover.

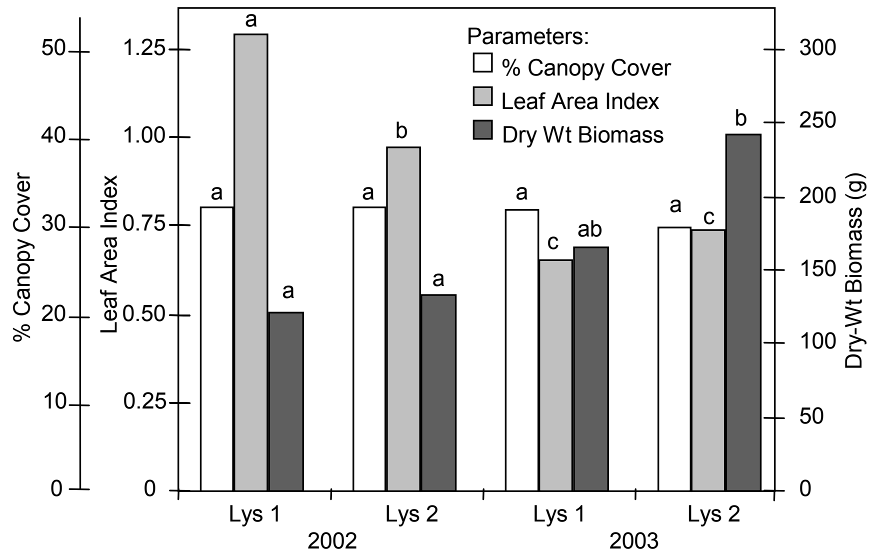

Figure 5. Percent cover, green LAI, and annual productivity comparing Lysimeters 1 and 2 in 2002 and 2003. Within-parameter bars with the same letter are not significantly different ($P < 0.05$).

possible future environmental settings (Ho et al., 2002). Natural analog studies help identify and evaluate likely shifts in cover environments that cannot be predicted with model extrapolations of short-term field tests (Waugh et al. 1994). Natural analog information is needed (1) to engineer cover systems that mimic favorable natural systems, (2) to bound possible future conditions for input to predictive models and field tests, and (3) to provide clues about the possible evolution of engineered covers as a basis for monitoring leading indicators of change. Natural analogs also help demonstrate to the public that numerical predictions have real-world complements. DOE and its partners have collaborated on studies of natural and archaeological analogs to discern possible long-term changes in the environmental setting of engineered covers, including climate change, pedogenesis (soil development), and ecological succession (Waugh et al., 2003).

Climate data are required for design and performance evaluations of engineered covers (Ho et al., 2002). Evaluations may require projections of long-term extreme events and shifts in climate states over 100s and 1,000s of years, as well as annual and decadal variability in meteorological parameters. DOE and its partners have demonstrated methods based on global change models and paleoecological evidence to establish a first approximation of possible future climatic states at the Monticello site. A preliminary analysis of paleoclimate data yielded average annual temperature and precipitation ranges of 2 to 10 °C and 80 to 60 cm, respectively, corresponding to late glacial and mid-Holocene periods (Waugh and Petersen, 1995). Instrumental records for stations within the Four Corners Region were then used as a basis for selecting soil and vegetation analog sites that span a reasonable range of future climate states for Monticello (Waugh et al., 2003).

Pedogenic (soil development) processes will change soil physical and hydraulic properties that are fundamental to the performance of engineered covers. Pedogenesis includes processes such as (1) formation of macropores for preferential flow associated with root growth, animal holes, and soil structural development; (2) secondary mineralization, deposition, and illuviation of fines, colloids, soluble salts, and oxides that can alter water storage and movement; and (3) soil mixing caused by freeze-thaw activity, animal burrows, and the shrink-swell action of expansive clays (Chadwick and Graham, 2000). DOE and its partners have measured key soil physical and hydraulic properties in natural and archaeological soil profiles at climate analog sites to infer possible future pedogenic effects on the performance of the Monticello cover (Waugh et al., 2003).

Plant communities will establish and change on soil covers, whether intended or not, in response to climate, to soil development, and to disturbances such as fire, grazing, or noxious plant invasion. Changes in plant abundance, evapotranspiration rates, root penetration, and animal burrowing may alter the soil water balance and stability of a cover. DOE and its partners draw evidence of possible future ecological changes from successional chronosequences. For example, at the Lakeview, Oregon, disposal site, possible future responses of plant community composition and LAI to fire were evaluated using a nearby fire chronosequence. Possible vegetation responses to climate change scenarios were evaluated at regional global-change analog sites. LAI, as an index of plant transpiration, ranged from 0.15 to 1.28 for the fire chronosequence and from 0.43 to 1.62 for dry and wet climate analog sites.

CONCLUSIONS

The U.S. Department of Energy in Grand Junction, Colorado, has learned several lessons from monitoring, designing, and evaluating the long-term performance of engineered covers for uranium mill tailings disposal cells that could be of benefit to designers of the next generation of covers.

Early covers that rely on compacted soil layers (CSLs) to limit water movement into tailings may fall short of permeability targets. Many inadvertently created habitat for deep-rooted plants. Root intrusion and soil development in several covers has increased the saturated hydraulic conductivity (Ksat) several orders of magnitude above design targets. At the Shiprock, New Mexico site, a saturated CSL and a high Ksat indicate that more water than expected might be passing into the tailings. DOE may measure flux directly to assure that ongoing efforts to remediate ground water are not compromised by seeping of contaminants from the disposal cell. Saturated flow into tailings is likely occurring in the Burrell, Pennsylvania disposal cell. However, at Burrell, because of low contaminant concentrations in the disposal cell, a risk assessment indicates that root intrusion and increased saturated flow are not adversely impacting human health or the environment (Waugh et al., 1999).

Relatively low precipitation, high potential evapotranspiration (ET), and thick unsaturated soils favor long-term hydrologic isolation of buried waste at arid and semiarid sites. Alternative ET covers, such as the one designed for the Monticello, Utah, Superfund site, mimic this natural soil-water balance. The Monticello cover relies on a thick soil sponge layer overlying a sand-and-gravel capillary barrier to store precipitation while plants are dormant, and native vegetation to dry the sponge layer during the growing season. Lysimeters were constructed to match the range of as-built conditions in the Monticello cover. Results show that since 2000, about 0.1 mm of drainage occurred in both lysimeters during an average precipitation year and before they were planted, an amount well below the EPA target of <3.0 mm/yr. However, the cover with a less compacted loam topsoil had a 40% greater water storage capacity than the cover with overly compacted clay loam subsoil. The lesson learned is that seemingly subtle differences in soil types, sources, and compaction can result in salient differences in performance.

An objective for building alternative covers, given unprecedented longevity requirements, is to accommodate long-term ecological processes with the goal of sustaining performance with as little maintenance as possible. Investigations of natural analogs can provide insights as to how ecological processes may influence the performance of engineered covers, processes that cannot be addressed with short-term field tests or existing numerical models. Evidence from natural analogs can improve our understanding of (1) meteorological variability associated with possible long-term changes in climate; (2) vegetation responses to climate change and disturbances; (3) effects of vegetation dynamics on ET, soil permeability, soil erosion, and animal burrowing; and (4) effects of soil development processes on water storage, permeability, and site ecology.

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INTEGRATING RESTORATION PRINCIPLES INTO ALTERNATIVE RCRA COVER DESIGN AT ROCKY MOUNTAIN ARSENAL NATIONAL WILDLIFE REFUGE

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ABSTRACT

Alternative designs for RCRA landfills may be more appropriate than prescribed or conventional designs, especially for sites in arid or semi-arid climates. Desiccation cracks in compacted clay, failing of geomembrane liners and poor habitat are among the problems associated with conventional designs. Alternative designs are constructed to mimic natural systems with a sufficient thickness of surface soil to store anticipated natural precipitation while sustaining established vegetation. During periods when infiltration exceeds evapotranspiration (e.g. late winter and spring in the Denver, Colorado region), the surface soil layer of alternative covers acts like a sponge to absorb and store precipitation. Evaporation and plant transpiration then act as a pump to dry out the soil so that more storage capacity becomes available. The objective of an alternative design is the same as for a conventional design, i.e. prevent percolation thus isolating ground water from contaminated leachate.

Important principles integrated into the design to promote ecological restoration of the sites include sufficient soil depth and fertility, appropriate cover soil placement density, cover soil texture specifications, diverse seed mixes and flexible maintenance activities. Details of these design features are presented.

INTRODUCTION

Rocky Mountain Arsenal National Wildlife Refuge (RMA) consists of approximately 27 square miles purchased in 1942 by the United States Army (Army) on which to manufacture chemical weapons. The map below illustrates the location of RMA within the Denver Metro area.

Figure 1. RMA site location.

After World War II, the Army leased on-site facilities to a series of companies for the production of chlorine, caustic soda, and pesticides. In 1952, Shell Chemical Company (Shell), now Shell Oil Company, became the primary lessee and continued to produce agricultural pesticides on-site until 1982. During this period, the Army and Shell used accepted waste disposal practices that resulted in contamination of soil, groundwater, and structures.

RMA is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List site. An on-post operable unit Record of Decision (ROD), which describes the site-wide remedy (FWENC, 1996), was signed by the Army, Colorado Department of Public Health and Environment (CDPHE), and the Environmental Protection Agency (EPA) in 1996, with concurrence from Shell and the USFWS. Shortly thereafter, a Site-Wide Implementation Plan, which outlines the selected remedy for RMA, was prepared by the Remediation Venture Office (RVO), which consists of the Army, the United States Fish and Wildlife Service (USFWS), and Shell. The ROD consists of 31 remedial projects that will be implemented over a period of approximately 12 years. The Program Management Contractor (PMC) selected to implement the remedial projects is Tetra Tech FW, Inc. Once the remediation of RMA is completed, the site will become a national wildlife refuge, as designated by the RMA National Wildlife Refuge Act of 1992, and will be managed by the USFWS.

The ROD and subsequent agreements with regulatory agencies allowed for the construction of Alternative Design RCRA covers over five remedy areas: Basin F Disposal Area, Basin A Section 36 Disposal Area, the Central Processing Area of the South Plants Area, the Shell Trenches and the Complex Army Trenches. The ROD also required a comparative analysis and construction of a demonstration of the Alternative RCRA Design in order to demonstrate cap performance equivalent to a conventional RCRA landfill cap design. To facilitate design, construction and monitoring of the demonstration covers, as well as the ROD specified Alternative Design RCRA covers, a working group was established composed of technical representatives from the RVO, PMC, EPA, CDPHE and Tri-county Health Department.

The Demonstration Project was constructed in the spring of 1998. It consisted of four test covers utilizing two different soil types and three different cover depths. The covers were seeded with a diverse mix of native grasses and forbs. The test year began September 1, 2000, and ended August 31, 2001. The four covers were irrigated to supplement natural precipitation during each month of the test year at a rate to achieve a monthly total goal of the 75th percentile of historical monthly precipitation in the region (1948-1996). More than 21 inches of water fell on the test covers during the test year. The success criterion by which the four covers were judged was a value of 1.3 mm of percolation per year. All of the covers were successful.

Following the successful completion of the field demonstration, the working group evaluated the Demonstration Project and established design criteria for the full-scale RCRA equivalent cover implementation projects.

OBJECTIVES

Objectives in the working group agenda included setting criteria for soil texture, placement density, and fertility; determining an appropriate seed mix; and suggesting a maintenance program to preserve cover function and sustainability of a native grassland vegetation community. The results of various investigation programs to determine these criteria are described.

METHODOLOGY/RESULTS

Soil Texture

As mentioned, all four of the test covers were successful in passing the percolation performance criterion established for the field demonstration. The computer model UNSAT-H (Fayer, et al. 1990) was used to compare the predicted percolation performance of samples of prospective borrow area soils, compacted to various densities, to the predicted performance of Test Cover soils when tested at their in situ densities. The model simulates infiltration, drainage, moisture redistribution, surface evaporation, and plant-water uptake from soil. It uses daily or hourly precipitation data and daily meteorological data to model surface fluxes of moisture and energy, as well as plant interactions in the hydrologic processes. Soil comparisons were made by varying parameters that describe the hydraulic characteristics of the soils, while holding constant all other model input parameters and data. Soils with shallower predicted percolation penetration depths are deemed better with respect to reducing percolation than soils with deeper percolation penetration depths. A soil Acceptance Zone (AZ) was developed to include soil textures that, when compacted within a prescribed density range, have predicted performance that is as good as or better than the soils in the test covers when tested at their in situ densities. In addition to the modeling comparisons, some agronomic constraints were also imposed on the AZ. Agronomic specialists within the working group determined that neither soils having a clay content greater than 40 percent nor a silt content greater than 60 percent should be used in the final covers. The agreed upon AZ is depicted in Figure 2.

Soil Placement Densities

Within the working group, two views regarding soil placement density were expressed. Purely engineering considerations suggested that high placement density (i.e. 90-95% of standard Proctor) could improve performance of the covers by limiting percolation. Ecological considerations insisted that placement densities below the Growth Limiting Bulk Density (GLBD) (Goldsmith 2001) and more consistent with in situ soil densities were appropriate in order to establish and sustain healthy plant communities.

To resolve these differing approaches, information for three soil density related features was collected. In situ soil density was measured on the test covers and at grassland locations on RMA supporting healthy vegetation. In addition, density sensitivity testing was conducted to show how predicted cover percolation performance varied with density.

Soils in the test covers at the RMA had densities that ranged from 72.1 to 82.8 percent of the maximum Proctor density when sampled in 2002. The constructed densities would have been somewhat lower, as some settlement of the covers was documented prior to 2002. Therefore, based on the success of the test covers, constructed densities as low as 72 percent of maximum Proctor density, if not lower, have been acceptable.

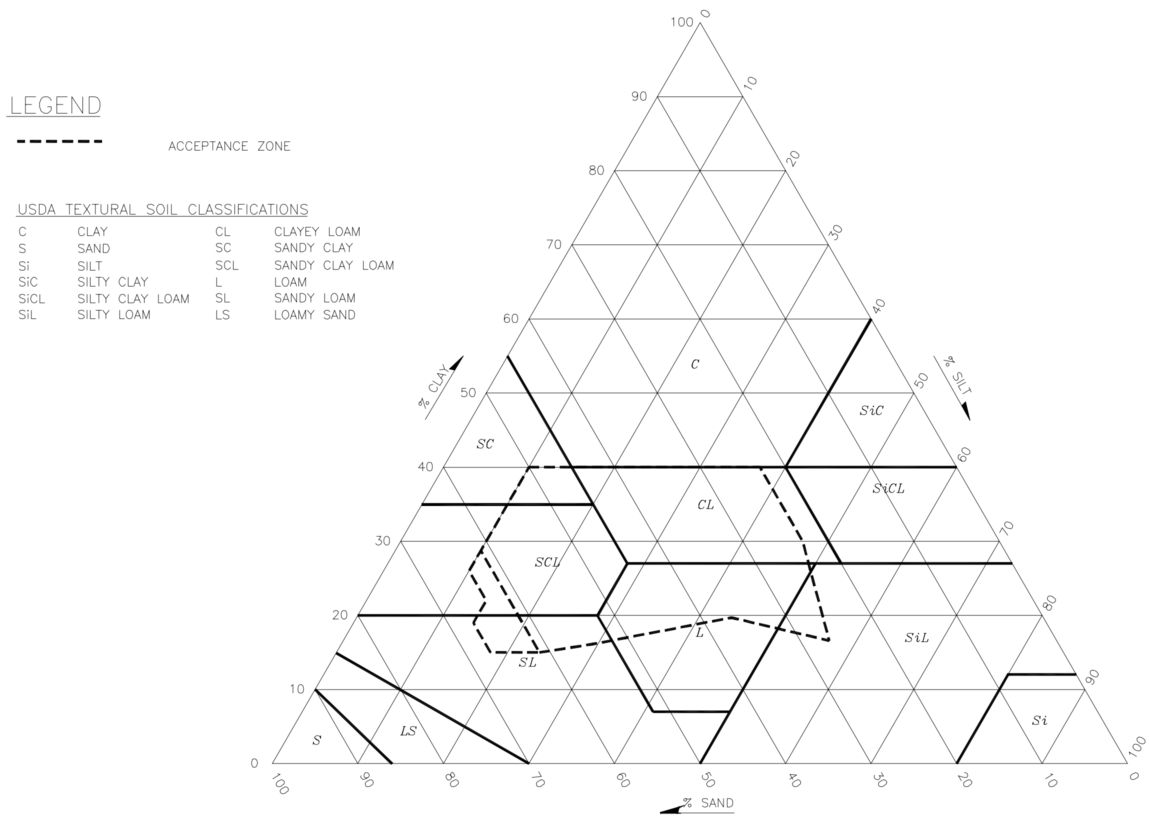

Figure 2. Acceptance Zone

As reported by Kiel et al .(2003), measured in situ bulk densities of undisturbed short-grass prairie soils at RMA have been close to 85 percent of the maximum Proctor density. These in situ densities are generally below the respective GLBDs for the soils.

When model sensitivity to changes in soil density was tested, UNSAT-H modeling results almost always predicted less percolation at higher soil compaction densities. The low hydraulic conductivity values for these densely compacted soils resulted in the model generating increased surface runoff, which in turn resulted in unrealistically low predicted infiltration rates into the soils. Surface erosion associated with increased surface runoff could be addressed with additional engineering applications. However, that type of design would defeat achieving one of the most important design considerations for the alternative covers at RMA (i.e. cover designs that are compatible with the long term land use as a National Wildlife Refuge). The resulting highly engineered designs would not blend into the surrounding landscape nor would highly compacted soils allow establishment and growth of native prairie grasses otherwise adapted to the region.

The basis for the alternative RCRA cover design is the sustained growth of a healthy plant community. Plant transpiration moves soil moisture from the rooting zone up through the plants to the atmosphere thus drying the soil and preventing percolation into the underlying contaminated material. A secondary objective of the alternative covers beyond preventing percolation of soil moisture into underlying waste material is to provide appropriate habitat for current and future refuge wildlife. Establishing a healthy, native grassland community on the cover sites is necessary to achieve both goals.

After considering the information outlined above, a construction density specification of 75 to 85 percent of maximum Proctor density was selected. That density range is generally below the GLBD, but higher than the lowest densities measured on the successful test covers. A wider density range might be suitable from the perspective of vegetation growth and acceptable percolation performance, but limiting the range to only 75-85 percent of maximum Proctor density reduces the potential for differential settlement on the covers, while still being a sufficiently wide range to be practical to construct. Additionally, it is expected that the cover densities would remain within or near this range since, as stated above, the range includes the typical in situ densities of undisturbed, vegetated prairie soils at RMA (i.e. 85 percent of maximum Proctor density).

Soil Thickness

Soil thickness is also an obvious consideration for limiting percolation on alternative RCRA covers. At RMA, soil thickness for covers was determined by considering UNSAT-H predictions, depth of maximum soil freezing, performance of various test cover thickness, long term erosion potential and rooting depth of native grasses.

Modeling results performed for much of the perspective borrow soil indicate that a soil thickness of approximately 24 inches would be sufficient to contain the majority of naturally occurring precipitation. This modeling result can be supported by observation of soil pits at RMA. The depth to the Bk soil zone is approximately 24 inches (James P. Walsh and Associates, Inc., 1991) in most of the soil considered appropriate to construct the covers. (Bk zone is identified by an accumulation of carbonates and indicates the depth to which average percolation has occurred over the current climatic time frame.)

Depth of the frost zone was also a factor determining soil cover thickness. When frozen soil is a consideration, utilities are commonly placed a minimum of 36 inches below the surface. For alternative covers at RMA, an 18-inch layer of concrete cobble will serve as a barrier to burrowing animals. If placed in the soil cover above the frost zone, this biota barrier would be subject to freeze/thaw activity and could migrate to the surface over an extended time period. Therefore, a minimum soil thickness of 42 inches was selected as a conservative thickness to address frost zone concerns.

Soil depth required to sustain a diverse plant community over time and through drought was an additional consideration. Weaver (1954) has documented roots of upland prairie grasses to reach depths of greater than 6 feet. The bulk of the root system for these species is contained in the surface 3 feet of soil. Kulakow (2003) measured root development on the test covers after four growing seasons and found a few roots growing to the bottom of each cover, but with the bulk of the root mass in the upper three feet. This information suggested that a soil cover thickness of 3 to 4 feet may be sufficient to sustain vegetation.

Soil loss due to erosion calculated for the 1000-year time frame indicated that a slight amount of soil thickness could be lost during the time period. In order to compensate for potential soil loss from erosion, 6 inches of soil was added to the 42 inches considered protective of the biota barrier for a total of a minimum of 48 inches. Test covers constructed with 42, 48 and 60 inches of soil material all successfully passed the field demonstration criteria (1.3 mm/year), and have supported a healthy, diverse plant community. Therefore, it is expected that 48-inch covers for the RCRA implementation projects will be sufficient.

Cover Soil Fertility

RCRA alternative covers at RMA will be constructed with relatively sterile and nutrient poor borrow soils from on site. Topsoil is not available and borrow material will be extremely low in organic matter and nitrogen. Borrow area characterization studies have indicated that levels of carbonates may be moderately high, pH moderately high and cation exchange capacity moderately low. Other soil agronomic properties measured in borrow areas are in the adequate range (Table 1). Analyses for micronutrients were not conducted.

Table 1. Soil agronomic properties.

Property	**Relative Value**
pH	Moderate
Electrical Conductivity	Low
Available Phosphorus	Adequate/low
Available Potassium	Adequate
% CaCO3 Equivalent	Moderately high
Cation Exchange Capacity	Moderately low
Sodium Adsorption Ration	Low

To ameliorate the effect of the lack of organic matter and nitrogen in borrow soil, as well as other plant nutrients in the low range of availability, compost will be tilled into the surface 8-12 inches of the constructed covers at a rate of 20 dry tons of organic matter per acre (e.g. compost with 50% organic matter by weight will be spread at a rate of 40 dry tons per acre). Compost will also improve other plant nutrient characteristics such as available phosphorus and cation exchange capacity, and improve soil physical attributes.

Borrow soils with a pH greater than 8.8 will not be used in cover construction. If soil placed during cover construction has a pH greater than 8.4, amendments (e.g. elemental sulfur) will be added to the surface 8-12 inches at a rate sufficient to reduce the pH to about 8.0.

Diverse Seed Mixes

For the "biological pump" to be most efficient at limiting percolation by drying the cover soil through transpiration, a diverse stand of vegetation dominated by grass species is appropriate. Cool season grasses are necessary to initiate transpiration early in the growing season and extend transpiration late in the season. Warm season grasses provide transpiration during hot summer months when cool season species may be dormant, but monsoon precipitation common. Both bunch grass and rhizomatous species are desirable to provide maximum structural diversity and erosion protection. Taller native species are preferred to maximize leaf area and thus transpiration. The tall species may also serve as a deterrent to prairie dog invasion of cover sites. Drought tolerance is also a desirable characteristic. Although all grassland species native to the region are drought tolerant, blue grama grass and buffalo grass are most drought tolerant and, although short, are included. Alkali sacaton was also included to provide a species that would be adapted to microsites of soil with moderately high pH. To further enhance species diversity, appropriate forb and "half-shrub" species were included as five percent of the seed mix.

To deter rooting into the grade fill and beyond, as well as preserve the integrity of the biota barrier, shrubs and other deep or tap-rooted species were excluded from the mix. The seed mix for use on alternative RCRA covers for the South Plants area at RMA is presented in Table 2.

Table 2. South Plants RCRA Cover Seed Mix

NATIVE GRASS SPECIES				
Scientific Name	**Common Name**	**Variety**	**Pounds PLS/Acre**	**%**
Buchloe dactyloides	Buffalo Grass	Cody	0.7	2.5
Buchloe dactyloides	Buffalo Grass	Native*	0.7	2.5
Bouteloua gracilis	Blue Grama	Alma	0.05	2.5
Bouteloua gracilis	Blue Grama	Native*	0.05	2.5
Panicum virgatum	Switchgrass	Nebraska 28	0.4	10
Bouteloua curtipendula	Side-oats Grama	Vaughn	0.8	10
Sporobolus airoides	Alkali Sacaton	Salado	0.02	2.5
Sporobolus cryptandrus	Sand Dropseed	Native*	0.01	2.5
Schizachrium scoparium	Little Bluestem	Pastura	0.6	10
Pascopyrum smithii	Western Wheatgrass	Arriba	4.2	30
Stipa comata	Needle-and-thread	Native	0.7	5
Elymus trachycaulus	Slender Wheatgrass	Pryor or Revenue	0.5	5
Elymus lanceolatus	Thickspike Wheatgrass	Critana	0.5	5
Koeleria cristata	Prairie Junegrass	Native	0.02	2.5
Elymus elymoides	Bottlebrush Squirreltail	Native	0.02	2.5
		Subtotal	9.26	95
NATIVE FORBS (Wild Flowers)				
Erysimum asperum	Wallflower		0.004	.25
Gaillardia aristata	Blanket Flower		0.03	"
Penstemon angustifolius	Narrow-leaf Penstemon		0.007	"
Linum lewisii	Blue Flax*		0.01	"
Helianthus annuus	Annual Sunflower		0.07	"
Cleome serrulata	Rocky Mountain Bee Plant		0.06	"
Liatris punctata	Blazing-star		0.03	"
Oenothera villosa	Tall Evening-primrose		0.004	"
Coreopsis tinctoria	Plains Coreopsis		0.003	"
Achillea millefolium	Yarrow		0.001	"
Lupinus argenteus	Silverleaf Lupine		0.2	"
Oenothera caespitosa	White Tufted Evening Primrose		0.004	"
Petalostemum purpureum	Purple Prairie Clover		0.005	"
Ratibida columnaris	Prairie Coneflower		0.003	"
Sphaeralcea coccinea	Scarlet Globemallow		0.01	"
Artemisia frigida	Fringed Sagebrush		0.001	"
Artemisia ludoviciana	Prairie Sage		0.001	"
Rosa arkansana	Prairie Rose		0.08	"
Vicia americana	Vetch		0.2	"
Astragalus crassicarpus	Ground-plum		0.01	"
		Subtotal	0.733	5
Grass species: "Native" (*) seed varieties shall be from appropriate climatic region. Sources for native seed variety shall be subject to inspection and concurrence by the Contractor before Subcontractor is authorized to proceed with seeding.				
Forb species: For *Linum lewisii* (*) variety "APAR" which is the European *Linum perenne* is not preferred. Preferred species is the *Linum lewisii*.				

FLEXIBLE MAINTENANCE ACTIVITIES

Although the revegetation goal for the covers is to establish a self sustaining plant community, it is anticipated that plant communities on the covers will require a limited maintenance program. Data for vegetation community development and trends will be collected annually for the cover sites at RMA. These data will be used to both compare to previously determined establishment success criteria and to develop annual maintenance plans. Maintenance activities can include prescribed burning, rotational grazing, weed control, mowing and other methods for maintaining a healthy plant community on the covers.

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FIELD APPLICATION OF LASER POINT DEVICE FOR LINE AND POINT INTERCEPT METHOD

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ABSTRACT

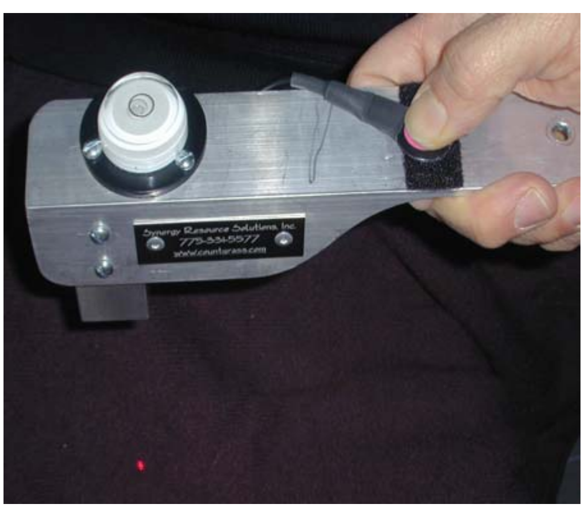
In an effort to increase speed, efficiency, and repeatability of point intercept and line intercept monitoring, Synergy Resource Solutions, Inc., developed a device that projects a 3-mm laser point on the vertical dimension. We have found it to increase efficiency and repeatability and to decrease observer bias. The Laser Point Device speeds the alignment portion of the process by using a single leg with leveling done by the observer. The device consists of a custom aluminum plate to hold a high-quality laser module with an instant on momentary pressure switch that is supported by a modified collapsible photography monopod and includes a bubble level as reference to maintain the laser at plumb. Additionally, data recording was customized to streamline data collection. This paper presents the Laser Point Device, sample data collection sheets, and suggests a protocol to increase efficiency.

INTRODUCTION

The laser point sampler is a small, accurate, easy to use, and affordable laser device for point intercept monitoring, line intercept monitoring, and any monitoring protocol that requires a repeatable, plumb/vertical line.

Point intercept and line intercept are commonly used methods for quantifying vegetation coverage. However, existing sighting devices are heavy, slow to use, and expensive. When observers attempt sighting a plumb line without a sighting aid, the selection of the monitoring points is often biased and sampling imprecise. Synergy's Laser Point Device produces a fine laser beam (3mm) that provides a precise, unbiased, plumb measurement point for basal and/or foliar cover monitoring. Moving vegetation in upper layers does not disturb the laser point. Therefore, sampling multiple layers of foliar canopy and measuring both foliar and basal cover are made simpler and more repeatable.

KEY FEATURES



- Lightweight (1 pound)
- Rapid application and alignment- each point takes 5 seconds or less (with practice alignment can come in 1 to 2 seconds on 80% or more of sample points)
- Increased precision- especially when compared to traditional methods (eyeball, dropped pin)
- Facilitates sampling of multiple canopy layers
- Eliminates the need for a plumb-bob or other device to determine foliar cover.
- No plumb-bob string to hang up in thorny vegetation (No sticking your hands where you don't want them to go)
- Inexpensive: ~$200.

Figure 1. Close-up of the Laser Point Device with Laser Beam.

TIPS AND TRICKS

- Find the balance point for the device in your hand and you will find that you can position the laser in the plumb position with high frequency, eliminating time for alignment.
- The procedure is generally most efficient with 2 observers, one to position the laser and another to determine the "hit" and record.
- Extending the monopod to a length where the device can be placed with the elbow locked against the hip increases stability and speed.
- Because the laser projects a plumb line regardless of height, it is often more desirable to run the tape across the tops of shrubs rather than create damage to foliage working the tape all the way to the ground.
- The tape can be at different heights along the line. Align the tape with the same flat edge along any of the monopod sections.
- The trigger can be pushed with a thumb on top of the plate or with a knuckle of the first finger below the plate.

LINE INTERCEPT PROTOCOL

- Lay out tape.
- Determine the minimum size that will be measured as a "gap".
- Start at the "zero" end of the tape and move the laser beam along the tape until the beam hits the first plant.
- Align the laser pointer above the tape so that half of the laser beam is on the tape and the other half on the ground.
- For each plant hit by the laser beam, record the starting and ending measurement on the data sheet (Figure 2).
- Line intercept is easier with the laser beam constantly lit.
- With practice line intercept can be run with just the "head" of the device, i.e. without the monopod.

Sweet Grass Ranch

Point Intersept Method, 100 m Transect

Location: Mountain Pasture	**Date:** Aug-8-2003	**Time:** 8:50 AM	
Transect: 5	**Observers:** JDA, JK	**Pictures:** 8:55 AM	
GPS Point 0 m: 5S	**100 m:** 5E		**Sheet 1/2**

	Growth Form							Growth Form					
M	**Graminoid**	**Forb**	**Shrub**	**Bare**	**Litter**	**Rock**	**M**	**Graminoid**	**Forb**	**Shrub**	**Bare**	**Litter**	**Rock**
1	F				X		26	F	A				
2	F			X			27			F		X	
3		X					28			F		X	
4	X		F				29	F		F X			
5	F					X	30			F		X	
6	F				X		31	F				X	
7			F		X		32	F					X
8			F X				33		F		X		
9			F		X		34			F		X	
10			F		X		35			F		X	
11			F		X		36			F X			
12	F	A					37	F		F		X	
13			F		X		38	F				X	
14			F			X	39		F				X
15	F	F	F X				40	F X					
16	F		F	X			41	F	A				
17	F				X		42			F			X
18	F X						43			F		X	
19	F						44			F X			
20		F				X	45	F X		F			
21					X		46			F		X	
22					X		47		F		X		
23			F		X		48	F		F			X
24	F		F X				49	F X					
25			F		X		50	F				X	

Notes:

X: Basal Cover, F: Foliar Cover, A: Annual Plant

Synergy Resource Solutions, Inc.

Figure 2. Point Intercept Field Data Sheet.

POINT INTERCEPT PROTOCOL

- Lay out 100m or 100ft tape so that it is straight and tight.
- Draw a line along the edge of the left side of one of the flat areas on the monopod leg.
- Fix the head of laser pointer so that it points in a 90 degree angle to the flat area with the place line.
- Line the laser pointer up on the tape so that the flat area touches the tape and the black line is lined up with the meter or foot mark.
- Press the trigger of the laser pointer when the bubble on the level is centered in circle and read what the laser beam is hitting.
- Record on field data sheet (Figure 3).
    - Mark as F (foliar) on the data sheet for the species if the laser beam is hitting leaves on the way down.
    - Mark with an X if the base of a perennial species or rock, bare ground, or litter is hit on the ground.
    - Mark with an A if the base of an annual species is hit.
- Point intercept can be less biased if the laser is not lit until the bubble is level.

Red Rock Ranch

Allotment:	3	**Date:**	16-Jun-03	**Time:**	16:20
Pasture:	Dry Creek	**Study Site:**	DC 7	**Observer:**	JDA, JK
Comments:		**GPS Point 0 ft:**	DC7S	**100 ft:**	DC7E

Species: AGSP		**Species:** ARTRW		**Species:** JUMO		**Species:** STTH		**Species:** FEID	
Begin	**End**	**Begin**	**End**	**Begin**	**End**	**Begin**	**End**	**Begin**	**End**
3.84	3.94	6.15	6.56	4.98	5.66	6.13	6.14	5.53	5.75
6.20	6.30	37.86	38.57	53.91	55.44	8.91	8.92	12.09	12.20
23.29	23.75	48.38	48.45	79.32	80.32	47.72	48.11	12.75	13.02
26.98	27.21	52.26	52.70			50.84	50.87	53.60	54.19
29.78	30.05	53.29	54.29			87.42	87.54	56.60	57.23
33.70	34.01	57.29	59.66			88.02	88.12	62.29	62.71
36.22	36.39	60.27	61.93					68.72	69.62
50.38	50.49	62.90	62.96						
50.58	50.62	94.44	95.50						
51.04	51.14	96.06	96.10						
65.95	66.09								
66.17	66.31								
88.63	88.75								

Synergy Resource Solutions, Inc.

Figure 3. Line Intercept Field Data Sheet.

ENGINEERING NATURALLY:
LEFTHAND CREEKCHANNEL IMPROVEMENT PROJECT

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ABSTRACT

The Lefthand Creek Channel Improvement Project in Longmont, Colorado rehabilitated a previously channelized 1.4 kilometer reach of Lefthand Creek to more natural conditions, created a wetland mitigation site for the project and for the Ken Pratt Boulevard (State Highway 119) Extension project, and reconstructed the artificially wide 100 year floodplain allowing construction of the Ken Pratt Boulevard extension and a City recreation center.

Through the teamwork of City staff; Colorado Department of Transportation; Colorado Division of Wildlife, and Carter & Burgess engineers, environmental planners, landscape architect, and wetland scientist, the project evolved from designing a trapezoidal concrete and riprap channel to creating a meandering creek with pools and riffles. Channel stabilization techniques included root wad and log structures built from materials salvaged on site, boulder placement, Wetland Rollsod® matting, and transplant of vegetation removed during channel relocation. Following grading, the site was seeded and plugged with native vegetation. Completed in 2002, the new corridor satisfies the City's planning requirements, provides high quality wildlife habitat, and is a scenic asset to the citizens of Longmont.

INTRODUCTION

The Lefthand Creek Channel Improvement Project in Longmont, Colorado is a flood control project also used for stream rehabilitation (FISRWG, 1998) and creation of mitigation wetlands.

Flowing from headwaters in an alpine basin south of Brainard Lake across the plains to its confluence with the Saint Vrain River in south Longmont, Colorado, Lefthand Creek is typical of Front Range streams. Since European settlement in the mid 1800s, the plains reaches of this creek have been heavily grazed, the native cottonwood forests cut for lumber and firewood, and the streambed channeled into a straight, steep-banked course to accommodate agricultural fields and bridge crossings. Additionally, irrigation diversion structures transfer flows at many points along the stream.

As the urbanization of Longmont has spread south from the historic downtown area, the City of Longmont (City) proposed grading a new Lefthand Creek 100 year flood channel to allow both extension of Ken Pratt Boulevard from Main Street (US 287) to a new connection at State Highway 119 and siting of 128 hectares of city, residential, and commercial development. Due to stream channelization, the 100 year floodplain in the project area upstream of the Lefthand Creek and Saint Vrain River confluence was approximately 1.2 kilometers wide.

Longmont goals to be addressed during the project initially included:

- Narrowing the Lefthand Creek floodplain to remove developable land out of the floodplain including the new 3.8 kilometer segment of Ken Pratt Boulevard and the new Longmont Recreation Center.
- Construction of a bicycle and pedestrian trail to the recreation center under the City Greenway Plan.
- Placement of utility sleeves for future development and preparation of a future Martin Street bridge location.
- Maintenance of the Bonus Ditch irrigation diversion structure downstream of the new Ken Pratt Boulevard Bridge.

SITE CONDITIONS

Initial Site Conditions

As we undertook to provide floodway solutions for Longmont, our studies included documentation of the current Lefthand Creek flood capacity, wetland area and condition, subsurface geology, groundwater, and historic conditions.

At project commencement in 1999, both sides of Lefthand Creek were actively cultivated with irrigated row crops and the Baker Farm with the only stream crossing in the area was the center of vegetable packing for distribution. Channelization of flows in Lefthand Creek and its tributary, Dry Creek, had eliminated the natural floodplains. Lefthand Creek conveyed only the 10 year flood of approximately 22 cubic meters per second (Carter & Burgess, Inc., 2000). Engineering analysis estimated the 100-year flood of 132 cubic meters per second to extend up to 480 meters north and 750 meters south. The active stream channel varied from 2.5 to 6.3 meters wide and flows were typically 0.3 to 0.6 meters deep.

Lefthand Creek, 1999, view to east toward location of future Ken Pratt Boulevard Bridge.
Note narrow wetland bands, trash, concrete chunks stabilizing banks, and adjacent truck trailer parking.

Wetland delineations showed narrow (1 to 9 meter) bands of emergent and scrub-shrub wetlands along the steep-banked stream. Dominant vegetation was native sandbar willow (*Salix exigua*) and peach-leaved willow (*Salix amygdaloides*) as well as non-native reed canarygrass (*Phalaroides arundinacea*) and crack willow (*Salix fragilis*). Scattered native plains cottonwoods (*Populus deltoides* subsp. *monilifera*) were also present. Canada thistle (*Breea arvensis*), a State of Colorado Top Ten Noxious Weed, infested much of the upper stream banks.

Geotechnical studies provided information on subsurface conditions (Kleinfelder, 2001). A layer of sand and gravel with cobbles was present approximately 2 meters below the surface of the fields adjacent to the channel. This layer is underlain by impermeable claystone. Crop irrigation and the Bonus Ditch diversion structure just downstream of the project area made site hydrological conditions complex. Groundwater monitoring showed site groundwater at depths of 1 to 1.5 meters in the adjacent to the upper creek banks during the growing season.

Historic Site Conditions

My research in the City Public Works files uncovered historic aerial photographs from 1949 and 1955 showing that the Lefthand Creek channel had been altered prior to the mid 1900s. Old stream meanders extending approximately 70 meters north of a channelized stream course and two areas of wide mature tree overstory are evident on a 1949 aerial photograph of the south Longmont area. In contrast, my on-site investigations of a relatively undisturbed upstream plains reach of Lefthand Creek at the Boulder County Parks and Open Space Brubaker Property showed two to three stream terraces with gentle side slopes are gentle approximately 0.3 to 1.3 meters high. The Brubaker Property is the site of a multi-year revegetation project undertaken by the County and Wildlands Restoration Volunteers. Dense riparian forests with cottonwood and crack willow border much of Lefthand Creek.

DESIGN PROCESS

The design process was a collaborative effort of civil, structural, and hydraulic engineers; landscape architects; environmental planners; and a wetland scientist (myself). Prior to selection of final design, the team eliminated four alternatives:

- No construction of channel improvements to narrow the floodplain and instead elevation of the Ken Pratt Boulevard extension on 1.3 meters of fill at an additional cost of $650,000.
- Construction of a dike along the existing stream channel.
- Purchase of addition land south of the stream to grade a new parallel overflow channel.
- Construction of a straight, trapezoidal, riprap lined channel with 45 meter top width, 2 meter channel depth, and 6 meter wide grass lined low terrace.

Seeing an opportunity to use the floodway project as stream rehabilitation for a very degraded reach of Lefthand Creek, the environmental planners and I recommended inclusion of stream meanders and natural riparian vegetation.

Our project coordination with the City of Longmont, U.S. Corps of Engineers, Colorado Department of Transportation, and Colorado Division of Wildlife identified further concerns including preservation of habitat for both sport fish and common shiner *(Notropis cornutus)* and stonecat *(Noturus flavus)*, rare fish species known to be present in the nearby Saint Vrain River as well siting of wetland mitigation for the Ken Pratt Boulevard Project. Following a series of meetings, project team members added the objectives of rehabilitating floodplain terraces and creek meanders, rehabilitation of aquatic and wildlife habitat, and creation of riparian communities and mitigation wetlands for both the Lefthand Creek and Ken Pratt Boulevard Extension Projects.

Final design specifications were a 75 meter top width channel, 1.8 to 2.1 meters deep to convey the 100-year flood. To achieve the ecological project objectives, the channel length was slightly increased and included a 3 meter wide meandering low flow channel with pools excavated every 7 to 9 stream widths. To avoid additional hauling and materials costs, excess graded material was placed inside curves to create gravel bars. Where possible within the constraints of the project corridor, designers maintained the existing stream channel minimum depth of the low flow channel for undisturbed fish habitat. Streambank grading specifications provided a low wetland terrace with an average 9 meter width, and a higher riparian terrace with an average 18 to 21 meter width and 4:1 slopes. The widened floodway channel was also able to accommodate tree and shrub plantings on stream terraces.

The U.S. Army Corps of Engineers permitted the project the Clean Water Act Section 404 Nationwide Permit #27 (Stream and Wetland Restoration Activities). The 404 permit specified 1:1 mitigation of wetland impacts. The Colorado Division of Wildlife provided Colorado Senate Bill 40 Wildlife Certification for state funded work in streams and streambanks.

CHANNEL CONSTRUCTION AND STREAM REHABILITATION

Channel Construction

The engineers timed channel grading for low flow conditions from October 2001 to January 2002. Under the direction of Duran Excavating, heavy earth moving equipment including scrapers and front-end loaders graded the new channel configuration. Following grading, riffles quickly developed in the gravel and cobble substrate of the new channel bottom. A backhoe with a flexible “thumb” provided the small scale grading and root wad and boulder placement to produce a natural stream form. This detail work was directed step by step under the expertise of Rod Van Velson of Colorado Division of Wildlife.

Water quality protection was an important consideration during construction. Initial construction built a temporary sediment basin with overflow channel back to the creek at the downstream end of the project to settle and detain silts. The sediment basin was planted with wetland species following construction. Construction proceeded from upstream to downstream to prevent repeated sediment and flooding impacts during grading to newly constructed sections. Construction equipment stream crossings were confined to limited areas.

Lefthand Creek at the west end of the project area was a “No Work Zone.” We left the south embankment of the existing channel intact as a berm to avoid impacts to the existing stream course, but specified grading of a wide flood overflow channel of the stream.

Bank stabilization

Project Special Provisions for channel stabilization included natural on-site materials salvaged from the old channel. We specified cottonwoods and peach-leaved willow too large to transplant as well as undesirable crack willow and elm (*Ulmus pumila*) for use as root wads and footer logs to stabilize meanders in the constructed channel. The backhoe operator placed root wads (the irregular root fan still attached to the trunk) at expected scour sites with the root mass extending into the creek a slight angle and buried the trunk in the streambank with protection by boulders selected for natural appearance.

New Lefthand Creek Channel, 2002, view to west.
Note streambanks stabilized with willow plantings, root wads, and boulders.

Revegetation and Landscape Plantings

Revegetation strategies included direct transfer of sod blocks from areas of wetland impact during channel grading. Sod blocks were removed and transferred in a front-end loader bucket. Species in the wetland sod blocks were mainly sandbar willow and non-native reed canarygrass. Reed canarygrass transplant, specified by the Colorado Division of Wildlife to provide immediate growth of wildlife habitat structure, also provided rapid soil stabilization. The front-end loader operator placed sod blocks on the outside banks of curves in new streambank locations to provide additional bank protection.

The landscape architect timed initial native landscape plantings for Fall 2001 to stabilize newly exposed soils with a nurse crop as well as appropriate wetland and upland species. He doubled seeding rates in wetland areas and added tall upland grass species to the slope seed mix to provide quickly growing wildlife cover. Prior to seeding, weed control personnel spot sprayed noxious weed infestations (mainly Canada thistle) with glyphosate labeled for water. In Spring 2002 following development of the new site hydrology, the second vegetation effort planted riparian trees and shrubs and plugged wetland species. Aquatic and Wetland Company provided the seed and nursery stock.

The City made a commitment to a three year maintenance plan which included temporary irrigation and as needed weed control and spot revegetation.

We included Wetland Rollsod® and mycorrhizal inoculant as Project Special Provisions for landscaping. Wetland Rollsod® (supplied by Bitterroot Nursery in Montana) is a 1 by 5 meter natural fiber mat preplanted with Baltic rush, softstem bulrush, and Nebraska sedge used for rapid development of wetland vegetation at the edge of streams. At the time of planting, landscape workers inoculated willow brush layer cuttings with AgBio-Ectos, a blend of ectomycorrhizal fungi used to promote nutrient take up by developing root systems.

Table 1. Species for Fall 2001 Seeding

Scientific Name	Common Name	Pounds/Acre	Total
Wetland Seed Mix			
Carex lanuginosa	Wooly Sedge	1	2.60 lbs.
Carex nebrascensis	Nebraska Sedge	0.5	1.30 lbs.
Eleocharis palustris	Creeping Spikerush	2	5.20 lbs.
Juncus balticus	Baltic Rush	0.25	0.65 lbs.
Panicum virgatum	Switchgrass	2	5.20 lbs.
Scirpus acutus	Hardstem Bulrush	1	2.60 lbs.
Scirpus americanus	Three-square bulrush	1	2.60 lbs.
Upland Seed Mix			
Pascopyrum smithii v. Arriba	Western Wheatgrass	8	120.0 lbs.
Elymus lanceolatus spp. lanceolatus v. Critana	Thickspike wheatgrass	3	45.0 lbs.
Andropogon gerardii v. Kaw	Big bluestem	4	60.0 lbs.
Bouteloua curtipendula v. Vaughn	Sideoats Grama	3	45.0 lbs.
Bouteloua gracilis v. Hachlia	Blue Grama	0.5	7.5 lbs.
Panicum virgatum v. Nebr. 28	Switchgrass	3	45.0 lbs.
Chrysothamnus nauseosus	Rubber Rabbitbrush	0.1	1.5 lbs.
Koeleria cristata	Junegrass	0.3	4.5 lbs.
Rhus trilobata	Skunkbrush Sumac	0.5	7.5 lbs.
Schizachyrium scoparium v. Pastura	Little Bluestem	3	45.0 lbs.
Ceratoides lanata	Winterfat	0.5	7.5 lbs.
Linum lewisii	Blue flax	0.5	7.5 lbs.
Gaillardia aristata	Gaillardia	1	15.0 lbs.
Ratibida columnifera	Prairie coneflower	0.1	1.5 lbs.
Avena sativa	Oats	3	45.0 lbs.
Triticum aestivum	Winter Wheat	3	45.0 lbs.

Table 2. Species for Spring 2002 Planting

Scientific Name	Common Name	Quantity	Unit	Size	Condition
Trees and Shrubs					
Amelanchier alnifolia	Saskatoon Serviceberry	7	ea.	#5	B&B, Clump
Shepherdia argentea	Buffaloberry	31	ea.	#5	Container
Crataegus crusgalli	Cockspur Hawthorn	20	ea.	6' Ht.	B&B, Clump
Populus angustifolia	Narrowleaf Cottonwood	20	ea.	2" Cal.	B&B, Sterile
Populus sargentii	Plains Cottonwood	29	ea.	2" Cal.	B&B, Sterile
Prunus americana	American Plum	9	ea.	#5	B&B, Clump
Prunus virginiana	Black Chokecherry	33	ea.	#5	B&B, Clump
Rhus glabra	Smooth Sumac	16	ea.	#5	Container
Ribes aureum	Golden Currant	1	ea.	#5	Container
Salix amygdaloides	Peachleaf willow	29	ea.	#5	Container
Salix exigua	Sandbar Willow	3656	ea.		Brush Layer Cuttings
Wetland Plants					
Eleocharis palustris	Creeping Spikerush	4000	ea.	3 cu inch Tubelings, 24" on center	
Juncus balticus	Baltic Rush	4000	ea.		
Scirpus validus	Softstem Bulrush	4000	ea.		
Scirpus americanus	Three-square Bulrush	4000	ea.		

Fish and Wildlife Protection

Prior to construction, the Colorado Division of Wildlife used electro-shocking to remove fourteen species of fish from the affected stream reach. The fish were kept in a holding pond in the newly constructed channel during construction. The Division bred captured common shiners and released 500 offspring into the regraded channel. The root wads and boulders placed for streambank stabilization also provided fish habitat. Salvaged cottonwoods 2.5 to 6 meters in length were placed in the wetland mitigation area to provide wildlife habitat.

POST CONSTRUCTION SITE CONDITIONS

2002 – First Growing Post Construction Growing Season

Although drought conditions persisted throughout the spring and summer of 2002 (Drought Links, 2002), my August survey showed that wetland plant communities had begun to establish in areas of standing water and sites adjacent to stream and stormwater flows of the new Lefthand Creek floodplain. Wildlife including deer, beaver, toads, and waterfowl are beginning to frequent the new flood channel. Wetland species along the creek included planted or seeded sandbar willow, softstem bulrush (*Schoenoplectus lacustris* subsp. *creber*, / *Scirpus validus*) hardstem bulrush (*Schoenoplectus lacustris* subsp. acutus / *Scirpus acutus*), three-square bulrush (*Schoenoplectus pungens* / *Scirpus americanus*), sedges (*Carex* spp.), and creeping spikerush (*Eleocharis palustris*). Volunteer native sandbar willow and blue vervain (*Verbena hastata*) were also present. Areas too dry for germination or survival of wetland species were developing a cover of weedy wetland and nonwetland species including kochia (*Bassia sieversiana*), purslane (*Portulaca oleracea*), goosefoot (*Chenopodium* spp.), reed canarygrass, curly dock (*Rumex crispus*), rabbitfoot grass (*Polypogon monspeliensis*), puncture vine (*Tribulus terrestris*), barnyard grass (*Echinochloa crus-galli*), alfalfa (*Medicago sativa*), and teasel (*Dipsacus fullonum*). One large patch of Canada thistle was present in an area of the preserved channel.

The irrigated upland grasses and flowers were becoming established in most of the planting areas. Most planted tree and shrubs were vigorous.

2003 – Second Post Construction Growing Season

Following the 5th wettest March on record (NOAA, 2004), groundwater levels in the floodway channel rose and germination of wetland species greatly increased. The bank stabilization structures and plantings protected streambanks from erosion as spring runoff spilled into the new overflow channel. By the end of growing season site visit in September 2003, well-vegetated, high diversity wetlands were present in new Lefthand Creek floodway channel and project goals of 1:1 wetland mitigation were met. Dominant plant species were native sandbar willow, switchgrass, foxtail barley (*Critesion jubatum*), slender wheatgrass, cattail (*Typha latifolia*), bulrush, spikerush and non-native reed canarygrass, barnyard grass, redtop (*Agrostis stolonifera*), and lady's thumb (*Polygonum persicaria*). Numerous seedling cottonwoods were present in the overflow channel south of Lefthand Creek. Soils were saturated to the surface, and driftlines were evident from spring and early summer flooding. Control of weedy species is expected to be an on-going concern. Some of crack willow used in stream stabilization structures had sprouted, Canada thistle was well-established in adjacent areas, and seedling Russian-olive (*Elaeagnus angustifolia*) was present in upper wetland meadows. Wetland boundaries are anticipated to fluctuate with precipitation cycles and runoff changes associated with area development.

Lefthand Creek, summer 2003, oblique aerial view to east. Note stream meanders, developing wetlands and landscape plantings. Ken Pratt Boulevard Bridge in background, trail at right.

DISCUSSION AND RECOMMENDATIONS

Teamwork and the willingness to work through different visions for the project outcome were essential to project success. Engineers needed the biologists and planners to point out ecological opportunities; people with a natural resources background needed the technical know how of the engineers to assure that project criteria would be met. Agency personnel brought years of field work into the project design and implementation. The most successful project components were the use of on-site materials in stabilization of the new stream channel, direct transplant of willows from the old channel to the new, the depth of skill and experience provided by the grading machinery operators and Division of Wildlife, the willingness of the City of Longmont to try new planting techniques, and, after a dry initial growing season, a record breaking snow to provide stream flows and restore groundwater levels for planting success.

Considerations for the next big stream restoration project include avoidance of non-native reed canarygrass in direct transplants and non-native crack willow in areas wet enough to allow resprouting.

CONCLUSIONS

The completed Lefthand Creek flood channel removed developable land from the 100 year floodplain, retained as much of the existing stream channel as practicable given the engineering constraints, and rehabilitated areas of the stream channel to a more historic condition suitable for a variety wildlife and native plant communities. Wetland mitigation has reached the goal of 1:1 wetland creation for project impacts. The success of the project shows that, with teamwork, urban flood corridor projects can integrate natural stream design techniques to rehabilitate degraded streams and provide a scenic amenity to city populations.

ACKNOWLEDGEMENTS

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VEGETATION CHARACTERISTICS ON DIFFERENT SOIL TREATMENTS IN A CREATED URBAN WETLAND

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POSTER PAPER

ABSTRACT

Several researchers have examined the value of using remnant topsoil as a source of seeds and plant propagules in restoration. The focus of this study was to determine the value of dredged stormwater pond sediment and remnant topsoil for wetland plant restoration. Plant cover, aboveground biomass, and plant species richness were measured within experimental plots. Experimental treatments consisted of sediment and mineral soil dredged from a stormwater detention pond and topsoil removed from associated wetland and upland areas. Analysis of variance indicated that aboveground biomass was greater on the stormwater sediment soil treatment when compared with either the mineral soil treatment or the combination (sediment and mineral) soil treatment. Plant species richness was greater on the mineral soil treatment than on the combination or the sediment soil treatments. Richness was also greater on the upland topsoil treatment than on the wetland topsoil treatment. Total plant cover was similar on all three soil treatments and both topsoil treatments. These results suggest that dredged pond sediment and remnant topsoil are potentially beneficial for urban wetland restoration.

REGENERATING INFILTRATION CAPACITY IN DRASTICALLY DISTURBED DECOMPOSED GRANITE SUBSTRATES.

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ABSTRACT

A primary result of soil disturbance in decomposed granite (DG) is that soil structure is degraded, soil surfaces seal and infiltration rates decrease. When precipitation exceeds infiltration, water begins to flow overland. Particle detachment and sediment transport begin, and sites become droughty. We evaluated infiltration on stable, revegetated and on bare saprolite cutslopes in DG substrates in northern California and compared infiltration rates to those of drastically disturbed, eroding sites. Incorporation of compost amendments of 24 % by volume (8 % dry weight) increased the infiltration rate of a DG subgrade material to that of the stable, disturbed-but-revegetated grassland. Water holding capacity was increased at matric potentials near field capacity but not at dry (-1.5 MPa) conditions. Rainwater drained quickly from saturated surface horizons into subsurface horizons within a day of each rainfall event on compost treatments, thus quickly regenerating infiltration capacity. Non-compost treatments remained near saturation longer after each rain. At one year after construction, compost only treatments lost about 20 % of their infiltration. However, when the plots were vegetated with a native grass (*Elymus multisetus*), infiltration remained at the initial, high rates. Non-treated plots became close-packed during saturating winter rains and developed thick, hard surface crusts during summer drought.

INTRODUCTION

Decomposed granites are erosive substrates because they have low clay contents and large mineral crystal sizes that disarticulate easily when weathered. Because the weathered but undisturbed (saprolite) bedrock has a high pore volume when compared to non-weathered (competent) granite, rain water percolates easily through the subsurface rock matrix. Ground water flow frequently pipes out in seeps when roadway embankments are cut into the hillside, causing saturation and surface erosion of the exposed materials. In addition, when rainfall impacts the exposed DG matrix, the silt-sized particles weathered from the DG disperse across the surface and close-pack, or crust, forming a seal with low infiltration rates. Infiltration of these slurry coated areas was measured to be approximately 10 to 20 % of the rate of the undisturbed DG material. As infiltration decreases, rainfall or snowmelt increasingly runs overland, accelerating erosion and sediment mobilization.

This study site is located in the Shasta Bally Batholith, an extensively weathered granitic pluton located 25 km west of Redding in northern California (State route 299, Shasta County, road mile 0.06) at Buckhorn Summit. The hillside has rapidly eroded in the previous decade, creating an oversteepened headcut and large debris fans at the base of the slope. Sediment washes out into the trafficway, reducing traffic safety.

In 2002, study plots were constructed along the base of the slope to evaluate the effectiveness of compost application for regenerating infiltration on these DG materials (data presented in this report). Following one year of evaluation of the compost amended plots, the rest of the slope was reconstructed using a “fill-cut” method, in which a small bulldozer cut benches into the slope, compacted them and then backfilled the surface 30 cm of the bench (perpendicular to slope) with an uncompacted blend of one part compost with three parts DG. The surface compost material received a supplemental application of about 750 kg/ha Biosol Mix. A 4 m wide coir blanket (700 g/m^2) was laid over the flat bench and down over the slope surface and pinned along the bottom edge with 30 cm long nails through 5 cm x 5 cm x 3 m battens. The next lift was constructed over the flat part of the blanket, keying the blanket in place and reinforcing the slope. Final overall slope angle was 35 º (1.5:1) H:V. Midway through one winter rain season, only limited surface flows occurred where rainfall percolated to the next blanket layer and piped out to the slope surface (Figure 1 bottom).

➘ original slope surface remnant

➚

← infiltration
← plots

Figure 1. (top) Field study site before treatment. Note gullies resulting from sealed slope surface and overland flow. Bare area behind the center slope is an old logging landing which percolates water down into the decomposed granite batholith, where it runs laterally and pipes out at about two-thirds the way up the slope. Remnant slope surface showing original 40º grade is located at right of slope under arrow. (bottom) Same slope following treatment. Finished slope was covered with coir blanket (700 g/m^2), which was keyed across the top of each 1.5 m lift. Rainfall simulation plots are located at the lower part of the slope left of the double arrows (left of double arrows).

We observed that the fine silt particles of this DG material seal the surface of the slope during rain drop impact, reducing infiltration. Reduced infiltration diverts more water to overland flow rather than to deep percolation, thus increasing surface erosion. We hypothesize that incorporation of coarse unscreened yard waste compost will increase the infiltration rate of the DG materials by shielding the surface from rain drop impact and by propping open macropores, which reduces overland flow. Increased plant available water and reduced surface crusting and mass wasting are expected to facilitate revegetation and stabilization of the slope.

METHODS

Plots were constructed at the bottom of the slope where materials could be placed by excavator bucket. Plots measuring 2 m x 2 m x 60 cm deep were constructed behind a 1 m x 1 m x 2 m gabion wall. Slope angle of these study plots was 2:1 (H:V). Plot treatments were zero compost (DG only), or 6 %, 12 %, and 24 % by volume (2, 4, and 8% by dry weight). Compost amendment volumes were calibrated using separate volumes of compost or DG. Each plot was replicated 4 times. Two duplicate sets of plots were constructed; one set was plug-planted with *Elymus multisetus* on 20 cm centers and the other was left unplanted. All plots were mulched with native grass straw.

Within one month after construction, during which time one significant rain occurred, each plot was subjected to simulated rainfall at a rate of 60 mm/hr. All surface flow from a 0.8 m x 0.8 m delineation frame was collected and the net infiltration was calculated by difference after steady state infiltration had been achieved (Battany and Grismer, 2000). After one year, which in this climate includes a cool wet winter and an extended summer period (May to November) with little or no rain, infiltration on all plots was remeasured. As a comparative example of a successful revegetation system, a nearby area that was regraded from a flat logging landing to a 30 º south facing slope was also measured (reference site). This area had a non-eroding litter layer of whole leaves and decomposing duff and was covered with perennial grasses and forbs and scattered invasive annuals.

Volumetric water content was also determined using time-domain transmissometry probes (Gro-Point, ESI Scientific, Vancouver, Canada). Volumetric water content was determined on 2 hour intervals at 20 and 40 cm depths.

Penetration resistance was measured with a Field Scout SC-900 (Spectrum Tech. Plainfield, IL, which recorded resistance (kPa).

RESULTS

Infiltration rates of the 24 % compost amendment increased to levels that did not significantly differ from the revegetated reference community (Figure 2). Lesser amounts of compost incorporation had proportionally lower infiltration rates. A year after construction, the 24 % compost treatment with plants remained at first-year levels. The control plots (no compost) and the 6 % compost amendment increased infiltration by plant rooting (veg treatment) or by freeze-thaw (non-veg treatment) compared to the first year infiltration rates.

The amended compost plots (Figure 3, upper two traces) contain the most water during rainfall events but they drain rapidly to subsurface horizons. At each rainfall spike, the top trace is data from 20 cm depth, which saturates quickly from rainfall inputs. The second trace is from 40 cm, which accumulates more water during the drain-down phase. The lower two traces indicate that the non-compost plots have lower water contents. At each rainfall event, the difference in water held by the compost plots (~ 47 %) compared to the control plots (~ 33 %) represents water sheeted off as surface runoff from the control plots. Furthermore, a greater proportion of the maximum moisture content is lost from the compost amended plots (~ 13 %) than the control plots (~ 5 %) during drain-down, regenerating the sorptive capacity of the soil for additional rainfall input.

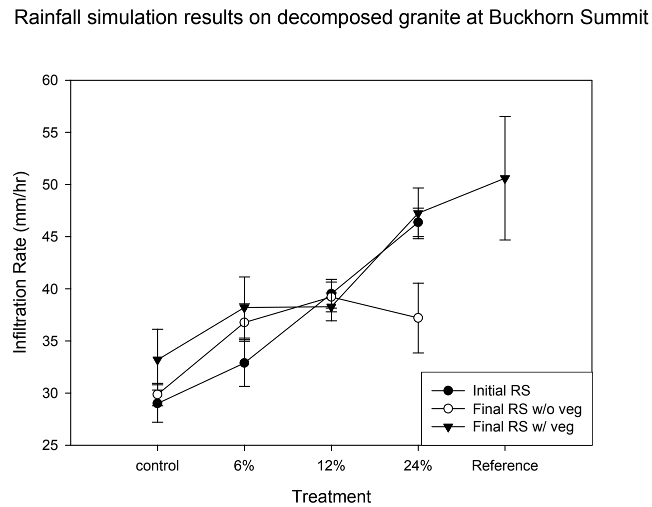

Figure 2. Infiltration measured by rainfall simulation (60 mm/hr) on 2 m x 2 m plots (2:1 slope). Closed circles indicate initial infiltration measured one month after the time of construction. Filled downward triangles indicate final infiltration after one year on plots with vegetation (plug-planted *Elymus multisetus* on 20 cm centers). The open circles indicate final infiltration on plots without vegetation. Plots with 24 % compost by volume (8 % by weight) did not significantly differ from the revegetated reference plots (one way ANOVA, mean separation by LSD, $p < 0.05$) and retained this higher infiltration rate for a year after construction.

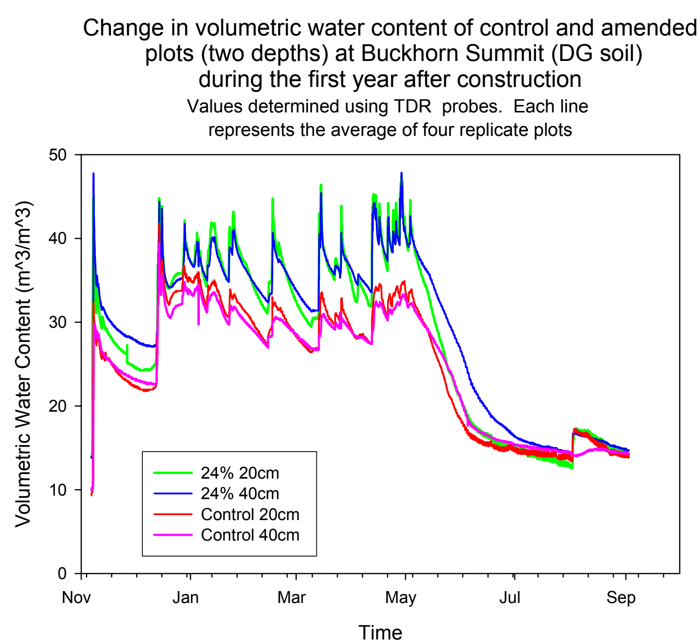

Figure 3. Percent volumetric water content of compost amended plots (24 % by volume) and non-amended plots on decomposed granite fill slope. Spikes represent rainfall events, followed by a short-term drain-down period (several weeks). Beginning in mid-May, a gradual dry-down (several months) occurs during the summer dry season.

At the summer drought began, the compost treatment at 40 cm contains approximately 50 % more plant-available moisture for plant growth compared to the nonamended plots (plot traces from May through July). This results from an increase in water holding capacity at matric potentials near field capacity but not under water stress conditions. Moisture content at –0.03 MPa was 25 % greater in the 24 % compost plot than in the non-amended control ($p < 0.05$), although the moisture capacity of the two treatments at –1.5 MPa did not differ. Better plant survival through the summer conditions would therefore be attributable to more extensive rooting and water infiltration, but not to greater water holding capacity at very negative matric potentials.

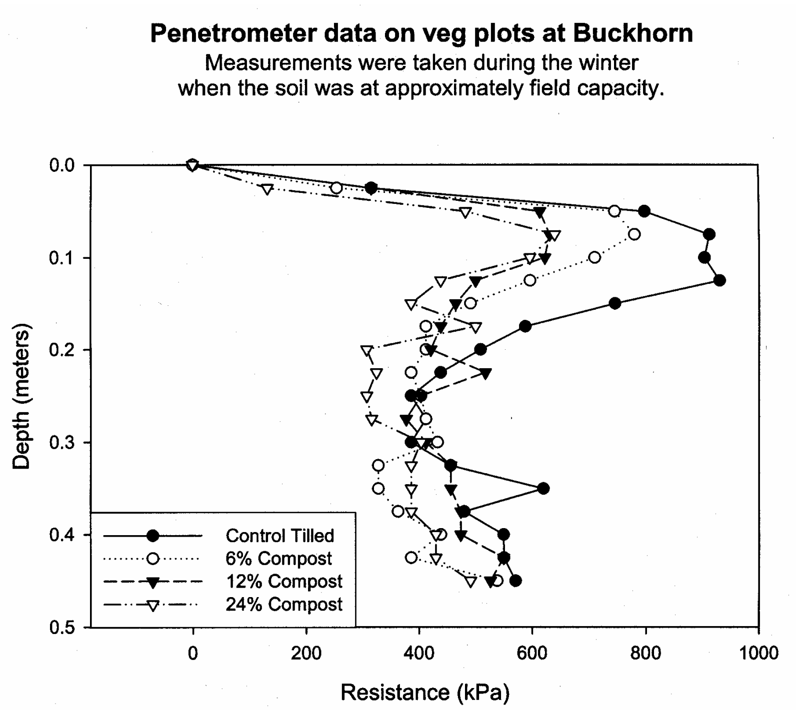

Figure 4. Penetrometer measurements during winter (unfrozen soil) showing compaction horizon that develops from 5 to 20 cm depth.

Compost amendments also reduced hard-setting of the subsurface horizon (Figure 4). Mechanism of compaction or compression was limited to the surface 20 cm, since lower horizons showed less effect of compost addition. Summertime measurements on dried soil are immeasurable using the penetrometer probe starting (> 3000 kPa) at the soil surface due to hardsetting and crust formation.

CONCLUSIONS

Coarse, unscreened yard waste compost increases infiltration rates to levels comparable to a stable revegetated reference site. Water is drained to subsurface horizons rather than being sheeted off as overland flow. Composts reduce penetration resistance and hardsetting. Greater water holding capacity facilitates revegetation of a harsh, droughty, eroding decomposed granite site.

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PLANT MATERIALS AND PLANTING METHODS FOR RIPARIAN RESTORATION IN THE SOUTHWEST

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ABSTRACT

Riparian plant communities, though small in overall area, are among the most valuable natural areas in the Southwest. The causes of degradation of southwestern riparian zones range from excessive cattle and elk grazing in montane watersheds to invasive woody exotic species and lack of natural flooding in the cottonwood forests of low elevation river valleys. Plant species and stock types selected for restoration efforts must be appropriate for the site characteristics such as elevation, soil texture and chemistry, and depth to water table. Propagation methodologies for pole cuttings and large containerized seedling stock have been developed to provide cost effective production of riparian planting stock with high rates of survival. Plant materials and planting methods for the restoration of the cottonwood forests are described for several sites along the middle Rio Grande in New Mexico.

INTRODUCTION

Properly functioning riparian areas serve key roles in providing fish and wildlife habitat, preserving water quality and water supply, and providing recreational opportunities. A comprehensive assessment of criteria useful in judging riparian area condition and attributes that constitute a proper functioning condition for lotic areas has been developed and refined (Prichard et al., 1993; Prichard et al., 1998). The continuum of southwestern riparian zones from alpine to hot deserts are susceptible to an array of natural and human-generated processes that can degrade the proper functioning of these critical watershed areas.

At lower elevations, agricultural development and flood control have imposed both structures and management resulting in severe disruptions of natural regeneration of the floodplain cottonwood forests. Dams have prevented or limited natural flooding resulting in the disruption of sediment deposition and hydrologic regimes that are required for the germination and establishment of the cottonwood and willow species that dominate the overstory in these forests. Levees have been constructed which constrain the floodplain and restrict the natural meanders of the river systems. Channeling streambeds to reduce flooding and increase water transport efficiency has resulted in human-dominated water conveyance systems. Drainage of riparian zones to create agricultural lands has altered shallow aquifers directly connected to rivers. River flow management prevents flooding and assures conveyance of water to downstream users. These hydrologic regimes have resulted in artificial hydrographs unsuitable to the natural regeneration or maintenance of these cottonwood forests. The near complete loss of natural cottonwood regeneration has resulted in the invasion of exotic woody species, Russian olive (*Elaeagnus angustifolia* L.) and saltcedar (*Tamarix ramosissima* Ledeb.) and the accumulation of enormous fuel loads making these degraded riparian areas very susceptible to wildfire. These floodplain cottonwood forests do not contain fire-adapted native species as do some forestlands at higher elevations and thus little natural regeneration occurs after fire.

At higher elevations, catastrophic wildfires can result in direct destruction of riparian areas. Massive erosion and deposition of sediments resulting from wildfire in forested watersheds destroy fisheries and wildlife habitat, recreational facilities, roads, and water supplies for communities. Despite these deleterious effects, the results of wildfire can regenerate decadent riparian plant communities over time. The destruction of riparian vegetation directly by cattle and elk grazing has resulted in vast stretches of streams that do not support properly functioning ecosystem processes. Watersheds suffering from long-term overgrazing are more susceptible to extreme flood events resulting in accelerated rates of channel lowering. This landscape alteration can destroy and prevent the regeneration of riparian plant communities and concurrently increase sediment deposition in low gradient stretches and alter downstream riparian areas. Past logging practices involving poorly designed and sited roads and skid trails as well as inadequate buffer zones surrounding streams have contributed to the degradation of montane riparian plant communities. Historic trails that have become roads in the national forest system were developed with ease of access as the dominant feature often resulting in roads dissecting riparian areas and disturbing stream courses. The recreational facilities in forestlands are generally situated streamside resulting in intensive vehicle and foot traffic in the surrounding riparian areas.

The quantity, quality, and timing of water supply as well as wildlife and fishery habitat and recreational opportunities depend on the proper functioning of riparian plant communities. The many and varied natural processes and human controlled activities that are disrupting these critical riparian areas should serve as an impetus to preserve pristine stream systems and their accompanying riparian plant communities as well as to develop cost effective restoration techniques. The discussion that follows will address the importance of species selection, site characteristics, techniques to propagate riparian plant materials, and the installation and maintenance of planting stock to facilitate restoration of riparian zones. Case studies will address some riparian restoration practices employed in southwestern ecosystems during the past decade.

SPECIES SELECTION AND SITE CHARACTERISTICS

The appropriate species to establish in degraded riparian zones may or may not be those present before the disturbance occurred. Some processes can alter the growing environment to such an extent that the pre-disturbance species are no longer suitable candidates. As an example, the imposition of flood control dams and managed flows can alter the salinity of soils by eliminating flooding. The effects of these water control structures and flow regimes on river hydrology and alluvial processes can modify the depth to ground water and the seasonal pattern of water table fluctuation. In such a case, the increased salinity may not allow establishment of the pre-disturbance species and a persistently deep water table may allow only certain planting stock types to be successfully used. In many instances, evaluation of plant communities in proper functioning riparian areas in the bioclimatic region will provide a guide to appropriate species.

The depth to ground water plays a key role in determining suitable riparian species. The primary rooting zone for obligate riparian plants is the capillary fringe above the water. The thickness of the capillary fringe is affected by the alluvium texture with finer textured alluvium having a broad zone of unsaturated soil with high moisture content. A thicker capillary fringe zone is advantageous in the sense of having greater water content per unit volume but is disadvantageous in the lower aeration resulting from less air-filled pores. The consequence of woody riparian species generally requiring coarse textured highly aerated soils often leads to suitable restoration sites having a thin capillary fringe with lower water content but more air filled pores.

The fluctuation of ground water levels in riparian areas is dependent on the connection of the shallow aquifer to the stream; thus, as the stream water level changes the depth to ground water changes. Changes in stream level are reflected in an annual hydrograph of stream discharge whether controlled by natural processes or by human manipulation. The ground water fluctuations resulting from the variation in stream flow requires monitoring by shallow wells to determine the extent and timing of ground water level changes. This data is the basis for determining the planting stock type that will allow root access to the capillary fringe and provide a high potential for successful plant establishment. In addition, this data is needed in species selection because species vary in optimum depth to ground water. As an example, the pole planting prescription for Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni* (S. Watson) Eckenwalder) at the Bosque del Apache National Wildlife Refuge is a ground water depth between 6 and 12 ft (1.8 to 3.6 m). However, the prescription for Goodding's willow (*Salix gooddingii* Ball) is 4 to 8 ft (1.2 to 2.4 m) (Taylor and McDaniel, 1998a).

Stream channel alteration by down-cutting coupled with lack of flooding due to water management structures has resulted in many riparian areas having such deep water tables and depleted near-surface soil water content that upland vegetation has invaded and proved much better adapted to the present hydrologic regime. In such situations, pole plantings may allow the establishment of riparian woody vegetation, but it is understood that such artificial regeneration will not create a self-perpetuating riparian plant community.

RIPARIAN PLANT MATERIAL STOCK TYPES

As explained above certain riparian situations will require specific stock types in order to optimize successful and cost-effective riparian restoration. In the Middle Rio Grande Valley and in many other low elevation cottonwood forest environments, the depth to ground water over much of the historic floodplain is too great to permit the use of traditional stock types with shallow root systems without appreciable aftercare. One gallon treepot stock (4 in. x 4 in. x 14 in.) (10 cm x 10 cm x 36 cm) of riparian understory shrubs such as New Mexico olive *(Forestiera pubescens* Nutt. var. *pubescens)* and skunkbush sumac *(Rhus trilobata* Nutt.*)* planted in these environments require numerous water applications per year for several years to obtain acceptable survival rates. The expense in irrigating such out-plantings has prompted an emphasis on non-rooted pole and whip plantings of large dormant cuttings and use of 30 in. (81 cm) tallpot containerized stock in such environments. Most cottonwoods and willows have strong adventitious root development from large vigorous cuttings and have proved to be successfully established via pole plantings. Experimental field plantings at the Los Lunas Plant Materials Center (LLPMC) and wildland plantings have shown that other species outside the Salicaceae family have some promise as pole/whip cuttings (Los Lunas Plant Materials Center, 1994; Los Lunas Plant Materials Center, 1998). These understory species include willow baccharis *(Baccharis salicina* Torr. & A. Gray in the Asteraceae*)*, desert false indigo *(Amorpha fruticosa* L. in the Fabaceae*)*, New Mexico olive (in the Oleaceae), and desert willow *(Chilopsis linearis* (Cav.) Sweet in the Bignoniaceae*)*. None of these species have as fast a growth rate as most cottonwoods and willows, thus pole production is not as rapid. In addition, these species appear to be more exacting in some cultural factors. These species do not appear to tolerate long storage periods in water as do pole cuttings taken from Salicaceae species. Several species have been successfully established in riparian areas from rooted poles/whips (desert false indigo, New Mexico olive and desert willow). The rooted poles of these species as well as Arizona sycamore and Arizona alder *(Alnus oblongifolia* Torr.*)* have been produced by mound layering techniques as described by Dreesen et al. (2002).

The factors that promote the use of pole plantings to access deep soil moisture in the capillary fringe have prompted other planting stock alternatives other than pole/whip plantings. The improved out-planting success found with deep containers in desert situations (Bainbridge 1994; Bainbridge and others 1995; Miller and Holden 1992) implies that access to deep soil moisture or greater soil volumes may be enhancing plant establishment. The ability of riparian woody plant root systems grown in tall containers to quickly contact deep soil moisture in the capillary fringe should afford greater likelihood of survival and growth. Determining whether to use such an approach involves comparing the cost and effort of using inexpensive shallow containerized stock which are easily planted but will require supplemental water versus using more expensive deep stock types which are more difficult to grow and plant but require little or no aftercare.

PLANT MATERIAL PRODUCTION OF RIPARIAN SPECIES

Pole Production Protocol

The current protocol for producing dormant pole cuttings of Rio Grande cottonwood, plains cottonwood (*Populus deltoides* ssp. *monilifera* (Ait.) Eckenw.), and narrowleaf cottonwood (*Populus angustifolia* James) at the Los Lunas Plant Materials Center (LLPMC) is based on an evolution of cultural techniques developed through over 15 years of pole production experience. The optimum soil types for pole production are coarse textured (loamy sands to sandy loams) to provide high aeration potential; this also necessitates more frequent but lower irrigation volumes. Fields at the LLPMC are flood irrigated and are typically laser-leveled which allows uniform distribution of shallow applications of water. Details on establishment of pole production fields including plant spacing, woven fabric mulch, seedling installation, and fertilization are presented in Dreesen et al. (2002).

The harvest of poles can begin during the winter following the second field-growing season when pole lengths of 12 to 15 ft (3.7 to 4.6 m) can be achieved with butt diameters of 2 to 3 in. (5 to 8 cm). Typically, pole harvesting is initiated in January and extends until bud-break (usually late March to early April). During pole harvest, side branches are pruned at the branch collar leaving only a few small branches at the top. The poles are bundled in groups of 5 with twine and transported to a staging area where the butt ends are placed in water tanks to assure maximum hydration before transporting and planting.

The initial pole harvest from a field involves severing the single stem at 4 to 6 in. (10 to 15 cm) above the ground. The following growing season this stump will sprout numerous stems some reaching 6 to 8 ft (1.8 to 2.4 m) in the first year and producing pole-size stems after one to two additional years. The stumps with numerous stems should be pruned in the late fall and winter to reduce the number of stems to the 5 to 6 most vigorous vertical stems.

Production of Cuttings and Seed of Montane Species in a Cold Desert Environment

The LLPMC is situated at an elevation of 4800 feet where the hot Chihuahuan Desert converges with the cold deserts of the Four Corners region. This cold desert environment experiences daily maximum temperatures exceeding 100 ^{o} F (38 ^{o} C) in summer and winter lows typically in the teens. The soils and waters are fairly alkaline. The establishment of stock plants of montane riparian species for seed and cutting production was needed to avoid the cost of travel for propagule collection, to avoid the possibility of finding no acceptable propagules, and to attempt to ensure vigorous stock plants by proper irrigation and fertilization. Early attempts with several montane willows (*Salix irrorata* Anderss. and *Salix monticola* Bebb) planted in sandy flood-irrigated fields were unsuccessful. The next approach involved planting in organic–rich beds. Trenches 18 in. (0.5 m) wide, 24 in. (0.6 m) deep, and 20 ft (6 m) long were excavated with a backhoe. These trenches were filled with reclaimed potting soil which had been stockpiled for a year; the mix contained variable proportions of spaghnum peat moss, composted pine bark, perlite, and pumice. One-gallon treepot stock plants grown from cuttings or seed were transplanted into these beds. The beds were irrigated with micro-sprinklers (e.g., Roberts Spot-Spitters®). Fertilization usually involved controlled release fertilizer top-dressing with a dose appropriate for the size of the stock plant. Sulfur is top-dressed each year to counteract the alkalinity of the irrigation water. Several montane species have thrived in these beds and yielded the following propagules: bluestem willow (*Salix irrorata* Andersson) seed and cuttings, blue elderberry (*Sambucus nigra* L. ssp. *cerulea*

(Raf.) R. Bolli) seed, redosier dogwood (*Cornus sericea* L.) seed and cuttings, and park willow (*Salix monticola* Bebb*)* cuttings.

Tallpot Production Methods

The Los Lunas Plant Materials Center has developed a specific pot configuration that helps solve some difficulties found with earlier tallpot designs such as weight, pot materials expense, and plant removal and planting. The pots are constructed of 4 in. (10 cm) diameter PVC thin walled sewer pipe. The 30 in. (76 cm) sections (1/4 of the standard 120 in. pipe length) are split lengthwise on opposite sides for about 27 in. (69 cm) with the top of the pipe remaining intact to maintain the pot as one piece. Additional details on the fabrication of tallpots can be found in Dreesen et al. (2002).

A standard nursery mix (composted pine bark, pumice, and peat) is used in tallpots to plant containerized seedlings. One-gallon tree pots have been transplanted into the tallpots; some of the root mass has to be removed from the corners of the root ball to allow placement and back-filling. Smaller containerized stock is also used for potting up: Super Cells (10 in3, 164 ml), Deepots D16 (16 in3, 262 ml), Deepots D40 (40 in3, 656 ml), and treebands (3 in. x 3 in. x 9 in.). Controlled release fertilizer (5 to 6 month delivery) at rate of 30 g is generally top-dressed after transplanting. Groups of tallpots are enclosed by straw bales to moderate pot temperature during summer and winter. Species with fast growth rates can be ready for outplanting one year after transplanting from one gallon tree pots into tall pots and can be ready in two years after transplanting from smaller containers.

PLANTING PROCEDURES FOR DIVERSE STOCK TYPES OF RIPARIAN SPECIES

Planting of Dormant Pole Cuttings and Whips

Various types of equipment have been employed for drilling holes for pole plantings ranging from hand-operated bucket augers with 8 ft (2.4 m) handles to large truck mounted augers typically used for power pole installation. The LLPMC has been using one type of auger for 10 years. A four-wheel drive farm tractor outfitted with a front-end loader has been adapted by replacing the loader bucket with a hydraulically powered auger head and an 8 ft (2.4 m) long 9 in. (23 cm) diameter bit with full flighting. The principal circumstance where this drilling approach has been unsuccessful is in dry sands or in cobbly alluvium where the hole frequently collapses. Trial and error probing of riparian zones will usually provide locations where the alluvial conditions allow full depth holes to be completed into the water table. When back-filling holes after pole placement, a tree guard 5 ft (1.5 m) tall and 18 in. (46 cm) in diameter constructed from poultry wire is inserted partially into the hole to anchor the tree guard. A team of 4 people (one equipment operator; two people planting poles, back-filling, and installing guards; and, one person supplying poles and guards) can install 35 poles per hour.

The tool used for planting coyote willow (*Salix exigua* Nutt.) whips is an electric spline drive rotary hammer that can accommodate a 1 in. (2.5 cm) diameter 36 in. (91 cm) long carbide-tipped bit. Coyote willow is planted where ground water is shallow so this tool provides a hole into the ground water or into the capillary fringe. The rotary hammers are especially useful when frozen soils are encountered which happens often during the late winter/early spring planting period. A portable generator is required capable of starting and running the 9 amp rotary hammer motor. A team of 4 people (2 drilling and 2 planting) can install 200 whips per hour.

If suitable alluvial conditions are encountered, proper planting procedures are followed, and appropriate after-planting care is employed, success rates around 90% at 5 years after planting can be achieved. Coarse alluvium with low salinity capable of supporting a hole into the water table is required to maximize success. If extreme fluctuations in ground water level are expected, the pole needs to be planted below the water table to ensure that the capillary fringe will surround the butt end of the pole during periods of maximum ground water depth. Planting requirements include a dormant vigorous large diameter cutting of sufficient length to extend into the water table and leave a substantial aboveground stem (at least 5 ft (1.5 m)). The cuttings should be kept well hydrated during storage and transport. Aftercare including tree guards (poultry wire cylinders) to protect from beavers and control of defoliating insects (e.g., cottonwood leaf beetle *(Chrysomela scripta)*) will improve establishment success if these pests are present in significant numbers. Exclosures to prevent domestic livestock and elk browsing of pole plantings are also required in situations where browsing pressure is substantial.

Planting Methods for 30 inch Tallpots

The auger used for pole planting (8 ft (2.4 m) long, 9 in. (23 cm) diameter bit) is also used for 30 in. (76 cm) tallpot installation. As with pole planting, the hole is drilled to the water table but loose soil is removed only from the top 30 in. (0.8m). This full depth hole penetrates any hardpan or other alluvial layers that might restrict root penetration into the capillary fringe. Most riparian woody species form well consolidated root balls if sufficient production time is available. If the plant canopy is too large to fit through the top of the pot, the slots can be extended so that the pot is split into two sections. Tree guards can be installed when back-filling if beaver or rabbit damage is expected. A team of 4 people can install 10 to 15 plants per hour.

In upland situations or where ground water is very deep, supplemental water may be required to enable establishment. The LLPMC has been testing the use of watering tubes to provide deep pipe irrigation. This approach has proved to be a highly successful irrigation method in desert environments (Bainbridge et al., 2001). One watering tube design uses a 3 in. (7.6 cm) PVC sewer pipe cut into lengths of 40 in. (100 cm). The large diameter pipe is used especially when viscous starch based hydrogel is employed to apply a slow release of water to the subsoil. When in use, the watering tube is capped to prevent evaporation and animal entry. This design is costly in terms of materials and labor for fabrication. Perforated 1" diameter PVC pipe has been used for watering tubes where cost is a factor and only water is used rather than viscous hydrogel.

The 9 in. (23 cm) diameter hole provides sufficient space for the tallpot root mass as well as the watering tube for deep irrigation. Optimally, water is applied to the soil surface at the time of planting to aid in filling backfill voids as well as providing near surface moisture. The watering tubes are filled with water at planting to charge deep soil moisture. Trials with starch-based water absorbent polymers have been conducted to determine whether the slow release of water in the tubes is superior to water alone. It appears that the hydrogel may provide high survival rates with fewer applications than would be required with water alone. It is anticipated that one or two water applications per year for a few years using deep pipe irrigation may be sufficient to provide high rates of establishment depending on precipitation timing and amounts.

RIPARIAN RESTORATION IN THE MIDDLE RIO GRANDE VALLEY

As described in the introduction, the riparian zone in the Middle Rio Grande Valley suffers many assaults on its biological integrity. Flood control structures and flow management regimes have prevented natural flooding necessary for cottonwood and willow regeneration. These activities have also resulted in the buildup of salts in the former floodplain. Exotic woody species have invaded vast stretches of the floodplain which were cottonwood forests historically. These exotics have also magnified the potential of severe wildland fires near urban corridors because of the massive fuel loads produced by these noxious invaders.

Some of the most successful projects in removing one of the primary exotics, saltcedar, have been conducted at the Bosque del Apache National Wildlife Refuge. Mechanical removal uses a three-step process of aerial stem removal, root plowing, and root raking at a total cost of about $1,500/ha (McDaniel and Taylor, 1999). The second control approach involves aerial application of herbicide (imazapyr plus glyphosate) followed by prescribed burning of dead standing saltcedar at a total cost of about $300/ha (McDaniel and Taylor, 1999).

Bosque del Apache National Wildlife Refuge used pole plantings of Rio Grande cottonwood and Goodding's willow in their early restoration efforts following saltcedar control (Taylor and McDaniel, 1998b). Later investigation proved that natural recruitment was possible subsequent to over-bank flooding during peak river flows in late May and early June; regeneration was greatest in sand deposits resulting from secondary channel development (Taylor et al., 1999). Large areas of historic floodplain at the Refuge were later restored using controlled flooding of land cleared of saltcedar; careful management of declining water levels in impoundments after flooding allowed establishment of a high proportion of cottonwoods and willows and little saltcedar.

Other approaches to simulate natural regeneration have examined the use of micro-irrigation on historic floodplain sites that no longer experience natural flooding (Dreesen et al., 1999). Maintenance of high surface soil moisture during seed dissemination, germination, and early growth stages of Rio Grande cottonwood has resulted in successful establishment. Micro-irrigation frequency is decreased and water depth application is increased gradually for several years until roots access the capillary fringe above the natural water table and the riparian vegetation is self-sufficient.

Planting along the Santa Fe River near Cochiti Pueblo

A section of the Santa Fe River within Cochiti Pueblo land is a perennial stream feed by springs and possibly seepage from Cochiti Lake. This riparian zone had been severely degraded by cattle grazing for decades prior to 1994. The Pueblo constructed fenced exclosures at 3 sites along the stream in 1993. The LLPMC installed 1250 Rio Grande cottonwood, lanceleaf cottonwood *(Populus x acuminata* Rydb. (pro sp.) [*angustifolia x deltoides*]), and Goodding's willow poles in February 1994. At the three sites, the capillary fringe was encountered in all augered holes but ground water was not encountered in any holes at the maximum auger depth of 8 ft (2.4 m). During the first growing season, the plantings suffered severe defoliation from a cottonwood leaf beetle infestation that affected long term survival. After 4 growing seasons, the survival of Rio Grande cottonwood accessions ranged from 42 to 85% and Goodding's willow ranged from 60 to 76% (Los Lunas Plant Materials Center, 1997). Poles planted close to the stream have annual height growth of about 6 ft (1.8 m). After 4 growing seasons these trees had heights approaching 30 ft (9 m) and calipers exceeding 10 in. (25 cm). The poles planted farthest from the stream have survived but put on considerably less growth.

Riparian Mitigation on the Corrales Reach of the Rio Grande

Riparian restoration studies were conducted on the Rio Grande north of Albuquerque as part of an Army Corps of Engineers project mitigating disturbance of riparian vegetation resulting from the rebuilding of 10 miles of levees. The Los Lunas Plant Materials Center installed approximately 18,000 pole and whip cuttings in 1997 and 1998. Cottonwood survival averaged 85% after the first growing season when data from all accessions were pooled. On those sites with a shallow water table (3 to 5 feet, 0.9 m to 1.5 m) and soils with sufficient cohesion to allow holes to be drilled to ground water, cottonwood survival was 98% after one year and 92 to 95% after two years (Los Lunas Plant Materials Center, 1998). On those sites with dry gravely sands, the holes collapsed preventing the pole from being placed into ground water; cottonwood survival ranged from 65 to 79% after one year. Goodding's willow survival was 87% on good sites after two growing seasons. On poor sites, survival ranged from 48 to 72% at the end of the first growing season.

The average survival of poles of New Mexico olive, desert false indigo, and willow baccharis were 70%, 60% and 52%, respectively, after 2 years. Survival ranged from 30 to 84% on the various sites when data for these 3 species are pooled. This variability probably resulted from differing soil conditions among sites as well as inconsistent pole hydration periods for different lots of poles. Coyote willow planted using rotary hammers at one site had survival percentages of 99% after 2 years. Because the coyote willows were densely planted (about one foot apart), the whips were not protected from beaver at one site with the result of total decapitation of over 5000 willow whips. Subsequently, these willows vigorously re-sprouted probably as result of carbohydrate reserves stored in the 3 ft (0.9 m) stem section planted below ground.

CONCLUSION

Site assessment examining such factors as water table depth and fluctuation, soil texture, soil salinity, and browsing pressure from livestock and wildlife is a prerequisite to successful riparian restoration. These factors along with elevation and ecoregion considerations will aid in the selection of appropriate restoration species. A number of plant material stock types and planting techniques are available to land managers confronted with restoring riparian areas in the Southwest. Stock types such as pole cuttings and tallpots offer opportunities to accomplish cost-effective establishment in demanding riparian environments.

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A SURVEY OF RECLAMATION AND RESTORATION PROJECTS IN THE SIERRA NEVADA MOUNTAINS

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ABSTRACT

This poster displays several high elevation projects from the Sierra Nevada Mountains. The challenges that these projects share include short growing seasons, poor soils, lack of appropriate seed, and logistical problems related to terrain, remoteness, and weather. The projects include road cuts, riparian corridors, mines, and a comparison of two ski resorts. For each project, I have described the installation procedures and supplied monitoring data when available. The accompanying photos have followed these projects over time. The information gained from these projects will not only add to our data bank for future project design and implementation, but will also add to our intuitive sense of how to work with the nuances of nature.

COMPARE AND CONTRAST

The Mt. Hood and the Pine Creek projects are located on U.S. Forest lands. However, they differed in design. While the USFS in Bishop California would not allow seed from collection sites that were not local, the USFS in Mt. Hood, Oregon allowed the use of commercial grass cultivars in combination with our local native collections. Both projects are progressing with plant community growth. We shall watch over the long run to see if the commercial species remain too aggressive for native seral advance at Mt Hood or if the lack of aggressive commercial species is detrimental to the Pine Creek project. No doubt the projects are different, one being a mine tailings project in the southern Sierras and the other being a road cut in the Cascades. Stay tuned as we watch varying philosophical approaches play out their hands.

Mt. Hood Highway Improvement

In 1998, the Federal Highway Administration initiated a highway and intersection improvement project at the Mt Hood Meadows ski resort that involved an overpass construction and extensive cut and fill construction. The project was set for completion late fall 2000. The U.S. Forest Service requested that local seed be collected for reclamation and we were awarded a two-year collection contract for the fall of 1998 and 1999. The species list (Table 1) included early seral colonizers that we found thriving on existing disturbed areas including the following list. The USFS complemented our native collections with commercial grass species.

Table 1. Seed mix for overpass and cut and fill construction.

Scientific Name	Common Name	Variety	PLS #/acre
GRASSES			
Elymus trachycaulus	Slender Wheatgrass	Pryor	5.00
Agropyron dasystachyum	Streambank Wheatgrass	Sodar	5.00
Agropyron trichophorum	Pubescent Wheatgrass	Greenleaf	7.00
Bromus carinatus	California Brome	VNS	7.00
FORBS			
Lupine latifolius	Broadleaf lupine		1.50
Anaphalis margaritacea	Pearly everlasting		0.50
Achillea millefolium	Yarrow		0.50
Solidago canadensis	Canada Goldenrod		1.00
SHRUBS			
Ceanothus velutinus	Snowbrush		2.00
Vaccinium membranaceum	Big leaf Huckleberry		0.50
Xerophyllum tenax	Beargrass		2.00
Total PLS #/acre			32.00

Once construction was completed, salvaged topsoil was re-applied to the new cut slopes. The slopes were hydro-seeded with the locally collected species. The hydro slurry mixture included organic soil amendments and tackifiers due to the steep slopes. A tackifier had also been sprayed onto the new cut slopes during the summer prior to the fall seeding to hold the soil in place until final seeding.

The tackified slopes held up through the first winter with over 200 inches of snow. The first summer growth included a good showing of the native colonizers as well as the slender wheatgrass.

Pine Creek Mine Reclamation

I presented this project at this conference two years ago just after this project was installed. The design was controversial at that time because issues were brought up during planning that involved species selection and the ongoing debate about natives, cultivars, and local genetic material. These issues still have a common thread with most projects that we are involved with today and the final reclamation plan at each project has varied due to the philosophical outlook of the parties involved. Last, I have photo documented the first two seasons of growth and, with minor exception, the project is showing great promise for long-term stability and seral advance.

The Pine Creek Mine is located at 7500 feet on the eastern front of the Sierras 15 miles northwest of Bishop California. The project involved stabilizing 90 acres of historic tailings ponds. Heavy winds and harsh winter conditions were continually sending sediments down the canyon. The United States Forest Service (USFS) reached an agreement with the current owner to stabilize these ponds by placing six inches of local alluvium on the ponds as a cap and seeding with a desired seed mix. Fortunately, the client analyzed the tailings and found them to be relatively benign and saturated with water. 8400 yards of alluvium were excavated from a historic barrow pit just east of the tailings. The cap was installed to leave a slight grade to the tailings and the seed blends were broadcast just prior to winter. Snow was falling during the last few days of seeding.

The USFS in Bishop California requested that the client arrange for a seed collection program that would supply the seed for this project. As with all projects, sufficient seed had to be supplied to cover 90 acres of reclaimed areas and this project required 19 PLS lbs per acre or 1710 PLS lbs. The USFS acknowledged that a priority ranking system would have to be applied to available seed such that if sufficient seed was not available of a given species, other local species could be used and additional seed may have to come from the closest available sources. Many of our current projects perform this ranking hoping to obtain the most local seed sources.

We agreed to collect as much local seed as possible but emphasized to the USFS that this priority should be balanced against our mutual desire to achieve physical stability at this site. Indeed, our goal at many such projects has been to harvest local species that exhibit aggressive colonizing behavior.

We have been involved with several projects where the native philosophy has compromised the potential for the project to succeed by excluding species that would provide short-term physical stability. For example, we have supplied seed blends that only contained highly dormant woody plant seeds that could take years to germinate under natural conditions.

In sum, we agree with the USFS and others that we should emphasize native and local source material but we feel that flexibility is also necessary to satisfy concerns for short-term site stability. In the end, we will continue to expand our inventory of early seral natives and hope to strike a good balance between short and long-term goals without introducing aggressive species that may interrupt normal seral advance.

The USFS settled on the seed mix listed in Table 2. A modified blend was created for the dune areas that emphasized the colonizers and included oats as an experiment on 50% of the dunes.

The USFS would not allow any commercial source species such as Slender wheatgrass, which is commonly used in the Lake Tahoe Basin as a short-lived perennial nurse crop. Likewise, they did not allow any commercial source Indian ricegrass. We were fortunate to obtain the forbs, most of which exhibited aggressive colonizing behavior on the disturbed sights where we found them. This seeding rate represents 138 pure live seeds per square foot.

We do not have any quantified data on the current conditions. However, a wide variety of the species have germinated on the tailings including all shrubs except the Bittercherry and Desert Peach. This is predictable for these two species. We hope to see them over the next few years. No seed has germinated on the dunes, even the areas where the oats were included. The loose; coarse nature of this soil has always presented problems for seed germination.

The debate regarding natives will continue and projects will continue to add depth to our experience. We are convinced that a balancing concept will evolve over time that prioritizes localized species but still accommodates non-local source natives and occasionally non-natives. In the meantime, we will continue to expand our efforts to collect and cultivate more natives that exhibit aggressive colonizing behavior.

Table 2. Agreed upon Seed Mix.

Scientific Name	Common Name	PLS #/acre
GRASSES		
Achnantherum hymenoides	Indian ricegrass	0.15
Poa secunda var. juncifolia	Bluegrass sandberg	2.50
Leymus cinereus	Wildrye Great Basin	4.00
Leymus triticoides	Wildrye creeping	1.25
Elymus elymoides	Squirreltail bottlebrush	1.30
Achnantherum speciosa	Desert needlegrass	0.25
SHRUBS		
Chrysothamnus nauseousus	Rubber Rabbitbrush	0.15
Purshia glandulosa	Desert bitterbrush	3.00
Artemisia tridentata tridentata	Basin sagebrush	0.50
Prunus emarginata	Bittercherry	0.25
Prunus andersonii	Desert peach	0.65
FORBS		
Mentzelia laevicaulis	Giant blazing star	0.10
Eriogonum umbellatum	Sulfur buckwheat	0.30
Eriogonum nudum	Nakedstem buckwheat	0.08
Eriogonum fasciculatum	Flat-top Buckwheat	0.10
Artemisia ludoviciana	Louisiana sagebrush	0.45
Argenome munita	Prickly poppy	0.20
Penstemon speciosa	Penstemon	0.10
Chaenactis douglasii	Dusty maidens	0.10
TOTAL PLS #/ACRE		15.43

Tale of Two Ski Resorts

The ski run projects at the two resorts below represent opposite approaches to reclamation. Both resorts are situated at 8-10,000 feet on north facing slopes in the Sierra's. The lower elevation ski runs at June Lake have been naturally colonized by native herbaceous species that have not required inputs from management. The plant communities have colonized without seed, fertilizer, or water. The plant community is dense enough to limit sediment movement by rain or wind. The challenge is to minimize disturbance on these developing plant communities. The ski resort actively removes woody plants to maintain the lowest profile possible.

The ski run projects at Sugar Bowl have been planted, fertilized, and irrigated with herbaceous plants. The plant community is predominantly non-native grass cultivars and pasture legumes complimented by local natives that we have harvested at their resort. As above, the resort must continually remove woody plants to maintain the low profile community.

Our challenge with ski resorts is to acquire more seed and plant material of the native species at these resorts that exhibit aggressive colonizing behavior. Critical species include western needlegrass, Squirreltail and a Carex that we have not identified yet. These three species dominate the upper elevations at several Tahoe area resorts. Irrigation is expensive and all parties agree that fertility inputs may have negative consequences to the regional watersheds, particularly in the Lake Tahoe basin. Likewise, minimizing inputs saves money.

A Tale of Two Wetlands

Federal and State mandates to improve Lake Tahoe water clarity have jump-started basin wide efforts at watershed restoration. Backed by funding from non-profit organizations and private landholders, projects are being initiated at an increasing rate. There are inherent benefits to this accelerated activity, including projects being able to dovetail resources. Another benefit involves economy of scale; as the restoration entities respond to increased activity, they become more efficient with materials and services, improving the productivity and cost effectiveness of their efforts.

The three projects in this column exemplify this benefit. The parties involved with the Trout Creek, the Keys, and the Washoe State quarry projects saw an efficient solution to moving large volumes of spoil and soil materials in a cost effective manner. The Trout Creek project created a large amount of topsoil as they excavated an historic streambed. The Keys project created 84,000 yards of spoil material that needed home and the Washoe State quarry needed a large amount of fill prior to restoration. The alternative to this synergy would have been expensive long distance trucking of these materials to remote disposal sites. Likewise, as nurseries are experiencing increased demand, we are supplying more local seed for grow out on a speculative rather than project-by-project basis.

Trout Creek

(Data provided by Western Botanical Services, the California Tahoe Conservancy, and the City of South Lake Tahoe)

The Trout Creek project is one of many in the Lake Tahoe basin sharing a goal to improve watershed quality and function, thereby improving the water quality of Lake Tahoe. The construction period covered two summers during 1998 and1999, allowing partial vegetative recovery prior to the re-introduction of flowing water. Funding included monitoring from Spring 2000 to Fall 2006. The project involved reconstructing 9000 feet of stream channel that had been negatively impacted by various activities over 100 years. The channel had been aligned down the west side of the meadow and a logging railroad had been constructed down the center. These historic disturbances as well as long term grazing had caused severe erosion and a decline in riparian functions including fish and wildlife habitat, vegetative quality, a declining water table, and less sediment retention.

Prior to and during the project, native seed was collected from this watershed and surrounding areas. Some of the seed was provided to the Nevada Division of Forestry nursery and grown out into wetland mats that were transported to the sight and used to line/armor the new channel banks. Likewise, wetland sod and willows were salvaged from the project site with some nursery stock supplied from off site. Construction involved excavating the historic channel and installing the wetland mats, salvaged sod, and direct seeding of surrounding disturbances. Some excavated material was used to fill the old river channel while some was exported to other project sites. Temporary irrigation was installed to ease the sod salvage and help to germinate newly seeded areas.

Table 3. Direct seeded species for the Trout Creek Project

Scientific Name	Common Name	Seed Source: Commercial or Local	PLS #/acre
Deschampsia caespitosa	Tufted Hairgrass	Both	2.00
Leymus triticoides	Creeping Wildrye	Both	6.00
Elymus trachycaulus	Slender wheatgrass	Commercial	4.00
Festuca rubra	Red fescue	Commercial	4.00
Penstemon rydbergii	Rydberg's penstemon	Local	0.12
Poa pratensis	Kentucky bluegrass	Local	2.00
Potentilla gracilis	Cinquefoil	Local	0.25
Agrostis excerata	Bentgrass	Local	
Arnica chamissonis	Leafy arnica	Local	
Carex spp.	Sedges	Local	
Epilobium glaberrinum	Smooth willow herb	Local	
Juncus spp.	Rushes	Local	
Hordeum brachyantherum	Meadow barley	Local	

A summary of monitoring results has been broken down as follows:

1) <u>Vegetation</u> Species diversity and plant vigor have increased dramatically, most likely due to the decreased depth to the water table. A general trend includes a decrease in mesic meadow species such as Deschampsia and Hordeum and an increase of some obligate species such as Carex utriculata. Thus the trend is toward a wetter plant community. Also, there has been a significant increase in the perennial forb cover including Arnica, Aster, Fragaria, Stellaria, and Trifolium. Finally, seeds of some Carex and Juncus species have not germinated from direct seedings. Seeds from both genera are known to have both seed coat and embryonic dormancies, which may take years to germinate naturally. Other species must be relied on for short-term germination and site stability.

2) <u>Invertebrates</u> Initial monitoring has documented a greater diversity of taxa, an increased frequency of organisms > 5mm length, and a decrease in the proportion of midges and other disturbance-tolerant organisms.

3) <u>Water quality</u> 19 surviving wells throughout the project have shown increases in ground water elevation from 4% to 120%. Surface water quality was measured above, within, and below the construction site. During the peak spring flow in 2003, the meadows attenuated the flow and significantly reduced outflow.

4) <u>Wildlife</u> Studies are preliminary but initial data shows an increase in waterfowl, mammals, amphibians, and invertebrates including more hydric species such as slugs.

5) <u>Fisheries</u> Post project monitoring is just beginning.

Upper Truckee River Restoration (Data provided by California Tahoe Conservancy)

The Upper Truckee River (UTR) drains the largest of Lake Tahoe's watersheds at South Lake Tahoe, California. In the 1950's, developers filled portions of the wetlands at the terminus of the UTR with up to six feet of sand and aligned the river, all for future development as part of the Tahoe Keys. Overtime, the project was halted and in 1988, the California Tahoe Conservancy (CTC) purchased the land. In May 2001 the CTC initiated a restoration plan that included the removal of 84,000 yards of fill and the restoration of the pre-existing riparian community. The CTC's ultimate goals include water quality protection, wetland restoration, wildlife habitat enhancement, and public access to the lake.

The excavation yielded 11 acres of basins at historical saturation elevations and a small amount of upland disturbance. Native sod was salvaged at the project and reinstalled after excavation. Topsoil was imported from nearby Trout Creek where a restoration project excavated a historic stream channel. (See Trout Creek project) Soil amendments, fertilizer, and inoculants were combined with the topsoil and incorporated into the surface. Temporary bladders were installed to prevent the river from flowing through the wetlands until the plant community is sufficiently developed to sustain water flow.

Wetland and upland/transition seed mixes (Table 4) were broadcast, followed by mulch and tackifiers. These mixes included both local native seed as well as commercial source species. Last, 32,000 commercial plugs, 3500 upland shrubs and 1500 willow stakes were installed.

Table 4. Seed mixes for the Upper Truckee River Restoration Project.

WETLAND SEED MIX

Scientific Name	**Common Name**	**Variety**	**PLS #/ACRE**
Deschampsia caespitosa	Tufted Hairgrass		4.00
Elymus glaucus	Blue Wildrye	Stanislaus	3.00
Elymus trachycaulus	Slender wheatgrass	Revenue	4.00
Leymus triticoides	Creeping Wildrye	Shoshonie	4.00
Festuca rubra	Red fescue		2.00
Total PLS #/acre			17.00

UPLAND/TRANSITION SEED MIX

Scientific Name	**Common Name**	**Variety**	**PLS #/ACRE**
Agropyron X Triticum	Sterile wheat hybrid		4.00
Artemisia tridentata vaseyana	Mountain big sagebrush		1.00
Bromus carinatus	California brome		4.00
Elymus elymoides	Squirreltail		4.00
Elymus trachycaulus	Slender wheatgrass	Revenue	4.00
Eriogonum umbellatum	Sulfur buckwheat		2.00
Leymus triticoides	Creeping Wildrye	Shoshonie	4.00
Linum lewisii	Lewis flax	Appar	0.25
Purshia tridentata	Bitterbrush		1.00
Total PLS #/acre			24.25

Blue Lakes Road Riparian Mitigation (A direct transplant project)

During the summer of 2003 a new 12-mile paved road was constructed into the Blue Lakes area south of Lake Tahoe, California. The project had setbacks including a summer down- pour that washed out sections of the newly graded road base. The pavement was completed just before winter set in but the Federal Highway Administration would not sign off on the project until a mitigation wetland was completed. The original specifications called for nursery propagation of 400 wetland plugs of species found in the surrounding meadows. Unfortunately, the contractor had not planned for the wetland plugs. The Forest Service reluctantly allowed for a direct transplant of the 400 plants from the surrounding meadows.

This project became significant because it deviated from the normal management practice of collecting seed in advance, contracting a nursery for grow out, and transplanting the species at the site. This conventional procedure is relatively expensive and requires a year or more of advanced planning. The transplant program took one day with a crew of six. The species were selected to reflect the frequency of occurrence in the surrounding meadow. The actual collection spots were spread out around the meadows to reduce the impact. The transplants were positioned on the site to conform to the expected water regimes. Thus, obligate species were placed at the low end were runoff would collect while the facultative species were placed on the higher ground approaching the road. The final species taken from the meadow are presented in Table 5.

Table 5. Species collected for the Blue Lakes Road Riparian Mitigation Project.

Scientific Name	No. of Plants Collected
Carex vesicaria	305
Carex athrostachya	25
Carex nebraskensis	40
Carex aquatilis	21
Hordeum brachyantherum	20
Deschampsia caespitosa	10

Even though these species were the dominant in each clump, many other plants were contained in each soil clump removed from the meadow. This project is coming into its first growing season. The costs were insignificant relative to the specified grow out procedures, and if the riparian community thrives, this procedure should be prioritized for future work.

Quarry Fill Washoe State Park, Lake Tahoe California (Data provided by California State Parks)

During the summer of 2001, 84,000 yards of fill was removed from an estuary at South Lake Tahoe and placed in an abandoned four-acre quarry at Washoe State Park. (See Keys project.) The fill was graded and compacted to re-create sheet flow and small swales, tying in with local topography and adjacent drainages. The finished surface was winterized with hydromulch and placement of straw wattles along the contour.

Comstock Seed collected seed during the 2000 and 2001 seasons and container plants were established with some of the seed.

During 2002, a blend of organic materials was incorporated into the surface including pine needles, wood chips, dairy manure, yard waste, and mineral additives. An excavator de-compacted the top 3 feet of fill material prior to incorporation of the organic material. Also, blow-down snags were collected from adjacent lodgepole forest and distributed throughout the site.

The seed (Table 6) was hand broadcast and covered with one inch of pine needle mulch. Containerized plants were planted during the fall once fall precipitation began. Last, some wattles were reset and interpretive signs were put out explaining the project and requested no disturbance.

During 2003 spring additional containerized plants were put in. The tree seedlings were watered once and some weeds were pulled.

Table 6. Plant materials used in the Quarry Fill Washoe State Park Project.

Scientific Name	Common Name	Type/Amount of Plant Material
DIRECT SEEDING		
Elymus elymoides	Squirreltail	40.00 PLS lbs
Hesperostipa comata	Needle and thread grass	0.75 BK lbs
Poa secunda	Sandberg bluegrass	2.00 Bk lbs
Lupine lepidus	Torrey's lupine	1.00 PLS lbs
Ribes roezlii	Sierra gooseberry	0.35 PLS lbs
CONTAINERIZED PLANTS		
Pinus jeffreyi	Jeffrey pine	70 quart containers
Pinus jeffreyi	Jeffrey pine	10 3-gallon containers
Pinus ponderosa	Ponderosa pine	485 2-0 cells
Salix lemmonii	Lemmon's willow	10 1-gallon containers
Elymus elymoides	Squirreltail	1562 supercells
Poa secunda	Sandberg bluegrass	550 supercells
Hordeum brachyantherum	Meadow barley	200 supercells
Hesperostipa comata	Needle and thread grass	30 supercells
Rosa woodsii	Mountain rose	200 supercells
Lupinus lepidus	Torrey's lupine	200 supercells
Eriogonum umbellatum	Sulfur buckwheat	200 supercells
Artemisia tridentata	Mountain sagebrush	200 supercells

HIGH ALTITUDE REVEGETATION EXPERIMENTS ON THE BEARTOOTH PLATEAU PARK COUNTY, MONTANA AND PARK COUNTY, WYOMING

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ABSTRACT

Since 1999, ERO Resources Corporation (ERO) has been conducting revegetation tests on the Beartooth Plateau to assist the Federal Highway Administration (FHWA) in planning revegetation along U.S. Highway 212, the Beartooth Highway. A portion of the Beartooth Highway is proposed for reconstruction. The road traverses alpine areas of the Beartooth Plateau between Red Lodge and Cooke City, Montana, and accesses Yellowstone National Park at its northeast entrance. ERO and the FHWA have conducted revegetation tests over 5 years to identify revegetation techniques that would maximize revegetation success for areas disturbed by construction activities. This paper summarizes the tests and other activities that have been conducted to date.

INTRODUCTION

The FHWA proposes to reconstruct portions of U.S. Highway 212, the Beartooth Highway, in Park County, Wyoming. The Beartooth Highway is a scenic highway that traverses subalpine and alpine areas on the Beartooth Plateau. In anticipation of the proposed reconstruction, FHWA and ERO began a series of revegetation tests in 1999, to determine the most appropriate revegetation techniques for alpine portions of the Beartooth Highway. ERO conducted an extensive literature review, which was summarized in the proceedings of the 15th annual High Altitude Revegetation Workshop (Payson 2002),. ERO consulted with several people knowledgeable in the reclamation of sensitive naturals areas, including Ray Brown, formerly with the Rocky Mountain Research Station, Dale Wick and Joyce Lapp of Glacier National Park, Eleanor Williams Clark of Yellowstone National Park, Mark Majerus of the USDA Bridger Plant Materials Center, Steve Parr of the USDA Meeker Plant Materials Center, and suppliers of plant materials seed, soil amendments and surface mulches. The revegetation tests examine seed mix densities, seed sources, topsoil salvaging, organic amendments, surface mulches, the planting of nursery stock, and growout of seed collected on the Beartooth Plateau.

1999 MONTANA BORROW AREA REVEGETATION TEST PLOTS

In September 1999, ERO placed revegetation tests plots in an existing gravel borrow area along the Beartooth Highway. The test plots were designed based on studies of revegetated disturbances in Rocky Mountain alpine environments. Three variables were tested: soil salvaging, seeding rates, and soil amendments. On half of the plots, fertilizer and Kiwi PowerTM, a soil amendment, were reapplied for 2 years after the revegetation plots were originally constructed. Native seed was collected on the Plateau and used for direct seeding of the revegetation test plots and for production of plant materials (Tables 1 and 2). Additional revegetation test areas (planting test plots) were created to determine the feasibility and cost effectiveness of planting greenhouse-grown seedling plant materials from locally collected seed. The plants included in the planting test plots are shown in Table 2. The four variables tested on the plots were:

- Composted organic matter plus fertilizer versus surface application of Kiwi Power™ and Fertil-Fibers NutriMulch™
- High seeding rate versus very high seeding rate
- Topsoil salvaging and replacement versus no topsoil
- Reapplication of fertilizer or Kiwi PowerTM versus no reapplication of fertilizer or Kiwi PowerTM

Table 1. Seed Mixes for the 1999 Montana Borrow Area Plots.

1999 Montana Borrow Area Seed Density					
Scientific Name	**Common Name**	**Lower Density Plots**		**Higher Density Plots**	
		PLS† (lbs/ac)	Seeds/ft2	PLS (lbs/ac)	Seeds/ft2
Deschampsia caespitosa	Tufted hairgrass	0.88	45	1.75	90
Poa alpina	Alpine bluegrass	1.48	45	2.95	90
Phleum alpinum	Alpine timothy	1.25	25	2.5	50
Festuca ovina	Sheep fescue	1.75	32.5	3.5	65
Trisetum spicatum	Spike trisetum	0.38	12.5	0.75	25
Antennaria lanata	Wooly pussytoes	0.40	45	0.8	90
Artemisia scopulorum	Rocky Mountain sage	1.02	45	2.05	90
Lupinus argentea	Lupine	7.50	4.5	15	9
Total		**14.66**	**254.5**	**29.3**	**509**

†PLS = Pure Live Seed

Table 2. Nursery-Grown Species Transplanted in 2000.

Scientific Name	**Common Name**	**Number Planted**
GRAMINOIDS		
Carex scirpoidea	Downy sedge	40
Carex paysonis	Payson sedge	40
Deschampsia caespitosa	Tufted hairgrass	40
Poa alpina	Alpine bluegrass	40
Phleum alpinum	Alpine timothy	40
Festuca ovina	Sheep fescue	40
Trisetum spicatum	Spike trisetum	40
FORBS		
Antennaria lanata	Woolly pussytoes	40
Artemisia scopulorum	Rocky Mountain sage	40
Geum rossii	Alpine avens	40
Sibbaldia procumbens	Sibbaldia	40
Trifolium parryi	Parry's clover	40
Total		**480**

2000 GARDNER HEADWALL AND WEST SUMMIT SLOPE PLOTS

The test plots created at the Gardner Headwall and West Summit Slope plots in 2000 address additional issues identified for the proposed project, such as new types of organic amendments, slope, and seed source. The 2000 Gardner Headwall and West Summit Slope revegetation test plots were designed for observation and some quantitative analysis, and were not designed to be statistically repeatable. This decision was made in an effort to limit disturbances to fragile alpine areas, but still permit evaluation of variables such as slope and aspect. The four variables tested in 20 revegetation test plots (12 at the West Summit, and 8 at the Gardner Headwall) for their effect on revegetation success were:

- 1:2 slope versus 1:3 slope (vertical:horizontal)
- Seed collected from the Beartooth Plateau versus commercially supplied seed (Table 3)
- Surface application of BioSol Mix™ versus surface application of Kiwi Power™ and Fertil-Fibers NutriMulch™
- Slope aspect

For the West Summit Slope plots, the test plots were on the south-, southeast-, north-northeast, and east-facing slopes of an old gravel borrow area north the parking lot. Twelve revegetation test plots were established at the West Summit Slope plots. Four experimental 14.86 m2 (160 ft2) plots and two 7.43 m2 (80 ft2) control plots were placed on approximate 1:2 slopes, and four 14.86 m2 (160 ft2) experimental plots and two 7.43 m2 (80 ft2) control plots placed on approximate 1:3 slopes.

At the Gardner Headwall pullout, eight revegetation test plots were established. The test plots at the Gardner Headwall were on a north-facing slope adjacent to a pullout on the south side of the Beartooth Highway. Four test plots, two organic amendment test plots, and two control plots, all measuring 7.43 m2 (80 ft2), were established on 1:2 slopes. Four experimental test plots, two organic amendment test plots and two control plots, all measuring 7.43 m2 (80 ft2), were established on 1:3 slopes.

Table 3. Seed Mixes for the 2000 West Summit Slope Plots and Gardner Headwall Plots.

2000 Gardner Headwall and West Summit Slope Plots Seed Mix Density			
Scientific Name	**Common Name**	**PLS (lbs/ac)**	**Seeds/ft2**
Deschampsia caespitosa	Tufted hairgrass	0.87	45
Poa alpina	Alpine bluegrass	1.48	45
Phleum alpinum	Alpine timothy	2.40	45
Total		**4.75**	**135**

2001 WEST SUMMIT FLAT PLOTS

In September 2001, 32 test plots 6.25 m2 (67 ft2) in size were placed in a flat portion of the borrow area at the West Summit. This location was selected for its uniform topography, existing disturbances on the site. Also, topsoil and subsoil removed from the 2000 test plots were placed here, leaving an ideal growing medium for placement of additional revegetation test plots.

The 2001 West Summit Flat plots tested three surface mulch treatments, two seeding rates, two methods of transplanting soil plugs, and one organic amendment. The treatments were:

- ⅔ cedar/ ⅓ fir wood chips v. bonded fiber matrix v. 70:30 straw:coconut fiber erosion control blanket
- Very low v. moderately low density seeding rate
- Sod transplants placed immediately v. sod transplants placed after 1-month stockpile
- Organic amendment application v. no organic amendment

Table 4. Seed Mixes for the 2001 West Summit Flat Plots.

2001 West Summit Flat Plots Seed Mixes					
Scientific Name	**Common Name**	**Moderate Density Rate**		**Low Density Rate**	
		PLS (lbs/ac)	**Seeds/ft2**	**PLS (lbs/ac)**	**Seeds/ft2**
Deschampsia caespitosa	Tufted hairgrass	0.35	20	0.175	10
Poa alpina	Alpine bluegrass	0.90	20	0.45	10
Phleum alpinum	Alpine timothy	0.85	20	0.425	10
Trisetum spicatum	Spike trisetum	0.35	20	0.175	10
Total		**2.45**	**80**	**1.23**	**40**

SEED GROWOUT EXPERIMENT

In anticipation of potential impacts to alpine and subalpine vegetation along the Beartooth Highway associated with the proposed reconstruction of the highway, the FHWA implemented a seed growout experiment to evaluate the effectiveness of collecting seed of reclamation plant species on the Beartooth Plateau and farming it as a seed crop. This process is called seed increase or seed growout. Seed was collected from both alpine and subalpine habitat on the Beartooth Plateau. The FHWA wanted to determine if seed growout is a cost-effective and reliable method of obtaining seed to revegetate disturbed alpine areas.

Two seed growout experiments currently are underway. Seed was collected for the first seed growout in 2000 (2000 Growout), and seeded/planted in the spring of 2001. Seed was collected for the second growout in 2001 (2001 Growout) and seeded/planted in spring 2002.

2000 Growout

In fall 2000, Wind River Seed collected seed from four alpine species on the Beartooth Plateau (Table 5). Two crops of weed were established in 2001, one in the spring and one in the fall. A portion of the 2000 growout crop was direct seeded and a portion was planted from nursery stock that Bitterroot Restoration Inc. grew from seed collected by Wind River Seed. Wind River has been growing out these species since 2001.

2001 Growout

An additional seed growout experiment was undertaken in the fall of 2001, Wind River Seed and Sabine Mellman Brown collected seed from the Beartooth Plateau in the fall of 2001. The seed was planted in 2002. Again, a portion of the growout crop was direct seeded and a portion was planted from nursery stock that Bitterroot Restoration grew from seed collected by Wind River Seed. The 2001 Growout experiment is divided into two parts.

First, a small-scale supplemental seed growout experiment (Supplemental Growout Experiment) was conducted to test forbs and sedges for use in revegetation (Table 6). The purpose of this experiment was to test the effectiveness of growing out forbs and sedges to add diversity to revegetation seed mixes and plantings.

Table 5. Seed and Plants for 2000 Growout Experiment.

Scientific Name	Common Name	Spring 2001 Direct Seeding		Fall 2001 Direct Seeding		Area Planted*	
		Proposed	Actual	Proposed	Actual	Proposed	Actual
		Ac.	Ac.	Ac.	Ac.	Ac.	Ac.
Deschampsia caespitosa	Tufted hairgrass	0.20	0.78	0	0.51	0.20	0.73
Poa alpina	Alpine bluegrass	0.20	0.36	0	0.30	0.20	0.43
Phleum alpinum	Alpine timothy	0.20	0.36	0	0.30	0.20	0.43
Festuca ovina	Sheep fescue	0.20	0**	0	0	0.20	0.06
Total		**0.8**	**1.5**	**0**	**1.11**	**0.8**	**1.65**

*No. of transplants of each species: tufted hairgrass = 8,600; alpine bluegrass = 5,350; alpine timothy = 5,100
**Insufficient seed was collected of this species to direct seed

Table 6. Seed Amounts for the 2002 Supplemental Growout Experiment.

Scientific Name	Common Name	Amount Seeded	Transplants	Transplants
		Lbs (PLS*)	Proposed	Planted
Agoseris glauca	False dandelion	0.25	0	783
Anaphalis margaritacea	Pearly everlasting	0.10	625	380
Aster foliaceus	Aster	0.25	625	625
Carex nigricans	Black alpine sedge	0.25	0	600
Carex paysonis	Payson sedge	0.25	625	691
Carex scirpoidea	Downy sedge	0.02	625	0
Phacelia hastata	Whiteleaf phacelia	0.20	625	11
Polemonium viscosum	Sky pilot	0.03	0	97
Potentilla diversifolia	Varileaf cinquefoil	0.20	625	985
Total		**1.55**	**3,750**	**4,172**

*PLS = Pure Live Seed

Table 7. Seed Planned for the 2004 Construction Seed Increase.

Scientific Name	Common Name	Amount Collected 2001	Transplants Proposed 2002	Transplants Planted 2002	Area to Grow/ Species	Additional Spring 2003 Transplants	2003 Target Amount	2004 Target Amount	Total Target Amount
		Lbs (Bulk)			Ac.		Lbs (PLS)*		
Danthonia intermedia	Timber oatgrass	0.485	6,060	1,800	0.08	100	15	15	30
Calamagrostis canadensis	Bluejoint reedgrass	-	800	-	-	-	-	-	-
Deschampsia caespitosa	Tufted hairgrass	1.091	460	460	0.03	-	5	5	10
Elymus glaucus	Blue wildrye	0.551	7,212	7,200	0.02	455	108	108	216
Elymus scribneri	Scribner's wheatgrass	0.919	7,884	8,000	0.62	650	119	119	237
Festuca idahoensis	Idaho fescue	-	-	-	-	-	-	-	-
Festuca ovina	Sheep fescue	0.023	-	1,000	0.02	200	4	4	8
Koeleria pyrimidata	Prairie junegrass	-	-	-	-	-	-	-	-
Penstemon procerus	Penstemon	4.536	530	396	0.02	-	4	4	8
Phleum alpinum	Alpine timothy	0.430	1,580	790	0.11	-	20	20	40
Poa alpina	Alpine bluegrass	0.662	-	1,750	0.26	-	74	74	148
Poa nevadensis	Nevada bluegrass	0.970	-	4,500	0.26	330	50	50	100
Stipa nelsonii	Nelson's needlegrass	0.551	-	2,997	0.08	195	12	12	24
Total		**10.375**	**25,210**	**29,593**	**1.88**	**1,930**	**416**	**416**	**832**

*PLS= Pure Live Seed

Second, a large-scale growout experiment was conducted to see if it is possible to grow enough seed (Table 7) for construction in 2004 (2004 Construction Experiment). The purpose of this experiment is to determine whether it is possible to grow seed that is not commercially available, has sporadic or limited commercial availability, or is better genetically adapted to subalpine environments than available commercial stock.

SUMMARY

ERO and the FHWA are conducting revegetation experiments on the Beartooth Plateau as part of planning for proposed reconstruction of portions of the Beartooth Highway in Park County, Wyoming. Monitoring of these revegetation test plots is ongoing, and is expected to yield valuable information about revegetation of alpine areas in the Rocky Mountains.

LITERATURE CITED

Payson, L. 2002. High Altitude Revegetation Experiments on the Beartooth Plateau, Park County, Montana and Park County, Wyoming. First Year Monitoring Results. In: Proceedings: High Altitude Revegetation Workshop No. 15. Colorado State University. Fort Collins, Colorado

SNAKE RIVER GRAVEL PIT REVEGETATION

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POSTER PAPER

ABSTRACT

The Snake River gravel pit revegetation project was located within the John D. Rockefeller Memorial Parkway, Teton County, Wyoming, approximately 0.85 miles southwest of the Flagg Ranch. (U.S. Highway 89/287). The project purpose was to restore wildlife vegetative habitat and indigenous communities on 30 acres of a 65 acre abandoned gravel mine site containing five ponds. Revegetation included planting 602,000 herbaceous plugs (5 species) and 35,000 willow cuttings (mixed species).

The $564,517 project was funded by the State of Wyoming, Department of Environmental Quality (DEQ), Abandoned Mine Lands Division (AML) in consultation with the National Park Service, EPA, COE and PHC Reclamation Inc., Cheyenne, Wyoming, Mr. Chris Walla, P.E., Project Manager.

Five species of wetland seeds were collected during the summer of 2002 from the nearby Snake River floodplain, stored, germinated, and grown during the winter/spring 2003. Seeds were grown at the Aquatic and Wetland Company (AWC) nursery during winter/spring in 5.7 cubic inch cones including the spike rush *(Eleocharis palustris)* (34,500); blister rush *(Carex vesicaria)* (34,500); beaked sedge *(Carex utriculata)* (176,000); water sedge *(Carex aquatilis)* (200,100); and bluejoint grass *(Calamagrostis canadensis)* (141,500). AWC and Intermountain Aquatics, Driggs, Idaho, completed the planting.

SH 160 EAST OF WOLF CREEK PASS REVEGETATION & WETLAND DESIGN IN THE COLORADO MOUNTAINS

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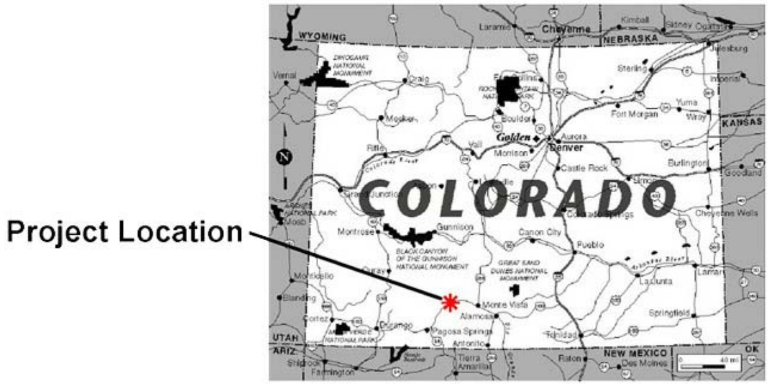
ABSTRACT

SH 160 east of Wolf Creek Pass passes through a narrow mountain canyon lined with steep, rocky cliffs and a scenic Douglas-fir forest. SH 160 is the principal highway between the southern Colorado towns of South Fork and Pagosa Springs and provides access to the Wolf Creek Pass Ski Resort. To improve safety and reduce hazards along this narrow, two-lane highway, the Colorado Department of Transportation (CDOT) and their multi-disciplined consultant team led by Carter & Burgess, Inc., are designing roadway improvements to provide wider shoulders and reduce roadway curves with better visibility for motorists.

The challenge is how to construct these highway improvements with minimal impact to the Rio Grande National Forest, endangered wildlife habitat and natural resources and restore native plant communities impacted by construction.

PROJECT SITE DESCRIPTION

SH 160 shares the canyon floor with the South Fork of the Rio Grande River, hiking trails, campgrounds, and sensitive wildlife and aquatic habitats. SH 160 runs parallel to the South Fork River through the full 7.5-mile length of the project. In many places the canyon floor width is less than 175 feet wide and flanked by 400-foot-high rocky cliffs. The predominant plant community is Douglas fir forest with riparian scrub-shrub and wet meadow wetland plant communities. The project is within the Montane Vegetation Life Zone, elevation ranges between 9,500 and 8,000 feet.



SH 160 – East of Wolf Creek Pass
Project Location Map

PROJECT CHARACTERISTICS

Environmental Impact Mitigation:

- Lynx Crossings
- Replant Native Vegetation
- Visual Impact Mitigation
- Wetland Creation

Budget for Highway Improvements:

- $130 Million (based on 2003 estimates)
- 2% for revegetation

Project Schedule:

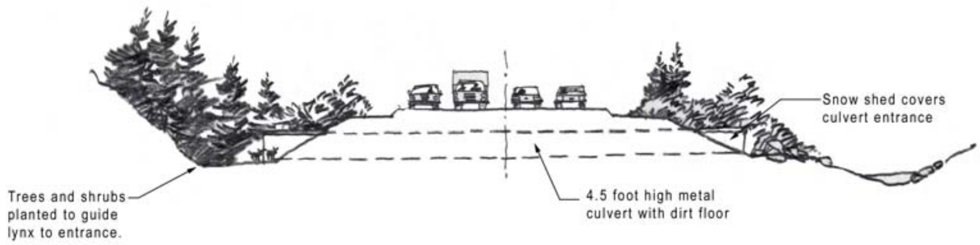
- 1997-1998 EA process
- 1998-2013 Design
- 2004-2015 Construction

Revegetation Features:

- Little available topsoil
- Use of slow release fertilizer and humates
- Trees and shrubs planted as seedlings
- Wetland restoration in roadside ditches and separate sites

COORDINATION WITH PROJECT STAKEHOLDERS

Coordination with the US Forest Service (USFS) and the US Fish and Wildlife Service (USFWS) began in 1997 during the Environmental Assessment. The Forest Service is concerned with impacts to the scenic character of the SH 160 corridor, its native vegetation and rock canyon walls, as well as improving access to USFS trails, picnic grounds and campgrounds. The USFWS is concerned with impacts to Canadian lynx, an endangered species recently released into this area. Approximately 7 acres of permanent impacts to wetlands are estimated to be the result of constructing road improvements.



SH 160 PLANNING AND DESIGN PROCESS

The need for SH 160 highway improvements comes from a 30% increase in Average Daily Traffic (ADT) from 1988 to 1997. SH 160's ADT is estimated to more than double in the next 20 years. SH 160 project events began with an environmental assessment during 1997 to 1998. The design of highway improvements began in 1998 and will continue through 2008. The first of numerous construction phases will begin in spring of 2004. SH 160's budget for road improvements is $130 million based on 2003 estimates. For the first construction phase, 2 % of the project cost will be spent on revegetation.

PROJECT CHARACTERISTICS

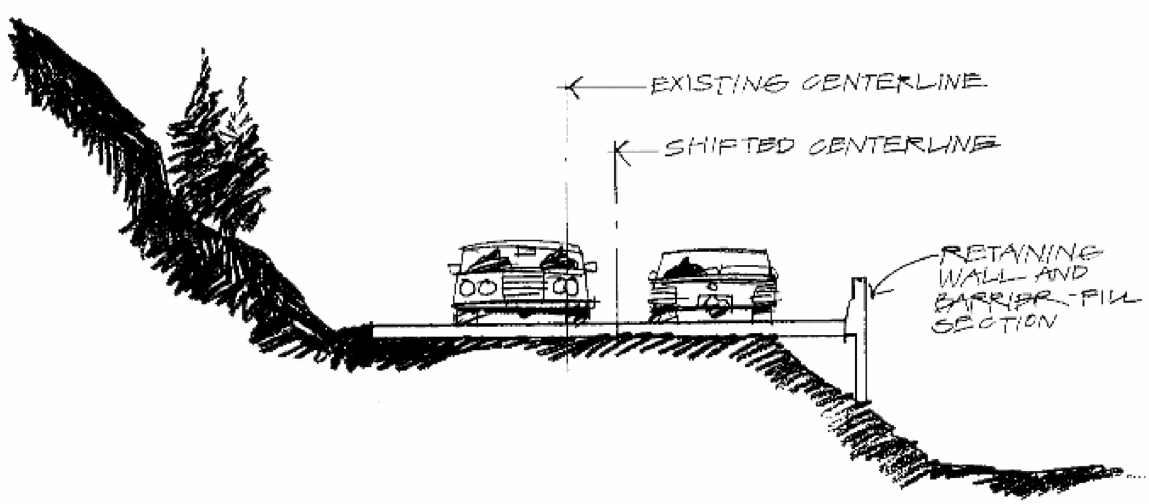
Mitigation for environmental impacts includes construction of four Lynx crossings under SH 160, restoration of native vegetation, visual impact mitigation for rock cuts, walls and tunnel entries and creation or restoration of 7 acres of wetlands. Highway mitigation design tools and strategies include:

- Rock cuts and retaining walls to blend with canyon features
- Roadway cross-section varies with the canyon terrain
- Two-way tunnel in narrowest part of the canyon
- Specially designed wildlife underpasses for lynx
- Re-establish native vegetation
- Restore impacted wetlands in roadside ditches
- Create new wet meadow and riparian wetlands

REVEGETATION DESIGN APPROACH

The challenges for revegetation along SH 160 include little to no topsoil, steep rocky slopes, and no on-site water available for plant establishment. For the first construction phase, topsoil will be salvaged from pasturelands impacted by road widening and replaced along the new road edge and wetland mitigation site. Topsoil will not be available for the remaining construction phases. Seed will be applied with a slurry mixture including a slow-release fertilizer and humate to make up for the lack of topsoil. Seedling-sized native trees and shrubs will be planted on areas disturbed by construction, matching the plant densities found along SH 160. A 2-year plant establishment period will require the contractor to conduct activities necessary for the successful establishment of seeding and plantings.

DOWNHILL RETAINING WALL



UPLAND PLANT SPECIES

- *Alnus tenuifolia* (alder)
- *Populus angustifolia* (narrow leaf cottonwood)
- *Populus tremuloides* (aspen)
- *Amelanchier alnifolia* (serviceberry)
- *Acer glabrum* (Rocky Mountain maple)
- *Padus virginiana* ssp. *melanocarpa* (chokecherry)

- *Jamesia americana* (wax flower)
- *Rosa woodsii* (Woods rose)
- *Symphoricarpos occidentalis* (western snowberry)
- *Potentilla fruticosa* (cinquefoil)
- *Picea pungens* (Colorado spruce)
- *Pinus ponderosa* (ponderosa pine)
- *Pseudotsuga menziesii* (Douglas-fir)
- *Salix* sp. (willow – site collected)

WETLAND MITIGATION FEASIBILITY STUDIES AND DESIGN APPROACH

It was difficult to find suitable sites to restore or create 7 acres of wetlands within SH 160's right-of-way. A mitigation feasibility study was conducted by Carter & Burgess, identifying 4 potential sites. Groundwater wells were installed and monitored for three years resulting in only one site next to an old river meander suitable for wetland expansion of 0.5 acres. The largest site next to private campgrounds did not have consistence groundwater levels to support wetland hydrology. Bedrock was found close to the ground surface at the Park Creek campground site. USFS found the third site to be valuable meadow habitat and unsuitable for wetland creation. CDOT found a fifth site east of the project limits and next to the South Fork. Preliminary groundwater readings have been favorable for the development of wetland hydrology. The 2 mitigation sites will meet the Sec 404 permit requirements for the first construction phase with the restoration of wetlands within the roadside ditches. A new wetland mitigation site will be needed for future construction phases.

WETLAND PLANT SPECIES

- *Populus angustifolia* (narrow leaf cottonwood)
- *Salix* sp. (willow – site collected)

CONCLUSIONS

The first construction phase for SH 160 will be an important test of the revegetation techniques proposed for the full corridor. The project landscape team will informally monitor the construction process, weather and site conditions to help evaluate revegetation success after construction. Results of this first phase of construction and subsequent phases will be shared at future High Altitude Revegetation Conferences.

PARTICIPANT LIST

We were pleased to have a total of 207 participants at the Fourteenth High Altitude Revegetation Conference. Representatives from one foreign county and 12 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 around the country and from as far away as South America were present.

For all of you that came, thank you for your participation. Make plans for attending in 2006. The High Altitude Revegetation Conference will be held in February or March, 2006 in Ft. Collins, Colorado. Pass the word to your colleagues, so that the 2006 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
Editor

Table 1. Geographical distribution of participants at the Fifteenth High Altitude Revegetation Conference (March 3-5, 2004).

Geographic Entity	Number of Participants	Percent of Total Participants
PERU	1	0.48
UNITED STATES		
California	1	0.48
Colorado	176	80.02
Iowa	1	0.48
Minnesota	1	0.48
Montana	9	4.35
Nebraska	1	0.48
Nevada	2	0.97
New Mexico	1	0.48
South Dakota	1	0.48
Texas	1	0.48
Utah	3	1.45
Wyoming	9	4.35
Total	207	100.00

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Colorado State University - Fort Collins, CO
Dates Held: 3/3/2004 to 3/5/2004

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SUMMARY OF SUMMER TOURS 1974-2003

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

YEAR	AREA TOURED	SITES TOURED
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
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
2000	Central Colorado	Boardwalk at Breckenridge, Eagle Mine, Independence Pass, and Climax Mine
2001	Estes Park, Colorado	Rocky Mountain National Park
2002	Western Colorado	I-70 Glenwood Canyon, CSU Intensive Test Plots, Upper Colorado Environmental Plant Center, Rocky Mountain Native Plants, Union Oil Shale Project
2003	Colorado Front Range Foothills	Hayman, High Meadow, Buffalo Creek and Walker Ranch Fire Sites

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