THESIS

THE APPLICATION OF ECOLOGICAL PRINCIPLES TO ACCELERATE RECLAMATION OF WELL PAD SITES

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JOSHUA ELDRIDGE ENTITLED THE APPLICATION OF ECOLOGICAL PRINCIPLES TO ACCELERATE RECLAMATION OF WELL PAD SITES BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

THE APPLICATION OF ECOLOGICAL PRINCIPLES TO ACCELERATE RECLAMATION OF WELL PAD SITES

Western Colorado is experiencing a boom in natural gas development. However, the semi-arid ecosystems of this area have difficulty recovering from energy related disturbances. The purpose of this study was to improve reclamation techniques of natural gas well pads on the Western Slope of Colorado to establish viable native plant populations. The reclamation techniques studied are intended to repair damaged ecological processes and help guide the trajectory of natural plant succession toward a more desired plant community. The study examined the effects and interactions of seedbed preparation, soil amendments, seed mixtures, and seeding methods. The experiment was conducted in pinyon-juniper and sagebrush steppe/salt desert scrub plant communities on five natural gas well pads near Parachute, Colorado. Soil and plant cover data were collected to assess the effectiveness of 16 different treatment combinations. The data were analyzed by using a generalized linear mixed model. There was a significant difference in precipitation between 2007 and 2008, with 2007 receiving only 53% of average precipitation while 2008 was slightly above the average precipitation of 300 mm. After two growing seasons, the data show that the use of wood chips as a soil amendment increased organic matter content and reduced non-native species. Rough seedbed preparation increased the establishment of native species, especially during years of below average precipitation. Island broadcasting resulted in an

increase of noxious plant cover in 2008. Additional monitoring over time is still needed before more conclusive statements can be made about the effects of the different seed mixtures. Soil testing revealed that soil salinity will need to be ameliorated in some areas for successful reclamation to occur.

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INTRODUCTION

Natural gas exploration and extraction has experienced a flurry of development in Western Colorado in recent years (COGCC 2008). This increase in natural gas extraction impacts the plant communities and wildlife habitats in these areas (BLM 1999). The construction activities associated with well pads, access roads, and pipeline right-of-ways remove existing vegetation and fragments wildlife habitat (BLM 1991, BLM 1999). The semi-arid conditions of this part of the West also make reclamation more difficult as water can be a limiting factor in plant establishment without the assistance of management or technology (Allen 1995).

Natural gas development creates disturbances that will require the reclamation of both physical and biological processes. The creation of well pads for natural gas extraction involves the removal of the existing vegetation cover and leveling of the site. Activities related to drilling result in soil compaction and the introduction of drilling related chemicals to the sites (BLM 1999). Like much of the arid and semi-arid lands in the Western United States, Garfield County in Western Colorado has large amounts of introduced and noxious weeds like *Bromus tectorum* L. (cheatgrass) that surround the areas of natural gas development (Allen 1995, Monsen and McArthur 1995). The interaction of disturbance, semi-arid conditions and weedy species produces an environment where successful reclamation is more challenging.

The objective of this research is to identify successful autogenic reclamation strategies for natural gas development on the Western Slope of Colorado. The specific hypotheses that were tested relate to soil amendments, seedbed preparation, seed mixtures and seeding methods. The first hypothesis tested was that wood chips as an incorporated soil amendment would reduce cover of non-native species. The second hypothesis was that a rough seedbed formed by the creation of micro-catchments would produce a higher cover of desired species. The third hypothesis tested was a seed mixture with native annual and perennial species would provide better cover and facilitate establishment of perennials better than a seed mixture with only native perennials. The final hypothesis was that island broadcasting, a technique using two separate seed mixes broadcast on the same plot to create vegetative islands of shrubs and forbs with the interspaces seeded with grasses, facilitates better shrub and forb establishment than the traditional broadcast method of a single seed mix spread over the entire area homogenously.

Successful land reclamation following well pad creation is needed to repair damaged ecological processes and to reestablish lost ecological services. Often times this is attempted simply by seeding with perennial species; an approach that is frequently unsuccessful at meeting reclamation standards. A better approach is to treat the causes of plant invasion (Sheley and Krueger-Mangold 2003, Krueger-Mangold et al. 2006), establish plant communities that can resist invasion (Krueger-Mangold et al. 2006), and maintain or restore proper ecosystem function (Redente and Depuit 1988, Whisenant 1999). This approach is based on the growing knowledge of plant succession and community assembly and can be referred to as successional ecology, successional management or assisted succession (Redente and Depuit 1988, Whisenant 1999, Sheley and Krueger-Mangold 2003, Cox and Anderson 2004, Krueger-Mangold et al. 2006).

Successional management is based on the concept that restoration must be founded on ecological principles that are universal and not just site specific prescriptions (Sheley and Krueger-Mangold 2003). The objective of successional management is to understand and manipulate the factors that modify successional processes to favor desired species (Sheley and Krueger-Mangold 2003). Successional management is linked to three causes of succession: site availability, species availability, and species performance (Pickett et al. 1987; Cox and Anderson 2004). These causes can be divided into two levels: the processes and components associated with each cause and then the factors that can modify each of the causes of succession.

The processes and components are: disturbance, dispersal, propagule supply, available resources, ecophysiology, life history, stress, and interference (Sheley and Krueger-Mangold 2003; Krueger-Mangold et al. 2006). The modifying factors of the causes of succession are varied and cover a broad range of subjects. Examples include: size and severity of disturbance, dispersal mechanisms and landscape features, land use, climate, soil resources, competition, and herbivory (Sheley and Krueger-Mangold 2003; Krueger-Mangold et al. 2006).

This research project attempted to integrate the aforementioned ecological processes and modifying factors into techniques that can be applied to the reclamation of natural gas well pads. The study of reclamation should not be separated into the different stages of reclamation, i.e. seedbed preparation, soil amendments, seeding method, etc., because in practice these are all performed together for the purpose of successful revegetation. It is important to know how these different practices of reclamation interact and affect the final outcome. Therefore, the common reclamation practices of seedbed preparation, soil amendments, seed mixes, and seeding method and their interactions were tested on the Western Slope of Colorado with the objective to try and identify techniques that will improve the success of natural gas well pad reclamation.

METHODS

Site Description

Parachute (39^{o}27'07"N 108^{o}03'08"W) is located on the Western Slope of Colorado in the Grand Valley at an elevation of 1551 m above sea level. Based on the data available from the Rifle, CO (39^{o}32'20"N 107^{o}47'00"W) weather station (NCDC Coop # 057031), this area receives approximately 300 mm of precipitation a year with an even distribution of precipitation throughout the year when averaged over decades (WRCC, 2007). However, the month to month variability is very high when examining data from any single year and year to year. The plant community in the valley bottom has largely been converted to cropland, but what native plant community remains is either salt desert scrub or sagebrush steppe (BLM 1999, West and Young 2000). The salt desert scrub and sagebrush steppe community types transition into a pinyon – juniper community as elevation increases, followed by a mixed mountain shrub community near the top of the Roan Plateau (BLM 1999). The pinyon-juniper and sagebrush steppe/salt desert scrub plant communities are the community types where this research is located. Research plots were placed on five well pads located between Parachute and Rifle, CO. Table 1 contains the pad name, latitude and longitude, plant community the pad is in, elevation, and area of disturbance resulting from the pad creation.

Table 1. Characteristics of natural gas well pads used for reclamation research on the Western Slope of Colorado.

Pad	Coordinates	Plant Community	Elevation (m)	Area of Disturbance (ha)
GM 13-2	39^0 27' 53" N 108^0 05' 02" W	sagebrush – salt desert	1618	0.65
PA 324-26	39^0 29' 23" N 107^0 58' 13" W	pinyon pine – juniper	1693	0.62
PA 42-29	39^0 29' 46" N 108^0 00' 55" W	pinyon pine – juniper	1792	0.78
RMV 215-21	39^0 30' 32" N 107^0 53' 41" W	sagebrush – salt desert	1628	0.47
RMV 40-20	39^0 30' 44" N 107^0 54' 50" W	sagebrush – salt desert	1661	0.61

The Roan Plateau and the underlying Green River Formation dominate the soil formation of this area. These soils are formed from semi-consolidated shales that contain significant amounts of oil shale (Harman and Murray 1977). The shales in this area are easily weathered and produce loamy soils. The main soil types in the area of investigation include; Arvada-Torrifluvents-Heldt, Torriorthents-Rock outcrop-Camborthids, and Rock outcrop-Torriorthents (Harman and Murray 1977).

Treatment Descriptions

The research plots and all associated treatments were installed in late October and early November of 2006 with the assistance of a local reclamation sub-contractor.

Soil Amendments

There are two soil amendment treatments for this experiment: wood chips (WC) versus no WC. An application rate equal to 90 Mg/ha of WC was applied to half of the sub-plots on all well pads. The WC were *Pinus sp.* acquired from a saw mill in Grand Junction, CO and varied in size from saw dust to 15 cm long chips. The WC were incorporated into the top 15 cm of the soil using multiple passes with a chisel plow and harrow. The incorporation of the WC is intended to affect soil nutrient availability (Baer et al. 2004, Blumenthal et al. 2003, Herron et al. 2001, Paschke et al. 2000), increase soil moisture capacity (Tahboub et al. 2008, Sanborn et al. 2004, Barzegar et al. 2002), increase the organic matter content of the soil, and stimulate microbial activity in the soil (Anderson and Domsch 1989, Tisdall et al. 1978).

Seedbed Preparation

There are two seedbed preparation treatments tested in this experiment, one that has a rough soil surface with micro-catchments (Figure 1) and one that is a smooth soil surface. There are four micro-catchments, measuring approximately 4.25 m^2 including the pit and mound, in each plot with one every 18 m^2 or approximately 25 % of the plot. The catchments were created by lowering the bucket on the front end of a tractor into the soil approximately 20-30 cm and driving forward one meter, then dumping the excavated soil on the opposite side of the catchment. The primary orientation of the micro-catchments was perpendicular to the prevailing wind direction on flat surfaces or perpendicular to the slope on steeper surfaces. The pile of soil was placed on the windward or downhill side of the catchment. The soil surface in between the micro-catchments is rougher than the smooth soil treatment, which was created using a harrow attached to a tractor.

Fig 1. Finished micro-catchments on rough seedbed treatment on reclamation test plots on the Western Slope of Colorado.

Seeding Methods

The seeding methods include island broadcasting and traditional broadcasting. Island broadcasting separated forb and shrub species from grass species in the seed mix. The forbs and shrubs were hand broadcast in islands with the interspaces seeded with grasses. On the rough seedbed plots the forb and shrub mix was hand broadcast over and around the micro-catchments. On the smooth seedbed plots the shrub and forb mix was hand broadcast in approximately the same spatial locations as the micro-catchments. This was designed to more closely mimic the surrounding landscape structure and possibly give shrubs and forbs a better chance for survival since competition with grasses is reduced. The traditional broadcast method had all plant life forms combined in one seed mix and hand broadcast homogenously over the entire plot.

Seed Mixes

There were two different seed mixes tested in each plant community in this experiment; one seed mix contained only native perennials and the other contained native annuals and perennials. The species composition of the seed mixes were slightly modified for the two plant communities studied. Table 2 lists the species that were used in this experiment. The complete seed mixtures including seeding rates are found in Appendix H. Because of modifications for plant community type and different seed mixtures, the seeding rate varied from 44 kg PLS/ha to 66 kg PLS/ha.

Table 2. Plant species seeded in the sagebrush steppe/salt desert scrub and pinyon-juniper plant communities. There were modifications to the mix depending on plant community type. For the island broadcasting seeding method the forbs and shrubs were separated from the grasses and seeded in different areas within the plot.

Scientific name	Common name	PLS/m^2	Seeding rate PLS kg/ha
Juniperus osteosperma	Utah juniper	3	2.2
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	248	0.6
Ericameria nauseosus var. nauseosa	Rubber rabbitbrush	151	1.1
Atriplex canescens	fourwing saltbush	54	4.7
Atriplex confertifolia	Shadscale saltbush	65	4.8
Hesperostipa comata	Needle and thread	108	3.4
Achnatherum hymenoides var. Paloma	Indian ricegrass	118	3.4
Pascopyrum smithii var. Ariba	Western wheatgrass	86	3.4
Elymus trachycaulus var. Revenue	Slender wheatgrass	108	3.4
Elymus elymoides	Bottlebrush squirreltail	140	3.4
Sporobolus airoides	Alkali sacaton	215	0.6
Pleuraphis jamesii	James' galleta	118	3.4
Pseudoroegneria spicata	bluebunch wheatgrass	97	3.4
Sphaeralcea coccinea	Scarlet globemallow	248	2.2
Penstemon strictus	Rocky Mtn penstemon	215	3.4
Linum lewisii	Lewis flax	226	3.4
Heliomeris multiflora	Showy Goldeneye	194	0.8
Vicia americana	American vetch	32	4.5
Hedysarum boreale	Utah sweetvetch	32	3.4
Helianthus annuus	Common sunflower	24	2.2
Cleome serrulata	Rocky Mtn Bee plant	43	3
Vulpia octoflora	Six weeks fescue	162	0.8

Experimental Design

The structure of the experiment was a split-split plot design. Pads were considered as blocks and on each block there were six whole-plots. There were three replications of both seedbed preparation types randomly assigned to the whole-plots. The sub-plot factor was soil amendment randomly assigned to half whole-plot areas on each of the six whole-plots. Seed mix and seeding method were jointly the sub-sub-plot factors, randomly assigned to the four plots within each sub-plot. This research uses a 2 x 2 x 2 x 2 factorial design that resulted in 16 different treatment combinations. There are three replicates for each treatment at each well pad. Therefore, each well pad has 48 sub-sub-plots for a total of 240 sub-sub-plots (referenced from here on as plots) across all five well pads. Each of the 16 treatments has 15 total replicates. The plot dimensions are 6 x 12m. There are eight plots to a whole plot, making the whole plot dimensions 25 x 27m. This includes a one-meter buffer strip between the plots. Fertilization with 45 kg/ha of granulated 0-45-0 (N-P-K) was broadcast from an all-terrain vehicle and 4.5 Mg/ha of straw mulch were applied using a straw blower and crimper across all plots. Plot layouts and descriptions for all pads are found in Appendix A. Figure 2 is a diagram that show how each whole plot was laid out. This plot lay-out was replicated three times for each seedbed type on each pad.

Figure 2 Example of plot lay out for reclamation test plots on the Western Slope of Colorado. The figure represents one whole-plot which is based on the seedbed type. The sub-plot is split by the use of wood chips (WC) or not. In this case it is split with the four plots on the left having WC. The remaining seed mixture and seeding method treatments were then randomly assigned to the sub-sub plot locations.

Seedbed Type	Rough	Rough	Rough	Rough
Soil Amendment	Wood chips	Wood chips	None	None
Seeding Method	Island Broadcast	Traditional Broadcast	Island Broadcast	Traditional Broadcast
Seed Mixture	Perennial	Perennial	Perennial	Annual + Perennial

Seedbed Type	Rough	Rough	Rough	Rough
Soil Amendment	Wood chips	Wood chips	None	None
Seeding Method	Island Broadcast	Traditional Broadcast	Traditional Broadcast	Island Broadcast
Seed Mixture	Annual + Perennial	Annual + Perennial	Perennial	Annual + Perennial

Data Collection

Plant cover was collected in July 2007 and July 2008. Plant cover was estimated using the point intercept method along line-transects. There were nine 12 m long transects spaced 61 cm apart per plot with hits recorded every meter. Each transect within a plot started at a different randomly selected location. There were a total of 108 points sampled per plot. Data collection included live cover by species, bare ground, litter, or rock. Aerial cover was estimated for each point, so any plant part from current year's growth that intercepted the line was recorded as a hit. From the data, calculations were made for total percent cover, percent cover of desired and invasive species, species richness and frequency.

Soil samples were collected during the summer of 2007 following the first growing season. A composite soil sample was collected from each plot. The composite sample consisted of three sub-samples from the top 15 cm of soil. Soil analyses included pH, electrical conductivity (EC), sodium absorption ratio (SAR), texture, and percent organic matter. Soil pH, EC, and SAR analyses were all done using a saturated paste extract. The EC was measured using a one cm conductivity cell and the SAR was measured by inductively coupled plasma. Texture was determined using an ASTM 152H hydrometer. Organic matter content was determined using a modified Walkley-Black procedure.

Data Analysis

There were five dependent variables: native seeded, native volunteers, non-natives, non-native noxious, and total plant cover. The native seeded variable includes those species that were seeded into the plot. The native volunteers include native species that were found in the plots but were not seeded. The non-native species were those plants that are not native to the area and does not include noxious species. The non-native noxious species are species that are considered noxious by the Colorado state noxious weeds list (CODOA 2005). Total plant cover is the combination of the four previous variables. The variables were not normally distributed, nor did they have homogenous variances by treatment due to high variability both within and between drill pads. A subset of the plots had high soil salinity and little plant cover. Therefore, it was determined that plots with electrical conductivity greater than 4 dS/m and plant cover less than 20% would be removed from the analysis to try and reduce variability.

Fifty-five plots were removed, but the remaining 185 plots had highly skewed distributions for all variables, except for the total plant cover, which had a near normal distribution. No transformation normalized the distributions or made the variances of the remaining variables homogenous by treatment. In order to account for the non-normal distributions and unequal variances of data, a generalized linear mixed model was fit using the statistical software SAS proc GLIMMIX (SAS Institute 2006). This procedure combines a generalized linear model and a mixed model, which allowed statistical models to be fit to data with unequal variances and non-normal distributions. In this case a negative binomial distribution model was determined to be the most suitable. Proc GLIMMIX also accounted for the multiple error terms created by the structure of the experimental design. The data were analyzed individually by year and as a repeated measures ANOVA with the data combined across years. The soils data were analyzed using the same GLIMMIX model that was used for the cover data. Log transformations were found to provide normal distributions and homogenous variances by treatment for the organic matter (OM) and electrical conductivity (EC) values.

RESULTS

Soils

The results of the soil sampling in 2007 showed that 135 of the 240 plots were saline (pH < 8, EC > 4 dS/m, SAR < 15) or sodic-saline (pH < 8, EC > 4 dS/m, SAR > 15). The average pH, EC, OM, and SAR values across all treatments were 7.6, 5.4 dS/m, 1.6%, and 7.1 respectively. Based on visual observations and the results of the soil and plant sampling, it appears that soil salinity is reducing plant cover and is creating interference with the treatment effects of this research. This determination led to the removal of 55 plots from the data analysis. The removal of plots changed the EC and SAR averages to 4.0 dS/m and 5.8, respectively.

The addition of wood chips (WC) was the only treatment that had a significant effect on any of the soil parameters. The WC addition significantly increased OM 38% from 1.3 to 1.8% OM (p-value 0.0001). Figure 3 shows the effect of WC on OM.

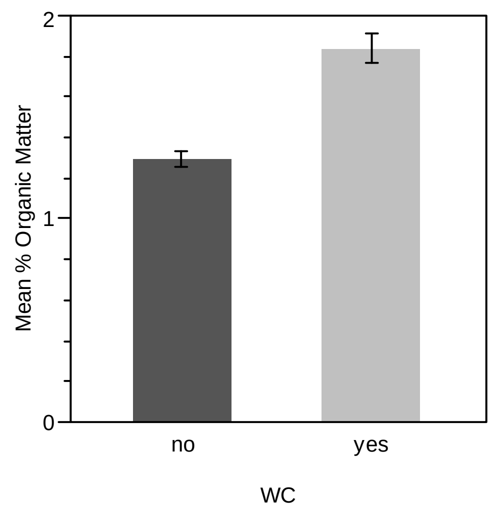


Fig 3. The effect of wood chip addition on organic matter on natural gas well pad reclamation on the Western Slope of Colorado. (Mean ± 1SE, p-value 0.0001)

Native Seeded Species

The native seeded species had different responses to treatments, depending on the year. The precipitation during the first growing season was 53% of average (100 mm) from November 2006 to June 2007. While precipitation during that same span in 2008 was 104% of average (193 mm). Native seeded cover in 2007 averaged 4.5% across all treatments with a standard deviation of 5.6 and ranged from 0 to 31%, with an average of six species present. Native seeded cover in 2008 showed a significant increase (p-value 0.01, Figure 4) with an average across all treatments of 13%, a standard deviation of 12.5 and a range of 0 to 74% with an average of nine species. The most successful shrub, forb, and grass species were: *Atriplex canescens* (fourwing saltbush), *Hedysarum boreal* (Utah sweetvetch), and *Pascopyrum smithii* var. Arriba (western wheatgrass).

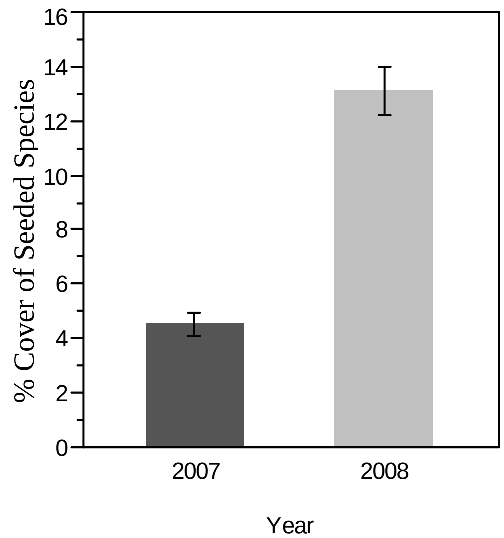


Fig 4. Mean native seeded cover in 2007 and 2008 for reclamation test plots on natural gas well pads on the Western Slope of Colorado. (Mean ± 1SE, p-value 0.01).

There were two treatment effects that were significant on native seeded species. The effects of seedbed preparation on native seeded species cover was statistically significant in 2007 (p-value 0.0006) and when averaged over both growing seasons (p-value 0.008, Figure 5), but was not significant in 2008 (p-value 0.14, Figure 6). The effects of seed mix on native seeded species varied by year with 2007 being statistically significant (p-value 0.002) and 2008 not being significant (p-value 0.22, Figure 7). Both

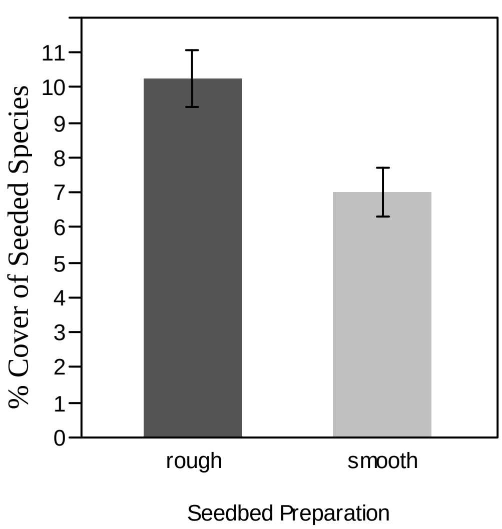


Fig 5. The response of native seeded species to rough (with micro-catchments) and smooth (without micro-catchments) seedbed preparation on natural gas well pads on the Western Slope of Colorado when averaged over 2007 and 2008. (Mean ± 1SE, p-value 0.008).

of these treatments also significantly increased native seeded species richness (p-values 0.01 for seedbed preparation and 0.0001 for seed mixture).

Figure 5 shows the effect of seedbed preparation when averaged over both growing seasons. The rough seedbed significantly increased native seeded species compared to the smooth seedbed treatment across both years (p-value 0.008). Figure 6 shows the response of native seeded species to seedbed preparation in each of the two growing seasons. There is a consistent pattern in which native seeded cover increases with the use of a rough seedbed regardless of available moisture (Figure 6).

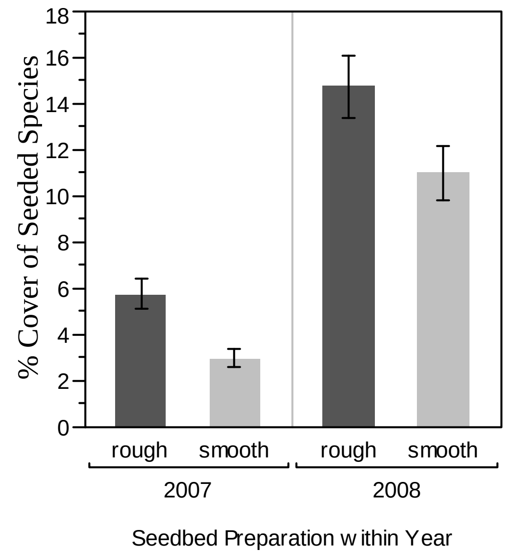


Fig 6. The response of native seeded species to rough (with micro-catchments) and smooth (without micro-catchments) seedbed preparation on natural gas well pads on the Western Slope of Colorado by growing season. (Mean ± 1SE, p-value 0.04)

There is a significant difference between seedbed treatments and year (p-value 0.04). The large increase in plant cover in both seedbed treatments in 2008 is attributed to the increase in precipitation during the second growing season. Regardless of the yearly precipitation totals, the effect of the rough seedbed preparation appears to be the same. That is, a rough seedbed results in an increase in plant cover, which may be especially important in low precipitation years.

Seed mixture significantly affected the plant community development in 2007, but the effect seems short lived as 2008 had a different response to the same seed mixtures. Figure 7 shows the effect of seed mix on native seeded species cover in each growing season. The first growing season had significantly higher cover with the annual plus perennial seed mix (p-value 0.002). But 2008 showed a reverse effect and was not statistically significant (p-value 0.22). There is a significant difference between the two years (p-value 0.0006) and the overall increase in plant cover in 2008 is attributed to the increase in precipitation.

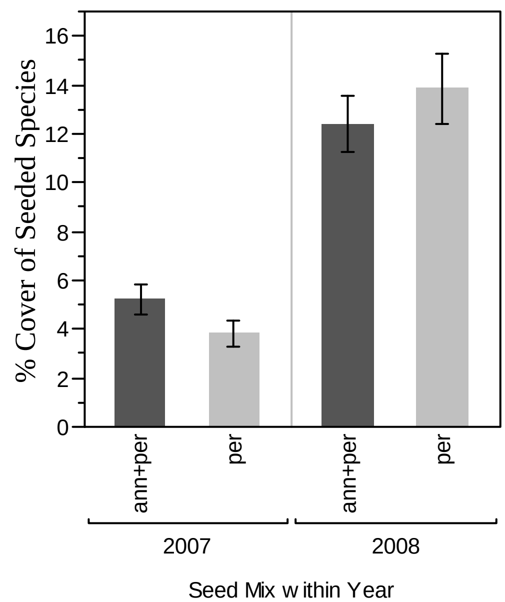


Fig 7. The effect of an annual plus perennial seed mixture and a seed mixture with only perennials on native seeded species in the first two growing seasons on natural gas well pad reclamation in Western Colorado. (Mean ± 1SE, 2007 p-value 0.002, 2008 p-value 0.22)

Native Volunteers

Native volunteer cover in 2007 averaged 1.9% across all treatments, with a standard deviation of 4 and a range of 0 to 29% with an average of one species. Native volunteer cover in 2008 increased to 2.5% across all treatments, with a standard deviation of 5.2 and a range of 0 to 41% with an average of two species. The three most common native volunteer species were *Bassia americana* (S. Watson) A.J. Scott (green molly), *Descurainia pinnata* (Walter) Britton (Western tansymustard), and *Erysimum asperum* (Nutt.) DC (western wallflower). The native volunteer species responded similarly to the non-native species in that the only significant treatment effect (p-value 0.01) was a reduction in cover with the addition of wood chips. This is likely due to similar life history characteristics between the early seral volunteers and the non-native species. The response of native volunteers will not be further discussed because they make up a small percentage of plant cover and responded in much the same way as the non-native species.

Non-Native Species

Non-native species cover in 2007 was 29.5% when averaged over all treatments, with a standard deviation of 21.7 and a range of 0 to 73% with an average of five species. Non-native cover in 2008 was 34% averaged over all treatments, with a standard deviation of 28 and a range of 0 to 90% with an average of six species. The three most common non-native species were *Sisymbrium altissimum L.* (tall tumblemustard), *Salsola tragus* L. (prickly Russian thistle), and *Eremopyrum triticeum* (Gaertn.) Nevski (annual wheatgrass).

The addition of wood chips has a negative effect on non-native plant cover in both years (p-value 0.003, Figure 8). In 2007, WC reduced non-native cover by 18% compared to a 27% reduction in 2008. The use of WC was the only treatment to have a significant effect on the cover of non-native species. This treatment shows a consistent pattern of reduced cover and there are indications that this effect could increase over time as demonstrated with the response of non-native species in 2008.

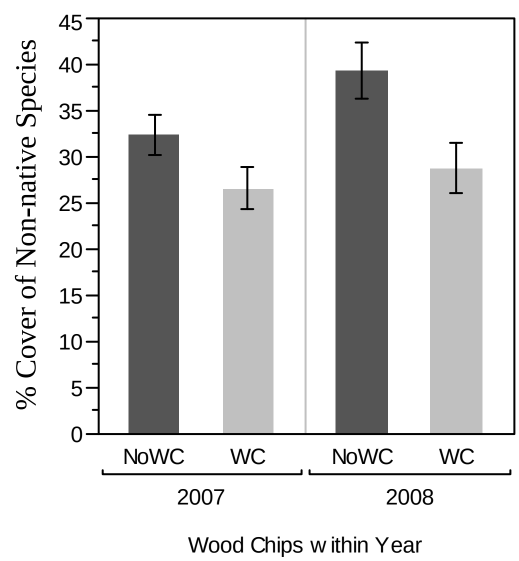


Fig 8. The response of non-native species to wood chips (WC) on natural gas well pad reclamation in Western Colorado in 2007 and 2008 (Mean ± 1SE, 2007 p-value 0.006; 2008 p-value 0.01)

Non-Native Noxious Species

Noxious species showed a significant increase in plant cover from 2007 to 2008 (p-value 0.0001, Figure 9). Noxious plant cover in 2007 was 0.2% when average over all treatments, with a standard deviation of 0.6 and a range of 0 to 4% with an average of one species. This increased to 4.5% in 2008, with a standard deviation of 6.2 and a ranged of 0 to 32% with an average of two species. The only noxious species encountered on the research plots were *Bromus tectorum* L. (cheatgrass), *Erodium cicutarium (L.) L'Hér.ex Aiton* (redstem stork's bill), and *Halogeton glomeratus (Bieb.) C.A. Mey* (saltlover).

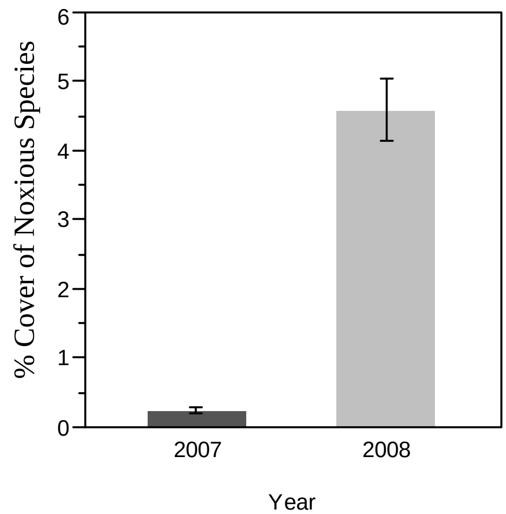


Fig 9. Noxious plant cover by year on natural gas well pads on the Western Slope of Colorado. (Mean ± 1 SE, p-value 0.0001)

There was a low incidence of noxious species in 2007 and no treatment showed an effect on the cover of noxious plants. There was an overall significant increase in noxious plants in 2008 (Figure 9). With the increase in noxious plants in 2008, the island broadcasting treatment showed a significant (p-value 0.02, Figure 10) increase in noxious species cover when compared to the traditional broadcast method.

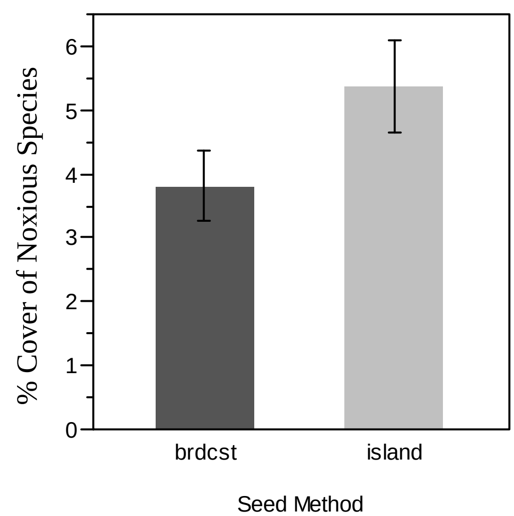


Fig 10. Noxious plant response to seeding method on natural gas well pads in Western Colorado in 2008. (Mean ± 1 SE, p-value 0.02)

Total Plant Cover

Total plant cover was significantly higher in 2008 than 2007 (p-value 0.0001, Figure 11). Total plant cover in 2007 averaged 36% cover across all treatments, with a standard deviation of 20.7 and a range of 0 to 80% with an average of 13 species. Total plant cover in 2008 averaged 54%, with a standard deviation of 24.6 and a range of 3 to 99% with an average of 19 species. The use of wood chips was the only treatment that had a significant effect on total plant cover.

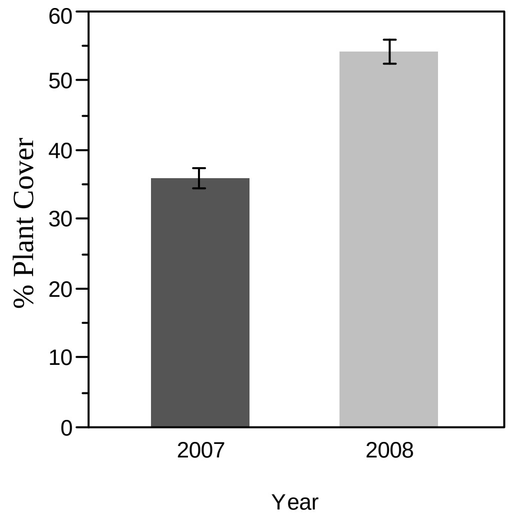


Fig 11. Total plant cover on natural gas well pads on the Western Slope of Colorado by growing season. (mean ± 1 SE, p-value 0.0001)

The WC reduced total plant cover when averaged over both growing seasons (p-value 0.001, Figure 12). There was an 18% reduction in total plant cover with the use of WC as a soil amendment. This reduction is mainly the result of a 27% reduction in non-native species cover with the addition of WC. On the other hand, the absolute means of native seeded cover increased 12% with the addition of WC. Although the overall cover was reduced with WC, the ratio of non-natives to natives improved in 2008 from a 3:1 without WC to a 2:1 with WC (Figure 13). The ratio between non-natives to native is important

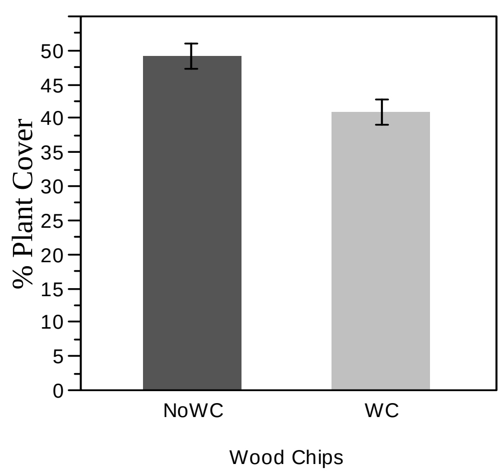


Fig 12. The effect of incorporated wood chips on total plant cover on natural gas well pad reclamation on the Western Slope of Colorado when averaged over two growing seasons. (Mean ± 1 SE, p-value 0.001)

because it shows that there is a difference in species composition that seems to favor the native seeded species with the addition of WC.

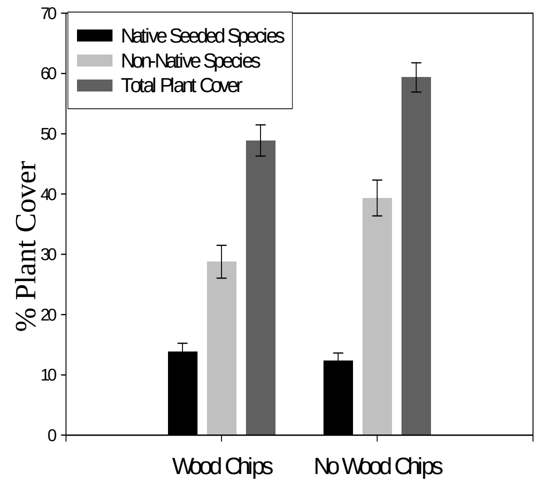


Fig 13. The effects of wood chips on native seeded species, non-native species, and total plant cover on natural gas well pad reclamation on the Western Slope of Colorado in 2008.

DISCUSSION

The large disparity in moisture conditions between the two years of this study provided an opportunity to see how the treatments would affect the plant community development in an average and below average year. Given the monthly and annual variability in precipitation for this area, it is important to identify techniques that can assist the establishment of desired native species during less than average years. It may be too early to tell if the native seeded species will continue to increase since it can take four to five years to reach full production potential (Doerr et al 1983) and precipitation is so variable. Levels of precipitation are going to affect how the seeded species continue to respond since water effects on plants accumulate over time as opposed to a single year of low precipitation (Kochy and Wilson 2004). However, early trends indicate that in another two to three years native species cover could match or even exceed that of the non-native species provided that there is adequate moisture available.

The use of WC as a soil amendment and the creation of a rough seedbed could have long lasting effects on the establishment of viable native plant populations on natural gas well pads. The effects of these two treatments were the most consistent of all treatments across both growing seasons. The rough seedbed improved native plant cover regardless of moisture conditions, which is important when trying to reclaim areas in arid and semi-arid environments and the wood chip treatment consistently reduced non-native species and significantly increased OM. Newman and Redente (2001) found that initial reclamation practices can have a long-term influence on plant community development, so if the trends from this experiment continue there is potential that these treatments may provide operators with new strategies that will lead to viable native plant communities.

The rough seedbed preparation improved all plant-cover variables in 2007, but in 2008 only the native (seeded and volunteer) species displayed higher cover in the rough seedbed. The rough seedbed increases the number of safe sites for germinating seeds by providing improved seed/soil contact and better moisture and temperature conditions than the smooth soil surface (Harper et al. 1965, Call and Roundy 1991, Winkle et al.1991, Smith and Capelle 1992, Chambers 2000). These effects should persist as long as the micro-catchments remain. Harper et al. (1965) stated that the number of individuals that become established is a direct function of the number of available safe sites provided on the soil surface. The one concern with micro-catchments in this study is that the pits accumulated large amounts of litter associated with windblown straw mulch and dead plant material. While over time this could improve soil quality with the increase in organic matter, the accumulated litter may have created an impediment to seedling emergence in some areas (Smith and Capelle 1992, Fowler 1988).

The use of WC as a soil amendment shows promise as a viable strategy for improving reclamation on natural gas well pads in this region. Wood chips increased the organic matter (OM) content of the soils, which has been shown to improve microbial activity (Anderson and Domsch 1989, Tisdall et al. 1978), water holding capacity, aggregate stability, and lowers soil bulk density (Tahboub et al. 2008, Sanborn et al. 2004, Barzegar et al. 2002). These are all soil characteristics that affect plant establishment and need improvement on well pads. Based on past research, it is assumed that the benefits of OM additions hold true for these sites as they were not directly measured.

The addition of a carbon (C) source, in this case wood chips, and the subsequent change in nitrogen (N) availability (Paschke et al. 2000, Herron et al. 2001, Blumenthal et al. 2003, Baer et al. 2004) resulted in a shift in the plant community composition that favored the cover of native seeded species. It was expected that the addition of a C source would result in a reduction of overall plant growth (Blumenthal et al. 2003). This result was also expected because one of the most abundant non-native species was Russian thistle and Redente et al. (1992) found that Russian thistle was significantly reduced at low levels of available N. The positive response of native seeded species in conjunction with the rough seedbed preparation provides two strategies that, if early trends continue, would result in a higher cover and frequency of desired species (Eschen et al. 2007, Harper et al. 1965).

Seed mixture had a mixed effect on native seeded species. In the first growing season the annual seed mix produced a higher cover of native species. This response was reversed in 2008 and the perennial species seed mix had higher percent cover. This response may be explained by the majority of annual species germinating in the first growing season, but their inability to set seed under dry conditions in 2007 resulted in a lower number of annuals in 2008. The perennial species that germinated in 2007 were able to over-winter and it is speculated that there was new germination in 2008 from seeds that remained dormant during the first growing season. Initially it was thought that the native annuals would be able to compete against and reduce the cover of the non-native annuals (Fargione et al 2003, Pokorny et al 2005), which was the case in 2007, but not in 2008.

The increase in noxious plants associated with island broadcasting could pose a threat to successful reclamation on these pads. Noxious species dominate the areas surrounding many of the pads and one objective of reclamation is to establish a plant community that can resist plant invasions. However, this treatment may actually provide an opening for noxious species to become established as the seeding rate with the island broadcasting was lower than the traditional broadcast treatment. The increase in noxious species, especially cheatgrass, with this treatment at the current seeding rate may make it too risky in areas where noxious species are a problem. If the seeding rate is increased to provide more direct competition then it may still prove viable at increasing shrub and forb establishment.

The final issue that this research uncovered, but is not able address is the impact of soil salinity on the reclamation of natural gas well pads. More than half of the 240 research plots displayed saline or sodic-saline soil conditions. The cause of the salinity is unclear at this time, but the spatial relationship between the location of the majority of saline plots and the location of the buried reserve pit indicate that there may be a relationship between the location of the reserve pit and soil salinity on the surface. Further investigation is needed to determine if there is a correlation between these two variables. More research is also needed on the effect of the wood chips on the soil microbial community.

There is actually an opportunity for the successful reclamation of these well pads to begin to influence the plant community around them. Currently the non-disturbed areas are dominated by noxious species with very little native grasses or forbs present. If a healthy native plant population can become established on these pads, they may actually provide a seed source for the surrounding areas. For this to come true, the native species must first become established on the well pads. This research provides support for two promising treatments that may help accomplish that goal.

CONCLUSION

The treatments tested were used to restore disrupted ecological processes and initiate an autogenic repair process for revegetation on natural gas well pads. The use of a rough seedbed and wood chips shows potential in manipulating plant community composition to favor native seeded species and help reduce non-native species cover. These were the only treatments that had consistent patterns over both growing seasons. The rough seedbed helped increase native seeded species cover compared to the smooth seedbed, especially during dry years. Wood chips significantly increased organic matter, consistently reduced non-native species cover and should help restore hydrologic and nutrient cycling processes that promote the establishment of a diverse, native plant community. Wood chips also reduced total plant cover, but actually resulted in a higher ratio of natives to non-natives compared to the no wood chip treatment. Noxious plant cover increased with the use of island broadcasting because there was reduced competition from grasses and a lower seeding rate than the traditional broadcasting. The use of native annuals in the seed mix did not consistently reduce non-native species and there is not enough data to determine if the annuals are facilitating perennial plant establishment. Continued monitoring is needed to determine long-term effects of these treatments on the reclamation of natural gas well pads on the Western Slope of Colorado. The detection and treatment of saline soils on natural gas well pads is going to be critical for a more successful reclamation effort.

LITERATURE CITED

Allen, E.B. 1995. Restoration ecology: limits and possibilities in arid and semiarid lands. pg. 7–15. In B.A. Roundy, E.D. McArthur, J.S. Haley, and D.K. Mann (compilers). *Proceedings: Wildland shrub and arid land restoration symposium*. General Technical Report INT-GTR-315. USDA Forest Service Intermountain Research Station Ogden, UT.

Anderson, T.H. and K.H. Domsch. 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology Biochemistry*. 21:471-479.

Baer, S.G., J.M. Blair, S.L. Collins, and A.K. Knapp. 2004. Plant community responses to resource availability and heterogeneity during restoration. *Oecologia.* 139:617-629.

Barzegar A.R., A Yousefi, and A. Daryashenas. 2002. The effect of addition of different amounts and types of organic materials on soil properties and yield of wheat. *Plant and Soil*. 247:295-301.

Blumenthal, D.M., N.R. Jordan, and M.P. Russelle. 2003. Soil carbon addition controls weeds and facilitates prairie restoration. *Ecological Applications.* 13:605-615.

Bureau of Land Management. 1991. Colorado Oil and Gas Leasing and Development: Final Environmental Impact Statement. Colorado State Office Branch of Fluid Minerals. Lakewood, CO. pg 4-1 – 4-10.

Bureau of Land Management. 1999. Glenwood Springs Resource Area Oil and Gas Leasing and Development: Final Supplemental Environmental Impact Statement. Colorado State Office. Glenwood Springs, CO pg. 3-3, 3-4, 4-12, 4-20, 4-21, 4-37

Call, C. and B. Roundy. 1991. Perspectives and processes in revegetation of arid and semiarid rangelands. *Journal of Range Management*. 44:543-549.

Chambers, J.C. 2000. Seed movements and seedling fates in disturbed sagebrush steppe ecosystems: implications for restoration. *Ecological Applications.* 10:1400-1413.

Colorado Department of Agriculture. 2005. Rules pertaining to the administration and enforcement of the Colorado Noxious Weeds Act. 8 CCR 1203-19.

Colorado Oil and Gas Conservation Commission. 2008. Colorado Weekly and Monthly Oil and Gas Statistics 12-8-08. www.cogcc.state.co.us/. Website accessed 1-2-09.

Cox, R.D. and V.J. Anderson. 2004. Increasing native diversity of cheatgrass-dominated rangeland through assisted succession. *Journal of Range Management.* 57:203-210.

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

Eschen, R., S.R. Mortimer, C.S. Lawson, A.R. Edwards, A.J. Brook, J.M. Igual, K. Hedlund. and U. Schaffner. 2007. Carbon addition alters vegetation composition on ex-arable fields. *Journal of Applied Ecology*. 44: 95-104.

Fargione, J., C.S. Brown, and D. Tilman. 2003. Community assembly and invasion: an experimental test of neutral versus niche processes. *Proceedings of the National Academy of Science.* 100:8915-8920.

Fowler, N.L. 1988. What is a safe site?: Neighbor, litter, germination date and patch effects. *Ecology*. 69:947-961.

Harman, J.B. and D.J. Murray. 1977. Soil Survey for Rifle Area, CO. United States Department of Agriculture. Soil Conservation Service.

Harper, J.L., J.T. Williams, and G.R. Sagar. 1965. The behavior of seeds in soil: I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. *The Journal of Ecology.* 53:273-286.

Herron, G.J., R.L. Sheley, B.D. Maxwell, and J.S. Jacobsen. 2001. Influence of nutrient availability on the interaction between spotted knapweed and bluebunch wheatgrass. *Restoration Ecology*. 9:326-331.

Kochy, M and S.D. Wilson. 2004. Semiarid grassland responses to short-term variation in water availability. *Plant Ecology*. 174:197-203

Krueger-Mangold, J.M., R.L. Sheley, and T.J. Svejcar. 2006. Toward ecologically-based invasive plant management on rangeland. *Weed Science.* 54:597-605.

Monsen, S.B. and E.D. McArthur. 1995. Implications of Early Intermountain Range and Watershed Restoration Practices. pg 16 – 25. In B.A. Roundy, E.D. McArthur, J.S. Haley, and D.K. Mann (compilers). *Proceedings: Wildland shrub and arid land restoration symposium*. General Technical Report INT-GTR-315. USDA Forest Service Intermountain Research Station Ogden, UT.

Newman, G.J. and E.F. Redente. 2001. Long-term plant community development as influenced by revegetation techniques. *Journal of Range Management*. 54: 717-724.

Paschke, M.W., T. McLendon, and E.F. Redente. 2000. Nitrogen availability and old-field succession in a shortgrass steppe. *Ecosystems.* 3:144-158.

Pickett, S.T.A., S.L. Collins, and J.J. Armesto. 1987. Models, mechanisms and pathways of succession. *Botanical Review*. 53:335-371.
Pokorny, M.L., R.L. Sheley, C.A. Zabinski, R.E. Engel, T.J. Svejcar, and J.J Borkowski. 2005. Plant functional group diversity as a mechanism for invasion resistance. *Restoration Ecology*. 13:448-459.

Redente, E.F. and E.J. Depuit. 1988. Reclamation of drastically disturbed rangelands. In *Vegetation science applications for rangeland analysis and management*. P.T. Tueller, ed. Kluwer Academic Publishers. Dordrecht, The Netherlands. Pg 559-584.

Redente, E.F., J.E. Friedlander, and T. McLendon. 1992. Response of early and late semiarid seral species to nitrogen and phosphorus gradients. *Plant and Soil*. 140:127-135.

Sanborn, P., C. Bulmer and D. Coopersmith. 2004. Use of wood waste in rehabilitation of landings constructed on fine-textured soils, central interior British Columbia, Canada. *WJAF*. 19:175-183.

SAS Institute Inc. 2006. *The GLIMMIX Procedure*. SAS Institute Inc. Cary, NC

Sheley, R.L. and J. Krueger-Mangold. 2003. Principles for restoring invasive plant-infested rangeland. *Weed Science*. 51:260-265.

Smith, M. and J. Capelle. 1992. Effects of Soil Surface Microtopography and Litter Cover on Germination, Growth and Biomass Production of Chicory (Cichorium intybus L.). *American Midland Naturalist*. 128:246-253.

Tahboub, M.B., W.C. Lindemann, and L. Murray. 2008. Chemical and physical properties of soil amended with pecan wood chips. *HortScience*. 43:891-896.

Tisdall, J.M., B. Cockroft and N.C. Uren. 1978. The stability of soil aggregates as affected by organic materials, microbial activity and physical disruption. *Australian Journal of Soil Resources.* 16:9-17.

West, N.E. and J.A. Young. 2000. Intermountain Valleys and Lower Mountain Slopes. In *North American Terrestrial Vegetation*. Second edition. M.G. Barbour and W.D. Billings Eds. Cambridge University Press. New York, NY. Pg 255-284.

Western Region Climate Center. 2007. Rifle, CO Period of Record General Climate Summary – Precipitation. www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?co6311. Accessed 01 Feb 2007.

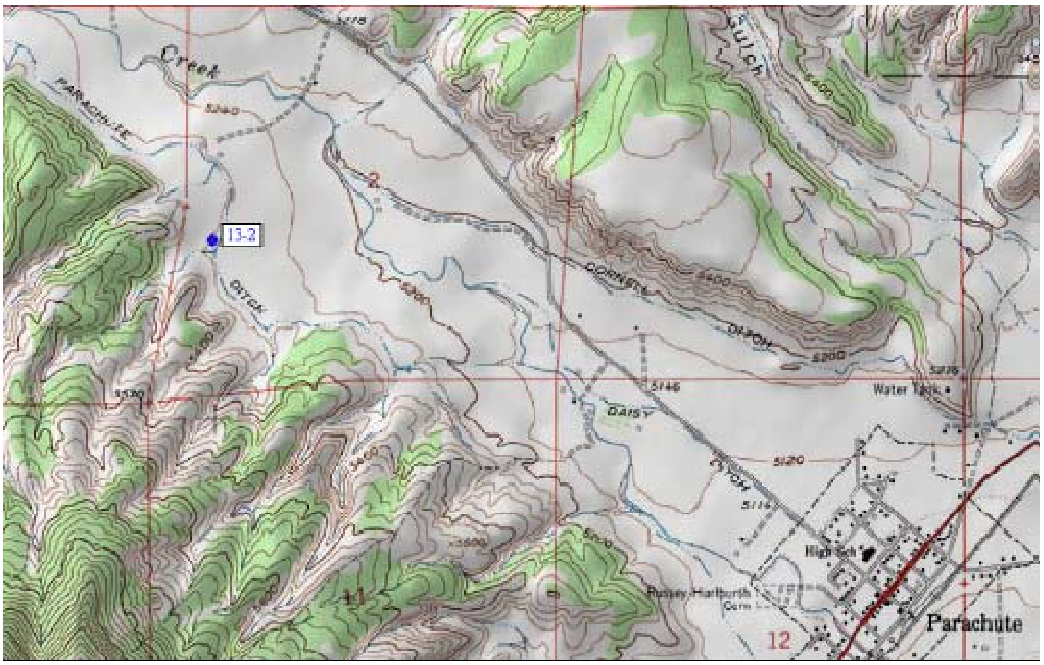
Whisenant, S.G. 1999. *Repairing Damaged Wildlands: A Process Oriented, Landscape-Scale Approach*. Cambridge University Press. Cambridge, UK.

Winkel, V.K., B.A. Roundy and J.R. Cox**.** 1991. Influence of Seedbed Microsite Characteristics on Grass Seedling Emergence. *Journal of Range Management*, 44: 210-214.

APPENDIX A – DRILL PAD LOCATIONS, DESCRIPTIONS AND TREATMENT LAYOUT

DRILL PAD LOCATIONS AND DESCRIPTIONS

GM 13-2



↑N

Figure A-1. Map displaying the location of GM 13-2 in proximity to the town of Parachute.

The natural gas well pad GM 13-2 (39^0 27’ 53” N 108^0 05’ 02” W) is located in the Grand Valley field in the Piceance Basin. This pad is approximately 3.2 km northwest of the town of Parachute and sits at an elevation of 1618 m. This pad is in a sagebrush-greasewood community. However, it is on private property and the majority of the surrounding area has been converted to agriculture. It sits just east of the foothills of part of the Roan Plateau. The plant community rapidly changes to a pinyon-juniper community as one ascends the foothills. Figure A-2 shows the approximate layout of the research plots on the well pad. Table A-1 displays the treatment combinations for the plots.

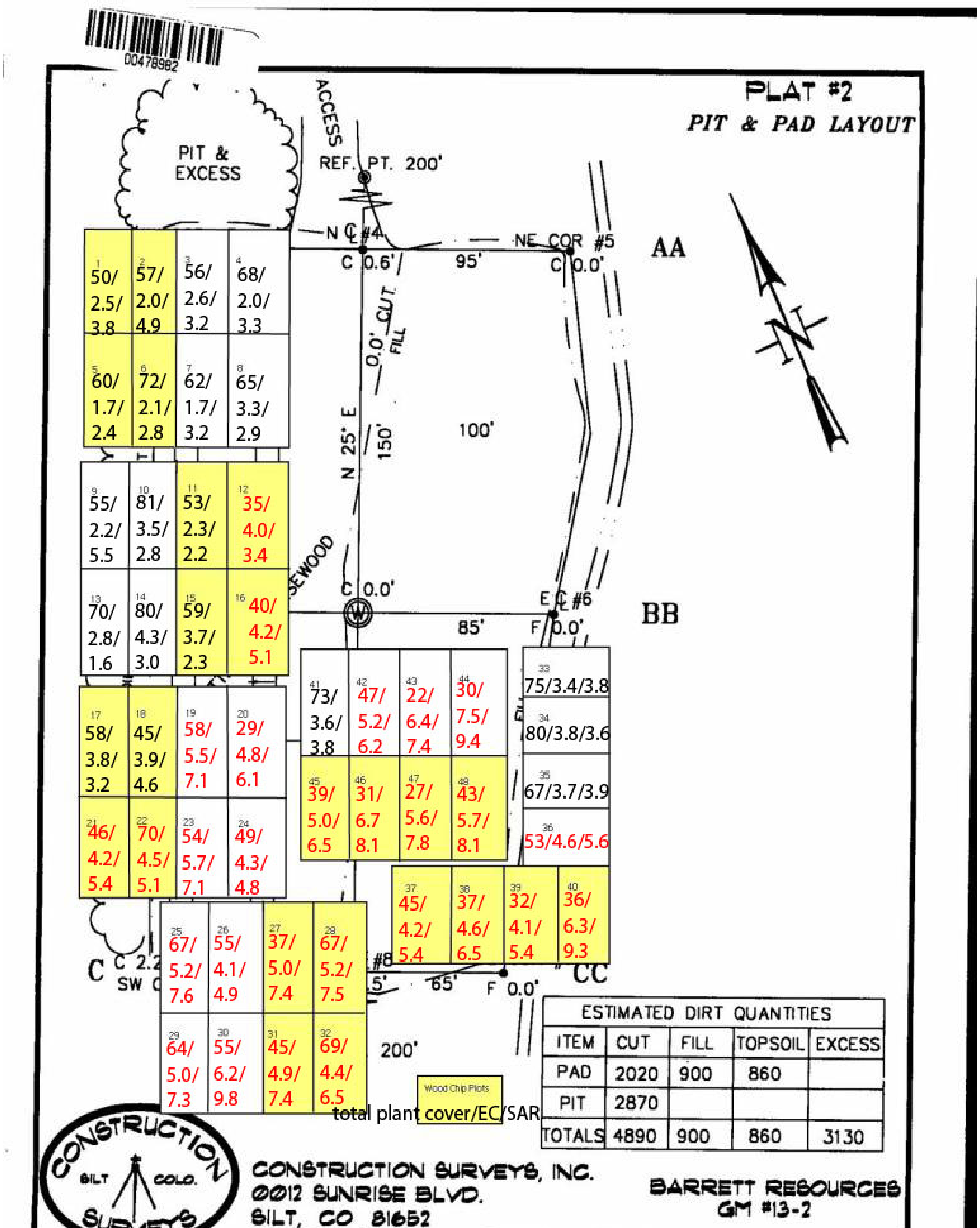


Fig A-2. Map of GM 13-2 showing the plot number, total plant cover, Soil EC, and SAR by plot. The yellow plots contain wood chips. The red text indicates saline or sodic-saline soils in the plots.

Table A-1. Treatment descriptions for plots on GM 13-2. The numbers are the plot number and correspond to the plot numbers in figure A-2. The treatment descriptions, from the top down, are the seedbed preparation, soil amendment, seeding method, and seed mixture.

GM 13-2

Rough	Rough	Rough	Rough	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	None	None	Wood chips	Wood chips
Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst
Annual	Perennial	Annual	Perennial	Annual	Annual	Annual	Perennial
1	2	3	4	25	26	27	28
Rough	Rough	Rough	Rough	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	None	None	Wood chips	Wood chips
Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Perennial	Annual	Annual	Perennial	Perennial	Perennial	Annual	Perennial
5	6	7	8	29	30	31	32
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
None	None	Wood chips	Wood chips	None	None	None	None
Island brdcst	Broadcast	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst
Perennial	Annual	Perennial	Annual	Annual	Perennial	Perennial	Annual
9	10	11	12	33	34	35	36
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
None	None	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips
Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Perennial	Annual	Annual	Perennial	Perennial	Annual	Annual	Perennial
13	14	15	16	37	38	39	40
Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	None	None	None	None	None	None
Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Annual	Annual	Perennial	Perennial	Annual	Annual	Perennial	Perennial
17	18	19	20	41	42	43	44
Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst
Perennial	Perennial	Annual	Annual	Annual	Perennial	Annual	Perennial
21	22	23	24	45	46	47	48

PA 324-26

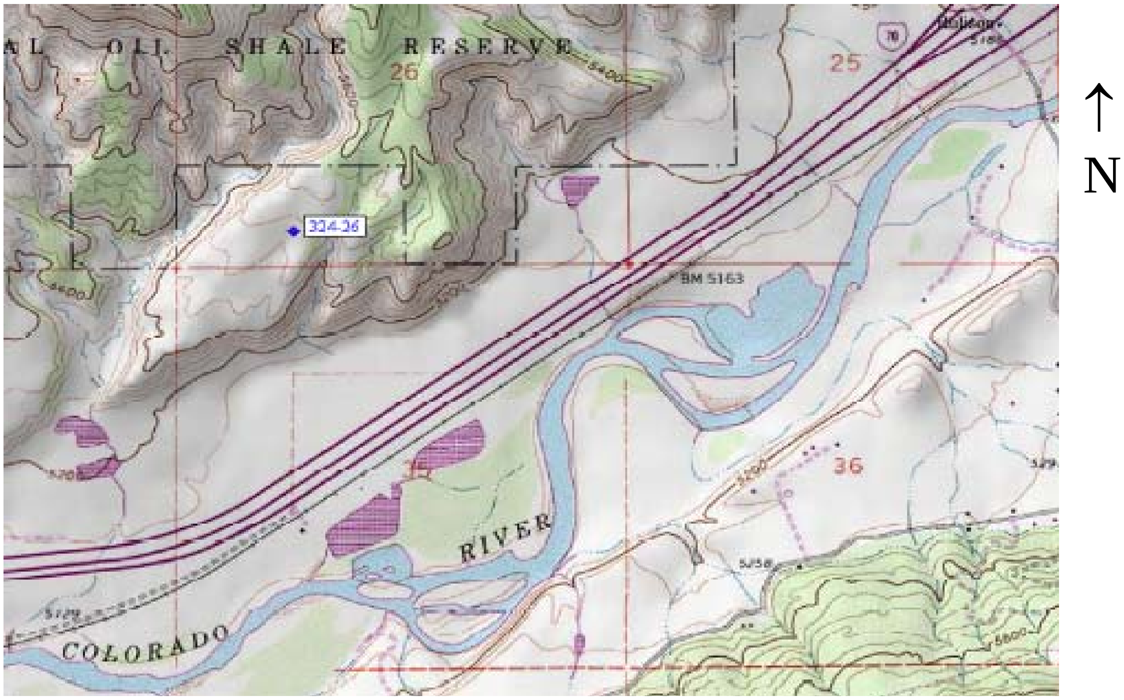


Figure A-3. Map showing PA 324-26 in relation to I-70 and the Colorado River.

The well pad PA 324-26 (39^0 29' 23" N 107^0 58' 13" W) is located north of I-70 in the Parachute field. This pad is approximately 8 km east of the town of Parachute on private property owned by Exxon Mobil. This pad is in the pinyon-juniper plant community and sits at an elevation of 1693 m. The surrounding area contains mostly native vegetation. The majority of the disturbance in this area is gas related with a few grazing cattle. Figure A-4 shows the approximate plot layout for the pad and Table A-2 displays the treatment combinations for the pad.

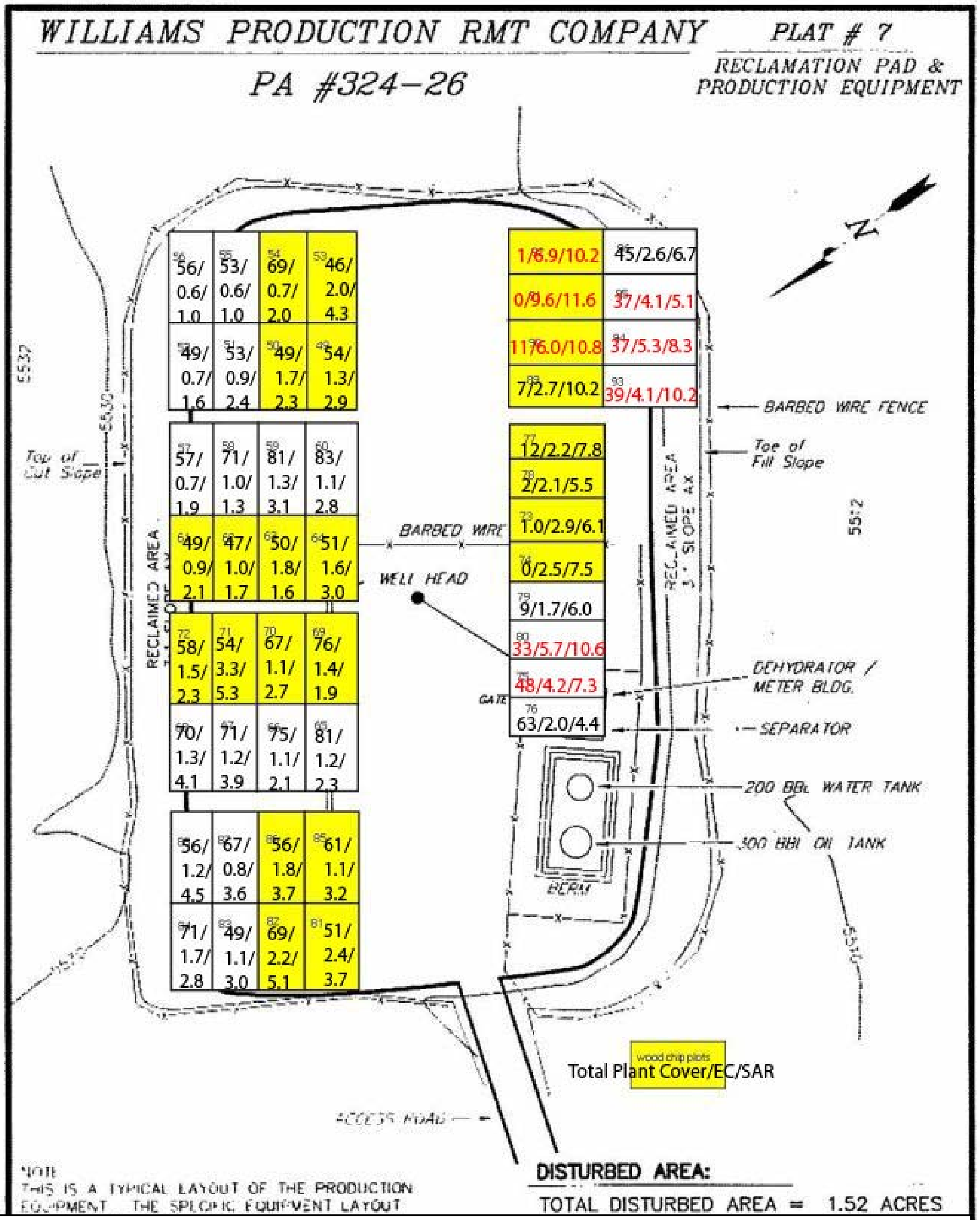


Fig A-4. Map of PA 324-26 showing the plot number, total plant cover, Soil EC, and SAR by plot. The yellow plots contain wood chips. The red text indicates saline or sodic-saline soils in the plots.

Table A-2. Treatment descriptions for plots on PA 324-26. The numbers are the plot number and correspond to the plot numbers in Figure A-4. The treatment descriptions, from the top down, are the seedbed preparation, soil amendment, seeding method, and seed mixture.

PA 324-26

Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	Wood chips	Wood chips	None	None
Brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst
Perennial	Annual	Annual	Annual	Perennial	Perennial	Perennial	Annual
49	50	51	52	73	74	75	76
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	Wood chips	Wood chips	None	None
Island brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Perennial	Annual	Perennial	Perennial	Annual	Annual	Perennial	Annual
53	54	55	56	77	78	79	80
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	None	None
Brdcst	Brdcst	Island brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Island brdcst
Annual	Perennial	Annual	Perennial	Annual	Perennial	Perennial	Annual
57	58	59	60	81	82	83	84
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
None	None	None	None	Wood chips	Wood chips	None	None
Island brdcst	Island brdcst	Brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Brdcst
Annual	Perennial	Annual	Perennial	Annual	Perennial	Perennial	Annual
61	62	63	64	85	86	87	88
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
None	None	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Island brdcst	Island brdcst	Brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst
Annual	Perennial	Annual	Perennial	Perennial	Perennial	Annual	Annual
65	66	67	68	89	90	91	92
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	Wood chips	Wood chips	None	None	None	None
Island brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst
Perennial	Perennial	Annual	Annual	Perennial	Annual	Perennial	Annual
69	70	71	72	93	94	95	96

PA 42-29

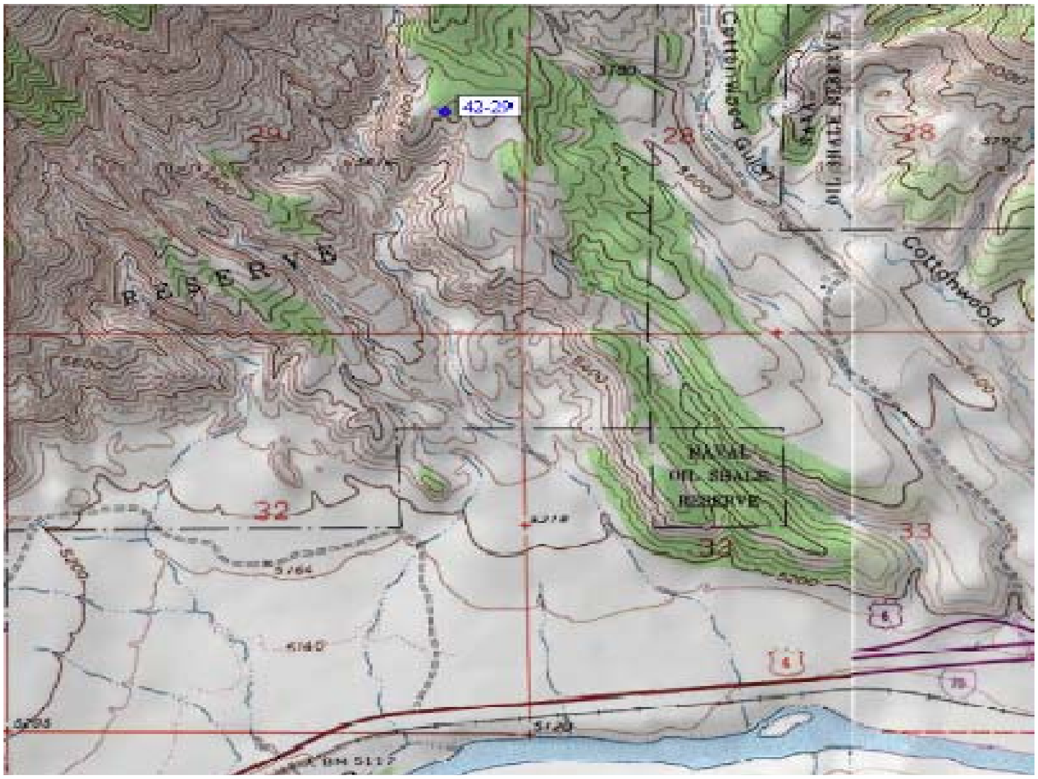


Figure A-5. Approximate location of PA 42-29 in relation to I-70 and the Colorado River.

The well pad PA 42-29 (39^0 29' 46" N 108^0 00' 55" W) is located north of I-70 in the Parachute field. This pad is approximately 5.3 km east of the town of Parachute and is on BLM property. This pad is in the pinyon-juniper plant community and is the highest pad in this study at an elevation of 1792 m. The surrounding area contains mostly native vegetation. The majority of the disturbance in this area is gas related with a few grazing cattle. Figure A-6 shows the approximate plot layout for the pad and table A-3 provides the treatment combinations for the pad.

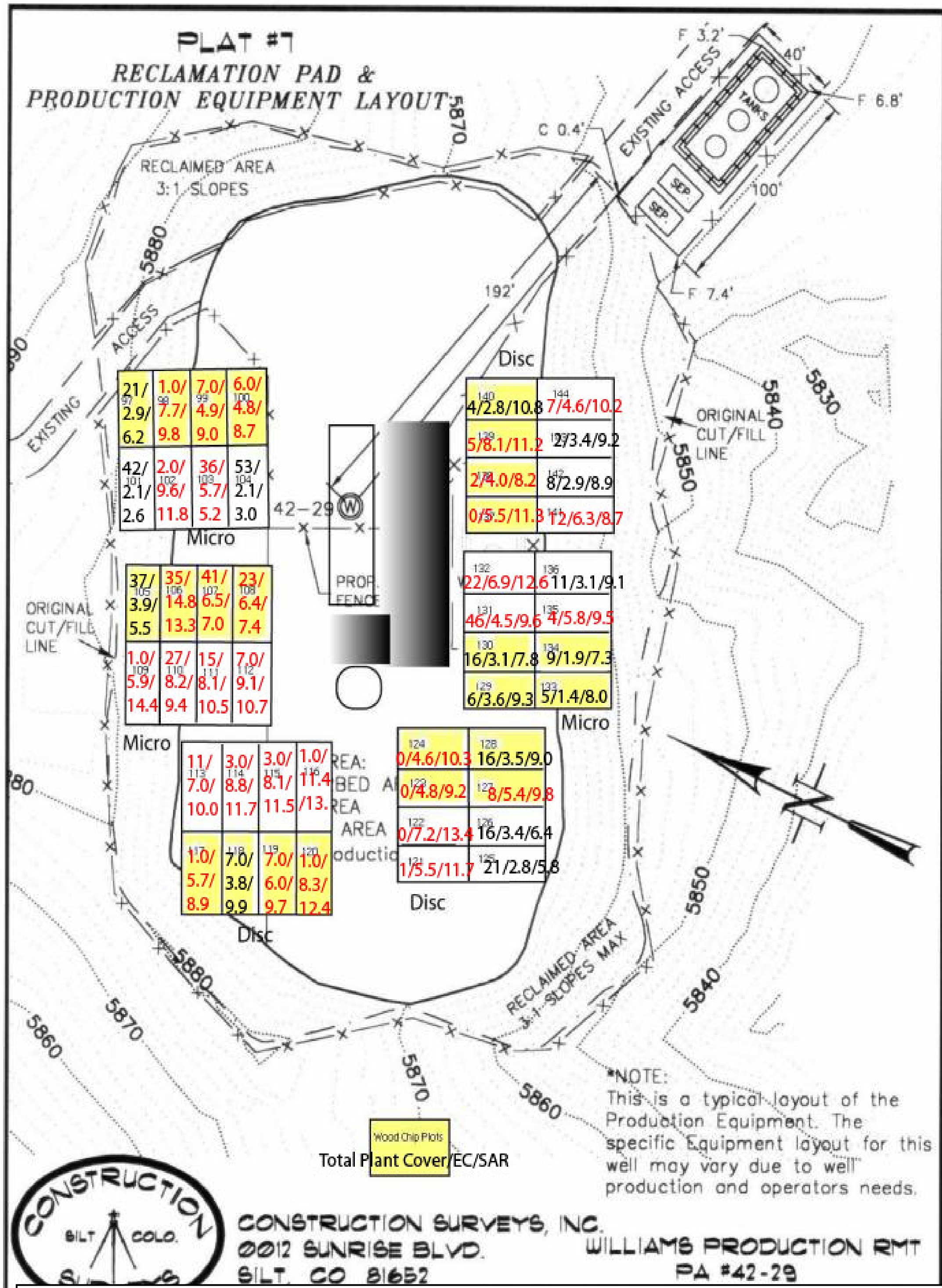


Fig A-6. Map of PA 42-29 showing the plot number, total plant cover, soil EC and SAR by plot. The yellow plots contain wood chips. The red text indicates saline or sodic-saline soils in the plot.

Table A-3. Treatment descriptions for plots on PA 42-29. The numbers are the plot number and correspond to the plot numbers in Figure A-6. The treatment descriptions, from the top down, are the seedbed preparation, soil amendment, seeding method, and seed mixture.

PA 42-29

Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	None	None	Wood chips	Wood chips
Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Annual	Perennial	Annual	Perennial	Perennial	Annual	Annual	Annual
97	98	99	100	121	122	123	124
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
None	None	None	None	None	None	Wood chips	Wood chips
Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst
Perennial	Perennial	Annual	Annual	Perennial	Annual	Perennial	Perennial
101	102	103	104	125	126	127	128
Rough	Rough	Rough	Rough	Rough	Rough	Rough	Rough
Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	None	None
Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst
Annual	Annual	Perennial	Perennial	Annual	Perennial	Perennial	Annual
105	106	107	108	129	130	131	132
Rough	Rough	Rough	Rough	Rough	Rough	Rough	Rough
None	None	None	None	Wood chips	Wood chips	None	None
Brdcst	Brdcst	Island brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Annual	Perennial	Perennial	Annual	Perennial	Annual	Perennial	Annual
109	110	111	112	133	134	135	136
Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
None	None	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Annual	Perennial	Annual	Perennial	Perennial	Perennial	Annual	Annual
113	114	115	116	137	138	139	140
Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	None	None	None	None
Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Annual	Annual	Perennial	Perennial	Perennial	Perennial	Annual	Annual
117	118	119	120	141	142	143	144

RMV 215-21

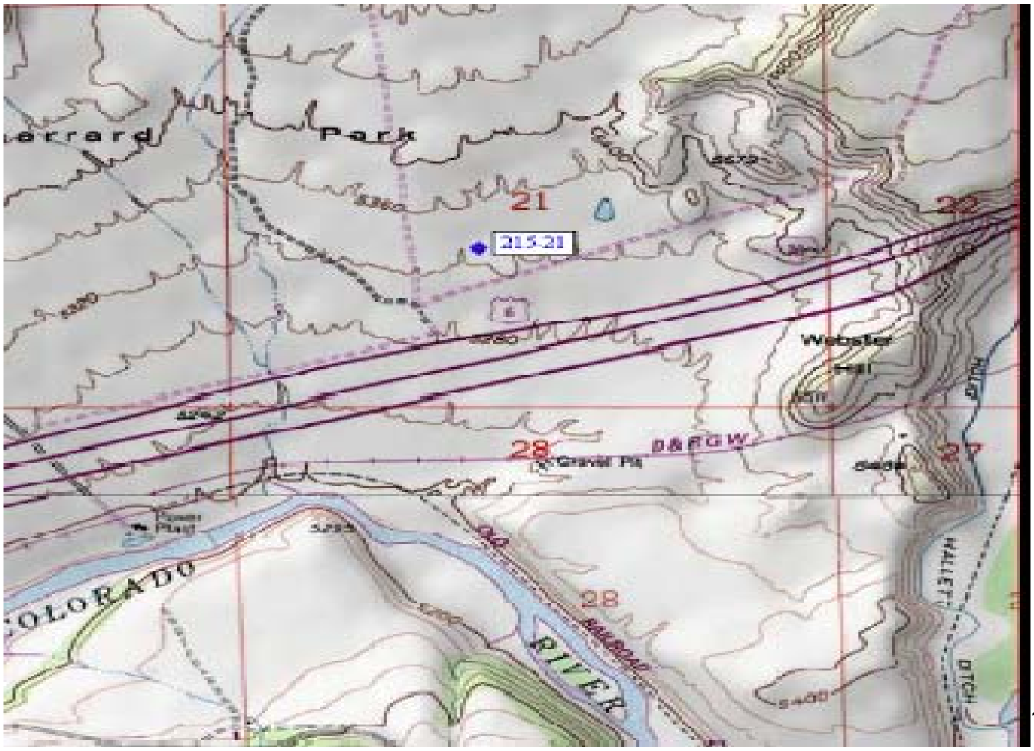


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Figure A-7. The location of RMV 215-21 in relation to I-70 and the Colorado River.

The well pad RMV 215-21 (39^0 30' 32" N 107^0 53' 41" W) is located north of I-70 in the West Rulison field. This pad is approximately 14.5 km east of the town of Parachute and is on private property. This pad is in the sagebrush-greasewood plant community and sits at an elevation of 1628 m. The surrounding area is dominated by native shrubs and cheat grass (*Bromus tectorum L*). The majority of the disturbance in this area is gas related with a few grazing cattle. Figure A-8 shows the approximate plot layout for the pad and Table A-4 provides the treatment combinations for the pad.

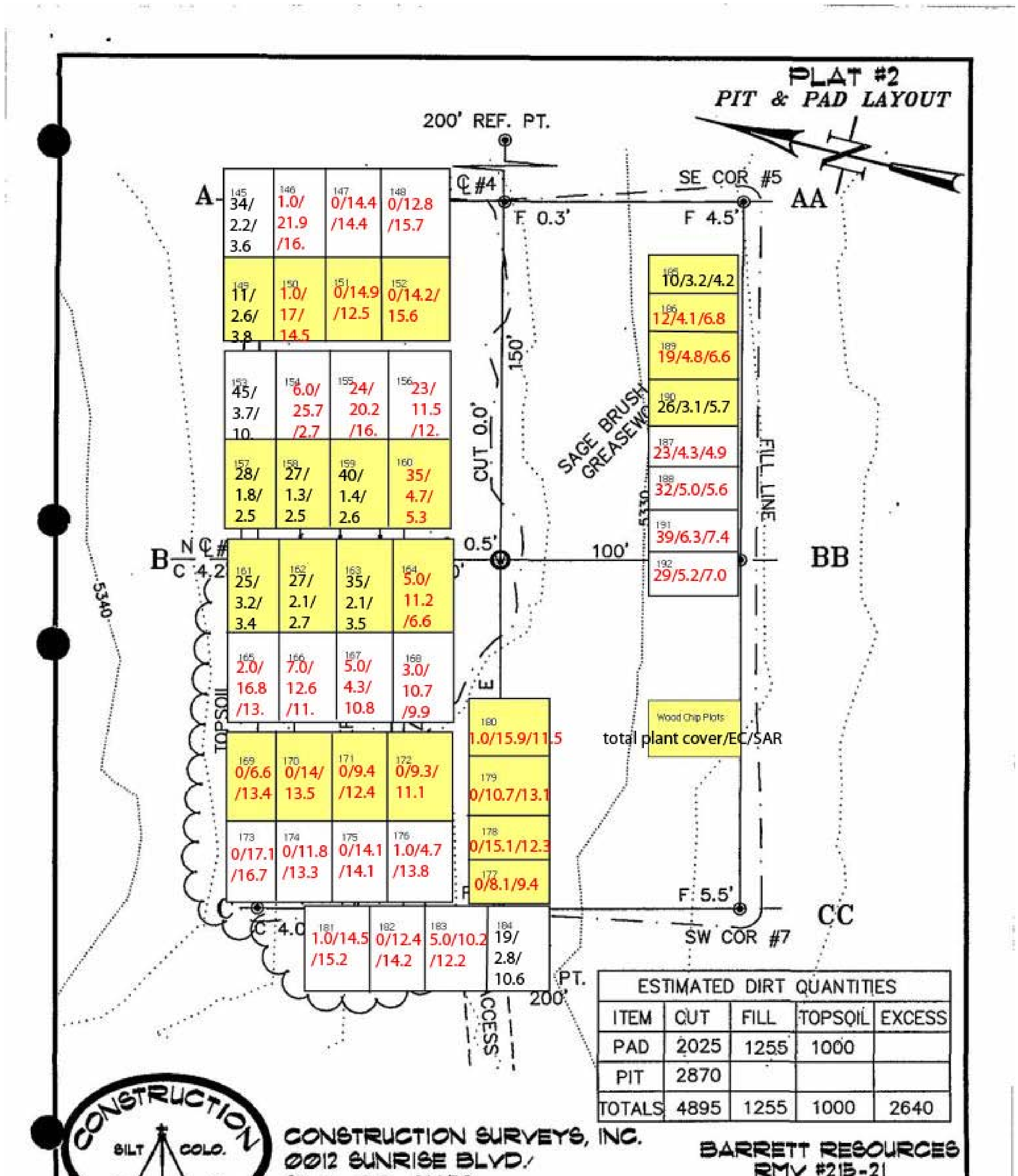

Fig A-8. Map of RMV 215-21 showing the plot number, total plant cover, soil EC, and SAR by plot. The yellow plots contain wood chips. The red text indicates saline or sodic-saline soils in the plots.

Table A-4 – Treatment descriptions for plots on RMV 215-21. The numbers are the plot number and correspond to the plot numbers in Figure A-8. The treatment descriptions, from the top down, are the seedbed preparation, soil amendment, seeding method, and seed mixture.

RMV 215-21

Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
None	None	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Perennial	Annual	Annual	Perennial	Perennial	Perennial	Annual	Annual
145	146	147	148	169	170	171	172
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	None	None	None	None
Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Perennial	Annual	Annual	Perennial	Annual	Annual	Perennial	Perennial
149	150	151	152	173	174	175	176
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
None	None	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Island brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Perennial	Perennial	Annual	Annual	Annual	Annual	Perennial	Perennial
153	154	155	156	177	178	179	180
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	None	None	None	None
Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Annual	Perennial	Perennial	Annual	Annual	Perennial	Annual	Perennial
157	158	159	160	181	182	183	184
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	None	None
Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Island brdcst
Annual	Perennial	Perennial	Annual	Perennial	Annual	Perennial	Annual
161	162	163	164	185	186	187	188
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
None	None	None	None	Wood chips	Wood chips	None	None
Brdcst	Island brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst
Annual	Annual	Perennial	Perennial	Perennial	Annual	Perennial	Annual
165	166	167	168	189	190	191	192

RMV 40-20

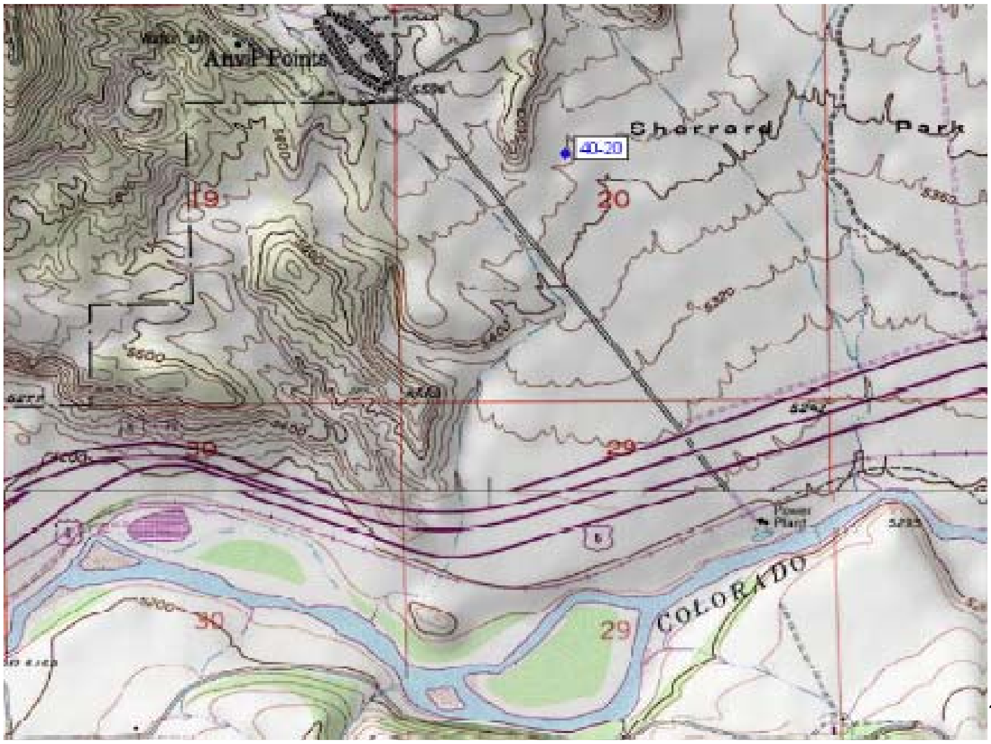

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Figure A-9. Location of RMV 40-20 in relation to I-70 and the Colorado River.

The well pad RMV 40-20 (39^0 30’ 44” N 107^0 54’ 50” W) is located north of I-70 in the West Rulison field. This pad is approximately 13 km east of the town of Parachute and is on private property. This pad is in the sagebrush-greasewood plant community and sits at an elevation of 1661 m. The surrounding area is dominated by native shrubs and cheat grass (*Bromus tectorum L*). The majority of the disturbance in this area is gas related with a few grazing cattle. Figure A-10 shows the approximate plot layout for the pad and Table A-5 provides the treatment combinations for the pad.

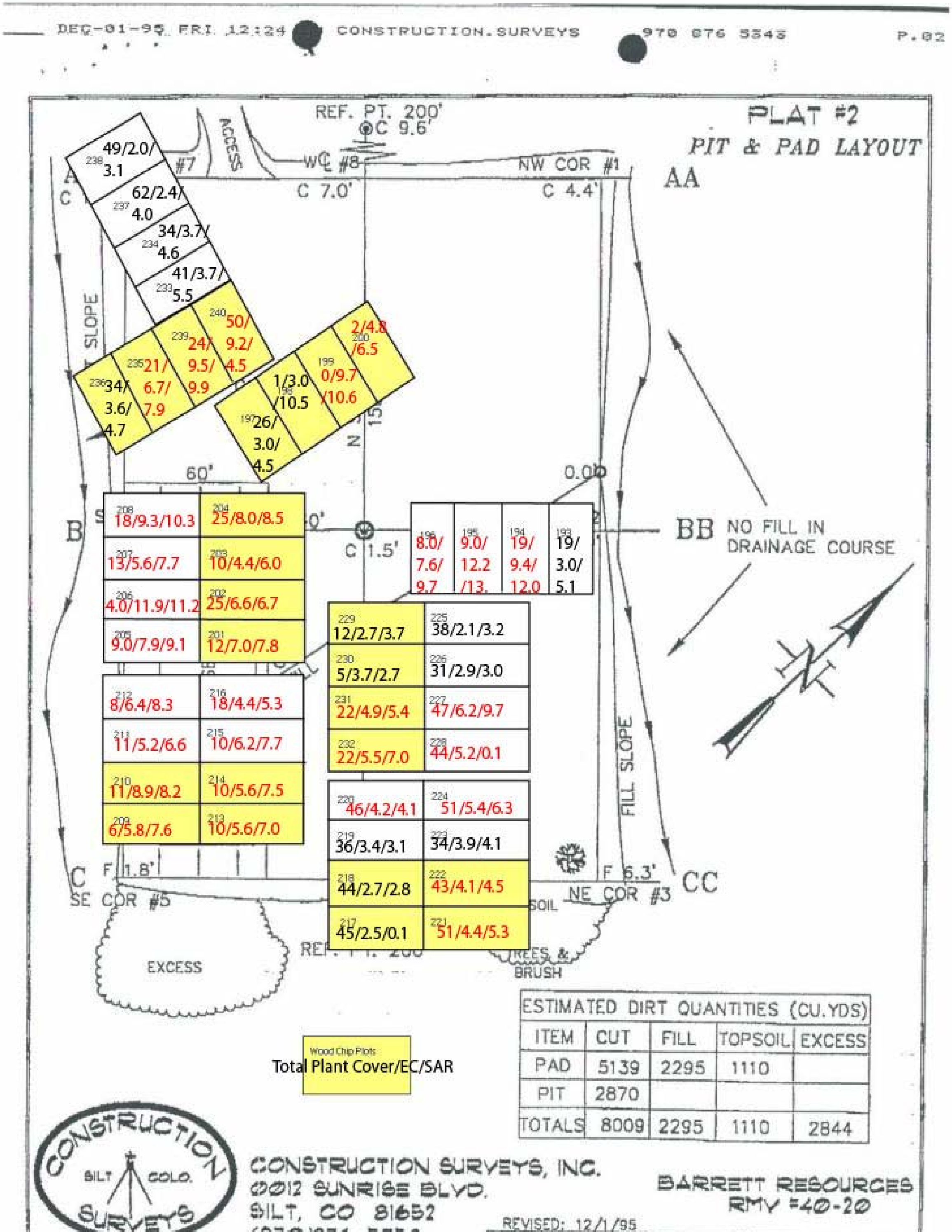

Fig A-10. Map of RMV 40-20 showing the plot number, total plant cover, Soil EC, and SAR. The yellow plots contain wood chips. The red text indicates saline or sodic-saline soils in the plots.

TableA-5. Treatment descriptions for plots on RMV 40-20. . The numbers are the plot number and correspond to the plot numbers in Figure A-10. The treatment descriptions, from the top down, are the seedbed preparation, soil amendment, seeding method, and seed mixture.

RMV 40-20

Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
None	None	None	None	Wood chips	Wood chips	None	None
Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Brdcst
Annual	Perennial	Annual	Perennial	Annual	Perennial	Perennial	Annual
193	194	195	196	217	218	219	220
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	Wood chips	None	None
Brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Island brdcst	Island brdcst	Island brdcst
Perennial	Annual	Perennial	Annual	Annual	Perennial	Annual	Perennial
197	198	199	200	221	222	223	224
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
Wood chips	Wood chips	Wood chips	Wood chips	None	None	None	None
Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst
Perennial	Annual	Perennial	Annual	Annual	Annual	Perennial	Perennial
201	202	203	204	225	226	227	228
Rough	Rough	Rough	Rough	Smooth	Smooth	Smooth	Smooth
None	None	None	None	Wood chips	Wood chips	Wood chips	Wood chips
Brdcst	Island brdcst	Brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst
Annual	Annual	Perennial	Perennial	Annual	Perennial	Perennial	Annual
205	206	207	208	229	230	231	232
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	None	None	Wood chips	Wood chips
Brdcst	Island brdcst	Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Brdcst
Annual	Annual	Annual	Perennial	Perennial	Annual	Annual	Perennial
209	210	211	212	233	234	235	236
Smooth	Smooth	Smooth	Smooth	Rough	Rough	Rough	Rough
Wood chips	Wood chips	None	None	None	None	Wood chips	Wood chips
Brdcst	Island brdcst	Island brdcst	Brdcst	Brdcst	Island brdcst	Island brdcst	Island brdcst
Perennial	Perennial	Annual	Perennial	Perennial	Annual	Perennial	Annual
213	214	215	216	237	238	239	240

APPENDIX B – DETAILED DESCRIPTION OF TEST PLOT CONSTRUCTION AND SAMPLING METHODS

TEST PLOT CONSTRUCTION METHODS

Recontouring and Seedbed Preparations

Two separate parties carried out the research plot installation which was overseen by the research associate from CSU, Joshua Eldridge. Mike Brady Construction, a contractor for Williams, closed the reserve pits and replaced the topsoil on each pad location. This is typically done using a hydraulic excavator and a bulldozer. Once the reserve pit is filled, the pad was recontoured to approximate the original contour of the site. The majority of the pad was then cross-ripped using a multi-shank ripper attached to the back of the bulldozer. There is a portion of the pad that is not reclaimed while the well is in production to allow access to the wellheads and production facilities. The rest of the pad was ripped to a depth of 60 cm or bedrock, if the soil is not 60 cm deep.

Phillips Seeding and Reclamation of Lafayette, CO constructed the revegetation portion of the reclamation. Before Phillips began any seeding, the corners of the treatment blocks were identified using metal T-posts. Seedbed preparation and fertilization then followed. The entire area to be reseeded was ripped using a chisel plow pulled behind a tractor. This was done to a depth of 30 cm and helped to further break up the compacted soils. Prior to ripping, 45 kg/ha of granulated 0-45-0 fertilizer was spread on the area to be reclaimed using a broadcaster attached to the back of an all terrain vehicle. The triple super-phosphate fertilizer was used to reduce the phosphorus deficiency that was detected during the initial soil sampling.

Incorporating the Wood Chip Amendment

The portion of the blocks that received wood chips was marked. The T-posts on the half of the block to receive wood chips were marked with yellow flagging. The wood chips were spread with a John Deere 660 manure spreader. The desired application rate was 90 Mg per hectare. There were 45 Mg delivered to each location. This results in approximately 7.5 Mg of wood chips per treatment block. The wood chips ranged in size from sawdust to 15 cm long chips.

The wood chips were incorporated into the rooting zone of the seedbed. This was accomplished by using the chisel plow and harrow. First, the wood chip plots were ripped with the chisel plow going the same direction that the wood chips were laid down. These plots were then harrowed to more evenly distribute the wood chips by moving them into the rip marks left by the chisel. The entire area was then chisel plowed a second time going across the plots perpendicular to the direction that they were ripped for the first pass. This resulted in incorporation of the wood chips to the desired depth of 15 cm.

Micro-catchment Creation

After the wood chips were incorporated, the individual plots were marked so that the micro-catchments could be placed in the appropriate areas of the plot. Each whole-plot contained eight individual plots with the dimensions of 6 m x 12 m and a 1 m buffer strip between plots. This resulted in a block with the dimensions of 25 m x 27 m. The plots were marked using wood stakes at the corners and labeled using a permanent marker indicating the plot number on two of the plot corners.

The micro-catchments were created using the bucket on the front of a tractor. There was one micro-catchment per 18.5 m^2 or 4 per plot. The location of the catchments was marked with spray paint before digging occurred and were placed in approximately the same location in each plot. The creation of the catchments consisted of the tractor operator driving up to the mark, lowering the bucket into the soil approximately 20 – 30 cm and driving forward a meter, then dumping the excavated soil on the opposite side of the catchment. The primary orientation of the micro-catchments was perpendicular to the prevailing wind direction on flat surfaces or perpendicular to the slope on steeper surfaces. The pile of soil was on the windward or downhill side of the catchment. The final dimensions of the catchments were approximately 183 cm L x 91 cm W x 25 cm D not including the pile of soil. There were three whole-plots with micro-catchments and three without micro-catchments. The three without micro-catchments were harrowed before seeding to fill in the rip marks left from the chisel plow. This was done to further differentiate the seedbed preparation treatments.

Seeding

All plots were hand broadcasted due to the small size of the plots. There were four seed mixes used for this experiment: an annual broadcast mix, a perennial broadcast mix, an annual island broadcast mix and a perennial island broadcast mix. The seed mixes were pre-weighed in the laboratory. The plots that were not island broadcast had the seed evenly distributed over the entire plot area. On the micro-catchment plots, the shrub and forb mix were broadcast over the catchments and the grass mix was broadcast in the interspaces between the catchments. The same strategy was used for the non-catchment plots as was used for the micro-catchment plots. The shrub and forb mix were broadcast in approximately the same areas that the micro-catchments would be located in. The grass mix was then broadcast in the interspaces of the islands.

All of the plots were then harrowed after seeding. The non-micro-catchment plots were harrowed by a tractor and the micro-catchment plots were harrowed with an ATV. The ATV was used because it had more maneuverability and was able to cover the seeds without excessively damaging the micro-catchments.

Mulching

The plots were all covered by certified weed-free straw. This was done by using a straw blower at a rate of 4.5 Mg/ha. The straw was crimped in place. Crimping the micro-catchment plots was not possible since it would damage the micro-catchments. Crimping was attempted in areas where it was possible to crimp without damaging the catchments, for example on the interspaces.

All phases of the plot installation were photo-documented and activities and progress of the day were recorded in a field notebook.

SAMPLING METHODS

Plant Cover

Plant cover data were collected during the first week of July in 2007 and 2008. Plant cover was estimated using a point intercept method along a line transect. There were nine line transects in each plot with a baseline starting along the short side (6 m) of the plot. Transects were spaced 61 cm apart from one another. Transects ran the length of the plot (12 m). The initial intercept point for each transect was randomly selected based on a random number table and each successive point was one meter apart. A total of 108 points were recorded for each of the sub-plots. Data collection included live cover by species, bare ground, litter, mulch, or rock. Aerial cover was estimated for these plots, so any plant part from current year's growth that intercepted the line counted as a hit. From the 108 data points, it was possible to determine total percent cover, percent cover of desired species and invasive species, species richness and frequency.

Plant cover data was also collected from surrounding undisturbed areas for comparison against the treatment combinations. A series of random coordinates for three line-transects was generated for each well pad location. The line transects were 100 m long and data was collected at every meter beginning at a random number based on the random number table and ending 100 m from that point. The data from the undisturbed areas were analyzed with the same methods as the data from the research plots.

Photo Documentation

Photographic documentation for each of the plots was taken at fixed locations within the plot. There was one photo taken from the location of the plot sign, to show the overall plant cover of that plot. There were potentially two photos taken within the plot with an aerial view of the vegetation. The first aerial photo was taken in the middle of the plot regardless of the seedbed treatment. A second aerial photo was taken above the micro-catchments, if in a rough seedbed plot. This gave a visual representation of the plant cover for each plot and can be used for comparison for subsequent years.

Soils Data

A composite soil sample was collected from each of the plots. The composite consisted of three sub-samples from the top 15 cm of each plot. The three sub-samples were placed in a bucket and thoroughly mixed before the composite sample was collected. The sampling equipment, including the bucket, were rinsed with deionized water and wiped down with a paper towel to decontaminate the equipment before the next sample was collected. Soil samples were also collected from the undisturbed area surrounding the well pads. The composite sample from the undisturbed area was collected from five points along the line transect used to collect the plant data. The analysis of the soils included pH, electrical conductivity, sodium absorption ratio, texture, and percent organic matter.

Biomass Data

Biomass data was collected in 2008 using a stratified sampling design to detect any differences in the seedbed preparation and seeding method techniques. The sampling design was stratified based on the spatial location of the micro-catchments and the corresponding seeded islands. The micro-catchments and islands were collectively called the catchment areas and the remaining areas of the plot were collectively considered the non-catchment areas. Biomass collection consisted of clipping a total of eight 0.5 m^2 quadrats per plot. Four quadrats were clipped in the catchment areas and four in the non-catchment areas.

The quadrats were placed in both catchment and non-catchment areas based on randomly generated coordinates. In the catchment areas there were two quadrats clipped on two of the four catchments of each plot, two in the pits of the catchment and two on the mounds. The pits and mounds were divided into quarters and one of the quarters in each of the pits and mounds were randomly chosen to be clipped. The non-catchment areas had randomly generated coordinates for the placement of the quadrats. The catchment areas were located in two 3-m zones positioned on the ends of the plot. The non-catchment areas were located in the 6 meters of the plot between the two catchment areas.

All of the current year's biomass within each quadrat was clipped to ground level and bagged by species. There was one set of bags for catchment areas and one for non-catchment areas. All plant samples were dried for 72 hours at 55 degrees Celsius. The biomass of each species bag was then weighed and compiled into an Excel spreadsheet for data analysis.

Biomass data were divided into the same cover variables that the cover data were, native seeded, native volunteer, non-native species, and non-native noxious. The values for each class of species within each plot were divided by the total biomass for that plot to determine relative biomass. The biomass data was analyzed using the same model and methods as the cover data, including the removal of the 55 saline plots.

APPENDIX C – PRECIPITATION, SOILS, AND BIOMASS RESULTS

RESULTS

There was data collected and analyzed for this project that was not presented in the previous sections. The following section includes graphics and discussion of the precipitation, soils and biomass results collected over 2007 and 2008.

Precipitation Results

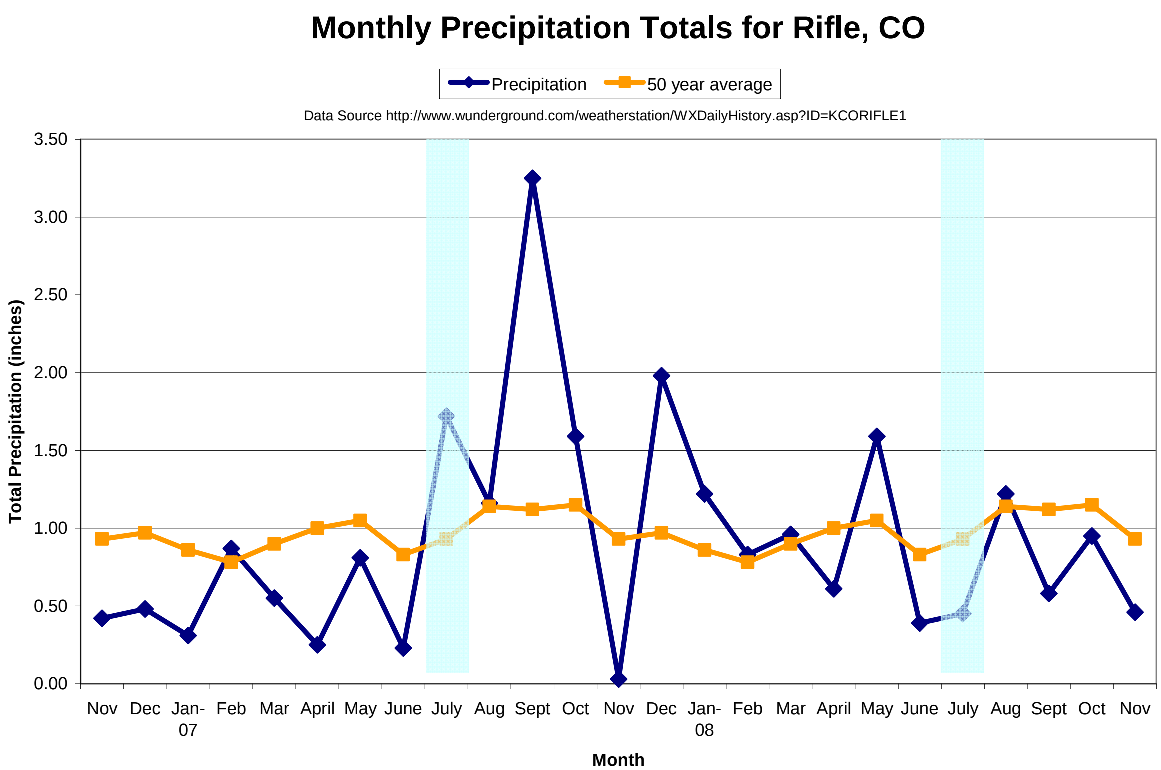

Fig C-1. Precipitation results for Rifle, CO from November 2006 to November 2008. The shaded areas indicate when sampling events took place.

The effects of precipitation were rather apparent in the differences of plant cover between 2007 and 2008. From the time the plots were installed in November 2006 to time of sampling in June of 2007 the project site received 53% of its average precipitation or just 100 mm. This lack of precipitation resulted in 36% total plant cover, with only 4.5% cover for native seeded species. Few, if any, of the perennial species were able to set seed the first growing season. The second growing season had better than average precipitation. From July 2007 to June 2008, precipitation was 130% of average or 389.5 mm. From November 2007 to June 2008, the area received 193.4 mm or 104% of average. This significantly improved total plant cover (56%) and native seeded cover (13%). Unfortunately, noxious plant cover also improved in 2008 to 4.6%, up from 0.2% cover. Precipitation can certainly be a limiting factor to successful reclamation on the Western Slope. Treatments, such as preparing a rough seedbed, can help mitigate the effects of low precipitation by reducing and capturing runoff during precipitation events.

Soils Results

The soils component of this research was inadequate for addressing the issues that arose during the course of this research. Soil samples were collected before the implementation of the research plots in late summer of 2006 and again during the summer of 2007 after the first growing season. The initial analysis did not indicate that there would be wide spread soil salinity issues although there were some samples with high EC and SAR values. Only one of the drill pads had the reserve pit closed and been regraded at the time of the initial soil sampling. Unfortunately, soil salinity proved to be widespread as 135 of the 240 plots were saline or sodic-saline.

There were 80 plots that were visually more barren than others and these were analyzed for heavy metals to try and identify a cause for the change in plant cover.

Heavy metals levels, however, were all below threshold levels and EC and SAR were the only two soil measurements that can help explain the reduced plant cover. Figures A-2 through A-10, found in Appendix A show each pad and plot lay out with the corresponding numbers for total plant cover, EC, and SAR. Values in red indicate saline or sodic-saline soils in a plot.

Biomass Results

The biomass results are not included in the main text of this thesis because of the uncertainty in the results. The distributions of the different variables fit a negative binomial, same as the cover data, but represent continuous data, rather than count data associated with cover measurements. This leaves the analysis a little suspect since it could not be verified that the GLIMMIX procedure in SAS was handling the continuous data appropriately. However, these results do help support some trends that were detected in the cover data. The following results are presented as relative production of biomass.

Native Seeded Species

Relative biomass for native seeded species across all treatments was 34%. There were two treatments that were significant at alpha = 0.05. These were the effects of WC (p-value 0.02)

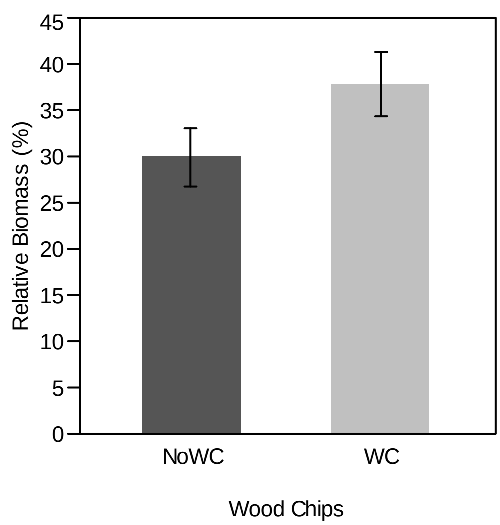

Fig C-2. The effects of wood chips on the relative biomass of native seeded species. (Mean ± 1 SE, p-value = 0.02) and the two-way interaction of seeding method and WC (p-value 0.02).

Figure C-2 shows that WC had a positive effect on the biomass of native seeded species. This effect was seen in the cover data but was not statistically significant. This result supports the idea that native species would perform better in a low nutrient environment created by wood chips, although this is an assumption because nutrient levels were not directly measured.

The two way interaction between WC and seeding method was also significant for relative biomass of native seeded species (p-value = 0.02). Figure C-3 shows that the native species responded differently in the island seeding method depending on the WC treatment. The significant difference in this treatment combination is the response of island broadcasting to WC. This response is being driven by the increase in grass production in this combination. The relative biomass of the catchment area with the island broadcasting is no different than that of the broadcast method (33.6 to 34.3%), but the relative biomass of non-catchment areas show an increase with the island broadcasting (44 to 34.6%) indicating that the grasses are improving production more than the shrubs or forbs in the presence of WC.

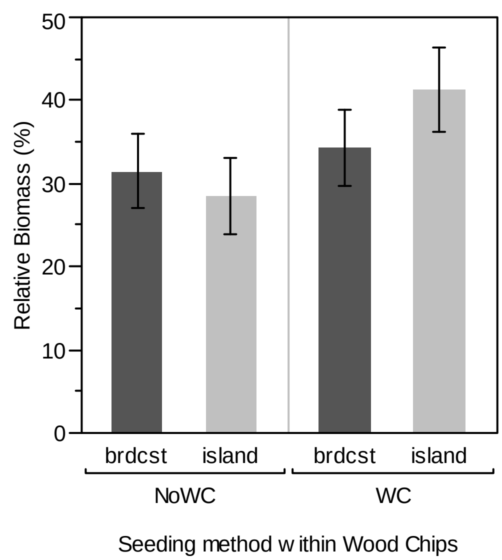

Fig C-3. The response of native seeded species to the interaction of wood chips and seeding method. (Mean ± 1 SE, p-value = 0.02)

Non-Native Species

Non-native species made up 52% of the relative biomass production across all treatments. The only statistically significant treatment for non-native species was WC (p-value = 0.02). Figure C-4 shows that there was a negative response for the non-native species in the presence of WC. This is the opposite response of the native seeded species, but is the same pattern that the cover data showed. However, the cover data had a larger reduction (27%) compared to the biomass data (12%).

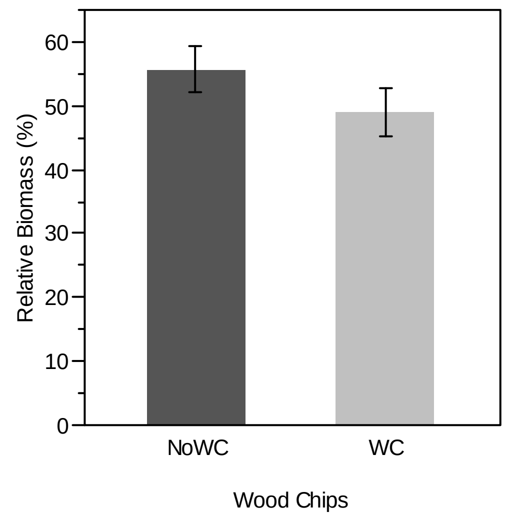

Fig C-4. The effects of wood chips on the relative biomass of non-native species. (Mean ± 1 SE, p-value = 0.02)

Noxious Plant Species

Noxious species comprised almost 6% of the relative biomass across all treatments. The only significant treatment for noxious species was the effect of seeding method (p-value 0.04). Figure C-5 shows that there was an increase in the relative biomass of noxious species with the use of the island seeding method. It should be noted that the analysis was

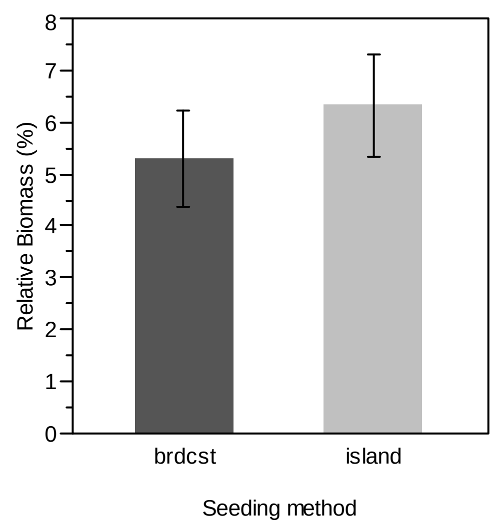

Fig C-5. The effect of seeding method on the relative biomass of noxious species. (Mean ± 1 SE, p-value 0.02) Note: significance determined in log scale; presented as untransformed data.

conducted on the log transformation of the data and figure C-5 presents the non-transformed data. There are two reasons for this response. The first is that the seeding rate for the island broadcasting was lower than the traditional broadcasting because the shrubs and forbs were separated from the grasses. The second explanation is that the island broadcasting reduced the more competitive grass species from areas of the plot. These areas were then more easily invaded by cheatgrass and redstem storkbill, the two most common noxious species.

APPENDIX D – TREATMENT COMPARISONS

TREATMENT COMPARISONS

One of the objectives of this research was to identify techniques that will improve reclamation success on well pads. The interaction of the treatments was also of interest since reclamation is a practice of multiple processes. Therefore the interactions of the four treatments and the outcome from the different treatment combinations are just as important as any of the single treatments effects. There were 16 different treatment combinations in this study and I wanted to know if any of these treatment combinations resulted in higher native cover and lower non-native cover. The following graphs display the response of native seeded, native volunteers, non-native, and noxious species to different treatment combinations.

Table D-1 describes the treatments associated with each treatment number. The numbers are set-up so that 1 – 8 have rough seedbeds and 9 – 16 have smooth seedbeds. Treatments are in pairs with the odd number treatments being wood chip treatments and with all other treatments remaining the same.

Table D-1. Description of treatments that make up the different treatment combination numbers.

Treatment #	Seedbed Prep	Wood Chips	Seed Mix	Seed Method
1	rough	WC	ann+per	island
2	rough	NoWC	ann+per	island
3	rough	WC	perennial	island
4	rough	NoWC	perennial	island
5	rough	WC	ann+per	broadcast
6	rough	NoWC	ann+per	broadcast
7	rough	WC	perennial	broadcast
8	rough	NoWC	perennial	broadcast
9	smooth	WC	ann+per	island
10	smooth	NoWC	ann+per	island
11	smooth	WC	perennial	island
12	smooth	NoWC	perennial	island
13	smooth	WC	ann+per	broadcast
14	smooth	NoWC	ann+per	broadcast
15	smooth	WC	perennial	broadcast
16	smooth	NoWC	perennial	Broadcast
Reference	NA	NA	NA	NA

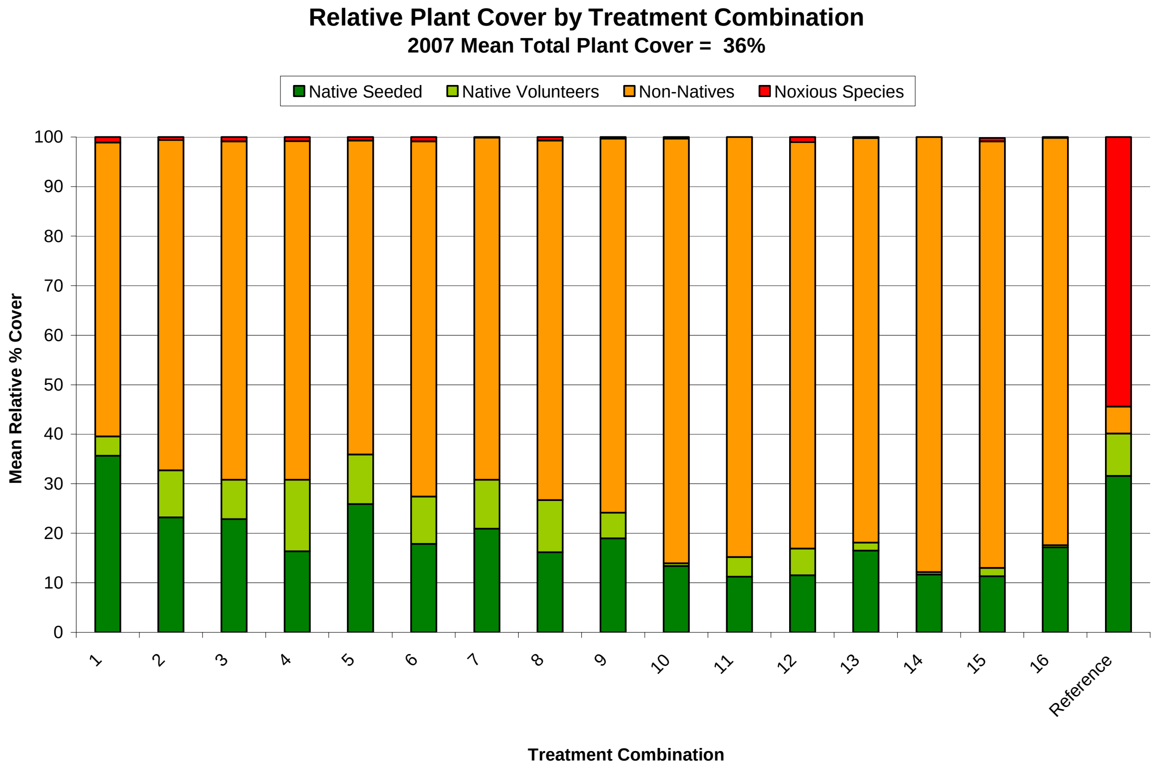

Fig D-1. Relative plant cover by dependent variable and treatment combination for 2007. A description of each treatment is presented in table D-1.

The data analysis found that there were no four-way interactions that were significant, meaning that there is no statistical difference between any of the 16 treatment combinations. However, there are two things to note on figure D-1. First, the dominance of noxious species in the reference areas as compared to the treatments. At this point in time noxious species did not make up a significant portion of cover on the pads, but with so much of the surrounding areas being dominated by noxious species it will only be a matter of time before they do. Second, the cover of the native seeded and native volunteers is consistently higher in treatments 1-8 (rough seedbed) compared to treatments 9-16 (smooth seedbed) in 2007.

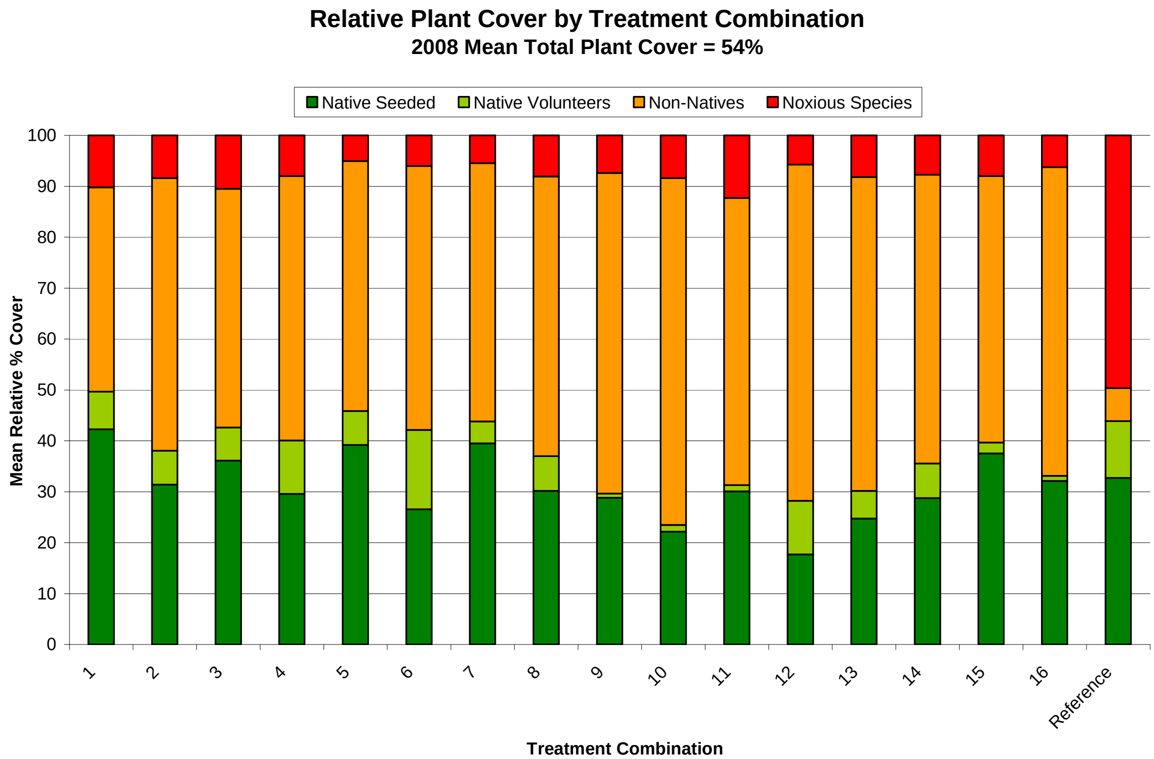

Fig D-2. Relative plant cover by dependent variable and treatment combination for 2008. A description of each treatment is presented in table D-1.

There were no significant differences between the treatment combinations in 2008. Natives increased in all treatments and the pattern between seedbed preparation methods is less pronounced in 2008. The other noticeable change is the increase in noxious plant cover on the plots compared to 2007. The reference area is still dominated by noxious species and with the increase in moisture in 2008 noxious species had better success moving onto the plots. The high variability in plant cover in both years made it difficult to determine if any treatment combination resulted in significantly higher natives and lower non-natives. Even though one particular treatment combination with all four variables cannot be determined to be the most successful, the treatment combination of rough seedbed and wood chips (odd numbered treatments 1 – 7) consistently provide higher cover of natives when compared to the other treatment combinations.

Treatment Comparison Photos

The following photos were taken during July 2008. The pictures attempt to display the average cover composition for each of the treatment combinations. The mean plant cover numbers below each photo set are the means for the treatment combination, not from the photos themselves.

Treatment 1. Combination of rough seedbed, wood chips, annual plus perennial seed mix, and island broadcasting.
Mean Plant Cover 2008 = 58%: Native seeded = 19%; Native volunteers = 3%; Non-natives = 29%; Noxious = 7%

Treatment 2. Combination of rough seedbed, no wood chips, annual plus perennial seed mix, and island broadcasting.
Mean Plant Cover 2008 = 68%: Native seeded = 17%; Native volunteers = 3%; Non-natives = 42%; Noxious = 6%

Treatment 3. Combination of rough seedbed, wood chips, perennial seed mix, and island broadcasting.
Mean Plant Cover 2008 = 57%: Native seeded = 17%; Native volunteers = 2%; Non-natives = 32%; and Noxious = 6%

Treatment 4. Combination of rough seedbed, no wood chips, perennial seed mix, and island broadcasting.
Mean Plant Cover 2008 = 63%: Native seeded = 14%; Native volunteers = 6%; Non-natives = 38%; and Noxious = 5%

Treatment 5. Combination of rough seedbed, wood chips, annual and perennial seed mix, and traditional broadcasting.
Mean Plant Cover 2008 = 55%: Native seeded = 14%; Native volunteers = 3%; Non-natives = 35%; and Noxious = 3%

Treatment 6. Combination of rough seedbed, no wood chips, annual and perennial seed mix, and traditional broadcasting.
Mean Plant Cover 2008 = 61%: Native seeded = 12%; Native volunteers = 6%; Non-natives = 39%; and Noxious = 4%

Treatment 7. Combination of rough seedbed, wood chips, perennial seed mix, and traditional broadcasting.
Mean Plant Cover 2008 = 56%: Native seeded = 17%; Native volunteers = 2%; Non-natives = 34%; and Noxious = 3%

Treatment 8. Combination of rough seedbed, no wood chips, perennial seed mix, and traditional broadcasting.
Mean Plant Cover 2008 = 67%: Native seeded = 16%; Native volunteers = 4%; Non-natives = 42%; and Noxious = 5%

Treatment 9. Combination of smooth seedbed, wood chips, annual and perennial seed mix, and island broadcasting.
Mean Plant Cover 2008 = 45%: Native seeded = 9%; Native volunteers = 1%; Non-natives = 30%; and Noxious = 5%

Treatment 10. Combination of smooth seedbed, no wood chips, annual and perennial seed mix, and island broadcasting
Mean Plant Cover 2008 = 76%: Native seeded = 12%; Native volunteers = 1%; Non-natives = 56%; and Noxious = 7%

Treatment 11. Combination of smooth seedbed, wood chips, perennial seed mix, and island broadcasting
Mean Plant Cover 2008 = 53%: Native seeded = 15%; Native volunteers = 1%; Non-natives = 30%; and Noxious = 7%

Treatment 12. Combination of smooth seedbed, no wood chips, perennial seed mix, and island broadcasting
Mean Plant Cover 2008 = 66%: Native seeded = 8%; Native volunteers = 6%; Non-natives = 48%; and Noxious = 4%

Treatment 13. Combination of smooth seedbed, wood chips, annual and perennial seed mix, and traditional broadcasting
Mean Plant Cover 2008 = 48%: Native seeded = 10%; Native volunteers = 2%; Non-natives = 32%; and Noxious = 5%

Treatment 14. Combination of smooth seedbed, no wood chips, annual and perennial seed mix, and traditional broadcasting
Mean Plant Cover 2008 = 60%: Native seeded = 10%; Native volunteers = 3%; Non-natives = 41%; and Noxious = 5%

Treatment 15. Combination of smooth seedbed, wood chips, perennial seed mix, and traditional broadcasting
Mean Plant Cover 2008 = 47%: Native seeded = 17%; Native volunteers = 1%; Non-natives = 25%; and Noxious = 4%

Treatment 16. Combination of smooth seedbed, no wood chips, perennial seed mix, and traditional broadcasting
Mean Plant Cover 2008 = 56%: Native seeded = 15%; Native volunteers = 1%; Non-natives = 36%; and Noxious = 4%

APPENDIX E – TREATMENT COST ANALYSIS

TREATMENT COST ANALYSIS

The costs for reclamation vary depending on the techniques, materials, and equipment used to perform the reclamation activity. The costs for the different treatment combinations for this study ranged from $2,231 to $4,690 per acre. These costs are based on estimates provided by Mark Phillips of Phillips Seeding and Reclamation and are based on the different procedures and materials used to establish the research plots. There were three materials used in the study: wood chips, seed, and mulch. The wood chips cost $400/acre, not including transportation cost. The seed ranged from $930-$1300/acre and mulch costs $200/acre. There were six activities performed to create the different treatment combinations. These activities included: 1) chisel plowing the top 30 cm of the soil ($180/acre); 2) incorporation of wood chips ($480/acre); 3) micro-catchment creation ($1200/acre); 4) seeding ($200/acre); 5) harrowing to increase seed to soil contact ($120/acre); and 6) mulch spreading and crimping ($600/acre). Table E-1 presents all of the treatment combinations and associated costs.

Of the three highest procedural costs, the cost for mulching is the most expendable and would save $600/acre. Mulch can be beneficial to reclamation, but may not be necessary to successfully meet the reclamation objectives. The data show that the use of wood chips and creating micro-catchments significantly improve native seeded cover, so it is recommended that these treatments be considered for future reclamation. There may be ways to reduce the costs of these practices. For example, wood chips can be created on site by chipping any woody materials that may be present when the well pad is created. This will not likely produce enough wood chips to meet the recommended application rate, but it may reduce costs. There may also be other opportunities to acquire wood chips through the BLM or Forest Service depending on the management and handling of beetle kill trees on the west slope. Finally, it may be possible to locate a timber mill that is closer to Parachute than Grand Junction. The costs of micro-catchment creation may also be reduced by utilizing different machinery or implements that were not used in this research.

Another area that costs can be reduced is in reformulating the seed mixtures. There are between 16-19 species used in the two seed mixes for this experiment. By removing the most expensive species and species that did not perform well, like *Sphaeralcea coccinea* (scarlet globemallow), *Penstemon strictus* (Rocky Mountain penstemon), *Vicia americana* (American vetch), *Pleuraphis jamesii* (James' galleta) and *Heliomeris multiflora* (showy goldeneye) it would reduce the seed costs by as much as $565/acre. This would bring the costs down to between $365-$735/acre for seed. Some of these species did become established, just not in large numbers. If the cost of seed is a concern, then it is recommended that these under-performing and expensive species be removed from the seed mixture.

Table E-1. Estimated costs by treatment combination and reclamation activity. All dollar values are per acre.

Rx #	Tillage	Wood Chip	Seed Mix	Seeding Method	Chisel to 12"	Wood Chips	Incorporate wood chips	Micro-catchment creation	Seed Mixtures	Seed Method	Harrow	Mulch and Crimp	Estimate Cost per Acre
1	rough	yes	annual+ perennial	island broadcast	$180	$400	$480	$1,200	$1,310	$200	$120	$800	$4,690
2	rough	no	annual+ perennial	island broadcast	$180	$0	$0	$1,200	$1,310	$200	$120	$800	$3,810
3	rough	yes	Perennial	island broadcast	$180	$400	$480	$1,200	$1,236	$200	$120	$800	$4,616
4	rough	no	Perennial	island broadcast	$180	$0	$0	$1,200	$1,236	$200	$120	$800	$3,736
5	rough	yes	annual+ perennial	traditional broadcast	$180	$400	$480	$1,200	$975	$200	$120	$800	$4,355
6	rough	no	annual+ perennial	traditional broadcast	$180	$0	$0	$1,200	$975	$200	$120	$800	$3,475
7	rough	yes	perennial	traditional broadcast	$180	$400	$480	$1,200	$931	$200	$120	$800	$4,311
8	rough	no	perennial	traditional broadcast	$180	$0	$0	$1,200	$931	$200	$120	$800	$3,431
9	smooth	yes	annual+ perennial	island broadcast	$180	$400	$480	$0	$1,310	$200	$120	$800	$3,490
10	smooth	no	annual+ perennial	island broadcast	$180	$0	$0	$0	$1,310	$200	$120	$800	$2,610
11	smooth	yes	perennial	island broadcast	$180	$400	$480	$0	$1,236	$200	$120	$800	$3,416
12	smooth	no	perennial	island broadcast	$180	$0	$0	$0	$1,236	$200	$120	$800	$2,536
13	smooth	yes	annual+ perennial	traditional broadcast	$180	$400	$480	$0	$975	$200	$120	$800	$3,155
14	smooth	no	annual+ perennial	traditional broadcast	$180	$0	$0	$0	$975	$200	$120	$800	$2,275
15	smooth	yes	perennial	traditional broadcast	$180	$400	$480	$0	$931	$200	$120	$800	$3,111
16	smooth	no	perennial	traditional broadcast	$180	$0	$0	$0	$931	$200	$120	$800	$2,231

APPENDIX F – LIMITATIONS AND UNCERTAINTIES

LIMITATIONS AND UNCERTAINTIES

This research certainly comes with some uncertainties and limitations. For one, the high amount of variability that was found within pads and between pads makes it difficult to identify treatment affects. The high variability contributes to means that may not be truly representative of the population of interest. For example, in 2008 the treatment combination of a rough seedbed, WC, perennial seed mix, and island broadcasting had an average native seeded cover of 16%, but ranged from 0 to 79% across all five pads. When the one plot that had 79% cover is removed the average drops to 11.5% with a range of 0 to 37%. This level of variability is present throughout all pads and treatment combinations.

One factor that likely contributed to the high variability is the effects of soil salinity on plant cover. For example, on RMV 215-21, there was a distinct line where on one side there was vegetation and on the other there was virtually nothing (Figure F-1). The soils on the left side of the line have an average EC of 11.1 and the right side has an average EC of 4.65. There were areas on other pads that had similar patterns,

Fig F-1. Area on RMV 215-21 displaying effects of soil salinity on plant cover. Red line marks the buffer zone between treatment plots.

but none as distinct as the one shown in Figure F-1.

Another interesting fact is that the line in Figure F-1 represents the approximate edge of where the reserve pit was located during the drilling phase. On all pads but one, PA 324-26, the plots over the location of the reserve pit are saline or sodic-saline. The reason PA 324-26 didn’t have the same spatial pattern as the others maybe because the reserve pit was located at the foot of a deep cut slope and so there is at least 10 ft of backfill over the top of the reserve pit. This depth of soil would make it more difficult for the salts from the reserve pit to move by capillary action to the soil surface. The connection between soil salinity and reserve pit location should be investigated further.

One final uncertainty was in the biomass collection. The sampling design was based on a specific spacing and location of the micro-catchments and seeded islands. However, in the field, micro-catchment layout did not match the sampling plan. The location of the micro-catchments were more spread out and occupied more of the plot than remembered during the sampling design phase. This oversight caused adjustments in the field, which were not a problem in the rough seedbed plots where the micro-catchments could be seen. However, in the smooth seedbed treatments, it was nearly impossible to determine if the seeded islands actually fell within the two 3 m zones on the ends of the plot that were originally planned to sample these treatments. The implementation of the seeded islands on the smooth seedbed attempted to imitate the spacing of the micro-catchments. If these were seeded in this manner it is likely that sampling within the 3 m zones on the ends of the plots did not capture all of the seeded islands. Therefore it is likely that we were not able to truly capture the treatment effect.

APPENDIX G – RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS AND CONCLUSIONS

The use of a rough seedbed improved native species establishment, especially during the less than average precipitation year. The incorporation of wood chips into the soil surface increased organic matter content and reduced non-native species cover. Wood chips also reduced total plant cover, but actually resulted in a higher ratio of natives to non-natives compared to the no wood chip treatment. Island broadcasting resulted in an increase of noxious species. The annual plus perennial seed mix did not consistently have the desired effect of out competing non-natives and facilitating the establishment of native perennial species. Continued monitoring is needed to assess the long-term impact of these treatments.

The possibility that natural gas development may increase soil salinity needs to be further investigated. More research in needed to determine what is causing the increase in EC and SAR. Additional research is also needed on the chemical and biological effects of wood chip amendments. Information on how the microbial community is responding to wood chip additions and what the effect is on soil nutrient availability is lacking.

The value of this study is in its application to a new field. Research on the reclamation of natural gas well pads is not well documented and there is a need for improved techniques. The approach to try and restore disrupted natural processes, like hydrologic and nutrient cycles, is important to advance reclamation. On the Western Slope of Colorado and the American West, the development of energy resources will continue to increase. It is important that the ecological services that these areas provide are not damaged beyond repair. These areas are also subject to plant invasions, so it is equally important that we establish viable native plant populations.

APPENDIX H – SEED MIXTURES BY SEEDING METHOD AND PLANT COMMUNITY

Table H-1. Island Annual and Perennial Seed mix for Pinyon-Juniper Plant Community

Scientific name	Common name	Origin	PLS/ m2	PLS kg/ha	% of Seed Mix
Pinyon-Juniper Community					
Island Mix-Annual					
Shrubs					
Juniperus osteosperma	Utah juniper	UT	3	2.2	0.2
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	15.2
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	9.2
Atriplex canescens	fourwing saltbush		54	4.7	3.3
					27.9
Forbs					
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	15.2
Penstemon strictus	Rocky Mtn penstemon	WY,UT	215	3.4	13.2
Linum lewisii	Lewis flax	WA	226	3.4	13.9
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	11.9
					54.1
Legumes					
Vicia americana	American vetch	CAN	32	4.5	2.0
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	2.0
					4.0
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	1.5
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	2.6
Vulpia octoflora	Six weeks fescue	CO	161	0.8	9.9
TOTALS			1630	32.3	100.0
Island Mix-Annual					
Graminoids					
Hesperostipa comata	Needle and thread	UT	108	3.4	10.1
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	11.1
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	8.1
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	10.1
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	13.1
Sporobolus airoides	Alkali sacaton	UT	215	0.6	20.2
					72.6
Legumes					
Vicia americana	American vetch	CAN	32	4.5	3.0
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	3.0
					6.0
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	2.2
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	4.0
Vulpia octoflora	Six weeks fescue	CO	161	0.8	15.1
TOTALS			1068	31.3	100

Table H-2. Island Perennial Seed mix for Pinyon-Juniper Plant Community

Scientific name	Common name	Origin	PLS/ m2	PLS kg/ha	% of Seed Mix
Island Mix-Perennial					
Shrubs					
Juniperus osteosperma	Utah juniper	UT	3	2.2	0.2
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	17.7
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	10.7
Atriplex canescens	fourwing saltbush		54	4.7	3.8
					32.4
Forbs					
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	17.7
Penstemon strictus	Rocky Mtn penstemon	WY,UT	215	3.4	15.4
Linum lewisii	Lewis flax	WA	226	3.4	16.1
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	13.8
					63.0
Legumes					
Vicia americana	American vetch	CAN	32	4.5	2.3
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	2.3
TOTALS			1402	26.3	100
Island Mix-Perennial					
Graminoids					
Hesperostipa comata	Needle and thread	UT	108	3.4	12.8
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	14.1
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	10.3
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	12.8
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	16.7
Sporobolus airoides	Alkali sacaton	UT	215	0.6	25.6
					92.3
Legumes					
Vicia americana	American vetch	CAN	32	4.5	3.8
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	3.8
TOTALS			840	25.2	100.0

Table H-3. Annual and Perennial Broadcast Seed Mix for Pinyon-Juniper Plant Community.

Scientific name	Common name	Origin	PLS/ m2	PLS kg/ha	% of Seed Mix
Broadcast Mix-Annual					
Juniperus osteosperma	Utah juniper	UT	3	2.2	0.1
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	10.3
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	6.3
Atriplex canescens	fourwing saltbush		54	4.7	2.2
Hesperostipa comata	Needle and thread	UT	108	3.4	4.5
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	4.9
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	3.6
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	4.5
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	5.8
Sporobolus airoides	Alkali sacaton	UT	215	0.6	9.0
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	10.3
Penstemon strictus	Rocky Mtn penstemon	WY,UT	215	3.4	9.0
Linum lewisii	Lewis flax	WA	226	3.4	9.4
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	8.1
Vicia americana	American vetch	CAN	32	4.5	1.3
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	1.3
					90.5
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	1.0
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	1.8
Vulpia octoflora	Six weeks fescue	CO	161	0.8	6.7
TOTALS			2405	49.7	100
Broadcast Mix-Perennial					
Juniperus osteosperma	Utah juniper	UT	3	2.2	0.1
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	11.4
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	6.9
Atriplex canescens	fourwing saltbush		54	4.7	2.5
Hesperostipa comata	Needle and thread	UT	108	3.4	4.9
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	5.4
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	4.0
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	4.9
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	6.4
Sporobolus airoides	Alkali sacaton	UT	215	0.6	9.9
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	11.4
Penstemon strictus	Rocky Mtn penstemon	WY,UT	215	3.4	9.9
Linum lewisii	Lewis flax	WA	226	3.4	10.4
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	8.9
Vicia americana	American vetch	CAN	32	4.5	1.5
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	1.5
TOTALS			2177	43.7	100.0

Table H-4. Island Annual and Perennial Seed Mix for Sagebrush-Greasewood Plant Community.

Sagebrush/Greasewood Community

Scientific name	Common name	Origin	PLS/ m2	PLS kg/ha	% of Seed Mix
Island Mix-Annual					
Shrubs					
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	16.8
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	10.2
Atriplex confertifolia	shadscale saltbrush	WY	65	4.8	4.4
Atriplex canescens	fourwing saltbush		54	4.5	3.6
					35.0
Forbs					
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	16.8
Linum lewisii	Lewis flax	WA	226	3.4	15.3
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	13.1
					45.2
Legumes					
Vicia americana	American vetch	CAN	32	4.5	2.2
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	2.2
					4.4
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	1.6
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	2.9
Vulpia octoflora	Six weeks fescue	CO	161	0.8	10.9
TOTALS			1477	31.3	100.0
Island Mix-Annual					
Graminoids					
Pleuraphis jamesii	James' galleta	TX	118	3.4	10.1
Sporobolus airoides	Alkali sacaton	UT	215	0.6	18.3
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	7.3
Pseudoroegneria spicata	bluebunch wheatgrass	WA	97	3.4	8.2
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	9.2
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	11.9
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	10.1
					75.1
Legumes					
Vicia americana	American vetch	CAN	32	4.5	2.7
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	2.7
					5.5
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	2.0
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	3.7
Vulpia octoflora	Six weeks fescue	CO	161	0.8	13.7
TOTALS			1175	34.6	100.0

Table H-5. Island Perennial Seed Mix for Sagebrush-Greasewood Plant Community.

Scientific name	Common name	Origin	PLS/ m2	PLS kg/ha	% of Seed Mix
Island Mix-Perennial					
Shrubs					
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	19.8
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	12.1
Atriplex confertifolia	shadscale saltbrush	WY	65	4.8	5.2
Atriplex canescens	fourwing saltbush		54	4.5	4.3
					41.4
Forbs					
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	19.8
Linum lewisii	Lewis flax	WA	226	3.4	18.1
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	15.5
					53.4
Legumes					
Vicia americana	American vetch	CAN	32	4.5	2.6
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	2.6
TOTALS			1249	25.3	100.0
Island Mix-Perennial					
Graminoids					
Pleuraphis jamesii	James' galleta	TX	118	3.4	12.5
Sporobolus airoides	Alkali sacaton	UT	215	0.6	22.7
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	9.1
Pseudoroegneria spicata	bluebunch wheatgrass	WA	97	3.4	10.2
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	11.4
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	14.8
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	12.5
					93.2
Legumes					
Vicia americana	American vetch	CAN	32	4.5	3.4
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	3.4
TOTALS			947	28.6	100.0

Table H-6. Annual and Perennial Broadcast Seed Mix for Sagebrush-Greasewood Plant Community.

Scientific name	Common name	Origin	PLS /m2	PLS kg/ha	% of Seed Mix
Broadcast Mix-Annual					
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	10.5
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	6.4
Atriplex confertifolia	shadscale saltbrush	WY	65	4.8	2.7
Atriplex canescens	fourwing saltbush		54	4.5	2.3
Pleuraphis jamesii	James' galleta	TX	118	3.4	5.0
Sporobolus airoides	Alkali sacaton	UT	215	0.6	9.1
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	3.7
Pseudoroegneria spicata	bluebunch wheatgrass	WA	97	3.4	4.1
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	4.6
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	5.9
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	5.0
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	10.5
Linum lewisii	Lewis flax	WA	226	3.4	9.6
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	8.2
Vicia americana	American vetch	CAN	32	4.5	1.4
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	1.4
					90.3
Annuals					
Helianthus annuus	Common sunflower	MT	24	2.2	1.0
Cleome serrulata	Rocky Mtn Bee plant	UT	43	3.0	1.8
Vulpia octoflora	Six weeks fescue	CO	161	0.8	6.8
TOTALS			2359	52.1	100
Broadcast Mix-Perennial					
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	248	0.6	11.6
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	151	1.1	7.1
Atriplex confertifolia	shadscale saltbrush	WY	65	4.8	3.0
Atriplex canescens	fourwing saltbush		54	4.5	2.5
Pleuraphis jamesii	James' galleta	TX	118	3.4	5.6
Sporobolus airoides	Alkali sacaton	UT	215	0.6	10.1
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	3.4	4.0
Pseudoroegneria spicata	bluebunch wheatgrass	WA	97	3.4	4.5
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	3.4	5.1
Elymus elymoides	Bottlebrush squirreltail	WA	140	3.4	6.6
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	3.4	5.6
Sphaeralcea coccinea	Scarlet globemallow	UT	248	2.2	11.6
Linum lewisii	Lewis flax	WA	226	3.4	10.6
Heliomeris multiflora	Showy Goldeneye	?	194	0.8	9.1
Vicia americana	American vetch	CAN	32	4.5	1.5
Hedysarum boreale	Utah sweetvetch	CO	32	3.4	1.5
TOTALS			2131	46.0	100.0

Table H-7. Non-plot Broadcast Mix.

Scientific name	Common name	Origin	PLS /m2	PLS kg/ha	% of Seed Mix
Non-plot mix					
Artemisia tridentata var. vaseyana	Mtn Big Sagebrush	WY	140	1.3	18.5
Chrysothamnus nauseosus var. nauseosa	Rubber rabbitbrush	WY	75	2.2	10.0
Atriplex canescens	fourwing saltbush		54	18.8	7.1
Achnatherum hymenoides var. Paloma	Indian ricegrass	UT	118	13.5	15.7
Pascopyrum smithii var. Ariba	Western wheatgrass	WY	86	13.5	11.4
Elymus trachycaulus var. Revenue	Slender wheatgrass	WY	108	14.6	14.2
Sporobolus airoides	Alkali sacaton	UT	108	1.1	14.2
Helianthus annuus	Common sunflower	MT	24	9.0	3.1
Cleome serrulata	Rocky Mtn Bee plant	UT	43	12.3	5.7
TOTALS			756	86.2	100.0