DETERMINING RECLAMATION POTENTIAL FOR STEEP OIL AND GAS SITES IN THE POWDER RIVER BASIN, WYOMING[1]

Brenda K. Schladweiler[2] and Dawn M. Gardner

Abstract. The collection of qualitative and quantitative data prior to any disturbance is an invaluable tool in the reclamation process, including the determination of future reclamation success of a given site. In conjunction with any federal or state rules and regulations associated with pre-disturbance data collection and due diligence of companies, determining overall reclamation potential prior to disturbance can outline construction limitations and ultimately increase final reclamation success. Primary resources that should be evaluated prior to disturbance include vegetation and soil characteristics. Since both pre-disturbance and revegetation communities are related to baseline and replaced soil characteristics, reclamation potential can be determined prior to disturbance at a specific location. This is especially critical on steep slope areas where thin and erosive soils may be present and where soil quality may be an issue.

Various 2010 vegetation and soil data were collected to determine reclamation potential on proposed oil and gas sites within steep terrain and limited soils in the Powder River Basin of northeastern Wyoming. Many of these sites were on areas of concern for eventual reclamation success by federal land managers. A resource matrix was developed to assist in the determination of overall reclamation potential for each site. In addition, vegetation surveys were conducted within previously reclaimed steep sloped areas to determine whether success could be achieved in such highly challenged landscapes.

Additional Key Words: coalbed methane, pre-disturbance assessment, vegetation, soils.

---

[1] Paper was presented at the 2011 National Meeting of the American Society of Mining and Reclamation, Bismarck, ND ***Reclamation: Sciences Leading to Success*** June 11 – 16, 2011. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Brenda K. Schladweiler is President and owner of BKS Environmental Associates, Inc., Gillette, WY 82717 and Rock Springs, WY 82902. Dawn M. Gardner BKS Environmental Associates, Inc., Gillette, WY.

Proceedings America Society of Mining and Reclamation, 2011 pp 552-566
DOI: 10.21000/JASMR11010552

http://dx.doi.org/10.21000/JASMR11010552

Introduction

Site-specific reclamation plans, including determination of reclamation potential prior to disturbance, are increasingly requested by federal regulators prior to the approval of oil and gas drilling permits. In conjunction with adhering to federal and state rules and regulations, oil and gas companies are conducting voluntary investigations of their assets to determine reclamation potential, in order to outline construction limitations and ultimately increase final reclamation success. Typically, site-specific reclamation plans and determination of reclamation potential are requested by regulators and conducted by energy companies for sites considered to be in highly challenged landscapes where achieving reclamation success is considered potentially low. Determination of reclamation potential prior to disturbance is especially critical on steep slope sites where thin and erosive soils may be present and where soil quality may be an issue.

The collection of qualitative and quantitative data prior to any disturbance is an invaluable tool in the overall reclamation process and for the development of site-specific reclamation plans including reclamation potential. Primary resources to evaluate prior to disturbance to determine reclamation potential include vegetation and soil characteristics. Since both pre-disturbance and revegetation communities are related to baseline and replaced soil characteristics, reclamation potential can be determined prior to disturbance at a specific site. The purposes of this study are to outline the process associated with determining reclamation potential prior to disturbance through the collection of various vegetation and soil characteristic and to determine whether reclamation success can be achieved in highly challenged landscapes in the northeastern portion of the Powder River Basin, Wyoming, based on the case study results.

Methodology

Qualitative Data Collection

Prior to the initial site visit to any given proposed disturbance site, maps for each area requiring a site-specific reclamation plan, according to the Bureau of Land Management (BLM) requirements, should be produced. Each site specific map should typically include well pad or access road disturbance boundaries, Natural Resource Conservation Service (NRCS) Ecological Site Descriptions (ESDs) and soil map units, along with modeled percent of disturbance boundary affected by slopes greater than 25% overlain on high resolution aerial imagery. During

the initial site visit, vegetation communities and soil series boundaries observed in the field should be drawn on the maps for later digitization of these attributes.

Primary vegetation characteristics determined in the field include dominant and minor vegetation communities present at the site, based on observations of the vegetation communities. The dominant plant species, based on ocular estimation of canopy cover, within each vegetation community should be documented, as well as other common species in the area. Plant species list for each vegetation community can be used later to develop seed mixes. Primary soil characteristics determined in the field include soil depth (i.e., depth to paralithic or lithic material), physical and/or soil limiting factors, soil texture (i.e., gross texture or dominant particle size), and soil series, if possible. Determination of these primary soil characteristics are used to estimate a recommended topsoil salvage or stripping depth. Derivation of salvage or stripping depths based on these characteristics can allow the salvage of soil based on suitability of the material rather than a standard stripping depth for all disturbed areas independent of soil characteristics. Based on the dominant vegetation community and soil series at each specific site, ESDs are field verified. Commonly, field verified ESDs are different from the NRCS ESDs due to the scale of NRCS mapping.

Soil series, soil amendments, and seed mixes are determined after the site visit based on the primary vegetation and soil characteristics collected in the field. Soil sampling for laboratory analysis is conducted when needed (i.e. where soil chemistry problems are highly probable). Soil series are determined through field soil characteristics (i.e., color, texture, etc.), exposed soil profiles when possible, and known soil/vegetation associations. Soil amendment recommendations are based on soil limiting factors or reclamation/stabilization categories. Seed mixes are based on soil series, ESDs, vegetation community, and plant species lists.

A reclamation/stabilization matrix was developed to determine the erosion potential hazard of each site based on vegetation community and topsoil salvage depth (Table 1). Reclamation potential is derived from soil depth, slope, soil texture, soil limiting factors, and reclamation/stabilization category (Table 2). Reclamation/stabilization category 4 has the highest erosion potential hazard and low reclamation potential and reclamation/stabilization category 1 has the lowest erosion potential hazard and good reclamation potential. Erosion control measures required for each site are based on the reclamation/stabilization category and

reclamation potential derived from the matrix. The addition of erosion control measures increases potential reclamation success.

Table 1. Reclamation/Stabilization Matrix

Vegetation Community	Soil Depth (inches)		
	0	0-6	6+
Breaks Grassland	4	3	2
Big Sagebrush Shrubland	3	2	1
Silver Sagebrush Shrubland	3	2	1
Juniper Woodland	4	3	2
Upland Grassland	3	2	1
Sandy Breaks	4	3	2
Greasewood Shrubland	3	2	1
Disturbed	4	3	2

Table 2. Reclamation Potential Based on Pre-Disturbance Conditions.

Pre-disturbance Conditions	Reclamation Potential		
	Low	Fair	Good
Soil Depth	0	0-6	6+
Slope >25%	Steep	Moderately Steep	Gentle/relatively flat
Aspect	South	West	North and East
Texture	Sandy and Clay	Loam and Silt	Loam
Limiting Factor	pH, SAR	EC	None
Reclamation Category	4 & 4A	3 & 3A	2, 2A, 1, and 1A
Suggested Erosion Control Measures	Seed, Velocity Controls, Erosion Control Blanket, Soil Amendments	Seed, Straw Mulch, Velocity Controls, Soil Stabilization Products, Soil Amendments	2= Seed, Straw Mulch, Velocity Controls, Soil Amendments 1= Seed, Straw Mulch, Soil Amendments
Reclamation Potential with Erosion Control Measures	Fair	Good	Good to High

Quantitative Data Collection

The study area is located west of Gillette, Wyoming, in Johnson County in the northeastern portion of the Powder River Basin. Topography in the Powder River Basin ranges from gently undulating rolling lands to steep, rough, broken lands. Based on NRCS precipitation zones for ESDs, the study area is located in the 10-14 inch (24.5-36.5 cm) Northern Plains precipitation zone (NRCS, 2008). Four reclaimed sites, including one access road and three well pads, as well as, four adjacent reference sites were sampled within the study area. The three reclaimed well pads are Loamy ESDs and had been reclaimed in fall 2006 (i.e., had completed four growing seasons at the time of sampling). The access road is a Shallow Sandy ESD and had been reclaimed in spring 2008 (i.e., had completed three growing seasons at the time of sampling). Most of the sampled sites were located in areas considered to be a concern for reclamation success by federal land managers. Each reclaimed site had varying proportions of slopes greater than 25% and limiting physical and/or chemical soil properties. Reference areas had similar slopes and soil properties as the corresponding reclaimed sites.

The point-line intercept transect method was used to collect quantitative vegetation data at each site. Four 50-meter transects were sampled at each reclaimed site and two 50-meter transects were sampled at each adjacent reference site. Sample points were located at 1-meter intervals along each 50-meter transect for a total of 50 sample points per transect. Aerial cover (first hit) at each sample point was determined using a mounted laser point device oriented to the left side of the transect. First hit readings were used to calculate absolute cover values with each first hit contributing 2% of the total cover value. Second hits (deflection of the laser from the first hit onto another species) were recorded and only used to calculate species diversity. First and second hits were recorded as vegetation species based on current year's growth, litter, rock, or bare ground. Litter included all non-living organic material and did not include standing dead vegetation from the current year's growth; the latter was considered 2010 vegetation. Rock included both rock (>2 inches at the intermediate axis) and gravel (<2 inches at the intermediate axis) (BLM, 2009). Hit data collected from the four 50-meter transects (n=4) at the reclaimed sites were averaged together to obtain one sample point per reclaimed site. Hit data collected from the two 50-meter transects (n=2) at the reference sites were averaged together to obtain one sample point per reference site.

Species diversity was assessed by recording all of the species observed within a 2-meter wide belt transect centered over the 50-meter cover transect, including second hit data, yielding a 100-meter squared species diversity belt transect. These observations provide a measurement of the total species diversity and species composition by lifeform for each site sampled. Species diversity was calculated by computing the mean number of species per transect for each reclaimed and reference area sampled.

Statistical Analysis

A one-sided two-sample t-test of the classical null hypothesis was used to compared mean total vegetation cover and mean total ground cover between the reclaimed and adjacent reference site (McDonald et al., 2003). The one-sided two-sample classic null hypothesis is that the mean of a given vegetation parameter (i.e., total vegetation cover or total ground cover) for the reclaimed site is equal to or greater than the mean of the same vegetation parameter for the reference site (α=0.10). Evidence in support of reclamation success is obtained when the null hypothesis is not rejected.

Results and Discussion

Access Road

The reclaimed right of way (ROW) had 38.50% absolute mean total vegetation cover and 52.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 48.00% and 13.50%, respectively (Table 3). Native cool season perennial grasses, dominated by western wheatgrass (*Elymus smithii*) and Indian ricegrass (*Achnatherum hymenoides*), had the highest relative mean cover at 70.13%, followed by introduced annual forbs, composed primarily of Russian thistle (*Salsola tragus*), at 9.09% . Native half and/or sub-shrubs and native full shrubs had 7.79% and 6.49% relative mean cover, respectively. The dominant native half and/or sub-shrub was broom snakeweed (*Gutierrezia sarothrae*). Rubber rabbitbrush (*Ericameria nauseosa*) was the dominant native full shrub. Other species observed included big sagebrush (*Artemisia tridentata*) and sticky-leaved rabbitbrush (C*hrysothamnus viscidiflorus*) (Table 4). A total of 10 lifeforms and 37 species were encountered within the reclaimed area (Table 5). The mean number of species per species diversity belt transect was 20.

The reference area had 50.00% absolute mean total vegetation cover and 65.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 35.00% and

15.00%, respectively (Table 3). Native full shrubs, dominated by big sagebrush, had the highest relative mean cover at 40.00%, followed by native cool season perennial grasses at 22.00%, composed primarily of needleandthread (*Hesperostipa comata*) and Indian ricegrass. Native half and/or sub-shrubs had 18.00% relative mean cover and were composed of broom snakeweed and yucca (*Yucca glauca*) (Table 4). A total of 12 lifeforms and 50 species were encountered within the reference area (Table 5). The mean number of species per species diversity belt transect was 33.5.

Based on non-statistical comparisons, the reference area had higher mean total vegetation cover, mean total ground cover, and mean litter/rock cover than the reclaimed ROW. The reclaimed ROW had higher mean bare ground than the reference area. The dominant lifeform in the reference area was native full shrubs, whereas, the dominant lifeform in the reclaimed area was native cool season perennial grasses. The total number of species encountered and species diversity were higher in the reference area than in the reclaimed area. Based on statistical analysis, mean total vegetation cover and mean total ground cover in the reclaimed area were equal to or greater than mean total vegetation and mean total ground cover in the reference area (Table 6).

Well 13-14

The reclaimed well pad had 66.50% absolute mean total vegetation cover and 95.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 5.00% and 28.50%, respectively (Table 3). Native cool season perennial grasses, composed primarily of western wheatgrass and green needlegrass (*Nassella viridula*), had the highest relative mean cover at 90.23%, followed by introduced annual grasses, composed primarily of cheatgrass (*Bromus tectorum*) and Japanese brome (*Bromus japonicus*), at 6.02%. Native half and/or sub-shrub and native full shrubs had 0.75% relative mean cover each. Yucca was the only native half and/or sub-shrub species observed and big sagebrush was the only native full shrub species observed (Table 4). A total of eight lifeforms and 21 species were encountered within the reclaimed area (Table 5). The mean number of species per species diversity belt transect was 13.75.

Table 3. Comparison of Absolute Mean Percent Cover Values of Reclaimed and Reference Sites Sampled in August

Vegetation Parameter	Sample Site (Absolute Mean % Cover Value)							
	Acess Road		Well 13-14		Well 43-15		Well 44-15	
	Reclaimed	Reference	Reclaimed	Reference	Reclaimed	Reference	Reclaimed	Reference
Vegetation Cover	38.50	50.00	66.50	51.00	56.00	55.00	61.00	59.00
Litter Cover	13.00	13.00	28.50	23.00	32.50	26.00	35.50	32.00
Rock Cover	0.50	2.00	0.00	1.00	0.00	1.00	0.00	0.00
Bare Ground Cover	48.00	35.00	5.00	25.00	11.50	18.00	3.50	9.00
Total Ground Cover	52.00	65.00	95.00	75.00	88.50	82.00	96.50	91.00

The reference area had 51.00% absolute mean total vegetation cover and 75.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 25.00% and 24.00%, respectively (Table 3). Native full shrubs, composed of big sagebrush and greasewood (*Sarcobatus vermiculatus*), had the highest relative mean cover at 37.25%, followed by introduced annual grasses, composed of cheatgrass and Japanese brome, at 33.33%. Native half and/or sub-shrubs had 3.92% relative mean cover, and were equally composed of yucca and broom snakeweed (Table 4). A total of 11 lifeforms and 44 species were encountered within the reference area (Table 5). The mean number of species per species diversity belt transect was 33.5.

Based on non-statistical comparison, the reclaimed area had higher mean total vegetation cover, mean total ground cover, and mean litter/rock cover than the reference area. The reference area had higher mean bare ground cover than the reclaimed area. Native cool season perennial grasses were the dominant lifeform in the reclaimed area, while native full shrubs were the dominant lifeform in the reference area. The total number of species and species diversity was higher in the reference than in the reclaimed area. Based on statistical analysis, mean total vegetation cover and mean total ground cover in the reclaimed area were equal to or greater than mean total vegetation and mean total ground cover in the reference area (Table 6).

Table 4. Comparison of Lifeform Mean Percent Cover Values of Reclaimed and Reference Areas Sampled in August 2010.

Lifeform	Sample Site (Relative Mean % Cover Value)							
	Access Road		Well 13-14		Well 43-15		Well 44-15	
	Reclaimed	Reference	Reclaimed	Reference	Reclaimed	Reference	Reclaimed	Reference
Introduced Annual Grasses	2.60	–	6.02	7.84	4.46	1.82	7.38	3.39
Native Cool Season Perennial Grasses	70.13	22.00	90.23	33.33	91.96	30.91	92.62	32.20
Native Warm Season Perennial Grasses	2.60	2.00	–	1.96	–	3.64	–	3.39
Native Grasslike Species	–	–	–	3.92	–	3.64	–	1.69
Introduced Annual Forbs	9.09	–	–	1.96	–	–	–	–
Introduced Perennial Forbs	1.30	–	–	–	–	–	–	1.69
Native Perennial Forbs	–	16.00	2.26	9.80	0.89	5.45	–	1.69
Native Half and/or Sub-shrubs	7.79	18.00	0.75	3.92	2.68	7.27	–	1.69
Native Full Shrubs	6.49	40.00	0.75	37.25	–	47.27	–	54.24

Table 5. Comparison of Species Diversity for Reclaimed and Reference Sites Sampled in August 2010.

Lifeform	Sample Site (Mean Number of Species Encountered)							
	Access Road Reclaim	Access Road Reference	13-14 Reclaim	13-14 Reference	43-15 Reclaim	43-15 Reference	44-15 Reclaim	44-15 Reference
Introduced Annual Grasses	2	1	2	2	2	2	2	1
Native Cool Season Perennial Grasses	5	8	7	7	8	7	5	6
Introduced Perennial Grasses	–	–	–	–	2	–	1	–
Native Warm Season Perennial Grasses	1	3	–	3	–	2	–	1
Native Grasslike Species	–	1	–	1	1	1	–	1
Native Annual Forbs	1	–	1	–	–	1	–	1
Introduced Annual Forbs	8	1	2	2	2	2	2	2
Native Perennial Forbs	9	24	5	19	3	17	8	12
Introduced Perennial Forbs	1	–	1	1	1	1	–	2
Introduced Biennial Forbs	2	1	–	1	1	1	1	2
Native Full Shrubs	4	4	2	3	1	1	2	2
Native Half &Sub-Shrubs	4	4	1	4	1	2	4	1
Introduced Half &Sub-Shrubs	–	1	–	–	–	–	–	–
Native Succulents	–	1	–	1	–	1	–	1
Native Trees	–	1	–	–	–	–	–	–
Total	37	50	21	44	22	38	25	32

Table 6. One-tail two-sample t-test of classic null hypothesis results.

Sample Site	N_{min}	N_{max}	Mean (%)	Standard Deviation	Actual Sample #	Degrees of Freedom	Sp	sqrt (1/n1+1/n2)	Calculated t	Tabular t[1]
					Total Vegetation					
Acess Road	26.00	54.00	38.50	12.90	4.00	4.00	12.52	0.87	-1.06	-1.533
Acess Road Reference	42.00	58.00	50.00	11.31	2.00					
13-14	56.00	72.00	66.50	7.19	4.00	4.00	7.95	0.87	2.25	-1.533
13-14 Reference	44.00	58.00	51.00	9.90	2.00					
43-15	44.00	66.00	56.00	9.93	4.00	4.00	13.65	0.87	0.08	-1.533
43-15 Reference	40.00	70.00	55.00	21.21	2.00					
44-15	46.00	78.00	61.00	13.22	4.00	4.00	11.47	0.87	0.20	-1.533
44-15 Reference	58.00	60.00	59.00	1.41	2.00					
					Total Cover					
Acess Road	36.00	66.00	52.00	16.25	4.00	4.00	14.92	0.87	-1.01	-1.533
Acess Road Reference	58.00	72.00	65.00	9.90	2.00					
13-14	92.00	100.00	95.00	3.83	4.00	4.00	3.94	0.87	5.87	-1.533
13-14 Reference	72.00	78.00	75.00	4.24	2.00					
43-15	84.00	90.00	88.50	3.00	4.00	4.00	6.22	0.87	1.21	-1.533
43-15 Reference	74.00	90.00	82.00	11.31	2.00					
44-15	92.00	100.00	96.50	3.42	4.00	4.00	5.77	0.87	1.10	-1.533
44-15 Reference	84.00	98.00	91.00	9.90	2.00					

[1] Tabular t derived from Zar (1984) for a one tailed test of alpha 0.1.

Blue text indicates the null hypothesis (the mean of a given vegetation paremerter in the reclaimed area is equal to or greater than the mean of the same given vegetation parameter in the reference area) is accepted because the calculated t value (i.e., test statistic) is greater than the tabular t value (i.e., critical t value) (McDonald et al., 2003).

Well 43-15

The reclaimed well pad had 56.00% absolute mean total vegetation cover and 88.50% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 11.50% and 32.50%, respectively (Table 3). Native cool season perennial grasses, composed primarily of western wheatgrass and green needlegrass, had the highest relative mean cover at 91.96%, followed by introduced annual grasses, composed of cheatgrass and Japanese brome, at 4.46%. Native half and/or sub-shrubs, composed of winterfat (*Krascheninnikovia lanata*), and native full shrubs, composed of big sagebrush, had 0.89% and 2.68% relative mean cover, respectively (Table 4). A total of 10 lifeforms and 22 species were encountered within the reclaimed area (Table 5). The mean number of species per species diversity belt transect was 12.

The reference area had 55.00% absolute mean total vegetation cover and 82.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 18.00% and 27.00%, respectively (Table 3). Native full shrubs, composed of big sagebrush, had the highest relative mean cover at 47.27%, followed by native cool season perennial grasses, composed

primarily of green needlegrass and bluebunch wheatgrass (*Elymus spicatus*), at 30.91%. Native half and/or sub-shrubs had 7.27% relative mean cover, with winterfat being the only species observed (Table 4). A total of 12 lifeforms and 38 species were encountered within the reference area (Table 5). The mean number of species per species diversity belt transect was 28.5.

Based on non-statistical comparison, the reclaimed area had higher mean total vegetation cover, mean total ground cover and mean litter/rock cover than the reclaimed area. The reference area had higher mean bare ground cover than the reclaimed area. Native full shrubs were the dominant life form in the reference area, while native cool season perennial grasses were the dominant lifeform in the reclaimed area. Total number of species and species diversity were higher in the reference area than in the reclaimed area. Based on statistical analysis, mean total vegetation cover and mean total ground cover in the reclaimed area were equal to or greater than mean total vegetation and mean total ground cover in the reference area (Table 6).

Well 44-15

The reclaimed well pad had 61.00% absolute mean total vegetation cover and 96.50% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 3.50% and 35.50%, respectively (Table 3). Native cool season perennial grasses composed primarily of western wheatgrass and green needlegrass had the highest relative mean cover at 92.62%, followed by introduced annual grasses at 7.38% (Table 4). No shrubs were observed on the cover transect. A total of eight lifeforms and 25 species were encountered within the reclaimed area (Table 5). The mean number of species per species diversity belt transect was 12.5.

The reference area had 59.00% absolute mean total vegetation cover and 91.00% absolute mean total ground cover. Bare soil and litter/rock absolute mean cover values were 9.00% and 32.00%, respectively (Table 3). Native full shrubs, composed primarily of big sagebrush, had the highest relative mean cover at 54.24%, followed by native cool season perennial grasses, composed primarily of western wheatgrass and green needlegrass, at 32.20%. Native half and/or sub-shrubs had 1.69% relative mean cover, with winterfat being the only species observed (Table 4). A total of 12 lifeforms and 32 species were encountered within the reference area (Table 5). The mean number of species per species diversity belt transect was 23.5.

Based on non-statistical comparison, the reclaimed area had higher mean total vegetation cover, mean total ground cover, and mean litter/rock cover than the reference area. The reference area had higher mean bare ground cover than the reclaimed area. Native full shrubs were the dominant lifeform in the reference area, while native cool season perennial grasses were the dominant lifeform in the reclaimed area. Total number of species and species diversity was higher in the reference area than in the reclaimed area. Based on statistical analysis, mean total vegetation cover and mean total ground cover in the reclaimed area were equal to or greater than mean total vegetation and mean total ground cover in the reference area (Table 6).

Conclusion

Mean total vegetation cover ranged from 38.50% to 66.50% in the reclaimed areas and from 50.00% to 59.00% in the reference areas. Mean total ground cover ranged from 52.00% to 96.50% in the reclaimed areas and from 65.00% to 91.00% in the reference areas. Mean litter/rock cover ranged from 13.50% to 35.50% in the reclaimed areas and from 15.00% to 32.00% in the reference areas. Mean bare ground cover ranged from 3.50% to 48.00% in the reclaimed areas and from 9.00% to 35.00% in the reference areas. Non-statistical comparison of the mean cover values indicates the reclaimed areas and the reference areas are relatively similar, after a minimum of three growing seasons.

Statistical analysis indicates mean total vegetation cover and mean total ground cover of the reclaimed areas were equal to or greater than the respective reference area mean total vegetation cover and mean total ground cover, after a minimum of three growing seasons. Although sample size was low and the data may not be normally distributed with homogeneous variances, the t-test is for small sample values and is a robust test against effects of non-normality.

Based on NRCS ESD reference sheets, average bare ground is 40-60% for the Shallow Sandy ESD in the 10-14 inch (24.5-35.6 cm) Northern Plains precipitation zone (NRCS, 2008a). Since the BLM field office regulating the current site does not have specific reclamation success criteria at this time, the BLM reclamation and reporting guide for Fortification Creek which is near the current study site, was used. Under this guide, reclaimed sites with three or more growing seasons are required to be revegetated within 80% of the ESD reference sheet average bare ground range (BLM, 2010). For Shallow Sandy ESDs this equates to an allowable limit of 48-72% bare ground. Mean total bare ground for the access road reclaimed site (48.00%) was

within the average range and allowable limit for the Shallow Sandy. For the Loamy ESD in the 10-14 inch (24.5-35.6 cm) Northern Plains precipitation zone, average bare ground based on the ESD reference sheets is 20-30% (NRCS, 2008b) and the 80% allowable limit is 24-36%. Mean total bare ground was below the average range and the allowable limit for all reclaimed well pad sites sampled (3.50-11.50%) (Table 7).

Table 7. Comparison of Sampled, NRCS, and BLM Mean Bare Ground Cover Percentages.

Sample Site	Sampled Value	NRCS Reference Sheet (Average)	BLM 80% of NRCS Reference Sheet (Allowable)
		Shallow Sandy ESD	
Acess Road	48.00%	40-60%	48-72%
		Loamy ESD	
Well 13-14	5.00%	20-30%	24-36%
Well 43-15	11.50%	20-30%	24-36%
Well 44-15	3.50%	20-30%	24-36%

Native cool season perennial grasses were the dominant lifeform in the reclaimed areas and native full shrubs were the dominant lifeform in the reference areas. However, native cool season grasses were the second most dominant lifeform in the reference areas. A dominance of native cool season perennial grasses and decreased shrub density in comparison to the reference areas is expected in early reclamation. As reclamation progresses over time, cool season perennial grass cover is expected to decrease as shrub density increases. This is especially likely given the linear nature of the reclaimed areas.

Overall, species diversity was lower in reclaimed areas than in the reference areas. Species diversity in the reclaimed areas ranged from 12 to 20 species encountered and from 23.5 to 33.5 species encountered in the reference areas. Lifeforms found within the reference areas were similar to lifeforms encountered in the reference area, just not in the same proportion. There were typically more native perennial forb, warm season perennial grass, shrub, and succulent species encountered in the reference areas than in the reclaimed areas. This difference in species composition and diversity is expected in relatively new reclamation. In time, species composition and diversity should become similar as native species encroach into the reclamation

and native cool season perennial grass cover decreases, thereby reducing competition for native forb species.

Relative to BLM general success criteria guidelines (BLM, 2010) introduced annual grasses, composed of highly competitive invasive species, such as cheatgrass, were less than 5% on all reclaimed areas sampled. Canada thistle (*Cirsium arvense*) was the only state listed noxious weed observed and it was only observed at the reclaimed site for Well 43-15. No county-listed weeds were observed in either the reclaimed or reference sites. At least three native perennial grass species, including one bunchgrass, a minimum of three native forb species, and a minimum of two shrub species were present at each reclaimed site.

All sites had completed at least three growing season at the time of sampling and qualitative data indicated adequate soil stabilization and vegetation cover (i.e., properly re-contoured, sufficient ground cover to control erosion evidenced by no sheet or rill erosion, establishment of desired species, etc.). Non-statistical and statistical comparison between reclaimed and adjacent reference site mean cover data and comparison of reclaimed bare ground data to BLM ESD standards indicates all sites are trending toward final reclamation success. These indications imply reclamation success can be achieved on highly challenged landscapes considered to be a concern for reclamation success by federal land managers.

Acknowledgements

BKS Environmental Associates, Inc. (BKS) of Gillette, Wyoming would like to thank Lance Oil and Gas Company, a fully owned subsidiary of Anadarko Petroleum Corporation, of Gillette, Wyoming, for allowing BKS to conduct this study on their properties and all BKS staff members for their help in completing the field work and this document.

Literature Cited

Bureau of Land Management. 2010. Appendix A Fortification Creek planning area reclamation monitoring and reporting guide. Bureau of Land Management Buffalo Field Office, Buffalo, WY.

McDonald, L. et al. 2003. Evaluation and comparison of hypothesis testing techniques fo bond release applications. Abandoned Coal Mine Lands Research Program, University of Wyoming, Laramie, WY.

Natural Resource Conservation Service. 2008a. Ecological Site Description Shallow Sandy (SwSy) 10-14" Northern Plains Precipitation Zone. United States Department of Agriculture, Natural Resource Conservation Service, Washington, D.C.

Natural Resource Conservation Service. 2008b. Ecological Site Description Loamy (Ly) 10-14" Northern Plains Precipitation Zone. United States Department of Agriculture, Natural Resource Conservation Service, Washington, D.C.

Zar,J. 1999. Biostatistical analysis *4th Edition*. Prentice Hall, Upper Saddle River, New Jersey. 663 pp.