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FY97-99 Vegetation Analysis of ALCD Soil Amended Landfill Cover Plots

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Abstract

A large-scale field demonstration comparing final landfill cover designs has been constructed and is currently being monitored at Sandia National Laboratories in Albuquerque, New Mexico. Two conventional designs (a RCRA Subtitle 'D' Soil Cover and a RCRA Subtitle 'C' Compacted Clay Cover) were constructed side-by-side with four alternative cover test plots designed for dry environments. The demonstration is intended to evaluate the various cover designs based on their respective water balance performance, ease and reliability of construction, and cost. A portion of this project involves the characterization of vegetation establishment and growth on the landfill covers. The various prototype landfill covers are expected to have varying flux rates (Dwyer et al 2000). The landfill covers are further expected to influence vegetation establishment and growth, which may impact site erosion potential and long-term site integrity. Objectives of this phase are to quantify the types of plants occupying each site, the percentage of ground covered by these plants, the density (number of plants per

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unit area) of plants, and the plant biomass production. The results of this vegetation analysis are presented in this report.

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STUDY AREA AND METHODS

The general study site is located 10-km southeast of Albuquerque, NM nearly midway between the Rio Grande and the crest of the Manzano Mountains. The site exists on a nearly level to slightly rolling bench with an elevation of approximately 1,600 m. The vegetation consists of natural southwestern rangeland species dominated by blue grama *Bouteloua gracilis* (H.B.K.) Lag. ex Steud., black grama *B. eriopoda* (Torr.) Torr, sideoats grama *B. curtipendula* (Michx.) Torr., and sand dropseed *Sporobolus cryptandrus* (Torr.) Gray with a few interspersed forbs and an occasional fourwing saltbush *Atriplex canescens* (Pursh) Nutt. The study site consists of an area approximately 91.4 m by 135 m (300 ft x 443 ft) with the six landfill types, each measuring 12.2 m by 91.4 m (40 ft x 300 ft), superimposed on the site as illustrated in Figure 1.

The study area was built in two phases. Phase I construction was completed in August 1995 and was composed of the first three southern most landfill designs. Phase I consisted of landfill test covers named the RCRA Subtitle 'D' Cover, Geosynthetic Clay Layer (GCL) Cover, and RCRA Subtitle 'C' Cover. These 3 landfills were seeded in the wet, late summer of 1995. Phase II construction of landfills were completed in August 1996. They consisted of the Capillary Barrier, Anisotropic Barrier, and Evapotranspiration (ET) Cover. Phase II landfills were seeded in the dry, late summer of 1996. Landfill treatments on both Phase I and Phase II sites were seeded with a similar mixture of native plants, consisting of Indian ricegrass *Oryzopsis hymenoides*, galleta *Hilaria jamesii* (Torr.) Benth., sideoats grama, blue grama, sand dropseed, and fourwing saltbush.

Each landfill type was divided into two equal subplots (east and west subplots) measuring 12.2 m by 45.7 m (40 ft x 150 ft) as illustrated in the schematic in Figure 2. Sprinklers were installed on the east sides of each landfill to allow for stress testing. On each subplot four permanently marked 20 m (65.6 ft) transects were established for use during the annual characterization of vegetation. A 5 x 10 cm microplot was placed at 1-meter intervals along each transect as described by Pase (1981) to determine plant cover. Larger 50 x 100 cm plots were placed at 5, 10, and 15-m intervals along each transect to determine plant density as described by Pase (1981). Annual standing plant biomass was determined by centering a 10 x 88 square meters grid over each landfill type and numbering the 880 square meter cells consecutively, 10 per row, starting from zero at the northeast corner and terminating with 879 in the southwest corner. Ten random numbers, five between zero and 439 and five between 440 and 879 were selected as the square meter clip plots on each landfill type. The clip plots provided five estimates of standing biomass on the eastern portion and five on the western portion of each landfill. Clipped samples were placed in paper bags and oven dried at 60⁰ C for 48 hours before weighing. Figure 3 shows photographs of the plant cover, plant density and clipping grids used in the field. Plant cover and density were estimated at the end of the growing season (October 1 - November 30) annually between the years 1997 through 1999 while biomass was estimated only at the end of the 1999 growing season.



Figure 1. Photograph and schematic of the Alternative Landfill Cover Demonstration project.

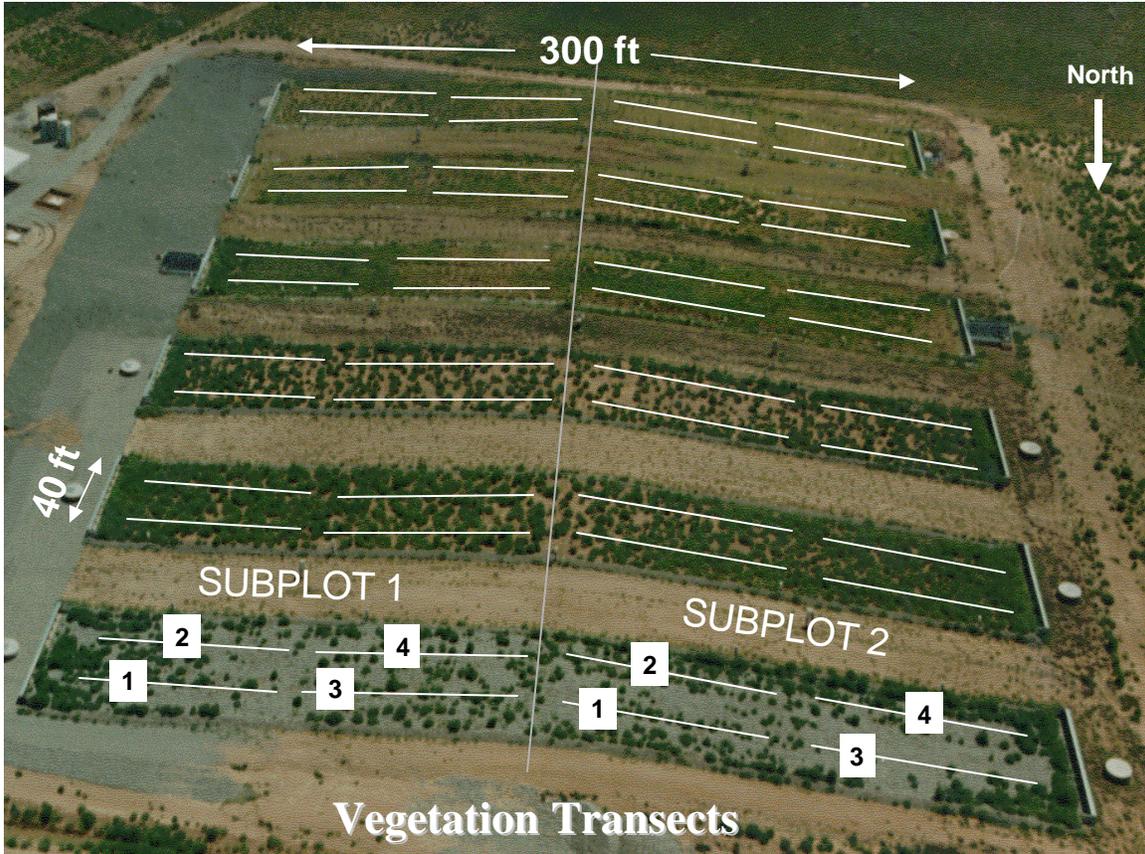


Figure 2. Schematic diagram of the vegetation transects used at the Alternative Landfill Cover Demonstration project.



Density count using 1 x 1 m grid



Vegetation clipping using 1 x 0.5 m grid



Species count using 10 x 5 cm grid

Figure 3. Photographs of grids used during vegetation counts and vegetation collections.

STATISTICAL ANALYSIS

Analysis of variance (ANOVA) as described by Steel and Torrie (1960) was used to make mean comparisons of eastern and western portions of each landfill treatment and pooled treatments within phases. Landfill comparisons and phases were compared by the t-test as described by Steel and Torrie (1960). All analyses were evaluated at $\alpha = 0.05$.

RESULTS

Fall 1997

Plant Cover: Precipitation during 1997 significantly enhanced grass and total plant cover on all Phase I landfill treatments in the fall of 1997. Grass cover averaged nearly 13% and 4% on the east versus the west plots on Phase I landfill covers (Table 1). Total plant cover averaged nearly 18% on east plots but only about 9% on the western portions of the landfill covers. Phase I landfill treatments showed RCRA Subtitle 'C' generally had greater grass, forb, and total plant cover than either the GCL or RCRA Subtitle 'D' treatments.

Phase II sites were completed in 1996 which was a relatively dry year for precipitation and has since, been followed by dry years. Western portions of the Phase II landfills averaged only 0.17% cover but significantly more than on the eastern portions. Weed, forb and shrub cover varied widely on both Phase I and Phase II sites and exhibited no consistent trend. No landfill cover differences were detected on Phase II treatments.

Plant Density: During fall 1997, grass density exhibited the same general trend in response to precipitation as plant cover. Grass density was greater on all Phase I east plots versus the western plots by averaging over twice as many plants per 0.5 m² area. Eastern plots averaged 14.5 while the western plots averaged 7.1 plants per 0.5 m² (Table 2). Weed, forb, and total plant density displayed a similar but less consistent trend as grass density on Phase I sites. RCRA Subtitle 'D' had the greatest total plant density primarily due to the thick stand of annual weeds. Plant density on RCRA Subtitle 'C', although similar to RCRA Subtitle 'D' plant density, consisted of a more uniform mix of grasses, weeds, and forbs.

Plant density was substantially greater on Phase I treatments than on Phase II treatments. On Phase II treatments, only weeds illustrated a consistent trend of more plants per unit area. West plots and east plots yielded 1.8 and 0.9 plants per 0.5 m², respectively, substantially less than on Phase I sites. Western Phase II plots, on the average, supported more grass, weeds, and total plant density than eastern plots, but Phase II plant density was generally less than 10% of that on Phase I sites.

Spring 1998

Plant Cover: In the spring of 1998, grass cover was enhanced by precipitation on both east and west plots on all Phase I treatments with cover ranging from 19.81% to 42.81% on the

eastern sides compared to 6.19% to 8.75% on the western portions of the landfill covers (Table 3). Weed cover was generally greater on the western plots than on eastern plots on all treatments except RCRA Subtitle 'D'. Across all Phase I sites, grass, forbs, and total plant cover was greater on eastern plots compared to western plots. Only total plant cover was influenced by landfill treatment in Phase I. GCL and RCRA Subtitle 'C' sites had greater total plant cover than RCRA Subtitle 'D', with grass and weeds providing the predominant amount of cover on all treatments.

No consistent trends due to precipitation were observed on Phase II sites. Weeds provided the majority of cover on all Phase II landfills. In areas where differences in total plant cover were detected, the differences were due to weed cover. Among landfill treatments, Anisotropic Barrier had greater weed and total plant cover than either Capillary Barrier or ET Cover treatment, but again the differences were due primarily to the high proportion of weedy cover.

Plant Density: In the spring of 1998 grass, weed, forb, shrub, and total plant density was greater on GCL and within all landfill treatments on the east portions of landfills as opposed to the western portions. However, grass and forb densities were greater on all Phase I east plots than on western plots. Weeds were the dominant vegetation within all Phase I landfill treatments. Weed density ranged from 28.7 to 32.9 plants per 0.5 m² (Table 4). Among Phase I landfill treatments, grass density was greatest on RCRA Subtitle 'C' while weeds were in greater density on RCRA Subtitle 'D', although not substantially greater than on GCL.

Plant density was considerably lower on all Phase II sites than on Phase I sites. Weed and total plant density were generally greater on the western portions than on eastern portions of landfill covers while forb density, although low, was greater on the eastern plots. Anisotropic Barrier and ET Cover landfill treatments had similar but greater total plant density than the Capillary Barrier. The Anisotropic Barrier and ET Cover plant densities were 8.8 to 9.4 plants per 0.5 m² respectively, compared to 4.8 plants per 0.5 m² on the Capillary Barrier treatment. Grasses and forbs were the predominant vegetation types on ET Cover while weeds predominated on the Anisotropic Barrier treatment.

Fall 1998

Plant Cover: When vegetation was sampled in fall 1998, grasses were the predominant cover type on Phase I eastern plots while weeds predominated the western portions of landfill covers. Within treatments, grass cover averaged 37% on east plots compared to about 16% on Phase I western plots while weed cover averaged 14% and about 4% on east versus west sides of landfill covers (Table 5). Within Phase I landfill treatments, forbs were the only vegetation type to respond to landfill treatment and they were a very minor component of total plant cover.

Weed cover on Phase II landfill covers was greatest on the western plot of the Anisotropic Barrier landfill cover. Within landfill treatments, eastern plots showed greater grass, forb, and total plant cover. Plant cover responses to precipitation were variable among landfill types.

Grass and forb cover was greatest on the Anisotropic Barrier but weed and total plant cover was by far greater on ET Cover.

Plant Density: In the fall of 1998, eastern plots showed enhanced grass density and the western plots showed increased weed and total plant density on all Phase I landfill treatments. Forbs and shrubs responded inconsistently to precipitation. Within landfill treatments, grass density averaged nearly two times greater on eastern plots (9.3 versus 5.6 plants per 0.5 m²), forbs were three times greater, and shrubs two times greater on all Phase I eastern plots (Table 6). However, weeds were over 15 times greater on Phase I western plots while weeds strongly influenced the total plant density. Grass was the only vegetative type that responded to precipitation among landfill treatments. Grass density averaged 10.5 plants per unit area on RCRA Subtitle 'C' but only about 5 per unit area on RCRA Subtitle 'D' and GCL landfill treatments.

On Phase II sites, plant density response was variable and inconsistent to first growing season precipitation. On the landfill types that did show a response in the fall of 1998, western plots generally had the greatest density for all classes of vegetation. Among landfill treatments, Anisotropic Barrier supported the greatest grass, weed, forb, and total plant density. Total plant density averaged 139, 63, and 28 plants per 0.5 m² on Anisotropic Barrier, ET Cover, and Capillary Barrier, respectively.

Fall 1999

Plant Cover: Periodic precipitation during the first growing season influenced plant basal cover only on the GCL landfill (Table 7). Grass cover (5.74%) and total plant cover (6.77%) was substantially greater on the eastern GCL landfill plot compared to the western portion (1.97% and 3.97% respectively). Forbs, provided more cover on the western than eastern portions of GCL landfill. Eastern portions of landfill covers contained approximately 7.79% grass and 8.66% total plant cover compared to western portions of Phase I landfills which had 3.97% and 5.25% respectively. Within treatments, weed cover on Phase I sites, was greater on the western portions (0.79%) than on eastern portions (0.18 %). Among landfill treatments, the only difference observed was in forb cover, which was greater on the GCL landfill (0.45%) than either the RCRA Subtitle 'D' or RCRA Subtitle 'C' landfills (0.03% and 0.08% respectively).

Perennial grass was the dominate vegetation type on Phase I landfills providing approximately 85% of the relative plant cover. Weeds, shrubs, and forbs produced only 7%, 6%, and 2% of the relative cover, respectively.

There was a significant landfill treatment influence on weed and total plant cover for pooled Phase II landfill treatments. ET Cover had significantly more weed (10.97%) and total plant cover (12.71%) than either of the other Phase II landfill treatments. Capillary Barrier treatment had the least weed (3.30%) and the least total plant cover percentage (3.38%) of all Phase II landfill treatments.

Annual weeds were the dominate vegetation cover type on Phase II landfills producing approximately 88% of the relative cover. Grasses provided approximately 11% of the relative plant cover and forbs only provided about 1% of the relative plant cover. Woody shrubs were not detected on Phase II landfill treatments at the end of the 1999 growing season.

Plant Density: When Phase I treatments were pooled, the western portions of landfills supported a more dense stand of annual weeds than the eastern portions (10.2 versus 1.3 plants per 0.5 m², respectively) (Table 8). Total plant density was also greater on western plots than the east plots due to the thick stand of weeds. Perennial grass density was influenced by Phase I landfill treatments with the greatest grass density on RCRA Subtitle 'C' site (7.5 per 0.5 m²), least grass density on GCL site (3.7 plants per 0.5 m²), and intermediate density on RCRA Subtitle 'D' site (4.8 plants per 0.5 m²).

Relative plant density was evenly shared by predominately perennial grasses and annual weeds with 44% with 47% respectively, on Phase I landfill treatments. Relative density of perennial forbs and woody shrubs was 7% and 2%, respectively on Phase I landfill treatments. On Phase II landfill treatments, the eastern plots increased the density of perennial grass only on the Anisotropic Barrier landfill with 3.4 plants per 0.5 m² compared to only 0.2 plants per 0.5 m² on the western plots.

Phase II landfill treatments significantly influenced plant density. For example, ET Cover treatment had more weeds, forbs, and total plants per unit area than Capillary Barrier landfill. Weed and total plant density was similar on ET Cover and Anisotropic landfill treatments.

Annual weeds were by far the most abundant plant form on Phase II landfills. Relative density of annual weeds was 95%; perennial grasses contributed 3% and forbs 2%. Woody shrubs were not detected on Phase II landfill sites.

Biomass: Plant biomass on the Phase I GCL landfill eastern plots was 228.3 gms/m², compared to 91.3 gms/m² on the west plots (Table 9). The plant biomass on other Phase I landfill covers was similar.

Biomass on the Phase II eastern plots were inconsistent. Also, biomass was inconsistent between the east and western plots on Phase II landfill covers. The Capillary Barrier eastern plot biomass was less than the western plots of the Anisotropic Barrier and ET Cover landfills. Among Phase II landfills, biomass was greatest on the ET Cover treatment with 192.6 gms/m² but biomass was equal and substantially less on the Capillary Barrier and Anisotropic Barrier landfill treatments with about 63 gms/m².

Photographs were taken in fall 1999 of each landfill cover (Figure 4). Various vegetation types that were noted in fall 1999 on the different landfill covers are shown in Figure 5.

1 - RCRA Subtitle D



2 - GCL



3 - RCRA Subtitle C



4 - Capillary Barrier



5 - Anisotropic Barrier



6 - Evapotranspiration



Figure 4. Photographs of vegetative cover on each landfill cover design.

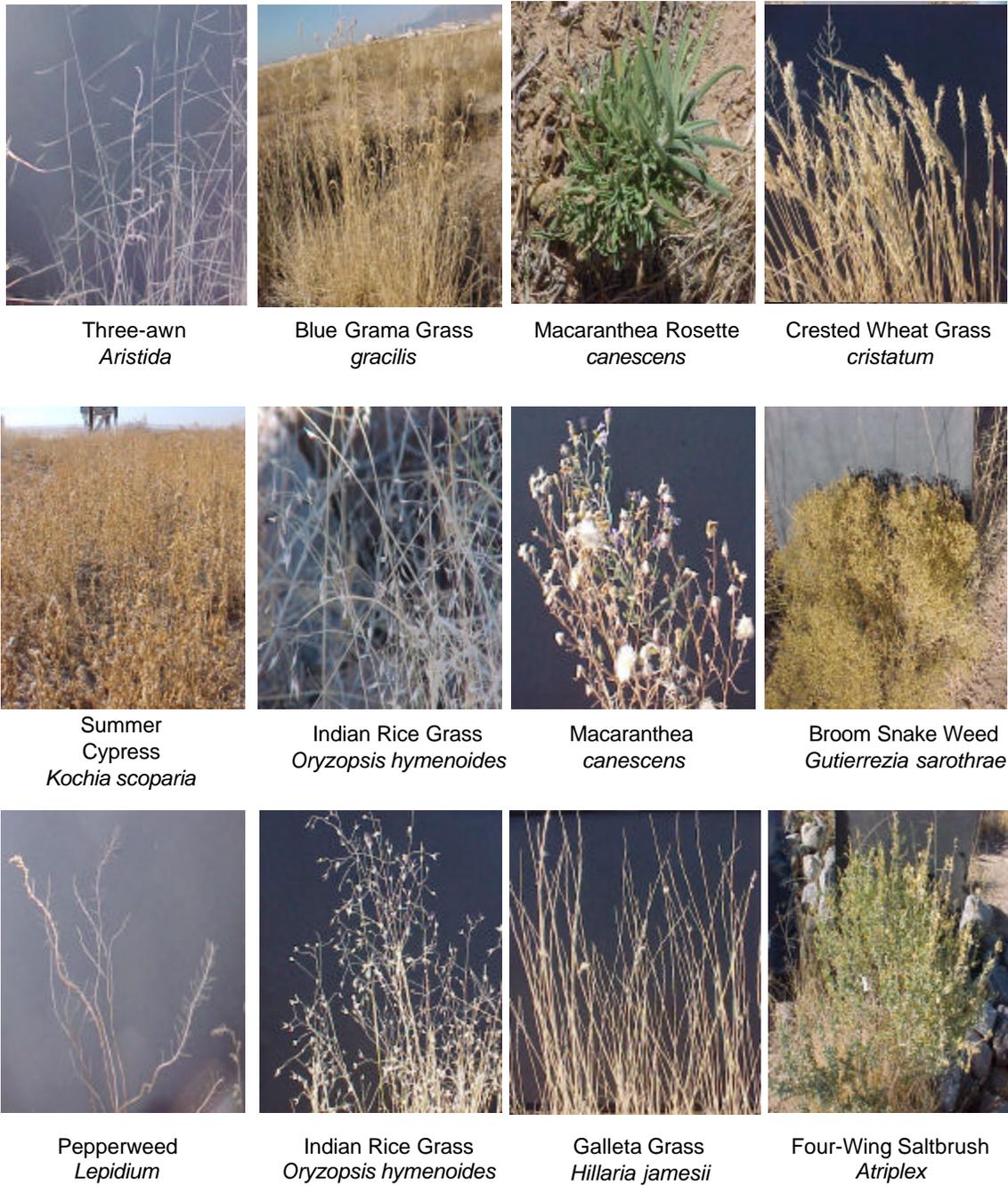


Figure 5. Landfill cover vegetation types.

GENERAL DISCUSSION AND OBSERVATIONS

Although cover, density, and biomass differences between Phase I and Phase II landfill treatments were not tested, it appears the seeded grasses and shrubs were better established on Phase I treatments than Phase II treatments. This was a result of several things with the major difference being amount of precipitation following construction of the two phases. This directly effected the interacting factors of soil moisture conditions and the growth season of seeded plants. The seed mixture consisted primarily of cool and warm weather plants. The warm season plants germinate and establish best when seeded early in the growing season. Also, the soil moisture conditions were much more conducive to seed germination and growth during the Phase I wet spring conditions than during the dryer Phase II summer conditions.

Vegetative cover consisted primarily of grass, while weeds occurred in greater number during all sampling periods on Phase I landfill treatments. The native sand dropseed and lesser amounts of sideoats grama and galleta dominated Phase I landfills at each sampling period although the native shrub, fourwing saltbush, and native forb, hoary aster *Machaeranthera canescens*, were widely scattered over the landfills. Introduced annual weeds, fireweed and Russian thistle, dominated vegetative cover and density on Phase II landfills throughout the study. The native perennial vegetation dominating Phase I landfills would be expected to provide more inherent site stability (i.e. less erosion) than the predominant annual plant vegetation dominating Phase II landfills. The slightly greater biomass production on Phase I compared to Phase II landfills also tends to support similar though less apparent conclusions.

Vegetative cover and plant vigor appeared to increase towards the toe of all landfills, perhaps a response to increased soil moisture from up slope runoff (approximately 5% slope to center of landfill). Pedicilate perennial plants were observed up slope on all Phase I landfills and an accumulation of fine soil particles were observed at the toe of all landfills, except the ET Cover (cobble mulch) treatment, indicating some surface erosion has occurred on all landfills except the cobble mulch treatment.

Table 1. Vegetation cover in the fall of 1998.

Landfill Type/Treatment	Vegetation Type				
	grass	weed	forb	shrub	total
	percent				
Phase I					
RCRA Subtitle D					
East Plot	8.38a ¹	3.00	0.06b	0.00	11.44a
West Plot	3.68b	3.69	0.25a	0.00	7.62b
<i>Mean</i>	<i>6.03b</i> ²	<i>3.34</i>	<i>0.16b</i>	<i>0.00</i>	<i>9.53b</i>
GCL					
East Plot	10.31a	3.38	0.56	1.13a	15.38a
West Plot	0.63b	2.69	1.13	0.00b	4.45b
<i>Mean</i>	<i>5.47b</i>	<i>3.03</i>	<i>0.84ab</i>	<i>0.56</i>	<i>9.90b</i>
RCRA Subtitle C					
East Plot	20.00a	2.19b	3.93a	0.38a	26.50a
West Plot	7.19b	6.69a	1.13b	0.00b	15.01b
<i>Mean</i>	<i>13.59a</i>	<i>4.44</i>	<i>2.53a</i>	<i>0.19</i>	<i>20.75a</i>
<i>Mean East Plot</i>	<i>12.89a</i>	<i>2.85b</i>	<i>1.52</i>	<i>0.50a</i>	<i>17.76a</i>
<i>Mean West Plot</i>	<i>3.83b</i>	<i>4.35a</i>	<i>0.83</i>	<i>0.00b</i>	<i>9.01b</i>
Phase II					
Capillary Barrier					
East Subplot	0.00b	0.06a	0.00	0.00	0.06
West Subplot	0.06a	0.00b	0.00	0.00	0.06
<i>Mean</i>	<i>0.03</i>	<i>0.03</i>	<i>0.00</i>	<i>0.00</i>	<i>0.06</i>
Anisotropic Barrier					
East Plot	0.00b	0.00	0.31a	0.00	0.31
West Plot	0.19a	0.00	0.00b	0.00	0.19
<i>Mean</i>	<i>0.09</i>	<i>0.00</i>	<i>0.16</i>	<i>0.00</i>	<i>0.25</i>
ET Cover					
East Plot	0.00b	0.06b	0.19a	0.00	0.25b
West Plot	0.25a	1.75a	0.00b	0.00	2.00a
<i>Mean</i>	<i>0.13</i>	<i>0.91</i>	<i>0.09</i>	<i>0.00</i>	<i>1.13</i>
<i>Mean East Plot</i>	<i>0.00b</i>	<i>0.04b</i>	<i>0.16a</i>	<i>0.00</i>	<i>0.20b</i>
<i>Mean West Plot</i>	<i>0.17a</i>	<i>0.58a</i>	<i>0.00b</i>	<i>0.00</i>	<i>0.75a</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 2. Plant density in the fall of 1999.

Landfill Type/Treatment	Vegetation Type				total
	grass	weed	forb	shrub	
plant density per 50 x 100 cm plot					
Phase I					
RCRA Subtitle D					
East Plot	8.9a ¹	81.4	0.2	0.0	90.5
West Plot	3.9b	76.5	0.3	0.0	80.7
<i>Mean</i>	<i>6.4b</i> ²	<i>79.9a</i>	<i>0.3b</i>	<i>0.0</i>	<i>85.6a</i>
GCL					
East Plot	13.6a	44.6a	1.1a	0.1	59.4a
West Plot	3.9b	23.7b	0.5b	0.1	28.2b
<i>Mean</i>	<i>8.7b</i>	<i>34.1b</i>	<i>0.8ab</i>	<i>0.1</i>	<i>43.7b</i>
RCRA Subtitle C					
East Plot	21.1a	39.9	2.2a	0.1a	63.3a
West Plot	13.6b	36.3	0.5b	0.0b	50.4b
<i>Mean</i>	<i>17.3a</i>	<i>38.1b</i>	<i>1.3a</i>	<i>0.0</i>	<i>56.7ab</i>
<i>Mean East Plot</i>	<i>14.5a</i>	<i>55.3a</i>	<i>1.2a</i>	<i>0.0</i>	<i>71.0a</i>
<i>Mean West Plot</i>	<i>7.1b</i>	<i>45.5b</i>	<i>0.4b</i>	<i>0.0</i>	<i>53.1b</i>
Phase II					
Capillary Barrier					
East Plot	1.3a	0.9b	0.1a	0.0	2.3b
West Plot	5.1b	1.5a	0.0b	0.0	6.6a
<i>Mean</i>	<i>3.2</i>	<i>1.2</i>	<i>0.1b</i>	<i>0.0</i>	<i>4.5</i>
Anisotropic Barrier					
East Plot	3.8	0.9b	0.1	0.0	4.8
West Plot	3.8	2.4a	0.1	0.0	6.3
<i>Mean</i>	<i>3.8</i>	<i>1.6</i>	<i>0.1b</i>	<i>0.0</i>	<i>5.5</i>
ET Cover					
East Plot	2.8	0.8b	1.0a	0.0	4.6
West Plot	2.0	1.6a	0.1b	0.0	3.7
<i>Mean</i>	<i>2.4</i>	<i>1.2</i>	<i>0.6a</i>	<i>0.0</i>	<i>4.2</i>
<i>Mean East Plot</i>	<i>2.6b</i>	<i>0.9b</i>	<i>0.4a</i>	<i>0.0</i>	<i>3.9b</i>
<i>Mean West Plot</i>	<i>3.7a</i>	<i>1.8a</i>	<i>0.1b</i>	<i>0.0</i>	<i>5.6a</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 3. Vegetation cover in the spring of 1998.

Landfill Type/Treatment	Vegetation Type				
	grass	weed	forb	shrub	total
percent cover					
Phase I					
RCRA Subtitle D					
East Plot	19.81a ¹	15.56	0.19	0.00	35.56a
West Plot	6.19b	21.00	0.19	0.00	7.38b
<i>Mean</i>	<i>13.00</i>	<i>18.28</i>	<i>0.19</i>	<i>0.00</i>	<i>31.47b²</i>
GCL					
East Plot	28.94a	18.13b	1.00a	0.00	48.07
West Plot	8.31b	39.88a	0.00b	0.00	48.19
<i>Mean</i>	<i>18.63</i>	<i>29.00</i>	<i>0.50</i>	<i>0.00</i>	<i>48.13a</i>
RCRA Subtitle C					
East Plot	42.81a	17.69b	0.00	0.00	60.50a
West Plot	8.75b	34.56a	0.00	0.00	43.31b
<i>Mean</i>	<i>25.78</i>	<i>26.13</i>	<i>0.00</i>	<i>0.00</i>	<i>51.91a</i>
<i>Mean East Plot</i>	<i>30.52a</i>	<i>17.13b</i>	<i>0.39a</i>	<i>0.00</i>	<i>48.04a</i>
<i>Mean West Plot</i>	<i>7.75b</i>	<i>31.81a</i>	<i>0.06b</i>	<i>0.00</i>	<i>39.62b</i>
Phase II					
Capillary Barrier					
East Plot	0.94a	23.69b	0.00b	0.00	24.63b
West Plot	0.06b	32.56a	0.31a	0.00	32.93a
<i>Mean</i>	<i>0.50</i>	<i>28.13b</i>	<i>0.15ab</i>	<i>0.00</i>	<i>28.78b</i>
Anisotropic Barrier					
East Plot	3.50	51.75	0.00	0.00	55.25a
West Plot	1.69	47.31	0.00	0.00	49.00b
<i>Mean</i>	<i>2.59</i>	<i>49.53a</i>	<i>0.00b</i>	<i>0.00</i>	<i>52.12a</i>
ET Cover					
East Plot	1.13b	30.13	1.25	0.00	32.51
West Plot	2.25a	30.69	0.75	0.00	33.69
<i>Mean</i>	<i>1.69</i>	<i>30.41b</i>	<i>1.00a</i>	<i>0.00</i>	<i>33.10b</i>
<i>Mean East Plot</i>	<i>1.95</i>	<i>35.19</i>	<i>0.42</i>	<i>0.00</i>	<i>37.46</i>
<i>Mean West Plot</i>	<i>0.33</i>	<i>36.85</i>	<i>0.35</i>	<i>0.00</i>	<i>38.54</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

²Different small case italic letters indicate significant differences ($P < 0.05$) between treatments.

Table 4. Plant density in the spring of 1998.

Landfill Type/Treatment	Vegetation Type				total
	grass	weed	forb	shrub	
plant density per 50 x 100 cm plot					
Phase I					
RCRA Subtitle D					
East Plot	9.6a ¹	45.0	0.1a	0.0	54.7
West Plot	5.4b	38.3	0.0b	0.0	43.7
<i>Mean</i>	<i>7.5b²</i>	<i>41.7a</i>	<i>0.1</i>	<i>0.0</i>	<i>49.3</i>
GCL					
East Plot	10.9a	31.1a	0.3a	0.2a	42.5a
West Plot	3.4b	21.6b	0.0b	0.0b	25.0b
<i>Mean</i>	<i>7.1b</i>	<i>26.3ab</i>	<i>0.2</i>	<i>0.1</i>	<i>33.7</i>
RCRA Subtitle C					
East Plot	14.9a	22.6	0.2a	0.1a	37.8
West Plot	11.7b	26.2	0.0b	0.0b	37.9
<i>Mean</i>	<i>13.3a</i>	<i>24.4b</i>	<i>0.1</i>	<i>0.1</i>	<i>37.9</i>
<i>Mean East Plot</i>	<i>11.8a</i>	<i>32.9</i>	<i>0.2a</i>	<i>0.1a</i>	<i>45.0a</i>
<i>Mean West Plot</i>	<i>6.8b</i>	<i>28.7</i>	<i>0.0b</i>	<i>0.0b</i>	<i>35.5b</i>
Phase II					
Capillary Barrier					
East Plot	1.5b	2.9	0.1	0.1a	4.6
West Plot	2.1a	2.8	0.1	0.0b	5.0
<i>Mean</i>	<i>1.8b</i>	<i>2.8b</i>	<i>0.1ab</i>	<i>0.1</i>	<i>4.8b</i>
Anisotropic Barrier					
East Plot	4.7a	4.3b	0.0b	0.0	9.0
West Plot	1.9b	6.7a	0.1a	0.0	8.7
<i>Mean</i>	<i>3.3b</i>	<i>5.5a</i>	<i>0.0b</i>	<i>0.0</i>	<i>8.8a</i>
ET Cover					
East Plot	5.7b	1.6b	0.5a	0.0	7.8b
West Plot	8.1a	2.9a	0.1b	0.0	11.1a
<i>Mean</i>	<i>6.9a</i>	<i>2.2b</i>	<i>0.3a</i>	<i>0.0</i>	<i>9.4a</i>
<i>Mean East Plot</i>	<i>4.0</i>	<i>2.9b</i>	<i>0.2a</i>	<i>0.0</i>	<i>7.1b</i>
<i>Mean West Plot</i>	<i>4.0</i>	<i>4.1a</i>	<i>0.1b</i>	<i>0.0</i>	<i>8.2a</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 5. Vegetation cover in the fall of 1998.

Landfill Type/Treatment	Vegetation Type				
	grass	weed	forb	shrub	total
percent cover					
Phase I					
RCRA Subtitle D					
East Plot	29.81a ¹	5.38b	0.01a	1.25b	36.45
West Plot	13.38b	12.95a	0.00b	4.75a	31.08
<i>Mean</i>	<i>21.59</i>	<i>9.16</i>	<i>0.00b²</i>	<i>3.00</i>	<i>33.75</i>
GCL					
East Plot	32.25a	2.13b	1.75	0.31a	36.44a
West Plot	11.69b	21.00a	1.25	0.06b	34.00b
<i>Mean</i>	<i>23.47</i>	<i>11.56</i>	<i>1.50a</i>	<i>0.19</i>	<i>36.72</i>
RCRA Subtitle C					
East Plot	46.31a	3.19b	0.75	1.58	51.83a
West Plot	22.75b	8.06a	0.50	1.25	32.56b
<i>Mean</i>	<i>34.53</i>	<i>5.63</i>	<i>0.63b</i>	<i>1.41</i>	<i>42.20</i>
<i>Mean East Plot</i>	<i>37.13a</i>	<i>3.56b</i>	<i>0.84</i>	<i>1.05</i>	<i>42.58a</i>
<i>Mean West Plot</i>	<i>15.94b</i>	<i>14.00a</i>	<i>0.58</i>	<i>2.02</i>	<i>32.54b</i>
Phase II					
Capillary Barrier					
East Plot	0.00	23.35a	0.19a	0.00	22.51a
West Plot	0.00	16.25b	0.00b	0.00	16.25b
<i>Mean</i>	<i>0.01b</i>	<i>19.30c</i>	<i>0.09b</i>	<i>0.00</i>	<i>19.38c</i>
Anisotropic Barrier					
East Plot	6.69a	29.06b	2.94a	0.00	38.69
West Plot	1.56b	37.13a	0.75b	0.00	39.44
<i>Mean</i>	<i>4.13a</i>	<i>33.09b</i>	<i>1.84a</i>	<i>0.00</i>	<i>39.07b</i>
ET Cover					
East Plot	2.69a	66.13a	0.09	0.00	68.91a
West Plot	0.94b	54.75b	0.00	0.00	55.69b
<i>Mean</i>	<i>1.81ab</i>	<i>60.44a</i>	<i>0.06b</i>	<i>0.00</i>	<i>62.31a</i>
<i>Mean East Plot</i>	<i>3.13a</i>	<i>39.18</i>	<i>1.08a</i>	<i>0.00</i>	<i>43.39a</i>
<i>Mean West Plot</i>	<i>0.83b</i>	<i>36.04</i>	<i>0.25b</i>	<i>0.00</i>	<i>37.12b</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 6. Plant density in the fall of 1998.

Landfill Type/Treatment	Vegetation Type				
	grass	weed	forb	shrub	total
plant density per 50 x 100 cm plot					
Phase I					
RCRA Subtitle D					
East Plot	6.6a ¹	12.8b	0.9	0.0b	20.3b
West Plot	4.8b	72.4a	0.6	0.1a	77.9a
<i>Mean</i>	<i>5.7b²</i>	<i>42.6</i>	<i>0.7</i>	<i>0.1</i>	<i>49.1</i>
GCL					
East Plot	8.6a	0.1b	3.9a	0.2a	12.8b
West Plot	3.7b	76.4a	0.9b	0.1b	81.1a
<i>Mean</i>	<i>6.1b</i>	<i>38.2</i>	<i>2.4</i>	<i>0.1</i>	<i>46.8</i>
RCRA Subtitle C					
East Plot	12.6a	0.1b	2.6a	0.5a	15.8b
West Plot	8.5b	65.4a	0.6b	0.1b	74.6a
<i>Mean</i>	<i>10.5a</i>	<i>32.8</i>	<i>1.6</i>	<i>0.3</i>	<i>45.2</i>
<i>Mean East Plot</i>	<i>9.3a</i>	<i>4.3b</i>	<i>2.4a</i>	<i>0.2a</i>	<i>16.2b</i>
<i>Mean West Plot</i>	<i>5.6b</i>	<i>71.4a</i>	<i>0.7b</i>	<i>0.1b</i>	<i>77.8a</i>
Phase II					
Capillary Barrier					
East Plot	0.1b	24.9	0.1b	0.0	25.1
West Plot	0.4a	30.7	0.2a	0.0	31.3
<i>Mean</i>	<i>0.3b</i>	<i>27.8c</i>	<i>0.1b</i>	<i>0.0</i>	<i>28.2b</i>
Anisotropic Barrier					
East Plot	2.3	123.1b	1.7a	0.0	127.1b
West Plot	1.7	149.9a	0.2b	0.0	151.8a
<i>Mean</i>	<i>2.0a</i>	<i>136.5a</i>	<i>0.9a</i>	<i>0.0</i>	<i>139.4a</i>
ET Cover					
East Plot	1.7	56.8	0.1b	0.0	58.6
West Plot	1.1	66.4	0.3a	0.0	67.8
<i>Mean</i>	<i>1.4a</i>	<i>61.6b</i>	<i>0.2b</i>	<i>0.0</i>	<i>63.2b</i>
<i>Mean East Plot</i>	<i>1.4</i>	<i>68.3</i>	<i>0.6a</i>	<i>0.0</i>	<i>70.3</i>
<i>Mean West Plot</i>	<i>1.1</i>	<i>82.3</i>	<i>0.2b</i>	<i>0.0</i>	<i>83.6</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 7. Vegetation cover in the fall of 1999.

Landfill Type/Treatment	Vegetation Type					total
	grass	weed	forb	shrub	percent cover	
Phase I						
RCRA Subtitle D						
East Plot	8.72	0.13	0.03	0.66		9.54
West Plot	3.38	0.59	0.03	0.53		4.53
<i>Mean</i>	6.05	0.36	0.03 <i>b</i> ²	0.59		7.03
GCL						
East Plot	5.74a ¹	0.09	0.19b	0.75		6.77a
West Plot	1.97b	1.15	0.72a	0.13		3.97b
<i>Mean</i>	3.85	0.62	0.45a	0.44		5.36
RCRA Subtitle C						
East Plot	8.91	0.28	0.09	0.38		9.66
West Plot	6.56	0.63	0.06	0.00		7.25
<i>Mean</i>	7.74	0.45	0.08b	0.19		8.46
<i>Mean East Plot</i>	7.79a	0.18b	0.10	0.59		8.66a
<i>Mean West Plot</i>	3.97b	0.79a	0.27	0.22		5.25b
Phase II						
Capillary Barrier						
East Plot	0.03	2.59	0.13	0.00		2.75
West Plot	0.00	4.00	0.00	0.00		4.00
<i>Mean</i>	0.02	3.30c	0.06	0.00		3.38c
Anisotropic Barrier						
East Plot	1.62	5.74	0.03	0.00		7.39
West Plot	0.06	5.94	0.31	0.00		6.31
<i>Mean</i>	0.84	5.84b	0.17	0.00		6.85b
ET Cover						
East Plot	0.66	11.63	0.09	0.00		12.38
West Plot	2.56	10.31	0.16	0.00		13.03
<i>Mean</i>	1.61	10.97a	0.13	0.00		12.71a
<i>Mean East Plot</i>	0.77	6.65	0.08	0.00		7.50
<i>Mean West Plot</i>	0.87	6.75	0.16	0.00		7.78

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 8. Plant density in the fall of 1999.

Landfill Type/Treatment	Vegetation Type				
	grass	weed	forb	shrub	total
plant density per 50 x 100 cm plot					
Phase I					
RCRA Subtitle D					
East Plot	6.0	0.0	0.0	0.2	6.2
West Plot	3.7	9.9	0.1	0.3	14.0
<i>Mean</i>	<i>4.7ab²</i>	<i>5.0</i>	<i>0.0</i>	<i>0.2</i>	<i>10.0</i>
GCL					
East Plot	5.2	2.5	1.6	0.3	9.6
West Plot	2.2	12.2	1.0	0.0	15.4
<i>Mean</i>	<i>3.7b</i>	<i>7.3</i>	<i>1.3</i>	<i>0.2</i>	<i>12.5</i>
RCRA Subtitle C					
East Plot	7.1	1.4	1.0	0.4	9.9
West Plot	7.8	8.6	1.7	0.1	18.2
<i>Mean</i>	<i>7.5a</i>	<i>5.0</i>	<i>1.3</i>	<i>0.3</i>	<i>14.1</i>
<i>Mean East Plot</i>	<i>6.1</i>	<i>1.3b¹</i>	<i>0.8</i>	<i>0.3</i>	<i>8.5b</i>
<i>Mean West Plot</i>	<i>4.6</i>	<i>10.2a</i>	<i>0.9</i>	<i>0.1</i>	<i>15.8a</i>
Phase II					
Capillary Barrier					
East Plot	0.3	9.0	0.1	0.0	9.4
West Plot	0.0	9.7	0.0	0.0	9.7
<i>Mean</i>	<i>0.2</i>	<i>9.3b</i>	<i>0.0b</i>	<i>0.0</i>	<i>9.5b</i>
Anisotropic Barrier					
East Plot	3.4a	54.7	1.4	0.0	59.5
West Plot	0.2b	73.4	1.2	0.0	74.8
<i>Mean</i>	<i>1.8</i>	<i>64.1a</i>	<i>1.3a</i>	<i>0.0</i>	<i>66.7a</i>
ET Cover					
East Plot	0.9	58.0	0.8	0.0	59.7
West Plot	3.5	40.4	0.7	0.0	44.6
<i>Mean</i>	<i>2.2</i>	<i>49.2a</i>	<i>0.8ab</i>	<i>0.0</i>	<i>52.1a</i>
<i>Mean East Plot</i>	<i>1.5</i>	<i>40.6</i>	<i>0.7</i>	<i>0.0</i>	<i>42.8</i>
<i>Mean West Plot</i>	<i>1.2</i>	<i>41.2</i>	<i>0.6</i>	<i>0.0</i>	<i>43.0</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 9. Annual biomass in the fall of 1999.

Landfill Type	East Plots	Treatment		
		West Plots	Average	
gms/m ²				
Phase I				
RCRA Subtitle D		121.5	91.7	106.6
GCL		228.3a ¹	91.3b	159.8
RCRA Subtitle C		159.6	119.7	139.6
	<i>Mean Phase I</i>	<i>169.8a</i>	<i>100.9b</i>	<i>135.3</i>
Phase II				
Capillary Barrier		79.3a	43.2b	61.3b ²
Anisotropic Barrier		60.5b	68.4a	64.5b
ET Cover		174.5b	210.8a	192.6a
	<i>Mean Phase II</i>	<i>104.8</i>	<i>107.5</i>	<i>106.1</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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