Sustainable Solutions

Spring Design Report 2017

Hannah Blankenship | Amethyst Kelly | Christian Ley | Katie Schlotthauer

Prepared for:

City of Enid Municipal Landfill

Oklahoma Department of Environmental Quality

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Introduction

In August 2016, the Oklahoma Department of Environmental Quality (ODEQ) approached the Biosystems and Agricultural Engineering (BAE) Department at Oklahoma State University with a design project at the City of Enid (COE) Municipal Landfill. Four senior design students partnered to form Sustainable Solutions, responding to the opportunity to aid the COE landfill with its current erosion problem. Erosion concerns on the north-facing slope include scarce vegetative growth, sediment deposition at the base of the slope, rill formation, potential trash exposure, and contamination of the on-site stormwater pond.

The COE composting program operates on the premises of the landfill. Therefore, yard waste compost and woodchips are available for use as soil amendments. A stormwater detention pond nearby could also potentially be utilized for irrigation. If on-site resources are successfully utilized to quell the erosion concerns, a similar cost effective design could be applied at other erosion-prone sites across the state.

Some current low-cost solutions on existing landfills around the state have been ineffective in solving the erosion problem long-term. Previously at the COE landfill, sections of the north-facing slope have been hydroseeded with an alternative daily cover (ADC) machine, covered with woodchips, then sprigged and seeded. Another landfill erosion control method employed in Oklahoma includes layering straw and topsoil on the slopes. Many solutions succeed for a short time but eventually fail, and the erosion problem persists. Therefore, more sustainable designs using local, cost effective resources must be implemented in order to prevent detrimental impacts to the environment.

Mission Statement

Designing green solutions for soil and water related problems.

Problem Statement

Research erosion prevention strategies that are applicable to Oklahoma landfills, and recommend a comprehensive design solution to mitigate erosion on the north-facing slope of the City of Enid Municipal Landfill. Figure 1 below depicts the current problem slope.

Figure 1: North-facing problem slope

Customer Requirements

The project requirements provided by the Oklahoma Department of Environmental Quality are as follows:

- Develop a solution that reduces erosion by covering all bare soil surfaces with vegetation
- Determine the feasibility of using on-site resources like compost and woodchips
- Organize erosion control method and product research as a reference for other landfills

Project Scope

Sustainable Solutions designed a menu containing effective strategies to reduce erosion on landfill slopes. The menu contains solutions organized by severity of the erosion problem, anticipated cost, and longevity of solution. For the COE recommendation, the feasibility of using local resources such as soil, compost, woodchips, leachate, biosolids, and stormwater was determined through research and testing. Different erosion control designs were evaluated with computer modeling, and an on-site experiment was implemented on the north-facing landfill slope to determine the most promising solution.

Deliverables

COE Recommendation

The COE comprehensive design recommendation was presented in a final presentation and report to COE representatives on May 4, 2017.

Design Solution Menu

Applicable erosion control products and methods were presented in the form of a menu to ODEQ representatives on May 4, 2017. Solutions were judged on the following criteria: severity and type of erosion, longevity, and cost.

The design solutions were first organized by the severity and type of erosion, which determines how intensive the mitigation practice must be. The design solutions were next divided by their expected effectiveness over time. The design solutions were further organized by comparative anticipated cost of installation and maintenance. Total cost can vary widely depending on the project site and timeline, and landfills will need to consult manufacturers for specific estimates that include resource expenses such as equipment, expertise, manpower, and maintenance costs related to additional applications, professional assistance, or monitoring.

Research

Product and Material Analyses

During the Fall Semester, Sustainable Solutions researched several erosion control strategies (see *Product Analysis* in Appendix K). Almost all solutions either increase the nutrient level of the soil, slow the velocity of runoff and encourage sedimentation, or both. Feasible solutions for COE's landfill slope were determined and modeled based on their availability on RUSLE2. Based on the computer modeling results and research findings, Sustainable Solutions chose five solutions to test on-site at the COE landfill.

Plot 1 - Compost Blanket

The compost blanket was chosen as a viable solution to mitigate erosion for several reasons. In order to conserve resources and reduce costs, the on-site compost was applied to the plot to enhance soil cohesion. The compost can fill in rills or erosion prone areas to protect it, preventing channelized flow and splash erosion. It improves the soil structure and nutrient levels to encourage vegetation to establish. The use of a compost blanket is an especially attractive solution due to its absorbent properties, as compost may be able to increase sorption during rainfall events.

Plot 2 - Control

As in a true science experiment, Sustainable Solutions chose to establish a control plot. The control plot was identical to the other test plots. It was seeded the same amount as the other plots and otherwise left alone in order to establish a reference for measuring the soil loss and vegetative cover of the other plots.

Plot 3 & Plot 4 - Manufactured and Homemade Compost Socks

Sustainable Solutions chose to test compost socks on-site because they are a simple and proven erosion control solution. Compost socks slow the velocity of water similar to wattles, but they also contain a nutrient-rich growing medium that can encourage vegetative growth. If cover establishes on the socks, they can form small permanent terraces and prevent erosion for many years.

Compost socks use large amounts of an available on-site material, and they are already utilized in Oklahoma. Both manufactured compost socks and homemade compost socks were tested because of the difference in nutrient availability of the composts. The feasibility and cost effectiveness of using landfill employees to stuff the homemade socks in the future was also considered.

Plot 5 - Homemade Wattles

Wattles were chosen as a potentially successful design solution based on computer modeling and recommendations from literature. The RUSLE2 software showed wattles have a low soil loss value when compared to other design solutions. Many references included wattles as an effective method for reducing erosion. Wattles slow the movement of water down the slope as well as catch the dislodged sediment from upslope before it is displaced further down the slope.

Homemade wattles were utilized in our experiment to take advantage of an available on-site material and potentially lower the overall cost. The COE landfill has a large supply of wood chips that could be incorporated into wattles sustainably as landfill operations continue. The only other materials necessary for constructing wattles are netting and stakes to secure the finished wattles on the slope.

Plot 6 - Biosolids and Woodchips

Biosolids and woodchips were chosen as viable materials because they exist on-site. Since wastewater sludge is already disposed of on the landfill, the COE could properly compost or stabilize the material in the future and apply it as a fertilizer when needed. Biosolids are a fertilizer that contain macro and micro nutrients essential for grass growth (Sullivan et al., 2007). Biosolids can be stabilized with lime in order to meet EPA pathogen reduction guidelines (EPA, 1993). The addition of lime can also aid in creating soil structure that restricts further water erosion. Lime was not added to the biosolids because the Class A composted biosolids acquired for the experiment had already been properly stabilized.

A study done by Cogliastro et al. (2001) proved that combining woodchips with biosolids created the most beneficial results (see *In-Situ Fertilizer Application* section of Appendix K). The woodchips reduce the mineralization rate of the biosolids to increase the longevity of the nutrient release. It is also possible that the woodchips reduce the water velocity flowing downhill to further aid in reducing erosion.

Design

Erosion Modeling Software

Overview

RUSLE2 is a computer modeling software that estimates total soil loss with the Universal Soil Loss Equation (USLE). The mathematical equations and technical advice in the model are based on conservation of mass and USLE principles.

The USLE is written in the form:

$$A = RKLSCP \qquad [1]$$

Where:

A = net detachment (mass/unit area)

R = erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = supporting practices factor

The model accounts for both rill and interrill erosion associated with rainfall and flow (USDA, 2008). Rill and interrill erosion are affected by four main factors: climate, soil, topography, and land use. The combination of these four factors are used to compute the expected degree of erosion. Users are not required to collect physical data related to plant yield, canopy cover, surface roughness, mechanical soil disturbance, and amount of biomass; these factors are built into the model's database. However, users can customize the model using site-specific variables such as rainfall, slope, soil type, etc. (USDA, 2008). The program can be used to model any location where soil may be impacted by rainfall and surface runoff, including construction sites and landfills. Erosion effects are further quantified by considering climate, soil, topography, and land use factors. Climate variables vary by region, and include temperature, precipitation, and erosivity factors. The model addresses variations in topography by accounting for slope length, steepness, and slope. Land use factors are the most important factor affecting erosion, due to the fact that erosion can easily be mitigated by altering the land use conditions (USDA, 2008).

Using survey data from the Enid Landfill, the RUSLE2 model was run using a slope length of 150 feet and a grade of 25%. The RUSLE2 modeling software was used to predict which erosion mitigation strategies would be most effective for the prevention of erosion in the Enid Landfill. In order to develop a preliminary design implementation strategy, the following design solutions were modeled using the Revised Universal Soil Loss Equation 2 (RUSLE2) software: vegetative cover, compost socks, silt fence, various sizes of wattles and bare ground as a control.

Modeling Procedures

The RUSLE2 model was used to predict which erosion mitigation strategies would be most effective at the COE Landfill. Sustainable Solutions input the slope characteristics of the COE north-facing slope and the soil conditions of the new borrow pit soil. Solutions that were available to model include bare ground, mulch berm, Bermuda grass coverage, high quality cool-season grass coverage, medium quality cool-season grass coverage, poor quality cool-season grass coverage, and Kentucky Bluegrass coverage. Several different iterations of compost sock, wattle, and silt fence solutions were also modeled with varying diameters and placements on the slope. Each test yielded a value for sediment delivery, soil loss, and event runoff, which Sustainable Solutions used to compare the effectiveness of solutions. The results of the computer modeling can be found on page 29. Figure 2 below displays an example screenshot of the modeling software.

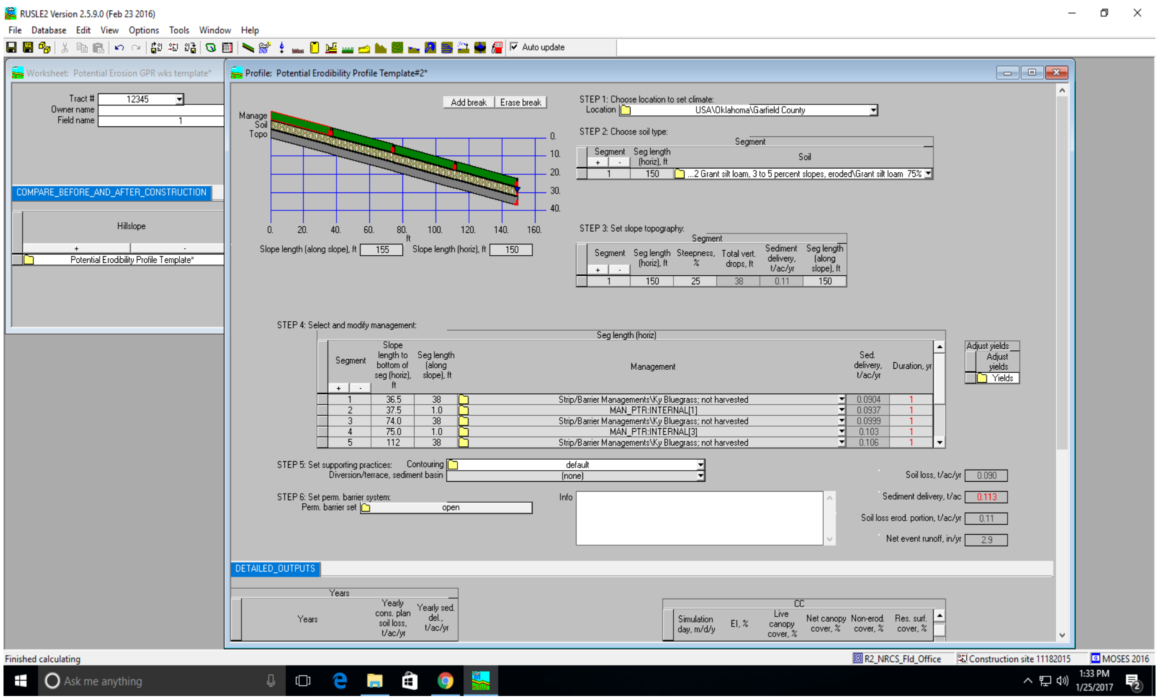

Figure 2: Example screenshot of RUSLE2 computer modeling

On-Site Testing Design and Procedure

Due to the unique soil and slope characteristics of the COE landfill, Sustainable Solutions decided to test erosion solutions on-site. Subjecting the solutions to the variable precipitation patterns of Oklahoma spring provided the most site-accurate results. Solutions were implemented on March 3, 2017, and testing concluded after six weeks on April 14, 2017.

Plot Selection

During the winter intercession, the COE regraded the entire north-facing slope, removing pre-existing vegetative cover, filling in most rills, and further compacting the soil and layer of woodchips. With so much cleared space available, the original plot sizes were increased to a width of 10 feet and length of 40 feet. Thus, each plot was 400 sq feet and the total seeded area was 2400 sq feet. There were 2 feet spaces between each plot to provide clear boundaries between each erosion control solution and vegetative coverage.

The plots were located near the top of the slope and to the east. Sustainable Solutions chose to locate the plots near the top to decrease runoff velocity and trap sediment before it reached mid-slope. Vegetative cover is better established at the base of the slope where sediment is usually deposited. Solutions were installed at the top of the slope to encourage sediment deposition before reaching the base and also to decrease the momentum gained by runoff allowed to flow down the entire length of the slope. Figure 3 shows an illustration of plot placement on the slope. The entire length of the slope is approximately 320 feet. The top of the plots were 90 feet from the top of the slope and base of the plots were 190 feet from the base of the slope.

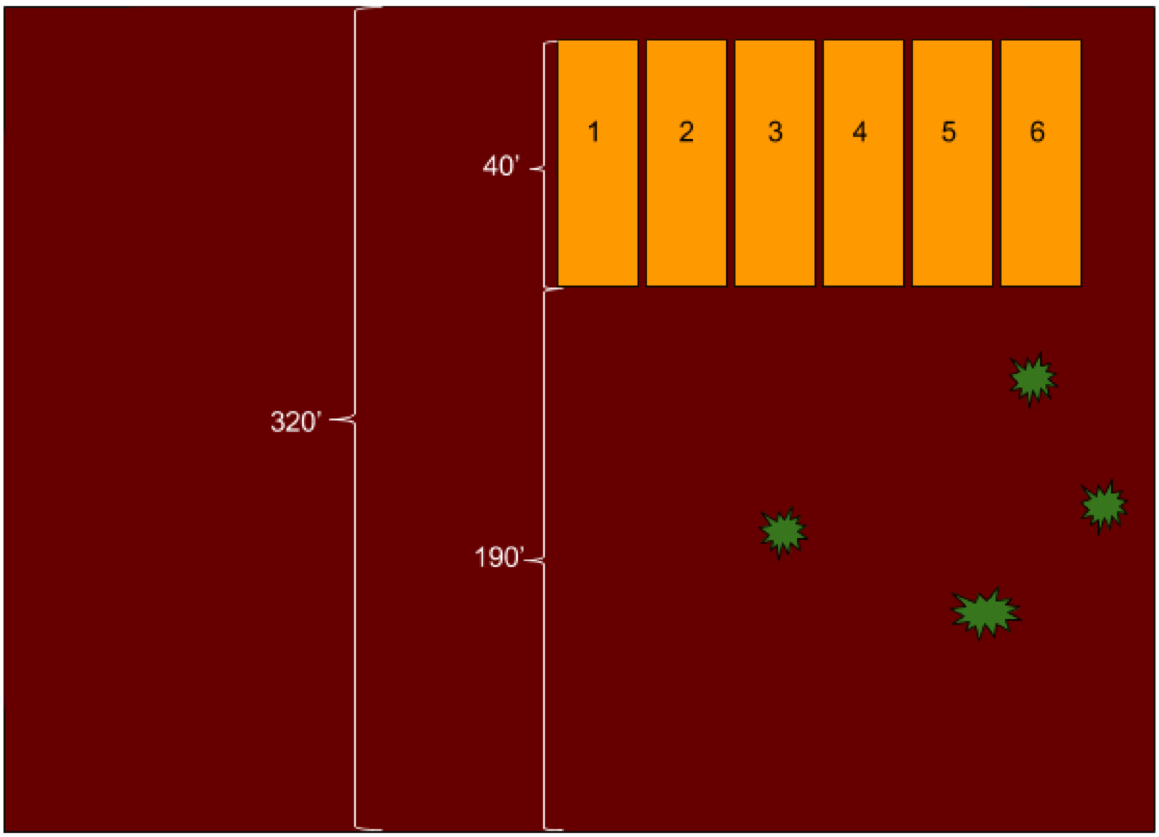

Figure 3: Illustration of plot placement on slope

Seeding

Sustainable Solutions drew on the expertise of Johnston Seed Company to choose a seed mix for the experiment. Vegetation suited for a landfill slope must be resilient, able to withstand drought conditions and tolerate poor quality soils. The timeline of the project also impacted the varieties chosen because we had to plant in early March.

Previously, the COE Landfill has seeded the slope with annual ryegrass, which thrives in the spring rains, pushing out competitors, and then shrivels in the drought of summer. Johnston Seed Company took a shotgun approach, recommending a seed mix of many varieties that will provide both short-term and long-term cover (Figure 4). The mix has been effective at establishing cover on landfill slopes in El Reno, OK and Chickasha, OK. Appendix G includes a more detailed summary of the seed mix composition and Appendix H includes several USDA plant fact sheets for the chosen varieties.

JOHNSTON
SEED COMPANY
319 West Chestnut
Enid, OK 73702
800-375-4613

VENDORS STATEMENT OF ANALYSIS

NATIVE GRASS MIXTURE

KIND	VARIETY	PURITY	GERMATION	TEST
Alfalfa	Not Stated	16.57	92.0+02.0=94.0	09/16
Bermudagrass	Not Stated	13.61	85.0+00.0=85.0	09/16
Blue Grama	Not Stated	04.31	31.0+52.0=83.0	09/16
Green Sprangletop	Not Stated	05.53	97.0+00.0=97.0	01/17
Fescue	KY 31	21.11	95.0+00.0=95.0	08/16
Little Bluestem	Not Stated	06.48	64.0+30.0=94.0	09/16
Sideoats	El Reno	08.16	84.0+08.0=92.0	10/16
Sweetclover	Yellow	16.66	90.0+02.0=92.0	07/16

INERT MATTER: 05.55 WEED SEED: 00.27 OTHER CROP: 01.75

NOXIOUS: None — ORIGIN: OK,CO,Canada,KS

LOT # G-9431 — NET WEIGHT: 9 LBS

Figure 4: Johnston Seed Co. seed mix tag

Johnston Seed Company donated 9 lbs of the seed mix, which was divided evenly into six buckets. Seed was hand scattered evenly across each plot, except Plot 6 where seed was incorporated into the biosolids and woodchips mixture.

Irrigation

In the past, the slope has not been irrigated over time, but the seed has been mixed with water at the time of planting at a rate of 4 gallons of seed to 900 gallons of water. At the time the on-site testing began, the water truck was out of commission. Therefore, plots were not watered at the time of planting. The on-site experiment was dependent on natural rainfall. Sustainable Solutions was not able to improvise an irrigation solution due to time constraints, but the on-site stormwater runoff pond could be used as an irrigation source in the future.

Material Transport

For simplicity in the field, a 5-gallon bucket was used to measure volume. Buckets of woodchips, compost, and soil were counted and loaded into a front end loader in order to be driven up the slope to the plots. Sustainable Solutions used two trucks from the BAE Lab and a front-end loader with a bucket capacity of 81 cubic feet to install all the test solutions.

Soil Loss Quantification

Sustainable Solutions wanted to quantify the amount of soil loss on each plot. Erosion pins were used to evaluate soil loss from the surface of the slope according to the method outlined in the erosion study conducted by Ghimire et al (Ghimire, 2013). Galvanized 8.5” aluminum stakes were inserted into the slope in a 2 x 4 grid pattern (Figure 5). The flat heads of the stakes were inserted to be level with the soil surface. The soil loss was measured at each stake using a small metric ruler. Data was collected three times during testing: week one, week three, and week six.

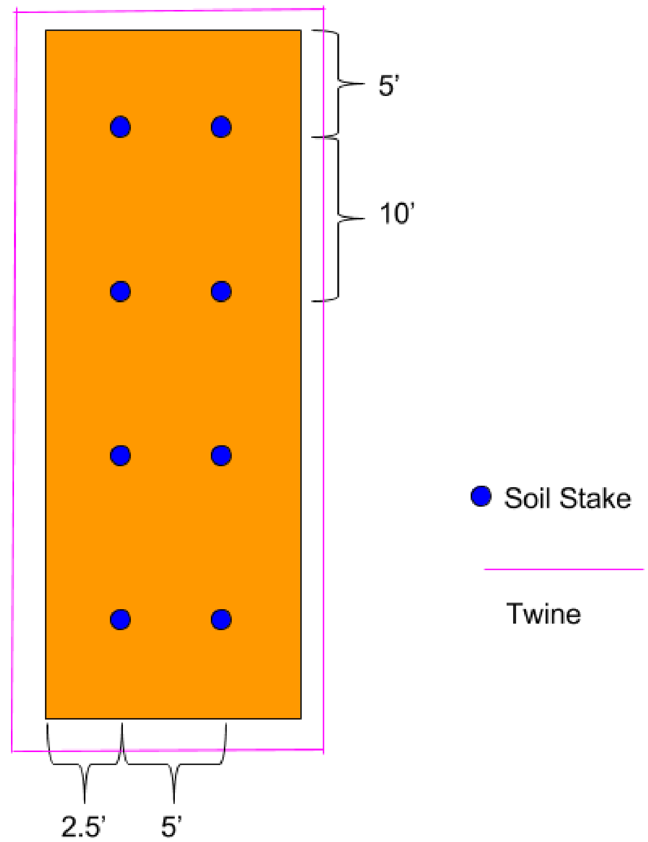

Figure 5: Illustration of soil stake placement

Vegetative Cover

Sustainable Solutions wanted to quantify the surface area coverage of grass on each plot. Vegetative cover results were reported as a percentage of total canopy cover across the entire plot. This gives an estimate of surface area covered by grass. At the conclusion of six weeks of testing, two photographs were taken of each plot. One photograph depicted the top half of the plot and one depicted the bottom half of the plot. The images were cropped to include only the area within the plot. Each image was imported into Adobe Photoshop to analyze the red, green, blue (RGB) values. The resulting histogram showed the total number of green pixels and the total number of pixels in the photograph. The numbers for the two pictures per plot were added together and used to calculate a percentage of green. This percentage would give the best estimate for the total amount of canopy coverage per plot.

Project Schedule

- March 3, 2017- Implement solutions on each test plot
- March 10, 2017 - Week 1 Data Collection
- March 24, 2017 - Week 3 Data Collection and Halfway point
- April 14, 2017 - Week 6 Data Collection and Clean up

A more detailed project schedule can be found in Appendix A.

Plot 1 - Compost Blanket

The plot was thoroughly seeded, and then COE on-site compost was raked onto the surface. Compost was applied at a thickness of 1.5 inches (135 to 270 cubic yards per acre) in order to cover 100% of the land surface area of the plot (USDA, 2014). No soil was visible in or through the compost blanket.

Plastic erosion control netting was applied over the entire compost blanket, and the netting was pinned into the slope using 4 inch galvanized garden staples. The netting stretched 5 feet over the plot edges to keep runoff from undercutting the blanket. See Figure 6 for the illustration and Figure 7 for an image of the completed installation.

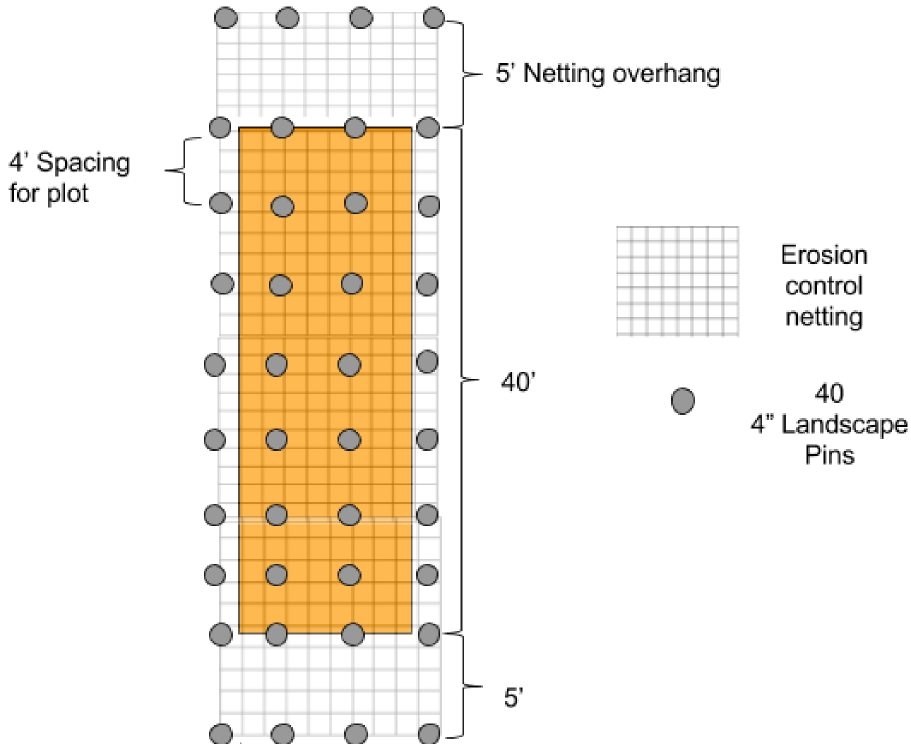

Figure 6: Illustration of compost blanket installation specifications

Figure 7: Image of installed compost blanket plot

Plot 2 - Control

The control plot was seeded and staked in the same manner as each of the test plots but otherwise left undisturbed. Figure 8 below depicts the control plot. Here the rough soil and pre-existing woodchips can be clearly seen.

Figure 8: Image of control plot

Plot 3 - Manufactured Compost Sock

The manufactured compost socks and netting were provided by Minick Materials in Oklahoma City, Oklahoma. The socks had an 8 inch diameter and were able to handle effective flow heights of 6 in. The socks are typically sold in 40 feet lengths and staked every 10 feet along the length. This industry standard was employed on our plots. Socks were sectioned into 10 feet lengths to fit the width of the plot and staked at both ends. 24 inch square wooden stakes were driven through the socks, approximately 1 feet into the slope.

The same netting was used for the manufactured and homemade compost socks, but the compost inside was different. Manufactured compost socks contained compost from Minick Materials, while homemade compost socks were filled with compost from the COE on-site compost pile at the landfill. Nutrient differences in the composts are displayed in Table 1.

Table 1: Comparison of Minick Materials' compost and Enid's compost

Property	Recommended Value	Minick Compost	Enid Compost
Moisture (%)	35 < x < 55	37.56	23.3
pH	6 < x < 8	7.6	8.3
Total N (%)	-	0.83	1.26
Phosphorous as P2O5 (%)	-	0.28	0.42
Potassium as K2O (%)	-	0.48	0.96
Total C (%)	-	19.59	10.06

Vertical spacing of the compost socks were determined by using RUSLE2 computer modeling. During the modeling phase it was found that placing the compost socks at 10 feet intervals gave the best results. Therefore, the first sock was placed perpendicular to the slope at the top of the plot at 0 feet. The second, third, and fourth socks were placed at 10 feet, 20 feet, and 30 feet below the top of the plot, respectively. Then, the ends of each compost sock were staked into the ground, driving approximately 1 feet of the wood stake into the ground. Figure 9 illustrates the installation specifications, while Figure 10 is an image of the installed compost socks.

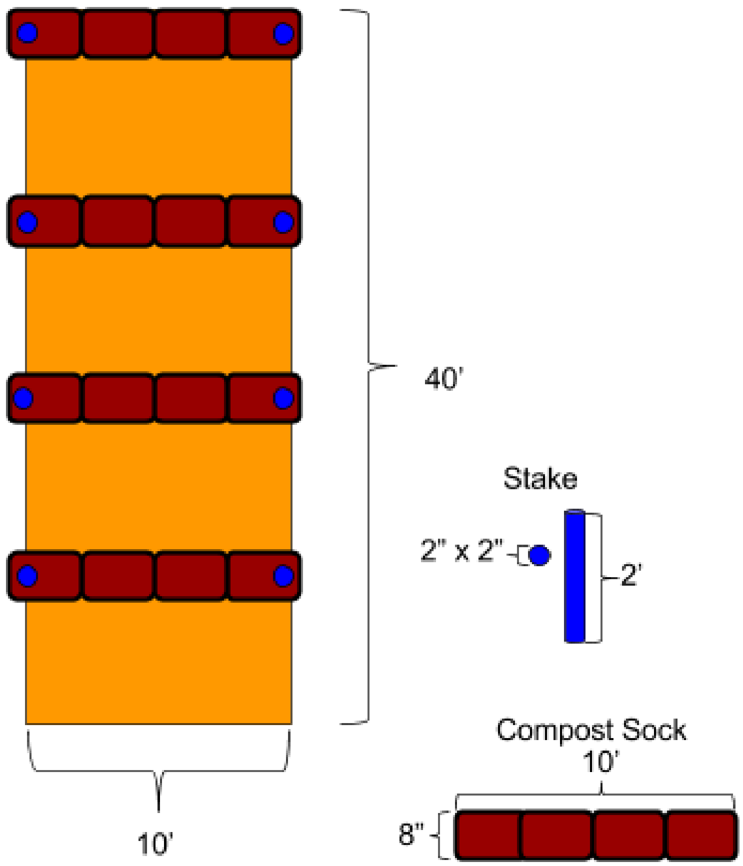

Figure 9: Illustration of compost sock installation specifications

Figure 10: Image of installed manufactured compost sock plot

Plot 4 - Homemade Compost Sock

This plot followed the same procedures, except on-site compost was used to fill the socks. First, the compost socks were filled with on-site compost. One end of each sock was secured and a pipe was inserted into the sock to assist with filling. Compost was shoveled into the pipe until it was full. The netting was shifted down the pipe and filled again. This process continued until the entire sock was full. The loose end was tied off and the socks were moved up the slope. The compost socks were placed perpendicular to the slope at 0 feet, 10 feet, 20 feet, and 30 feet from the top of the plot. Then the end of each compost sock staked with the 24 inch wooden stakes. Refer to Figure 9 above for the illustration of the compost sock installation specifications. See Figure 11 below for an image of the installed homemade compost socks.

Figure 11: Image of installed homemade compost sock plot

Plot 5 - Wattles

The wattle netting was provided by ASP Enterprises in Wichita, Kansas. The RUSLE2 simulation was conducted with four wattles placed perpendicularly on the slope 10feet apart. The on-site tests were meant to mimic the RUSLE2 set up as closely as possible, but the design was modified to utilize the 20 feet donated by ASP Enterprises. The 6 inch wattles were assembled on-site. The netting was cut into two 10 feet long pieces and then secured on one end with zip ties. The netting was then stretched around a pipe to keep the netting open while filling. The netting was slowly pushed off the pipe as it was filled. This process continued until the wattle was full and the remaining end was secured. This made the wattle shorter than intended. The wattle was short about 6 inch on each side after it was placed in the middle of the plot. The wattles were placed perpendicularly along the slope, 13.3 feet apart starting 13.3 feet from the top of the plot, as can be seen in Figure 12. The wattles were also originally going to be staked through the center, but were instead staked at an angle, roughly two feet apart, from either side due to the wood chips larger size. The installed wattles can be observed in Figure 13.

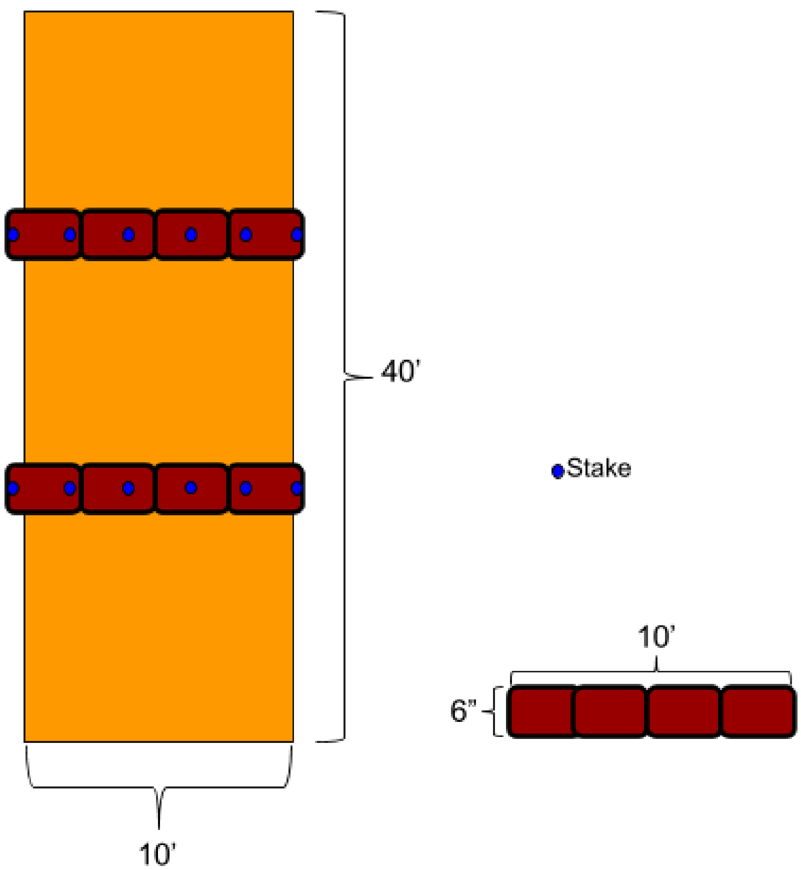

Figure 12: Illustration of wattle installation specifications

Figure 13: Image of installed wattle plot

Plot 6 - Woodchips & Biosolids

Johnston Seed Company recommended a 60-75 lb nitrogen/acre fertilizer application to establish grass growth. The nitrogen requirement for each 400 sq. feet plot is therefore 0.69 lb N/plot based on 75 lb N/acre. Biosolids application was based solely upon nitrogen content; therefore a total of 0.69 lb of N from the biosolids was targeted.

Class A biosolids (compost) were acquired from the Midwest City Water Resources Recovery Facility. The OSU Soil, Water and Forage Analytical Laboratory (SWFAL) results provided at the facility gave a total nitrogen content of 34.0 lbs/ton dry basis (See Appendix F for the SWFAL report).

$$lbs\ of\ biosolids = \frac{75\ lb\ N}{acre} * \frac{0.01\ acre}{plot} * \frac{dry\ ton}{34.0\ lb\ N} * \frac{2000\ lb}{ton} => \ 44\ lb$$

An approximate mineralization rate of 36% was assumed (Sullivan et. Al., 2007). Therefore, a total of 60 lb of Class A biosolids were required for the plot.

The amount of on-site wood chips added to the mixture was based on the study performed by Cogliastro et. al. (2001). See *In-Situ Fertilizer Application* section of Appendix K for more information about the use of woodchips with biosolids. They suggested using 200m^3/hectare. However, the compost provided by Midwest City contained a high (and unknown) proportion of woodchiped yard waste, so we divided in half the amount of recommended wood chips added to the plot.

$$gallons\ woodchips = \frac{200\ m^3}{ha} * \frac{ha}{2.47\ acres} * \frac{264.2\ gal}{m^3} * \frac{0.01\ acre}{plot} * \frac{1}{2} => 107\ gallons$$

Twenty-five gallons of native soil were added to the biosolids mixture to give substance for the grass germination. Since the slope soil was not tilled or loosened, this soil was added to give any supplementary nutrients and structure for the biosolids to cling to. The amount added was not based on any official standards.

The berm-like structure was designed to hold a large amount of woodchips behind it. Two foot wooden stakes were driven into the ground at about 1 feet depth. They were placed at 2 feet intervals at the base of the plot to stretch the length of the plot; 2 feet were added to each end of the wall to catch any potential excess runoff. Excess garden netting was cut into 2 feet x 10 feet sections. The netting was secured in a vertical position 1 feet high by folding the netting in half and zip tying at the top and bottom of the stake to create a wall.

First, 5 5-gallon buckets full of on-site soil and 60 lb of dry biosolids compost were mixed together in the front end loader bucket. Then 21 5-gallon buckets full of wood chips were evenly raked onto the plot. The plot was seeded by hand and then the soil mixture was raked evenly across the surface. Three rolls of 4′ x 50′ netting was cut to length, matching the plot dimensions, and secured using 4″ garden staples at 10′ intervals down the plot length at the netting edges. A runoff catchment was built 3′ downslope of the plot and filled with wood chips. The specifications for the plot can be observed in Figure 14, while the installed products can be seen in Figure 15.

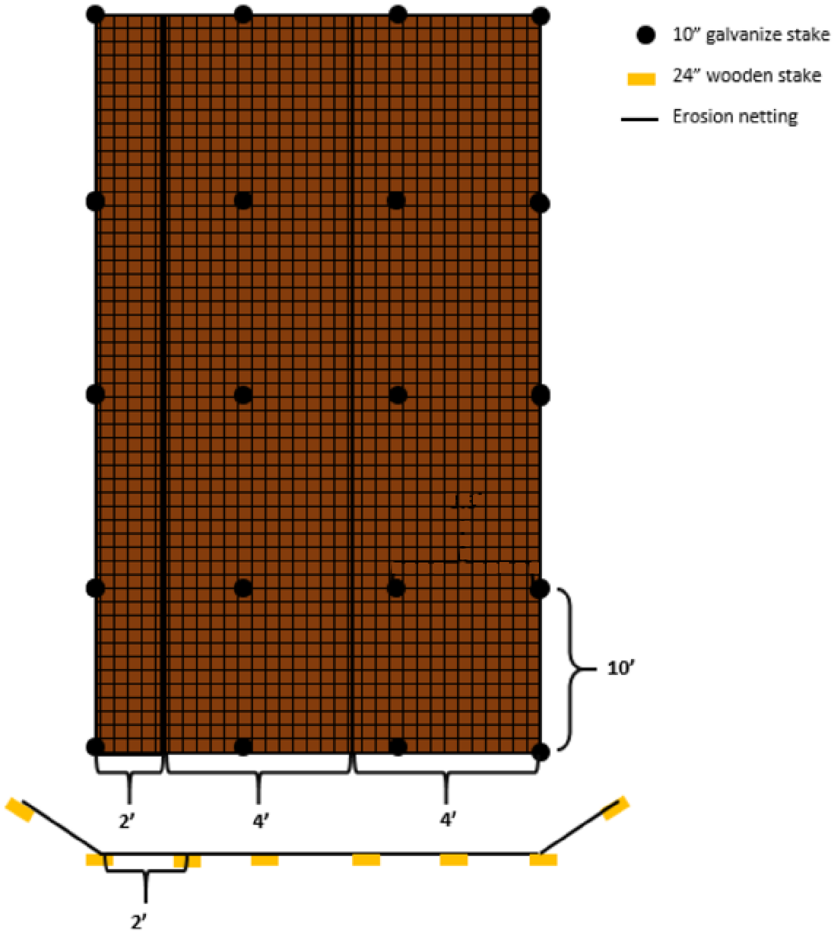

Figure 14: Illustration of biosolids and woodchips installation specifications

Figure 15: Image of installed biosolids and woodchips plot

Budget

Sustainable Solutions incurred a total project cost of nearly $900.00. See Table 2 below for the list of items purchased for the duration of the project. The largest line item was travel cost. The approved reimbursement was $2,400.00, but many materials were donated, including the compost socks, wattles, and grass seed.

Table 2: Project Costs

Item	Cost
Travel (7 trips)	517.45
Stakes	48.69
Pins	49.66
Zip Ties	11.96
Netting	147.42
Biosolids	21.64
Spray Paint	4.48
Twine	13.94
Buckets	19.38
Total:	834.62

On-Site Testing Results

Computer Modeling Results

The following erosion mitigation strategies were modeled using RUSLE2: cool-season vegetative cover at different stands, compost socks, silt fence, various sizes of wattles, and bare ground as a control. According to the model, the percentage of vegetative cover has a direct impact on the amount of sediment delivery, soil loss, and event runoff. A higher percentage of vegetative cover on the slope correlated with a lower prevalence of soil loss. For example, the model predicted that a plot with strong vegetative cover will exhibit a sediment delivery rate of 0.07 tons/acre/year, whereas a plot with poor vegetative cover will have a sediment delivery rate of 3.1 tons/acre/ year.

Compost socks were modeled as a potential erosion mitigation strategy. The model allows the user to choose the diameter and placement of the compost socks on the plot. In this case, the compost socks were evaluated in the model with four different placements (See Table 3). According to the model outputs, the sediment loss did not change based on the compost sock placement and diameter. However, the model did not seem to account for the synergistic effects of the nutrients added to the soil by the compost. The nutrients added to the soil may increase the vegetative cover, which would reduce soil loss in return.

Wattles were also modeled with RUSLE2. The results were fairly similar to the soil loss predictions for the compost socks; the sediment loss rates range from 0.073-0.076 tons per acre per year. According to the model, the diameter of the wattle does not impact the sediment delivery, as the rate of sediment delivery was only dependent on the number of wattles and not dependent on wattle size. However, the soil loss rates were dependent on the number and location of the wattles. As more wattles were added to the model, the rate of soil loss actually decreased from 0.071 tons/ac/yr (1 wattle) to 0.062 tons/ac/yr (4 wattles).

Table 3: RUSLE2 computer modeling results for Enid Landfill

Conservation Operation	Sediment Delivery (t/ac/yr)	Soil Loss (t/ac/yr)	Event Runoff (inch/yr)
Bare Ground	170.000	167.000	7.7
Woodchips Berm	0.073	0.071	2.7
Bermudagrass	0.048	0.048	2.9
Cool-season grass:			
- Strong growth	0.071	0.071	2.7
- Moderate stand	0.322	0.320	3
- Poor stand	3.050	3.000	4
8″ Compost Sock:			
- 1 Compost Socks (Top)	0.072	0.055	2.7
- 2 Compost Socks (Bottom and 50%)	0.074	0.074	2.7
- 4 Compost Socks (Top, 75%, 50%, 25%)	0.075	0.055	2.8
Silt Fence:			
- Base of slope	0.071	0.071	2.7
- 2 Silt Fences	0.071	0.071	2.8
- 4 Silt Fences	0.069	0.062	2.8
Wattle:			
6 inch- 1 per plot (Bottom)	0.073	0.071	2.7
6 inch- 2 per plot (Bottom and 50%)	0.074	0.067	2.7
6 inch- 4 per plot (Bottom, 75%, 50%, 25%)	0.076	0.062	2.8

Conservation Operation	Sediment Delivery (t/ac/yr)	Soil Loss (t/ac/yr)	Event Runoff (inch/yr)
9 inch- 1 per plot (Bottom)	0.073	0.071	2.7
9 inch- 2 per plot (Bottom and 50%)	0.074	0.067	2.7
9 inch - 4 per plot (Bottom, 75%, 50%, 25%)	0.076	0.062	2.8
12 inch - 1 per plot (Bottom)	0.073	0.071	2.7
12 inch - 2 per plot (Bottom and 50%)	0.074	0.067	2.8
12 inch - 4 per plot (Bottom, 75%, 50%, 25%)	0.076	0.062	2.9

Qualitative Observations

Plot 1 - Compost Blanket

The compost blanket seemed to encourage the most grass growth, as can be seen in Figure 16. Sediment did shift mildly in the plot as evidenced by the areas where soil was deposited above the netting and areas where the soil level had dropped below the netting. It seems that the netting significantly decreased soil loss and distributed water more evenly around the surface of the plot. There were no rills forming at the base of the plot. More research is necessary to determine how much of a difference the netting made in keeping the compost and sediments in place. There was a noticeable population of insects at this plot.

Figure 16: Image of compost blanket plot at week 6

Plot 2 - Control

A single rill was being formed at the base of the plot, which means the water flowing over the plot was not distributed evenly. See Figure 17 below to observe the control plot. There was a small amount of grass growth, possibly covering 1% of the plot that was fairly evenly distributed across the surface.

Figure 17: Image of control plot at week 6

Plot 3 - Manufactured Compost Socks

Grass growing between the compost socks shows that the socks were successful in slowing the velocity of the stormwater enough for seeds to take root. As expected, the sediment deposited above the socks formed terraces, as seen in Figure 18. Any grass that was growing above the socks was covered with sediment that dried to form hard clay steps. It looked like the woodchips in the purchased compost floated to the top of the socks or alternatively that the loose particles of compost inside the socks had washed away, leaving the bigger woodchips pieces. See Figure 19 for an image of the changed composition of the compost socks.

Figure 18: Image of manufactured compost sock plot at week 6

Figure 19: Image of changed composition in manufactured compost sock

Plot 4 - Homemade Compost Socks

Grass growing between the compost socks shows that the socks were successful in slowing the velocity of the stormwater enough for seeds to take root. As expected, the sediment deposited above the socks formed terraces (see Figure 20). Any grass that was growing above the socks was covered with sediment that dried to form hard clay steps. A few sprouts of grass were growing in the formed sediment step. There was slight undercutting under one of the socks, possibly because the terrace formed by the deposited sediment was so high, as seen in Figure 21. The compost within the sock was coated with a 1-2 cm layer of deposited sediment, so any grass that would grow on the sock would have to persist long enough to grow roots deep enough to reach the nutrients in the compost.

Figure 20: Image of homemade compost sock plot at week 6

Figure 21: Undercutting of homemade compost sock

Plot 5 - Homemade Wattles

The homemade wattle plot exhibited taller grass growth than the control plot, with similar dispersal of growth (see Figure 22). The wattles caught a lot of sediment, and the stakes that had been vertical were knocked over by the amount of sediment. The wattles themselves were packed with trapped sediment.

Figure 22: Image of homemade wattle plot at week 6

Plot 6 - Woodchips & Biosolids

The plot had a good variety of grass growth. The coverage was evenly dispersed and more mature than the control plot, possibly due to the added nutrients. It seemed like the structure of the woodchips and the netting helped to evenly distribute runoff. A bug population was present at the plot. The homemade woodchips berm trapped a lot of sediment and did not lose woodchips. Its structure was still intact. See Figure 23 for the plot at week 6.

Figure 23: Image of biosolids and woodchip plot at week 6

Sediment Loss Results

Aluminum garden staples were used to monitor erosion from the surface of the slope according to the method outlined in the erosion study conducted by Ghimire et al (2013). Galvanized 8.5″ aluminum stakes were inserted into the slope in a 2x4 grid pattern. The flat heads of the stakes were inserted to be level with the soil surface. During each of the three site visits, the amount of soil loss was measured at each staple. The soil loss for each plot was measured and recorded at 1, 3, and 6 weeks after installation. Several rainfall events occurred between Week 3 and Week 6, which caused an increased amount of erosion and sedimentation. The average soil loss for each plot each data collection period, as well as the cumulative loss are summarized in Table 4 below. The weekly data sheets with the soil loss for each erosion pin are included in Appendix I.

As observed in Table 4, the plots with manufactured compost socks and homemade compost socks exhibited the highest cumulative soil loss amounts of 1.2 cm and 1.3 cm, respectively. This higher rate of soil loss may be due to the terracing effect of the compost socks or the uneven distribution of soil above the plot area. The next highest rate of soil loss occurred on the control plot, with a cumulative soil loss of 0.9 cm. The lowest rates of soil loss occurred on the compost blanket, homemade wattle, and on the biosolids and woodchips plots with soil loss amounts of 0.5 cm, 0.5 cm, and 0.6 cm, respectively. The results of this study indicate that the implementation of compost blankets, wattles, and an addition of biosolids and woodchips may be viable solutions to mitigate soil loss and erosion issues. Both the compost blanket and the biosolids and woodchips additions were covered by erosion control netting; this may be the factor that prevented these plots from exhibiting high rates of soil loss.

Once the soil loss data was collected and reviewed, it was determined that there might not be an ideal method to estimate soil loss on the plot. Some of the erosion pins were covered with soil, while other erosion markers indicated that soil was lost. This resulted in positive and negative values for soil deposition, though both are part of the problem. Thus, it would not be acceptable to average the soil deposition values for each plot. After reviewing the soil loss data, the average soil loss for each plot was calculated by averaging the amount of soil depth that was lost from each erosion measurement pin. Soil addition values were not included in the calculations and may have skewed the numerical data. At the end of the testing period, the cumulative soil loss was tabulated as well.

Table 4: Cumulative and weekly sediment loss for each plot

	Average sediment loss in cm			
Plot	Week 1	Week 3	Week 6	**Cumulative**
Compost Blanket	0.0	0.0	0.5	**0.5**
Control	0.0	0.1	0.8	**0.9**
Manufactured Compost Socks	0.0	0.0	1.2	**1.2**
Homemade Compost Socks	0.0	0.3	1.0	**1.3**
Homemade Wattles	0.0	0.1	0.5	**0.6**
Biosolids and Woodchips	0.0	0.3	0.2	**0.5**

Vegetative Cover Results

Vegetative cover data was based on percentage of total canopy cover across the entire plot. This gives an estimate of surface area covered by grass. Two photographs were taken of each plot- one depicting the top half of the plot and one depicting the bottom half of the plot. The images were cropped to only include the area within the plot. Each image was imported into Adobe Photoshop to analyze the RGB (Red, Green, Blue) values. The histogram gave the total number of green pixels and the total number of pixels in the photograph. These numbers were used to calculate a percentage of green. Therefore, the total amount of canopy coverage could be estimated.

Table 5 below shows the percent grass coverage for each plot. The compost blanket encouraged more grass growth than any of the other plots with about 1.67% coverage. The biosolids and woodchip plot also encouraged grass growth with about 1.02% grass coverage over the entire plot. The other 3 plots showed similar coverage to the control plot, which was to be expected. This is because the compost and biosolids added nutrients to the soil, while the other 3 plots had no nutrients added to encourage grass growth.

Errors in the photographs could be observed through lighting, slope angle, inconsistent terrain, and image cropping. Although, each photograph was taken at approximately the same time and in the same position. Therefore, since the errors are consistent, the numbers can be compared relative to each other.

Table 5: Percent grass coverage per plot

Plot	Percent Coverage
Compost Blanket	1.67%
Control	0.86%
Manufactured Compost Socks	0.84%
Homemade Compost Socks	0.86%
Homemade Wattles	0.84%
Biosolids and Woodchips	1.02%

Recommendations

Site Specific Recommendation

The results of on-site testing indicate that an integrated solution involving nutrient addition to the soil and constructing a barrier to impede the movement of runoff and sediment may provide the best results. The most successful test plots employed both erosion control tactics. Based on cost effectiveness and incorporating on-site materials, Sustainable Solutions recommends that the COE use a compost blanket and homemade woodchips berms to establish vegetative cover on the landfill slope.

It was estimated that approximately one-third of the slope is already covered with vegetation. It was observed that more grass grows on the west side and base of the slope. The critical region constitutes the mostly barren surface from the top of the slope to two-thirds of the way down. Once erosion issues on the upper slope are controlled, vegetation should really thrive in the already sparsely vegetated areas. Cost and material estimates are based on covering the bare two-thirds of the slope. The total area of this critical region is estimated as 260,000 sq. feet.

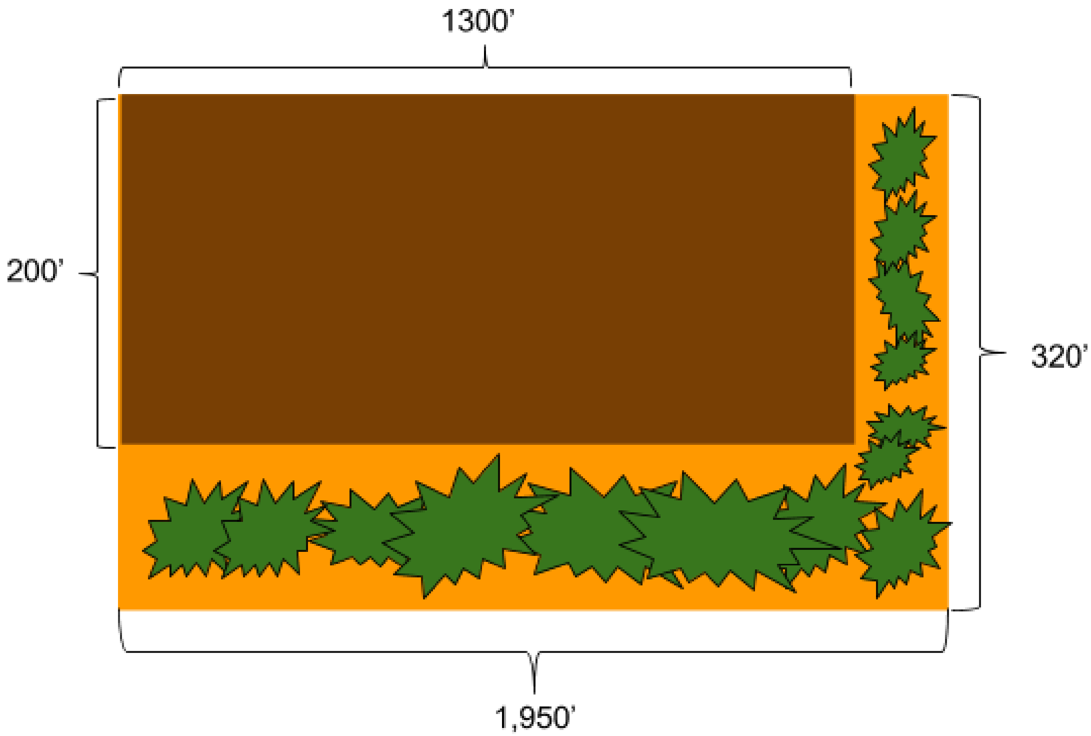

Figure 24: Illustration of surface area of the slope for calculations

Sustainable Solutions recommends that the COE purchase the test seed mixture from Johnston Seed Company because it uses many different seed varieties to ensure year-round coverage. The composition of the seed mix is included in Appendix G and grass variety data sheets are located in Appendix H. The seed can be hydroseeded with the concover truck before the compost blanket is applied. Fertilizer is not necessary because adequate nutrients are available in the compost blanket.

The success of the compost blanket plot proved that the landfill's on-site green waste compost has enough nutrient capacity to increase vegetative growth. However, using certified, nutrient-rich compost from a retailer may increase the quality and speed the growth rate of the vegetative cover. As compost becomes available on-site, it can be spread to a 1 inch thickness on the bare surface of the slope. The test plot compost blanket had a 1.5 in thickness. The depth of the blanket for the whole slope was decreased because of the availability of compost and the large size of the area to cover. There is the possibility of purchasing compost to spread on the slope, and it is included as a higher cost option in the cost analysis. Estimate show that the approximately two-thirds of the slope (critical region) is bare, so it would take 35,000 cubic feet (430 front end loader buckets) to cover the bare area with a 1 inch thickness.

The compost blanket on the test plot was held in place with plastic garden netting and small metal pins. Figure 25 gives a close up image of the installed netting. It is not feasible or cost effective to cover the entire slope with plastic netting and pins, but the netting did seem to play a significant role in decreasing the soil loss and evenly distributing runoff. Therefore, installing netting on the slope is included in the cost analysis as a higher cost option. The lower cost option, homemade woodchips berms, should have a similar effect, slowing the velocity of water and discouraging the compost from washing away. Ideally, the compost blanket should be inspected after each major rainfall. If areas of the blanket have washed out, another layer of compost should be applied (EPA, 2012).

Figure 25: Image of compost blanket netting

Figure 26: Image of homemade woodchip berm

The homemade woodchip berm accompanying the biosolids and woodchip plot trapped a lot of sediment over the six week testing period (see Figure 26). A homemade woodchip berm, made with plastic garden netting, wooden stakes, and zip ties would be a cost effective alternative to buying manufactured wattles or compost socks while still accomplishing the same purpose of slowing runoff velocity and trapping sediment. See Figure 27 for an illustration of the berm design. Sustainable Solutions recommends starting with two homemade woodchip berms the entire length of the slope. During on-site testing, rills formed between plots because the runoff took the path of least resistance between the lengths of different socks and wattles (See Figure 28). Thus, it is important that the woodchip berms span the entire length of the slope. In addition, both ends of the berm should angle upwards to discourage rill formation on the edges of the critical site (See Figure 29).

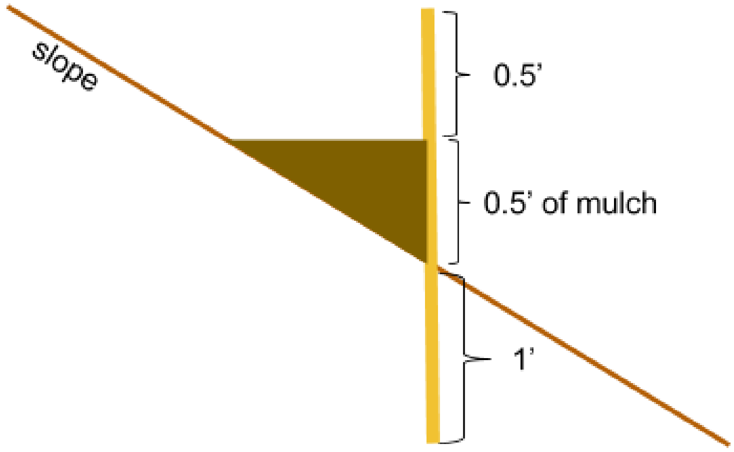

Figure 27: Illustration of woodchip berm construction

Figure 28: Image of rill formation between plots

The first woodchips berm should be placed near the top of the slope, about 100 feet down. The second berm should be placed about 200 feet from the top of the slope. If, after observation, the woodchip berms are trapping a substantial amount of sediment, more woodchips berms can be installed 50 feet and 150 feet from the top of the slope. See Figure 29 below for an illustration of recommended berm placement. These homemade berms can be constructed like the example in the biosolids and woodchips plot design, with slight adjustments. Considering the sturdiness of the test berm, woodchip height can be decreased to 6 inches. The woodchip berms will need to be maintained seasonally and possibly after large storm events. Maintenance may include the addition of woodchips if it has washed away, replacing broken sections of netting, or removing sediment.

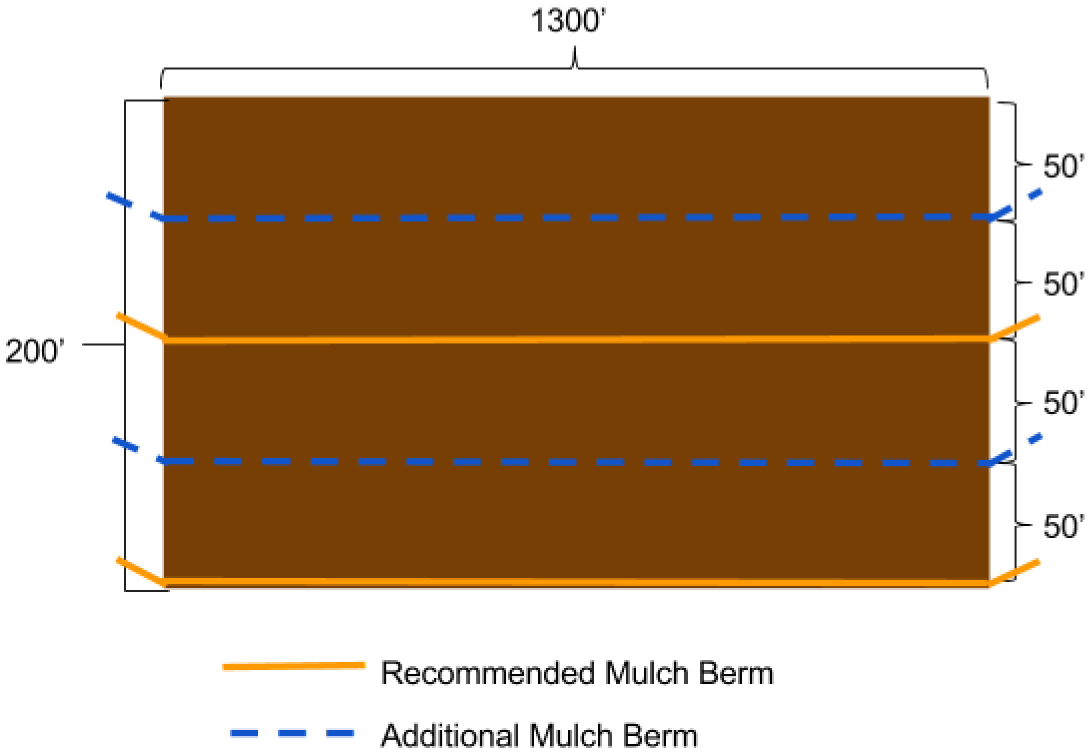

Figure 29: Illustration of recommended woodchip berm placement on slope

For future slopes, a cost effective solution may be to incorporate compost into the surface slope cover soil to increase nutrient content. Creating earthen terraces may also be helpful. For a cost-effective slope fertilizer, Sustainable Solutions encourages the COE to look into composting their wastewater sludge on-site at the landfill. Midwest City has a comparable operation.

Site Specific Cost Analyses

The Do-Nothing Option

The COE has the option not to implement an erosion control solution and continue in noncompliance. Sustainable Solutions reached out to Amber Edwards, DEQ's Solid

Waste Compliance Manager, to gather information on procedures and fines. Typically, the landfill would receive an initial warning and a $500 fine. Henceforward, landfill management would have to meet regularly with DEQ officials to establish a plan to return to compliance and pay a $500 - $1000 fine each month until the issue was resolved. The cost analysis assumed a fine of $1000 each month. This sustained monthly fine adds to an annual cost of $12,000.

Grass Seed

The grass seed used in testing is available for purchase through Johnston Seed Company in Enid. The mix has been effective at establishing cover on landfill slopes in El Reno and Chickasha. The pure live seed (PLS) lb cost is $4.38. The COE can choose between two recommended seeding rates, one for a typical landscape and one for a site in critical condition. Table 6 displays the total cost for each condition.

Table 6: Seed cost options

Condition	Seeding Rate (lbs PLS/acre)	Cost/Acre	Total Cost
Landscape	11.68	$51.00	$306.00
Critical	26.1	$104.00	$624.00

Compost Blanket

The cost of covering the slope with three different materials was calculated. The purchased compost estimate is based on prices from Minick Materials in Oklahoma City. The purchased biosolids estimate is based on prices from Midwest City's Wastewater Treatment Plant. The on-site compost costs nothing in the estimate, but in reality, there is an opportunity cost because the landfill may become less popular with taxpayers if they can no longer come and get compost for free. Each of these materials will increase the nutrient level of the soil and catalyze grass growth.

The calculations for covering the entire slope are based on a 1 in deep blanket covering a surface area of 260,000 sq feet. This square footage accounts for the previously defined critical area. Labor costs are not included in the calculations.

Table 7: Cost comparison for compost blanket materials

Cost Level	Material	Cost/yd^3	Cost to cover slope
High	Purchased Compost	\$30.00	\$24,120.00
Medium	Purchased Biosolids	\$20.00	\$16,080.00
Low	On-site Compost	\$0.00	\$0.00

Homemade Mulch Berms

To build two 1300 feet mulch berms along the slope, the COE can purchase plastic mesh netting, wooden garden stakes, and zip ties according to Table 8. The estimated total cost is \$972.00 for both berms. The netting is plastic mesh 1 feet tall by 150 feet long. The stakes are 2 in wide by 2 in thick and 2 feet long. The netting is staked every 5 feet for stability. Each stake is driven approximately 1 feet into the ground. The netting is zip tied at the top and bottom of the stake, using two zip ties per stake. Mulch is piled against the netting to an effective height of 6 inches. Labor costs are not included in the cost calculation.

Table 8: Cost of woodchip berm materials

Item	Unit	Unit Cost	Number	Cost
12" netting	150' roll	\$25.50	18	\$460.00
24" stake	pack of 6	\$5.00	87	\$435.00
8" zip tie	pack of 100	\$7.00	11	\$77.00
			Total:	**\$972.00**

Wattles

The cost analysis for wattles was determined by a quote from our contact at ASP Enterprises. The cost estimate was $1.00 per foot for an 8 inch or 9 inch diameter wattle. The analysis was also confirmed by comparing similar products from other sources. The total cost calculations are based on two 1300 foot wattle lengths that could replace the homemade mulch berms if the COE would rather have an outside manufacturer install a product. The total cost is displayed in Table 9. Labor costs are not included.

Table 9: Cost of manufactured wattles

Item	Unit	Unit Cost	Number	Cost
8" wattle	1 feet	$1	2600	$2,600

Netting

If the COE chooses to cover the compost blanket with plastic netting to hold it in place, the estimated cost is $5,877.00 using Sta-Green Steel Landscape Pins and Sta-Green Wildlife Black Polypropylene Netting (lowes.com). These materials are sold at local stores, and a better cost may be negotiated if the COE reaches out to the manufacturer with a large order. The netting will never degrade, and based on the on-site test, maintenance will be minimal. More detailed costs are displayed in Table 10. Labor costs are not included.

Table 10: Cost of netting materials

Item	Unit	Unit Cost	Number	Cost
7' netting	100' roll	$14.98	377	$5,647.46
4" pin	pack of 75	$9.98	23	$229.54
			Total:	**$5,877.00**

Design Solution Menu

One of the goals of Sustainable Solutions was to provide an Oklahoma-wide design solution recommendation. This recommendation cannot be as specific as the one provided for the COE due to the infeasibility of testing on-site materials and performing on-site experiments at every Oklahoma landfill location. The team decided to provide a menu that will allow different locations to find a design solution for their erosion issues based on the severity and type of erosion, the longevity of the design solution, and the cost. The menu is designed as a flowchart that easily guides the reader to suggested design solutions. Once the reader has selected the design solution that seems most appropriate, he or she can continue down the page to find a short explanation of how the product works and some product type suggestions. Consulting with manufacturers for a site-specific cost analysis is necessary, so solutions are loosely arranged by cost. However, the menu is a first step resource for landfill managers looking for innovative erosion control ideas. This menu was created based on the initial comprehensive erosion control design solution list located in the fall report. The solutions contained in the menu were selected based on feasibility and practicality in the state of Oklahoma. See Appendix J for the full design menu.

Conclusion

Impacts and Sustainability

The versatility of the erosion control menu may extend its useful life indefinitely. While certain products may be discontinued over time, many solutions will remain viable. Depending on how frequently the menu is updated and how well it is maintained, it could serve as a resource for municipal landfills for years to come.

Vegetative cover is one of the menu items that may require the least amount of updating. Unless a new type of grass is proven more suitable or the landfill cover soil composition changes drastically, the grasses recommended by the menu will not change. The menu's soil amendment options will vary on a case-by-case basis depending on accessibility of resources. The nutrient availability of the compost may vary widely, the leachate may not always be in compliance for irrigation, and it may not always be economically feasible to treat the wastewater sludge. Additionally, if the amount and composition of these amendments are not monitored closely, contaminated runoff can pose a serious threat to the environment and human health.

Lastly, production of specific products such as wattles and rolled erosion control products on the erosion control menu could be discontinued over the years. The market should always contain similar or improved products to keep the menu up-to-date.

Landfills are continuously expanding to keep pace with the inflow of trash. Thus, bare soil surfaces prone to erosion and sediment loss are a perpetual issue. An erosion control menu should not only provide solutions for the already-existing slopes but also provide proactive erosion control techniques and products to implement while building new cells, preventing the severity of erosion problem that Sustainable Solutions has been tasked with researching and ultimately saving taxpayer dollars.

Overall, the erosion control menu can be a cost effective and sustainable resolution to the erosion concerns continually plaguing some Oklahoma landfills.

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Appendices

Appendix A [Project Schedule]

Jan 31	Computer Modeling	
Feb 1	Computer Modeling	
Feb 2	Computer Modeling	
Feb 3	Finish Computer Modeling, Finalize On-site Test Choices	
Feb 6	Work on Menu, Finalize On-site Test Choices	
Feb 7	Work on Menu	
Feb 8	Work on Menu	
Feb 9	Work on Menu	
Feb 10	Enid Trip, stake & size test plots	
Feb 13	Order All Products	
Feb 14	Work on Menu, On-site Design	
Feb 15	Work on Menu, On-site Design	
Feb 16	Work on Menu, On-site Design	
Feb 17	Work on Menu, On-site Design	
Feb 20	On-site Design	
Feb 21	On-site Design	
Feb 22	On-site Design	
Feb 23	On-site Design	
Feb 24	On-site Design	
Feb 27	On-site Design	
Feb 28	On-site Design	
Mar 1	Finalize On-site Procedure, all products obtained	
Mar 2	On-site Design	
Mar 3	Enid Trip, assemble & begin recording data	
Mar 6	Work on Menu	
Mar 7	Work on Menu	
Mar 8	Work on Menu	
Mar 9	Work on Menu	
Mar 10	Enid Trip, first data collection	1 week
Mar 13	SPRING BREAK	
Mar 14	SPRING BREAK	
Mar 15	SPRING BREAK	
Mar 16	SPRING BREAK	

Mar 17	SPRING BREAK	2 week
Mar 20	Work on Menu, Report	
Mar 21	Work on Menu, Report	
Mar 22	Work on Menu, Report	
Mar 23	Work on Menu, Report	
Mar 24	Rough Draft Report Due; Enid Trip, halfway mark data collection	3 week
Mar 27	Work on Report	
Mar 28	Work on Report	
Mar 29	Work on Report	
Mar 30	Work on Report	
Mar 31	Work on Report	4 week
Apr 3	Work on Report	
Apr 4	Work on Report	
Apr 5	Work on Report	
Apr 6	Work on Report	
Apr 7	Second Rough Draft Report Due	5 week
Apr 10	Work on Report, Presentation, Demo	
Apr 11	Work on Report, Presentation, Demo	
Apr 12	Work on Report, Presentation, Demo	
Apr 13	Work on Report, Presentation, Demo	
Apr 14	Enid Trip, end on-site testing, clean everything up	6 week
Apr 17	Work on Report, Presentation	
Apr 18	Work on Report, Presentation	
Apr 19	Work on Report, Presentation	
Apr 20	Work on Report, Presentation	
Apr 24	Work on Report, Presentation	
Apr 25	Work on Report, Presentation	
Apr 26	Work on Report, Presentation	
Apr 27	Work on Report, Presentation	
May 1	Work on Report, Presentation, Menu, Demo	
May 2	Work on Report, Presentation, Menu, Demo	
May 3	Work on Report, Presentation, Menu, Demo	
May 4	Final Presentation & Project Demonstration	

Appendix B [Work Breakdown Structure]

1. Research

1.1. Preliminary Web Research

1.2. Technical Literature Review & Patent Analysis

1.2.1. Erosion

1.2.2. Hydroseeding

1.2.3. Compost & Alternative Cover

1.2.4. Alternative Fertilizers

1.2.4.1. On-Site Leachate Composition

1.2.4.2. Wastewater Sludge Composition

1.2.5. Cover Management

1.2.6. Support Practices

1.3. On-Site Soil & Water Analysis

1.3.1. Web Soil Survey

1.3.2. Soil, Water, and Forage Analysis Lab (SWFAL) Testing

1.3.2.1. Cover Soil

1.3.2.2. Slope Soil

1.3.2.3. Compost

1.3.2.4. Con Cover™

1.3.2.5. Stormwater

2. Design and Model

2.1. RUSLE2 Computer Modeling

2.2. Viable On-Site Design Options

3. Test

3.1. On-Site Test for Effectiveness

3.1.1. Soil Movement

3.1.2. Surface Area Coverage

4. Deliverables

4.1. Final Report

4.1.1. Erosion Control Menu

4.1.2. COE Recommendation

4.2. Final PowerPoint Presentation

4.2.1. Client Evaluation

Appendix C [Task List]

Research Phase

- Research solutions for landfill slopes, steep slopes, and slopes with low soil quality
  - Research feasibility of alternative slope covers online
  - Review pertinent technical literature and patents
- Research erosion control methods
  - Make an exhaustive list of products
  - Narrow down based on general feasibility
  - Estimate product cost and longevity
- Research vegetation type best suited for current slope and soil composition
  - Determine soil composition
    - Perform soil type analysis from USDA Web Soil Survey
    - Test soil samples with OSU's Soil, Water, and Forage Analytical Lab
  - Meet with Turf Management extension agent
  - Ask for recommendation from seed company representatives
- Compare soil amendment options and feasibility of using on-site resources
  - Analyze composition of on-site leachate collection water and wastewater sludge
  - Interpret compost, Con Cover™, and stormwater SWFAL results
  - Research methods for incorporating leachate, sludge, mulch, and compost
- Develop quantitative engineering specifications
  - Obtain a copy of the landfill site plans
  - Determine total surface area within our scope
  - Research RUSLE2 and determine input variables
- Research relevant EPA regulations and DEQ permitting
  - Research water quality, leachate application, and sludge application standards
- Do cost analysis on alternative designs
  - Compare initial costs
  - Compare maintenance costs

Design Phase

- Do computer modeling with RUSLE2
  - Model current Enid Landfill slope conditions
    - Use USDA Soil Web Survey to input soil composition
  - Model alternative erosion control methods
- Determine on-site indicator variables of success
  - Design procedure to monitor/quantify vegetation growth
  - Design procedure to monitor/quantify soil loss
- Finalize design options to test on-site
- Organize researched solutions into user-friendly menu

Testing Phase

- Test five feasible solutions on landfill slope
- Interpret experimental results
  - Arrange solutions into menu of options categorized by:
    - Cost
    - Erosion Type & Severity
    - Longevity

Finalize & Present Results

- Write final report
- Present menu and recommendation to the City of Enid and DEQ

Appendix D [Failure Modes and Effects Analysis]

	Importance to Customer	10	9	7		
#	**KPIV**	**Sediment Loss**	**% Vegetative Cover**	**Vegetative Health**	**Total**	**% Rank**
1	Do nothing	7	7	7	182	18.2%
2	Nutrient Availability	1	7	7	122	12.2%
3	Erosion Control and Nutrients- Manufactured Compost Sock	1	6	6	106	10.6%
4	Erosion Control- Homemade Compost Sock	1	5	5	90	9.0%
5	Erosion Control- Handmade Wattle	1	5	5	90	9.0%
6	Biosolids & Mulch	1	7	7	122	12.2%
7	Watering Frequency	1	7	7	122	12.2%
8	Grass Breed	1	8	8	138	13.8%
9		1	1	1	26	2.6%
					998	

Appendix E [Safety Considerations]

Safety considerations must be taken into account when implementing new designs. Sustainable Solutions' design concepts for the Enid Landfill project contain potential risks that must be noted and addressed. The wastewater sludge that is discussed as a potential soil amendment contains harmful pathogens classified as class B biosolids that can cause illness to surrounding citizens. The pathogens can be transmitted through soil, animal, and water movement. The sludge must be contained and handled properly before use. Other safety procedures for handling the sludge must be strictly adhered to as well.

The application of soil additives, such as the on-site leachate water, also poses a threat to surrounding land and water. If a nutrient is applied in excess it can cause overgrowth of plants or eutrophication in surrounding bodies of water. These undesired effects can be avoided with careful calculations before application or with the use of solutions to minimize runoff.

Many of the design concepts include the use of machinery or equipment such as hydroseeders or a pneumatic system used to spread a compost blanket. Unfamiliar equipment can cause unintended accidents. The situation is further exacerbated by the use of the equipment on a steep slope. Employees expected to use the equipment will need to be adequately educated on the operation process and accompanying machinery safety. The possibility of unearthing trash during the implementation of some menu design solutions also causes concern. The unearthing allows for contaminates to be spread and garbage to blow off of the landfill. Caution must be exercised during all design solutions to maintain continuity of the outer soil layer.

Overall, health of the environment and people must be taken into full consideration when deciding upon nutrient amendments or erosion control products.

Appendix F [Midwest City Compost SWFAL Analytical Results]

Soil, Water & Forage Analytical Laboratory

Oklahoma State University Division of Agricultural Sciences and Natural Resources
045 Agricultural Hall
Stillwater, OK 74078
Email: soiltesting@okstate.edu
Website: www.soiltesting.okstate.edu

ANIMAL WASTE ANALYSIS REPORT

RAY RIDLEN
OKLAHOMA CO EXT OFC
2500 NE 63RD STREET

OKLAHOMA CITY, OK 73111
(405) 713-1125

Name : CITY OF MWC

Location : COMPOST PILE #107

Lab ID No.: : 829425
Customer Code : 55
Sample No. : 97
Received : 1/30/2017
Report Date : 2/7/2017

TEST RESULTS FOR: Solid SOURCE: Compost

TEST	As Received	As Received lbs/ton	Dry Basis lbs/ton
Moisture	5.6 %		
Dry Matter	94.4 %		
pH	6.5		
EC	3410 µS/cm		
Soluble Salts:	2284.7 ppm	4.6	4.8
Total N	1.61 %	32.1	34.0
Phosphorus (P2O5)	1.78 %	35.7	37.8
Potassium (K2O)	0.40 %	8.0	8.5
Calcium (Ca)	6.47 %	129.3	137.0
Magnesium (Mg)	0.32 %	6.4	6.8
Sodium (Na)	0.03 %	0.6	0.7
Sulfur (S)	0.6 %	12	13
Iron (Fe)	7569.9 ppm	15.1	16.0
Zinc (Zn)	535.7 ppm	1.1	1.1
Copper (Cu)	265.3 ppm	0.5	0.6
Manganese (Mn)	471.9 ppm	0.9	1.0
Total C	23.16 %	463.2	490.7

Ray Ridlen
Signature

Appendix G [Johnston Co. Grass Mix Composition]

JOHNSTON SEED CO.
P. O.BOX 1392
ENID, OK 73702
580-233-5800
1-800-375-4613

NO.______

Name: Attn:
Address:

City: State:
County: Zip:
Acres: Phone:
Fax:

KIND	VARIETY	#PLS/A	% OF MIX	PLS#/A	PRICE/PLS	COST/A
Little Bluestem	VNS	4.00	10%	0.4000	10.00	4.00
Little Bluestem	Cimarron	4.00		0.0000	12.50	0.00
Big Bluestem	VNS	6.00		0.0000	8.00	0.00
Sand Bluestem	Chet	6.00		0.0000	10.00	0.00
Indiangrass	VNS	6.00		0.0000	10.00	0.00
Indiangrass	Chey	6.00		0.0000	10.00	0.00
Switchgrass	VNS	3.00		0.0000	0.00	0.00
Switchgrass	Blackwell	3.00		0.0000	8.50	0.00
Switchgrass	Kanlow	3.00		0.0000	6.50	0.00
Switchgrass	Alamo	3.00		0.0000	6.50	0.00
Sideoats Grama	VNS	5.00		0.0000	0.00	0.00
Sideoats Grama	El Reno	5.00	10%	0.5000	7.50	3.75
Blue Grama	VNS	2.00	10%	0.2000	10.00	2.00
Blue Grama	Lovington	2.00		0.0000	12.50	0.00
Buffalograss	Texoka	8.00		0.0000	7.50	0.00
Sand Lovegrass	Bend	1.00		0.0000	10.00	0.00
Tall Dropseed	VNS	1.00	10%	0.1000	10.00	1.00
Green Sprangletop	VNS	1.70	20%	0.3400	8.00	2.72
Sand Drop	VNS	2.00		0.0000	8.00	0.00
Eastern Gama	Iuka	8.00		0.0000	11.00	0.00
Western Wheatgrass	Barton/VNS	8.00		0.0000	9.50	0.00
Tall Wheatgrass	Jose	7.00		0.0000	4.00	0.00
Alkali Sacaton	VNS	2.00		0.0000	25.00	0.00
Ill. Bundleflower	VNS	10.00		0.0000	7.50	0.00
Partridge Peas	VNS	2.00		0.0000	12.50	0.00
Maxmillian Sunflower	VNS	2.00		0.0000	20.00	0.00
Purple Prairie Clover	VNS	4.00		0.0000	20.00	0.00
Fescue	KY31	15.00	10%	1.5000	0.85	1.28
Bermudagrass	VNS	8.00	10%	0.8000	5.70	4.56
Alfalfa		10.00	10%	1.0000	3.00	3.00
Yellow Sweet Clover	VNS	10.00	10%	1.0000	3.25	3.25
			100.0%	5.8400		25.56

COST/ACRE	25.56
COST/PLS#	4.38

Prepared by______________________________2/14/2017

Appendix H [USDA Plant Fact Sheets]

ALFALFA

Medicago sativa L.

Plant Symbol = MESA

Contributed by: USDA NRCS Plant Materials Program

USDA NRCS National Plant Materials Center
Beltsville, MD

Uses

Crops: Alfalfa is harvested as hay which is processed or fed directly to livestock, or for seed production. It is also used in pellets as forage supplements.

Livestock: This plant is grown in combination with grasses in improved pastures. It is grazed by all types of domestic livestock. Caution should be taken when using alfalfa for grazing due to its high bloat hazard.

Wildlife: Alfalfa is an excellent food for antelope, deer, elk, Canada goose, and sage and sharp tail grouse. It is fair food for sandhill crane, mallard, Hungarian partridge, and pheasant.

In addition to providing high quality hay, grazing, and wildlife forage and protection, alfalfa is an important source of leaf meal used for fortifying baby food and other special diet foods prepared for human use. Large quantities of dehydrated alfalfa are also used in manufacturing concentrated feeds for poultry and livestock.

Status

Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness

This plant may become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Please consult with your local NRCS Field Office, Cooperative Extension Service office, or state natural resource or agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at plants.usda.gov.

Description

Medicago sativa L., alfalfa, is a long-lived perennial legume. Flowers vary in color from purple to yellow and are borne in loose clusters. Pods of alfalfa range from the sickle type to those that are twisted into spirals. Each pod contains several small kidney-shaped seeds. Alfalfa's stems are erect and grow from a woody crown to about 2 to 3 feet tall. New growth occurs from buds in the crown. The plant has a tap root which may penetrate deep into the soil. Leaves are alternately arranged on the stem and are normally trifoliate.

Adaptation and Distribution

Alfalfa grows best on deep, well-drained, friable soils. Lands subject to frequent overflows or high water tables are unfavorable for alfalfa. The pH of the soil should be 6.5 or above.

Alfalfa is distributed throughout the entire United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment

A seedbed must be smooth, firm, free of weeds and trash, and contain adequate moisture for germination and emergence. Land grading must be sufficient to ensure good surface draining. Alfalfa should not be seeded as a first crop on newly leveled land where fill may settle and cause poor surface drainage.

Five pounds of scarified, properly inoculated pure live seed (PLS) per acre evenly drilled ¼-inch deep on adapted, properly prepared sites will produce adequate stands. A combination drill and packer is desirable.

Cultipacking soil before and after seeding is helpful to establishing a stand. Seeding depths should be no greater than ¼ inch on finer textured soils and no greater than ½ inch on sandy soils Spring seedings can be made 30 days before the average date of last killing frost. Other dates of seeding may be made during the late summer.

Management
In general, graze or cut for hay when alfalfa is in early bloom. Graze or cut to about a 2-inch height. Successive grazings and cuttings for hay should occur at ¼ bloom stage or after a 5 to 6 week recovery period. Alfalfa can best withstand grazing if rotated frequently or grazed in small strips. The last cutting of alfalfa should be made 3 to 4 weeks before the first killing frost date.

Alfalfa may cause livestock to bloat. Care should be used in managing such grazing to reduce the possibility of this hazard.

Pests and Potential Problems
Alfalfa is susceptible to the spotted or pea aphid, alfalfa weevil, stem nematode, bacterial wilt, snout beetle, and several leaf spots.

Cultivars, Improved, and Selected Materials (and area of origin)
Alfalfa is the oldest crop grown for forage and there are many cultivars available on the open market. More than 440 publicly and privately developed cultivars were approved for certified seed production in the U.S. between 1962 and 1992. For a specific state or region of the U.S., use cultivars that are adapted and have been tested for local performance. Cultivars are readily available from commercial seed vendors.

Control
Please contact your local agricultural extension specialist or county weed specialist to learn what works best in your area and how to use it safely. Always read label and safety instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USDA, NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

Edited: 05Feb2002 JLK; 25may06jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

Plant Fact Sheet

ITALIAN RYEGRASS

Lolium perenne L. ssp. *multiflorum* (Lam.) Husnot

Plant Symbol = LOPEM2

Contributed by: USDA NRCS Northeast Plant Materials Program

Britton & Brown 1913
Illustrated Flora of the Northern States and Canada
@ PLANTS

Alternate Names
Lolium multiflorum Lam., annual ryegrass

Uses
Italian ryegrass is primarily used for quick cover in erosion control plantings.

Status
Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness
This plant may become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Please consult with your local NRCS Field Office, Cooperative Extension Service office, or state natural resource or agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at plants.usda.gov.

Description
Italian ryegrass is quite similar to perennial ryegrass except it is an annual or biennial, depending on climate and/or length of growing season. It may grow a little taller than perennial ryegrass, from 2 to 3 feet tall. Plants have a bunchy form, with numerous long, narrow, stiff leaves near the base of the plant. The under surfaces of leaves are bright, glossy, and smooth. Inflorescence stems are nearly naked. The seeds of this sub-species have awns (bristles).

Adaptation
These grasses have a wide range of adaptability to soils, but thrive on dark rich soils in regions having mild climates. They do not withstand hot, dry weather or severe winters. They will stand fairly wet soils with reasonably good surface drainage.

Italian ryegrass is distributed throughout the entire United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment
A fine, firm seedbed gives the best results. Mulched seedings on graded soil germinate readily. Spring seedings of ryegrass may occur in March, April, or May. Seeding rates will vary with local conditions and purpose of plantings. Generally, a seeding rate of 20 to 25 pounds per acre is used if ryegrass is seeded alone. Lesser amounts per acre are used in mixtures, depending upon uses and companion species. Do not exceed 4 pounds per acre in mixes with alfalfa.

Management
This section is under development.

Pests and Potential Problems
This section is under development.

Cultivars, Improved, and Selected Materials (and area of origin)

Ryegrasses cross-pollinate freely so many types have developed. It is difficult to maintain their genetic purity; consequently, Italian ryegrass is marketed as common ryegrass or domestic ryegrass, and it is often a mixture of annual and perennial species. There is no certification of this seed since pure varieties of Italian ryegrass are almost non-existent.

Seed of cultivars and common annual ryegrass is readily available from local commercial suppliers.

Control

Please contact your local agricultural extension specialist or county weed specialist to learn what works best in your area and how to use it safely. Always read label and safety instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USDA, NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Prepared By & Species Coordinator:

USDA NRCS Northeast Plant Materials Program

Edited: 05Feb2002 JLK; 060802 jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

Plant Fact Sheet

BERMUDAGRASS

Cynodon dactylon (L.) Pers.

Plant Symbol = CYDA

Contributed by: USDA NRCS Plant Materials Program

USDA NRCS National Plant Materials Center
Beltsville, MD

Caution: This plant is considered noxious in several states and invasive by several sources. Please check the Noxious and Invasive portion of PLANTS for additional information. Please consult with your local resource specialist prior to using.

Uses

Erosion control: Bermudagrass is used for critical area planting (including channels and pond banks), grassed waterways, and vegetated flumes.

Turf: This grass is suitable for lawns and public areas, and is recommended for problem soils and heavy traffic areas.

Livestock: Bermudagrass provides fair to good pasture and hay with proper management. Forage quality is dependent on soil fertility and stage of growth.

Wildlife: Bermudagrass has forage value for deer, geese and ducks in open, sunny areas.

Recreation: Turf types of the grass form attractive, traffic-resistant, weed-free, and low maintenance ground covers for areas with half to full day sun.

Status

Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness

This plant may become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Please consult with your local NRCS Field Office, Cooperative Extension Service office, or state natural resource or agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at plants.usda.gov.

Description

Bermudagrass, is of probable Asian origin and was documented as an important grass in the United States by 1807. It is a long-lived, warm season perennial that spreads by rhizomes, stolons, and seed. Stems are leafy, branched, and 4 to 6 inches tall. Under favorable conditions, stems may be 12 to 18 inches high. Stems are short jointed. Leaves are flat and spreading. The ligule is a circle of white hairs. Leaves may be hairy or smooth. Seedheads are usually in one whorl of 3 to 7 spikes, each about 1 to 2-1/2 inches long. Some robust forms may have up to 10 spikes in 2 whorls.

Adaptation and Distribution

Although a few hardy strains of Bermudagrass persist in areas with sub-zero winter temperatures, it has achieved importance only in areas of relatively mild winters. Once established on moderately deep to deep soils, Bermudagrass maintains dense sod, non-irrigated, with 16 inches of rainfall. It can withstand sedimentation and long periods of inundation. It prefers full sun and can grow rapidly at air temperatures exceeding 100°F.

Bermudagrass prefers deep soils but produces well on moderately shallow sites under irrigation and good management. It persists on poor soils but require high nitrogen levels for best appearance. It withstands pH ranges from about 5.0 to 8.5 and is boron tolerant. It tolerates saline soils with up to 18 millimhos of electrical conductivity in the soil solution.

Bermudagrass is distributed throughout the majority of the United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment
Stands may be established by use of seed, sprigs, or plugs planted during mid-spring to mid-summer followed by frequent applications of fertilizer and water. Early planting is most important in areas of marginal adaptability.

Beds for seeding or planting should be firm, smooth, and free of weed seed. For turf plantings, absolute smoothness is necessary for close mowing following establishment. Seed, sprigs, or plugs should be placed into moist soil.

For pasture or hay, drill 3 pounds pure live seed per acre at 1/2 inch depth or less. For turf, use 10 pounds of seed per acre. Higher seeding rates are advisable if seed must be broadcast. If using sprigs, broadcast by hand or with hydro-equipment. Punching and irrigation, if needed, must be done immediately following spreading to keep the sprigs from drying out. Surface soil moisture must be kept high while roots and shoots develop at the sprig nodes.

Fifteen bushels of sprigs per acre disk punched or covered with 1-1/2 inches of soil followed by irrigation as needed ordinarily gives fully established stands in one growing season. On saline soils planting in the side of furrows is desirable so salts will accumulate on the ridges above grass rows.

Use of sod rolls or plugs cut from sod is often a preferred method of establishing turf-type Bermuda on critical sites. Plugs of 3 inch diameter planted on 15 to 18 inch centers will ordinarily establish complete cover in 1 growing season with adequate fertilizer, moisture and half-day to full sun. Complete sodding is preferred for very critical areas or where immediate foot traffic is contemplated. Care immediately following planting is less critical on plantings of sod or plugs than turf-type sprigs.

Management
High quality turf will require frequent very low mowing, fertilizer, and water for vigorous growth. Clippings must be removed. A sharp reel-type mower will avoid unsightly scalping. Good to fair quality turf can be maintained on short water and low fertilizer schedules, thereby reducing mowing frequency.

Bermudagrass will persist as a weed-free ground cover on soils of moderate to high water-holding capacity. Where desirable and permissible, mid-winter controlled burning can be used to reduce thatch. Most herbicides used at recommended rates with reasonable care can be used to control undesirable plants without destroying fully established Bermudagrass. Applications of nitrogen every 2 to 5 years will be needed to maintain vigorous stands on most sites.

Both pasture and hay require good rainfall and heavy fertilizer application for high yield and quality. Thirty to forty pounds of nitrogen should be applied in split increments for each ton of anticipated dry forage yield. Highest yields are obtained on good soils in areas of high average annual temperature with ample water. Harvest or graze at 3 to 4 week intervals for best yields of total digestible nutrient and protein.

Pests and Potential Problems
Several white grubs are known to feed on the root system, however they are normally not a major pest.

Cultivars, Improved, and Selected Materials (and area of origin)
'Santa Ana', 'Tifway', 'Tifgreen', 'Tifdwarf', 'Tufcote', 'Brazos', 'Quickstand', 'Coastal', 'Coastcross-1', and 'Midland'. All form dense, fine-textured, weed-free sods and tolerate drought, close mowing and heavy traffic, even on problem soils. Seeds, springs, and sod are all commercially available.

Control
Please contact your local agricultural extension specialist or county weed specialist to learn what works best in your area and how to use it safely. Always read label and safety instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USDA, NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

Edited: 10Aug2000 JLK; 05jun06 jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

BLUE GRAMA

Bouteloua gracilis (Willd. ex Kunth.) Lag. ex Griffiths

Plant Symbol = BOGR2

Contributed by: USDA NRCS Plant Materials Program

© W. L. Wagner
Smithsonian Institution
@USDA NRCS PLANTS

Uses

Livestock: In southern states, blue grama grows as a bunchgrass; in northern states or areas of heavy grazing pressure, it is a sod former.

Erosion control: Blue grama is suitable for mixtures of grasses used in erosion control, low maintenance turf plantings, and surface mine revegetation.

Status

Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Description

Bouteloua gracilis, blue grama, is a major warm season grass found throughout the Great Plains. The plant is fairly short, reaching 10 to 20 inches with narrow basal leaves of 3 to 6 inches. Blue grama grows in definite bunches and reproduces by tillering and by seed. Mature seed heads are curved, resembling a human eyebrow. Blue grama can be found growing in association with buffalograss, western wheatgrass, needlegrasses and in some areas the bluegrasses.

Adaptation and Distribution

Blue grama demonstrates good drought, fair salinity, and moderate alkalinity tolerances. In its dormant state, it will also tolerate burning. Blue grama will not tolerate dense shade, flooding, a high water table, or acid soils.

Blue grama is distributed throughout the western United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment

As with all native grasses, proper ground preparation is one of the most important considerations. The seedbed should be firm but not solid; cultivation to kill the roots of cool-season grasses is essential. Planting may be done by either drilling or broadcasting, with the seed being sown no more than 1/4 to 1/2 inches deep at a rate of 1 to 3 pounds PLS/acre. Seeding in late spring is recommended in the Great Plains; earlier seeding is recommended in areas further south. In the Southwest, seeding should be done during the period from June 15 to July 15. Mulching and irrigation is recommended on harsh sites. Soil tests should be made to test the soils for deficiencies. Blue grama will tolerate low-nutrient soils better than acidic conditions. Planting should be done by a native grass seed drill. In western areas plant blue grama in a sorghum cover crop, stubble, or in with the crop itself.

Management

Once the grass is established, it is very palatable to livestock all year long. Since growing points are at or near the ground surface, the grass withstands fairly close grazing. For best yields, defer grazing during the growing season every 2 to 3 years. Blue grama cures well on stem, making it a good grass for grazing during the dormant season. Renovation of sodbound stands is also recommended. Weeds can be controlled by use of herbicides, mowing or controlled grazing.

Pests and Potential Problems

There are no known serious pests of blue grama grass.

Cultivars, Improved, and Selected Materials (and area of origin)
Improved materials include the cultivars 'Lovington' (NM), 'Hachita' (NM), and 'Alma' (NM) and the selected class release Bad River Ecotype (SD). Seeds are available at most commercial seed sources.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

Edited: 01Feb2002 JLK; 31may06jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

Plant Fact Sheet

TALL FESCUE

Lolium arundinaceum (Schreb.) S.J. Darbyshire

Plant Symbol = LOAR10

Contributed by: USDA NRCS Plant Materials Program

Robert H. Mohlenbrock
USDA, NRCS 1989
Midewestern Wetland Flora
@ USDA NRCS PLANTS

Alternate Names
Schedonorus phoenix (Scop.) Holub, *Festuca arundinacea* Schreb.

Uses
Tall fescue has been over-used in the past, prior to the understanding of its endophyte status and implications. For decades KY-31 tall fescue was planted widely as a forage and erosion control plant because it is widely adapted and easy to establish and long lived under harsh conditions and mistreatment. It is now recognized that the presence of the endophyte (in this grass and others) contributed to both the tough nature of the grass and the poor performance of grazing animals in the warmer months. It is suspected that this endophyte infected cultivar has been deleterious to wildlife as well. For these reasons, there are efforts by some groups to ban the use of tall fescue in some states, and it still may be overused. Please consult the links on the PLANTS Profile for this species for additional information.

Now there are many cultivars of this species, some of which are produced without endophyte contamination of the seed for forage production use. Fine leafed cultivars are intended as turf grasses, and often are intentionally endophyte infected to capitalize on the competitive advantage that the endophyte confers to the plant. Testing services are available to have existing stands of this grass evaluated for endophyte presence. Infected tall fescue is used best as pasture or hay when it is stockpiled for feeding only after fall frosts and freezes have occurred.

The old standby KY-31 (with endophyte) is a very good critical area treatment grass due to its tolerance of poor soils and abuse or neglect. However, the user should be sure this grass will meet all the planting objectives and that there are not good alternative species before specifying its use.

Status
Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness
This plant may become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Please consult with your local NRCS Field Office, Cooperative Extension Service office, or state natural resource or agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at plants.usda.gov.

Description
Tall fescue is a robust long-lived, comparatively deep rooted, bunchgrass. The leaves of forage types are broad, while turf types have been selected for narrow leaves. The flat leaves are smooth and shiny on the underside, with pronounced ribs on the upper surface. The stems are 3-4 feet tall, supporting a nodding panicle that is 4-12 inches long. There are 227,000 seeds per pound.

Adaptation and Distribution
Tall fescue is adapted to cool and humid climates and most soils with a pH of 5.5 to 7.0. Tall fescue will grow fairly well on soils low in fertility, but it is better adapted to fertile conditions. Tall fescue will produce top growth when soils are as cold as 40 degrees F, and it continues growth into late fall in the south.

Tall fescue is distributed throughout the majority of the United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment
Tall fescue is easy to establish due to its rapid germination and good seedling vigor. It may be planted by any common method such as grass seeders, hydroseeding, and broadcasting. Seeding rates for turf are very high in order to obtain a dense, even turf-usually 50-100 pounds per acre. In mixtures with other seed for critical area treatment work, the tall fescue component is typically 10-15 pounds per acre.

Management
While tall fescue is tolerant of abuse and low fertility, it does respond to fertilizer inputs. Follow the soil test recommendations for turf and forage uses. The management considerations for forage use of endophyte infected stands are discussed under **Uses**.

Cultivars, Improved, and Selected Materials (and area of origin)
Several cultivars are recommended in the Northeast for turf; consult university extension publications for the latest ratings. For cool season grass critical area uses, KY-31 is difficult to beat, but there are often other alternatives to this species which will have better wildlife benefit.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

Edited: 05Feb2002 JLK; 060817 jsp

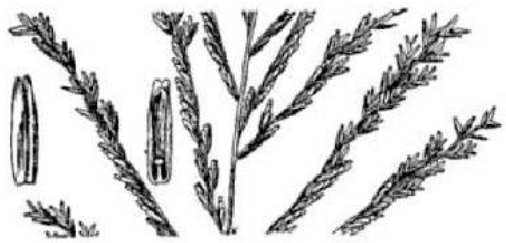
For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

Plant Fact Sheet

GREEN SPRANGLETOP
Leptochloa dubia (Kunth) Nees

Plant Symbol = LEDU

Contributed By: USDA NRCS National Plant Data Center



From Hitchcock (1950)
@ plants.usda.gov

Alternate Names
zacate gigante, green spangletop.

Uses
Green sprangletop is grazed readily by all livestock, especially when green and succulent.

Status
Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status, such as, state noxious status and wetland indicator values.

Description
Grass Family (Poaceae). Green sprangletop is a native, warm-season, short-lived, perennial bunch grass. The height ranges from 1 to 3 feet. The leaf blade is 6 to 18 inches long, usually flat, and sometimes folded. The leaf sheaths are sometimes longer than the internodes, flattened, and often purplish. The ligule is hairy. The seedhead is a spreading, open, nodding panicle 4 to 12 inches long, consisting of 5 to 20 slender, well separated branches 2 to 5 inches long. Each spikelet is 5- to 8-flowered.

Distribution: For current distribution, please consult the Plant Profile page for this species on the PLANTS Web site.

Management
During the dormant season, it furnishes good quality forage, but should be supplemented with a protein concentrate. It is used in range seeding mixtures. When this grass is a key management species, no more than 50 percent of current growth by weight should be removed at any season. Summer and fall grazing deferments of at least 90 days improve vigor, increase seed production, and provide forage for winter use. The seedhead turns pale and droops at maturity.

Establishment
Growth starts about April. If moisture is scarce, it may become semi-dormant in the summer and make new growth after the fall rains. It becomes dormant in the late fall. It may produce two seed crops, one in the spring and one in the fall. It is best adapted to deep sandy soils in Florida and to rocky hills and canyons in the rest of its range. It is seldom found on deep clay or deep sandy soils in the western part of its range.

Cultivars, Improved and Selected Materials (and area of origin)
Please contact your local NRCS Field Office.

Reference
Leithead, H.L., L.L. Yarlett, & T.N. Shiflett. 1976. 100 native forage grasses in 11 southern states. USDA SCS *Agriculture Handbook No. 389*, Washington, DC.

Prepared By & Species Coordinator:
Percy Magee, USDA NRCS National Plant Data Center, Baton Rouge, Louisiana

Edited: 13may02 ahv; jul03 ahv; 20sep05 jsp; 070116 jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at 202-720-2600 (voice and TDD).

To file a complaint of discrimination write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence Avenue, SW, Washington, DC 20250-9410 or call 202-720-5964 (voice or TDD). USDA is an equal opportunity provider and employer.

Read about Civil Rights at the Natural Resources Convervation Service.

LITTLE BLUESTEM
Schizachyrium scoparium (Michx.) Nash
Plant Symbol = SCSC

Alternate Names
Common Names: povertygrass, broom bluestem, broom beardgrass, prairie beardgrass, small feathergrass
Scientific Names: *Andropogon scoparius*

Description
General: Little bluestem is a tufted (sometimes with short rhizomes), warm-season (C_4), perennial grass broadly distributed and native to the U.S. and Canada. Because of this broad distribution, little bluestem exhibits significant ecotypic variation. Plants vary in height, color, length of leaves, flowering, and clump diameter (USDA, 1983; Uchytil, 1989). It grows from 1 to 3 feet tall with culms slightly flattened. The blades are folded, sometimes rolled inward, and smooth to hairy. They are 2 to 12 inches long, 1.5-6 mm wide, pointed with sheaths keeled and usually smooth. The ligule is a fringed membrane 0.5-2.5 mm long. The culms terminate in a single raceme 1-3 inches long. The pediceled spikelets are 3-6 mm long with pedicels flattened. The awns of the fertile lemmas are 9-16 mm long, bent and twisted. The anthers are 2-4 mm long (Sedivec and Barker, 1997). Seed averages 225,000 to 250,000 bearded seeds per pound (Uchytil, 1989).

Distribution: Little bluestem is found throughout the lower provinces of Canada and all states of the U.S., except Nevada and Washington. For current distribution, please consult the Plant Profile page for this species on the PLANTS Web site.

Habitat: This midgrass is a tallgrass prairie increaser and mixed prairie decreaser. Little bluestem typically occurs on dry upland sites, especially on ridges, hilltops, and steep slopes. It also occurs on limey subirrigated sites and in prairie fens. It is found in areas receiving 10 to 60 inches of mean annual precipitation and plant hardiness zones 3 to 9.

Adaptation
Little bluestem is adapted to soils ranging from sandy to clay-loam in texture. It begins growth in late spring after cool-season species have already developed (Uchytil, 1989). It has been observed that little bluestem phenology follows a well-defined pattern. Periods of active growth as well as stage of maturity are directly related to the length of the growing season (Miller, 1967; USDA, 1983).

Uses
Pasture/rangeland/prairie restoration: This species provides fair to good forage while young. It is rated fair for cattle and horses, but is usually too coarse for sheep and goats. Ungrazed wolf plants with seed stalks often give the false impression of non-use for the plant community. Shorter plants between the wolf plants have usually been grazed quite extensively. Crude protein is 12 to 14 percent in May, dropping off considerably in July through September to less than 4 percent (Sedivec and Barker, 1997). Little bluestem has been used extensively in prairie restoration projects primarily because of its adaptation to a diversity of sites, drought tolerance, growth habit, and wildlife appeal.

Erosion control: Little bluestem has moderate drought tolerance and broad adaptation to diverse sites. It can form mats from short rhizomes on wetter sites although this species is usually thought of as a bunchgrass (clumps) on dry, upland sites. It is deep-rooted, and somewhat slow to establish from seed.

Wildlife: Little bluestem is one of the best grasses for nesting and roosting habitat. The clump type of growth habit and many fine leaves at the base provide excellent nesting sites. The seeds are consumed by small mammals and birds, including upland game birds, rosy finches and juncos, as well as chipping, field, and tree sparrows. The seeds are of high value especially as a food source for birds that spend the winter on grasslands, such as prairie chickens and sharp-tailed grouse (Jones, 1963). Meadowlarks nest in areas where little bluestem grows. The dusky skipper butterfly caterpillars overwinter in tube tents above the base of the clumps (Knopf et al., 1997).

Landscaping: Little bluestem is becoming more popular for home landscaping because it is a colorful and easy-care addition. New varieties are being developed that don't lodge (falling over at the base) and are more disease resistant. New growth can be bluish, maturing to a reddish-gold color. The seed develops to a fluffy silver-white. The plumes are showy when seed has matured which adds interest to a cut arrangement. Frost accents the plants and the reddish tint provides color during the winter (Mahr, 2007). This is a prairie grass for the garden that is truly exceptional in mass plantings. Use in full sun.

Ethnobotany: Some tribes used little bluestem switches in ceremonial sweat lodges. The Lakota word means "small red grass". Dried leaves and stems were rubbed into soft fiber for moccasin lining and insulation (Johnson and Larson, 1999).

Status
Please consult the PLANTS web site (http://plants.usda.gov) and your State Department of Natural Resources for this plant's current status (e. g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness: This plant may become weedy or invasive in some regions or habitats and may displace more desirable vegetation if not properly managed. The seed is light and fluffy, and may spread to the surrounding areas, especially in a garden or landscape setting. Seed is generally dispersed a short distance from the parent plants. The maximum dispersal is only 5 to 6 feet and seedling vigor is weak (Uchytil, 1989). Consult with your local NRCS Field Office, Cooperative Extension Service office, state natural resource, or state agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at http://plants.usda.gov/. Consult the Related Web Sites on the Plant Profile for this species for further information.

Management
Little bluestem begins growth later in the spring after the cool-season species have already developed. It tolerates glyphosate when dormant, and other herbicides as labeled for grasses. Weed control can be accomplished by mowing, especially the first year when the planted grass is short. It is minimally affected by fire if burned dormant and changes little in frequency of occurrence due to fire. Little bluestem is relatively resistant to fire under moist conditions. The growing points (apical meristem) are slightly more than an inch above the soil surface (Uchytil, 1989). Little bluestem in the immature growth phase is considered a nutritional, palatable grass for all classes of livestock in June and early July in studies in North and South Dakota. Palatability is lower than many other native warm-season grasses, especially when seed stalks are present. Proper grazing management is critical to improve grazing efficiency. Little bluestem is an increaser under season long grazing systems. Higher stock densities such as rotational grazing systems will achieve greater use of more plants. Recommended stubble height of 3 to 4 inches is required to assure stand longevity. Although not usually recommended for hay production, little bluestem can make fair to good hay when part of a native hayland mixture (Sedivec et al., 2008). It is a popular species to include in prairie restoration seedings because of its wide adaptation and high wildlife value. Plants will sometimes die from the center out in the clump if the plants become too dry. Burning at the opportune time can help to reduce the population of cool-season competing vegetation, as well as woody species.

Pests and Potential Problems
A leaf spot disease was found to be widespread in a little bluestem nursery established at Mandan, North Dakota, from plants collected in North Dakota, South Dakota, and Minnesota. *Phyllosticta andropogonivora* was consistently isolated from leaves showing leaf spot symptoms. The fungus was also isolated from native prairie plants. The fungus was pathogenic to little bluestem, big bluestem (*Andropogon gerardii*), and sand bluestem (*Andropogon halli*) (Krupinsky and Tober, 1990).

Environmental Concerns
This grass is primarily a bunchgrass that will spread some by seed. The seed is light and fluffy and it will move to adjacent areas. Bare soil may allow seed to germinate, but it is usually not a problem. Random plants in a natural landscape are usually not considered undesirable because it is a native species.

Control
Please contact your local agricultural extension specialist or county weed specialist to learn what works best in your area and how to use it safely. Always read label and safety instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USDA NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Seeds and Plant Production
Seed into a firm seedbed in early spring for best results. Seed as a solid stand (8 inches or less row spacing) at approximately 4.5 lb/acre (eastern ND rate), or 30 seeds per linear foot of row, or 2.5 lb/acre for 24-inch rows. Glyphosate may be used for weed control immediately

after seeding to kill everything green and growing. Other herbicide weed control options are also available. Consult with the local extension service or Land Grant University for assistance with recommendations on herbicides and application rate. Always read and follow the label directions when applying herbicides. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. government and does not imply its approval to the exclusion of other products that may also be suitable.

Seed is best harvested from the plant using a commercial stripper at 600 to 800 rpm at the hard dough or mature seed stage. This is because of the light, fluffy seed, and the uneven maturity. Straight combining is another method of harvest when most of the seed has matured. Average dockage of combined seed is 60 percent. Seed should be air dried for a couple of days. Seed for the bin should be dried to 12 percent or less, and sacked seed should be 15 percent or less. Average yield is 200 to 300 lb/acre irrigated and 75 to 150 lb/acre dryland. Processing the seed is fairly difficult because of the fuzziness of individual spikelets. It should be debearded first. A hammermill works well with a 3/16-inch screen at 550 rpm, and then a debearder at 200 rpm for 45 to 60 minutes. Scalping or final cleaning may be done using a 4-screen fanning mill. Post-harvest management requires rotary mowing, rototilling, or cultivating between rows in the fall or spring; or burning on a regular basis in early spring (Smith et al., 1989).

Plants may be grown in the greenhouse using standard greenhouse procedures. Deeper containers (4 inches or more) are recommended because perennial grasses develop extensive root systems. A critical factor in growing little bluestem is day length. A study in North Dakota required 18 hours of artificial light each day for continued growth of seedling little bluestem plants (USDA, 1983) during the winter months.

Little bluestem has high genetic diversity.

Cultivars, Improved, and Selected Materials (and area of origin)

'The Blues', 'Prairie Blues', 'Blue Heaven', 'Carousel', and several other varieties have been developed for landscaping and ornamental use. Sources for conservation planting showing the year of release, and origin include the following:

Coastal Plains Germplasm	2016	TX
STN-176 Germplasm*	2015	TX
STN-461 Germplasm*	2015	TX
Ozark Germplasm	2010	MO
Suther Germplasm	2008	NC
Prairie View Indiana Germplasm	2005	IN
OK Select Germplasm	2003	OK
Spirit Ecovar (Canada)	2003	SK,MB
Southlow Michigan Germplasm	2001	MI
Itasca Germplasm	2001	ND,SD,MN
Taylor Ecovar (Canada)	2000	MB,SK
Southern Iowa Germplasm	1999	IA
Northern Iowa Germplasm	1999	IA
Northern Missouri Germplasm	1999	IA
Central Iowa Germplasm	1997	IA
Badlands Ecotype	1996	ND,SD
'Cimmaron'	1979	KS,OK
'Camper'	1973	NE,KS
'Blaze'	1967	NE,KS
'Aldous'	1966	KS
'Pastura'	1964	NM

*Carrizo Blend is a commercial post-harvest blend of STN-176 Germplasm and STN-461 Germplasm. The blend should contain no more than 50 ± 10% of each of the two germplasms.

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Citation

Tober, D. and N. Jensen. 2013. Plant guide for little bluestem (*Schizachyrium scoparium*). USDA Natural Resources Conservation Service, Plant Materials Center, Bismarck, North Dakota 58501

Published: May 2013

Edited: May 2016

For more information about this and other plants, please contact your local NRCS field office or Conservation District at http://www.nrcs.usda.gov/ and visit the PLANTS Web site at http://plants.usda.gov/ or the Plant Materials Program Web site http://plant-materials.nrcs.usda.gov. PLANTS is not responsible for the content or availability of other Web sites.

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

Plant Fact Sheet

SIDEOATS GRAMA

Bouteloua curtipendula (Michx.) Torr.

Plant Symbol = BOCU

Contributed by: USDA NRCS Plant Materials Program

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Smithsonian Institution
@USDA NRCS PLANTS

Uses

Erosion Control: This grass is adapted to most soil conditions. Successful seedings are obtained in rocky, stony, or shallow soils. It is a fair to good erosion control plant when mixed with the other plants naturally associated with it.

Grazing: This is one of the most important range grasses. Although not as palatable as some of the smaller gramas, e.g. blue grama, it is more palatable than many of the other grass species. It produces a much greater volume of forage than blue grama, and this tends to make up for its slightly lower palatability. It remains green later in the fall and usually begins growth in the spring before other gramas. It cures well, and maintains a fairly high feeding value throughout the year.

Wildlife: Furnishes some forage for deer and antelope when green. Elk use this plant throughout the year.

Status

Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values). It is considered threatened in several states.

Description

Bouteloua curtipendula, sideoats grama, is a medium-size perennial bunchgrass, 15 to 30 inches tall or occasionally taller. This is the largest and most coarse of the grama grasses. It has a bluish-green color, sometimes with a purplish cast (especially in the spring), and cures to a reddish-brown or straw color. Leaves are coarser than other species of gramas, straight, comparatively stiff, and mostly basal. Ten to thirty small, non-comb-like spikes are borne mostly along one side of each central seed stalk. These spikes drop when mature, leaving a long zigzag stalk.

Adaptation and Distribution

Sideoats grama is found on rocky open slopes, woodlands, and forest openings up to an elevation of about 7,000 feet.

Sideoats grama is distributed throughout most of the United States. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment

Seeding of improved strains of this grass is accomplished by drilling in firm, weed-free seedbeds at the rate of 2-1/2 to 5 pounds (or more) pure live seed per acre. Protect from grazing from date of seeding through the second growing season. Seedings should be delayed until good soil moisture is present.

Management

Sideoats grama is not as resistant to grazing as blue grama because of its taller growth habit, but sideoats grama stays green longer and can be grazed for a longer period. Reduced forage production, carrying capacity, and loss in cattle weight is a direct result of overgrazing. Sideoats grama is a normal component of a large number of range sites. The grass lengthens the grazing season and increases forage production, in addition to providing variety in the feed. Sideoats grama will return to most ranges under good management. Practices that will bring the grass back include proper grazing use, planned grazing systems, and brush control.

Pests and Potential Problems
There are no serious pests of sideoats grama.

Cultivars, Improved, and Selected Materials (and area of origin)
Released cultivars include'Butte' (NE), 'El Reno' (OK), 'Haskell' (TX), 'Niner' (NM), 'Premier' (Mexico), 'Trailway' (NE), and 'Vaughn' (NM); informal releases include Killdeer (ND) and Pierre (SD); and source identified releases include Northern Iowa Germplasm, Central Iowa Germplasm, Southern Iowa Germplasm (all from IA). Seeds are available at most western commercial seed sources.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

Edited: 01Feb2002 JLK: 31may06jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

Plant Guide

COMPOSITE DROPSEED

Sporobolus compositus (Poir.) Merr. var. *compositus*

Plant Symbol = SPCOC2

Contributed by: USDA NRCS Elsberry Plant Materials Center and the National Plant Data Center

Ann Gardner
Ada Herbarium, Iowa State University

Alternate Names

Sporobolus asper, *Sporobolus asper* var. *hookeri*, rough dropseed, tall dropseed, zacaton

Uses

Forage: Composite dropseed is a minor portion of the vegetative composition in most of the areas in which it grows. It is not a particularly valuable forage species. The forage value of composite dropseed, compared to other grasses, is fair for livestock and poor for wildlife. It is most palatable in the spring when plants are in the vegetative developmental stage and palatability declines as culms mature. In Kansas composite dropseed tends to increase in overgrazed bluestem pastures, but it tends to decrease in short-grass prairies.

Prairie restoration and Roadside plantings: On upland hardwood forest-tallgrass prairies in central Oklahoma, the diet of cottontail rabbit is dominated by composite dropseed, Heller's rosette grass (*Dichanthelium oligosanthes*), and *Croton* species. Disturbed habitats were maintained by removal of woody overstory vegetation with herbicide and burning. Differences in the botanical composition and quality of rabbit diets between disturbed and undisturbed habitats were of little biological significance.

Status

Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Description

General: Grass Family (Poaceae). Composite dropseed is a tall (2 to 4 ft.), native, perennial, warm-season bunchgrass. Culms are erect, solitary or in small tufts, simple or branching, 24 to 48 inches tall, solid and glabrous. Some varieties have short rhizomes. Inflorescences are narrow panicles, 2 to 12 inches long and partially to completely included in the upper sheaths. The inflorescences are either white or pale purple in coloration. Composite dropseed flowers during late summer to early autumn. The stems and leaves bleach whitish during winter.

Distribution: For current distribution, please consult the Plant Profile page for this species on the PLANTS Web site.

Habitat: Composite dropseed occurs on prairies and foothills on dry clayey to silty soils. It is most abundant on soils that are intermittently wet and dry. It does not grow on either deep sandy soils or on soils with a high water table. In the Great Basin composite dropseed grows on dry often sandy sites in Juniper communities and in fallow fields below 2,100 ft.

Adaptation

Composite dropseed is more drought tolerant than many grasses of the bluestem prairie, but it is not as drought hardy as sand dropseed (*Sporobolus cryptandrus*).

Establishment
Pretreatment of composite dropseed seeds with potassium nitrate resulted in 39% germination.

Management
Burning in early spring favors warm-season composite dropseed, whereas late spring burning favors cool-season species. Forage yield of composite dropseed increased following a spring burn during both wet and dry years in an Ashe's juniper (*Juniperus ashe*) community in southeastern Texas. An autumn burn favored the growth of composite dropseed in a southern Texas chaparral community.

A field study addressed the effects of fire, cattle grazing and the interaction of these two disturbances on plant species abundance and community structure in an tallgrass prairie in Oklahoma. Plant species composition was sampled across 4 levels of increasing disturbance intensity: ungrazed + unburned (undisturbed), grazed + unburned, ungrazed + burned, and grazed + burned. Burning occurred during mid-April. Grazing occurred from mid-May to September at a moderate to heavy stocking rate. Burning decreased the percentage cover of composite dropseed from 11.7 to 4.8, when averaged across grazing treatments and years. Grazing had no effect on the percentage cover of composite dropseed. The common species in the plant community were classified as either matrix or non-matrix species. Matrix forming species are superior competitors that consume the majority of resources, and non-matrix species occupy areas between the matrix forming dominants. In this study the matrix species were perennial grasses: big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and composite dropseed. The non-matrix species were perennial and annual forbs, and the annual grass cheatgrass (*Bromus tectorum*). Collectively, the matrix and non-matrix species exhibited an opposite response to both burning and grazing treatments. Collectively, fire increased the cover of matrix-forming grass; composite dropseed was an exception. Grazing decreased the cover of matrix grasses and increased the cover of forbs. Cheatgrass was the most common non-matrix species. Burning reduced the percentage cover of cheatgrass from 30.0 to 1.8, when averaged across grazing treatments and years.

Pests and Potential Problems
This plant may become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Please consult with your local NRCS Field Office, Cooperative Extension Service office, or state natural resource or agriculture department regarding its status and use. Weed information is also available from the PLANTS Web site at plants.usda.gov.

Control
Please contact your local agricultural extension specialist or county weed specialist to learn what works best in your area and how to use it safely. Always read label and safety instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USDA NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Seeds and Plant Production
An average seed lot of composite dropseed contains 759,362 seeds per pound. Observations indicate that cross-pollination in composite dropseed is possible but probably infrequent. Nevertheless, standard isolation procedures should be used in composite dropseed seed production.

Cultivars, Improved, and Selected Materials (and area of origin)
Contact your local Natural Resources Conservation Service (formerly Soil Conservation Service) office for more information. Look in the phone book under "United States Government". The Natural Resources Conservation Service will be listed under the subheading "Department of Agriculture."

"Northern Missouri Germplasm" is a source identified ecotype for northern Missouri counties. It was collected from native prairie remnants in Missouri counties north of the Missouri River and from east to west across northern Missouri. The potential uses of Northern Missouri Germplasm include roadside plantings, prairie restoration, landscaping, and increasing species diversity in prairie communities. Seed is available from the USDA NRCS Elsberry Plant Materials Center, 2803 N. Hwy. 79, Elsberry, Missouri.

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Prepared By
USDA NRCS Elsberry Plant Materials Center and James Henson, National Plant Data Center

Species Coordinator
USDA NRCS Elsberry Plant Materials Center, Elsberry, Missouri

Edited: 23March2006 jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

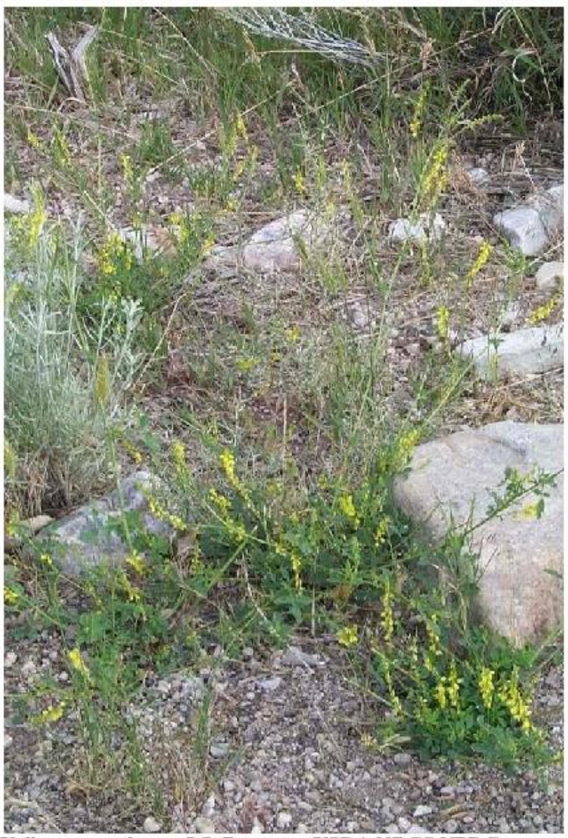
United States Department of Agriculture
Natural Resources Conservation Service

Plant Guide

YELLOW SWEETCLOVER & WHITE SWEETCLOVER
Melilotus officinalis (L.) Lam. & *M. alba* Medik

Plant Symbol = MEOF, MEAL2

Contributed by: Idaho NRCS State Office and Aberdeen, ID Plant Materials Center



Yellow sweetclover. J.S. Peterson. USDA NRCS NPDC

Alternate Names

Ribbed millet; Field millet; Cornilla real; Official melilot

Uses

Wildlife

Sweetclover provides food and cover to a variety of birds and mammals. The stems and leaves can make up a large portion of the diet of elk, deer and antelope. Mule deer diets can be comprised of over 70 percent sweetclover in summer and early fall (Sullivan, 1992). Elk prefer the forage in summer and fall while mule deer and antelope use it for forage throughout the year (Kufeld et al. 1973); however, the plants become coarse, stemmy and less palatable late in the season.

Sweetclover is utilized by birds as cover and food. Sharp-tail grouse, greater prairie-chicken, gray partridge, ring-necked pheasants and many quail species eat the seed (Wasser et al., 1986). It has been recommended to improve sage grouse habitat (Beck and Mitchel, 1997) and for use in reducing post-burn soil erosion in green strips (Braun, 2006). It provides good nesting materials for ducks and good habitat for pheasants, grouse and other upland birds as well as bitterns and passerine species. Small mammals eat the seed and use the plants for cover and nesting.

Pollinators

Sweetclover flowers are attractive to bees and butterflies (Ogle et al., 2007). The scientific name *Melilotus* comes from the Latin Mel (honey) and *Lotus*, another genus within the Legume family. It is a popular species for honey production (Baldridge and Lohmiller, 1990). Honey yields of up to 200 pounds per colony have been obtained (USDA, 1937). Seed production improves with supplemental pollinators. Seed production fields utilizing natural pollinators yield between 50 and 100 pounds of seed per acre, while fields using one to two colonies of honey bees yield up to 700 pounds of seed per acre (Baldridge and Lohmiller, 1990).

Livestock

Sweetclover can be used for hay, silage or pasture. It is; however, less palatable than many other legumes because of its bitter taste caused by the chemical coumarin in the plant tissues. Cattle graze it sparingly at first but increase intake as they become used to the bitter taste. It is somewhat more palatable in spring and early summer than later in the season when stems become woody. It has fair to good palatability for cattle, sheep and horses. Sweetclover has been used to improve forage production for livestock on low forage value sites.

Sweetclover hay yields are good, but it can be difficult to harvest (Baldridge and Lohmiller, 1990). Forage and hay yields range from approximately 2,000 to 6,000 pounds per acre depending on variety and location (Meyer, 2005). Hay must be cut in the bud to 10% bloom stage. Waiting until full flowering results in stemmy, lower-quality hay.

The National Academy of Sciences (1971) gives the following nutritional values for sweetclover:
crude protein 15%; digestible protein 10.2% (cattle), 10.8% (goats), 10.5% (horses), 10.4% (rabbits), and 10.6% (sheep).

Bloat caused by sweetclover is less of a problem than with alfalfa and clover species. The chance of bloat can be reduced by providing other dry feed in addition to sweetclover and by providing adequate water and salt (Meyer, 2005).

Reclamation
Rapid growth and easy establishment make sweetclover a popular choice for reclamation seedings. Additionally it works well in seed mixtures for road cuts, post-fire, mine spoils and other disturbed sites (Thornburg 1982). Sweetclover, like other legumes, increases nitrogen in poor soils. The large taproot increases aeration and water absorption by opening the subsoil (Baldridge and Lohmiller, 1990).

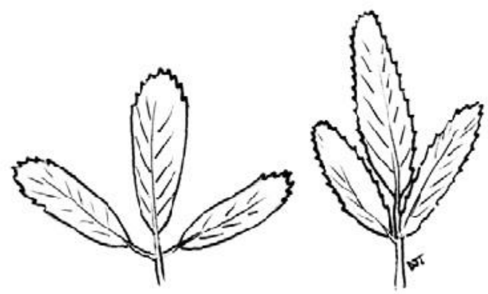
Medical
Sweetclover contains coumarin which breaks down when the plant is spoiled or damaged to dicoumarin (Schipper, 1999). This compound is used as a blood thinner and anticoagulant in rat and mouse poisons and also for treating human ailments. (Smith and Gorz, 1965). Coumarin is the cause of sweetclover bleeding disease which affects cattle after prolonged grazing on moldy or damaged sweetclover hay. For more information, refer to the "Pests and Potential Problems" section of this guide.

Green manure
Prior to World War II, sweetclover was an important green manure crop. Its ability to grow rapidly and fix nitrogen made it an ideal green manure. Interest in sweetclover for green manure dwindled rapidly after World War II when commercial fertilizers became readily available. When used for green manure, plowing under sweetclover residue increases soil nitrogen content when compared to just harvesting top growth for forage.

Description
General: Legume Family (Fabaceae). Yellow and white sweetclover have historically been separated by taxonomists. According to Isley (1998) in addition to flower color, the two species can be separated by flower size (white are 4-5 mm long, while yellow are 5-7 mm long) and the ridge patterns on the fruit (white are reticulate, while yellow are cross-striate). New evidence however suggests that synonomizing the two species under *M. officinalis* may be warranted.

Sweetclover flower. Patrick J. Alexander

Broadly speaking, sweetclover is an annual to biennial forb reaching 5 feet (1.5 m) in height. Leaves are trifoliate (3 leaflets) with short stems. Each leaflet is 8-38 mm long and 3-16 mm wide with teeth along the entire margin, unlike alfalfa which only has teeth on the distal half of the leaflet. Leaves can be hairy or not, but are most commonly smooth. Flower stalks bear 20 to 65 flowers.



Alfalfa leaf (left) and sweetclover leaf (right). Derek J. Tilley

Yellow sweetclover is reported to be shorter growing, more widely branching, finer stemmed, more drought tolerant and easier to establish than white sweetclover (Meyer, 2005).

Like other plants in the legume family, sweetclover forms root nodules when infected with the correct rhizobium bacteria, creating higher levels of soil nitrogen.

Seeds are small and similar in appearance to alfalfa seed. There are an average of 260,000 seeds/lb. Sweetclover seed requires scarification before germination. Natural scarification occurs via freeze-thaw cycles, fire, or passage through an animal's digestive track. Seed can remain viable for 40 or more years.

Distribution:
Sweetclover was introduced to North America from Europe in the 1700's (Meyer, 2005). The species is now widespread throughout North America in a broad array of habitats and plant communities.

For current distribution, consult the Plant Profile page for this species on the PLANTS Web site.

Habitat:
Sweetclover plants inhabit roadsides, riparian zones and other communities from low to middle elevations. It is common in mountain shrub communities, cottonwood bottomlands, Rocky Mountain juniper habitats and on bluebunch wheatgrass – big sagebrush ecological sites from sea level to 8,500 ft.

Status
Consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Weediness
Sweetclover was considered a weed in North America until the early 1900's when its value as a range and pasture plant was realized (Baldridge and Lohmiller, 1990). Since then it has been used extensively for rangeland seedings, soil stabilization, and reclamation projects as well as for pasture.

Its ability to establish in disturbed areas and to spread from seedings has caused it to again be viewed as a weedy species by many land managers. Under optimum conditions sweetclover can invade into adjacent native plant communities and compete with desirable native species.

Adaptation
Sweetclover is the most drought tolerant of the commercially available legumes (Ogle et al., 2008b). It has been used effectively in areas receiving as little as nine inches mean annual precipitation, though it does best in 12 to 20 inch precipitation zones (Thornburg 1982).

Sweetclover commonly establishes from seed during years with abundant spring rains and remains in the plant community for at least two growing seasons. Then during periods of drought it may be totally lacking in the plant community, until again a good moisture years occurs and it becomes abundant once again.

Sweetclover seedlings can tolerate 10 to 14 days of early spring flooding (Baldridge and Lohmiller, 1990).

Yellow and white sweetclover are adapted to all soil textures, but they perform best on medium textured sandy to clayey soils (Baldridge and Lohmiller, 1990). Sweetclover will not tolerate acidic soils; a pH of 5.5 is the plant's lowest limit. It can however withstand slight to moderate saline conditions as high as 10 mmhos/cm² (Ogle et al., 2008a).

Sweetclover is highly tolerant of frost and cold temperatures. The plants have evolved contractile roots, which pull the plant crown down into the soil in the fall, allowing the plant to survive cold winter temperatures.

Sweetclover is not shade tolerant. It will invade sunny open disturbed areas, but does not move into areas with an established perennial canopy.

Establishment
Seed should be planted in a firm, weed-free seedbed at a depth of 1/8 to 1/2 inch. Ground can be prepared with tillage equipment and then packed to firm the seedbed. Seed can be planted up to 2 inches deep but will take much longer to germinate than shallower planted seed. Seed must be chemically or mechanically scarified prior to seeding or planted in the fall to stratify naturally. Most seed bought commercially is pre scarified (Baldridge and Lohmiller, 1990). Seed should be inoculated with the proper rhizobium bacteria for nitrogen fixation. When properly inoculated, sweetclover will not need supplemental nitrogen. Add phosphorus and potassium as indicated by soil tests.

Sweetclover is not generally recommended for pure stands unless it is being used as a green manure crop. Under this condition plant at a rate of 4 lb/ac.
If using sweetclover as part of a seeding mixture for conservation cover, dryland pasture or range plantings, the percentage of the seeding mixture should not exceed 10 percent of the mixture. This is due to its competitive nature with other establishing species. Plant at a rate of 0.10 to 0.25 lb/ac (Ogle et al., 2008b).

Under irrigated pasture conditions, use approximately 1 lb/ac of sweetclover in grass mixtures.

Sweetclover seed is easy to clean and to store. Any seed purchased should exceed 95% purity and 85% germination.

Plant prior to spring or summer rains depending on location. Range seedings should be completed in the late fall or winter to allow for natural stratification of the seed. Sweetclover can be planted at any time under irrigated conditions (must use scarified seed) but should be planted at least 6 weeks prior to hard frosts (Wasser et al., 1986). Drill or broadcast with an alfalfa- type drill or with a grain drill equipped with a legume seed box. Sweetclover can also be planted using a grain drill if seed is mixed with an inert carrier such as rice hulls. For this application the grain drill should be set to seed one bushel of barley per acre. For large rangeland seedings or on rough terrain, sweetclover can be broadcast aerially.

Management
Establishing stands should not be grazed during the year of establishment. Begin grazing the second year when new growth is 6 to 8 inches tall. Stocking rates may need to be increased from normal rates in order to keep plants from becoming stemmy and less palatable. If plants become coarse and stemmy, mowing to a stubble height

of 10 to 12 inches may be necessary to achieve regrowth (Meyer, 2005).

Plants should not be heavily grazed or closely mowed in the fall as growth will be hindered the following year. Poor fall management results in loss of plants through winter-kill, and provides less forage the following year. Hay must be cut at least 10 to 12 inches in height for good regrowth to occur since regrowth comes from stem buds (Baldridge and Lohmiller, 1990).

Burning sweetclover stands can damage tissues and kill existing plants; however, burning typically aids in establishing better stands by creating openings for plants to spread and by scarifying seed in the seed bed.

There are no herbicides labeled for application on establishing seedlings or on established sweetclover fields (Meyer, 2005).

Sweetclover can be an effective hay or silage if managed properly. It has not been widely used due to its coarse stems which take longer to dry than the leaves, resulting in leaf loss during baling. Swathers with conditioning equipment decrease curing time and resulting hay is comparable in feed value to alfalfa (Meyer, 2005). Harvest for hay at the bud to 10% bloom stage. Harvesting in late bloom stage decreases forage yield and reduces digestibility and overall forage quality (Meyer, 2005).

Because of the danger of sweetclover bleeding disease, sweetclover should be baled drier than other grass or legume hay to reduce risk of molding. For small bales dry to at least 12% moisture, larger bales should be dried to 13 to 14% moisture (Meyer, 2005).

Sweetclover silage should be about 65% moisture content when stored in silos and green chop bunks or piles. When stored as haylage or low-moisture silage it should have a moisture content of 55 to 65%. All silage should be cut at the proper growth stage, fine chopped and filled rapidly to aid packing. Silage should be covered to exclude outside air to prevent mold. Any moldy surfaces should be removed prior to feeding (Meyer, 2005).

Pests and Potential Problems

Sweetclover plants contain coumarin, which is the cause of sweetclover bleeding disease. Coumarin breaks down to dicoumarin when a plant becomes damaged or moldy. Dicoumarol is an anticoagulant which causes hemorrhaging in cattle and can be fatal. Animals will have difficulty clotting, and may bleed to death from small external or internal injuries. Do not feed sweetclover to livestock for at least three weeks prior to castrating or dehorning and 30 days prior to calving. Sheep and horses are less prone to sweetclover bleeding disease due to their more selective eating habits (Schipper, 1999).

The best way to avoid sweetclover bleeding disease is to use certified seed of low-coumarin varieties such as Norgold or Polara. Problems can be avoided if hay is properly dried and cured, or by supplementing moldy hay with other better quality feed. It takes several weeks of eating moldy sweetclover hay to cause bleeding disease.

Bloat is less common from sweetclover than with alfalfa or clover, but can occur.

Sweetclover weevil (*Sitona cylindricollis*) reduces sweetclover stands. Brown root rot, common leaf spot and gray stem canker can also pose problems. 'Yukon' is reported to be resistant to brown rot and gray stem canker. Control common leaf spot by cutting before defoliation becomes severe. Gray stem canker can be controlled with a good crop rotation and by cutting fields cleanly (Smith and Gorz, 1965).

In areas of the southwest, Arizona fescue (*Festuca arizonica*) and mountain muhly (*Muhlenbergia montana*) contain allelopathic chemicals that reduce germination of sweetclover and inhibit radicle growth (Reitveld, 1977).

Environmental Concerns

Sweetclover volunteers and spreads easily. It is considered a weed in some areas.

Seed Production

Plant sweetclover seed at 2.1 to 2.5 lbs/ac in 24 inch rows and at 1.5 to 2.0 pounds per acre in 36 inch rows for seed production fields (Ogle et al., 2008b). To facilitate seed production and between row weed control, it is desirable to plant sweetclover in spaced rows instead of solid stands. Most plants germinate from March to April but can germinate anytime water is available. Sweetclover rarely flowers during the first growing season. First year shoots will die back with freezing temperatures, and second year growth initiates from the subterranean crown. Flowering occurs in May to June with seed set in June through July. Sweetclover will produce only one seed crop.

Honey bees are essential for seed production. Seed production fields utilizing natural pollinators on average yield between 50 and 100 pounds of seed per acre, while fields using colonies of honey bees yield up to 700 pounds per acre (Baldridge and Lohmiller, 1990).

Seed is ready to harvest when pods turn brown, dark gray or white. Fields should be swathed when 30 to 60 percent of the pods are brown to black, and immature seed should be allowed to cure in the swath (Meyer, 2005). Swathed rows can be picked up with a combine, but care should be taken not to leave rows on the ground too long or seed can be lost from shattering. Swath and combine in early morning when plants are damp. This will improve feeding through the machines and reduce seed shatter. Use slow cylinder speeds for maximum seed yields (Baldridge and Lohmiller, 1990).

Control

Moderately good sweetclover control can be achieved with a number of broadleaf herbicides. Sweetclover plants are more difficult to kill in the second year of growth.

Once established it is very difficult to completely control sweetclover. Chemical herbicides such as 2,4-D will kill existing plants, but new stands will establish from seed deposited in the soil. Seeds may remain dormant in the seedbed for many years, and new stands can establish years after control.

A regimen of concentrated grazing during the late summer and fall can reduce root reserves in established plants. This in turn will cause plant mortality the following year, lowering plant densities to an acceptable level (Meyer, 2005).

Contact your local agricultural extension specialist or county weed specialist to determine the best control methods in your area and how to use them safely. Always read label and safety instructions for each control method. Trade names and control measures appearing in this document are only to provide specific information. USDA NRCS does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Cultivars, Improved, and Selected Materials (and area of origin)

There are several released cultivars of sweetclover. Most of these have not, however, performed any better than common seed sources. Currently the majority of marketed seed comes from uncertified lots (Stevens and Monsen, 2004). Goldtop, Madrid, Norgold and Yukon are the yellow sweetclover releases; while Evergreen and Polara are releases of white sweetclover (Meyer, 2005).

'Evergreen' is a late maturing white sweetclover released by the Ohio Agricultural Experiment Station in 1935. It is known for its difficulty in producing high seed yields.

'Goldtop' was released in 1956 by the Wisconsin Agricultural Experiment Station. It has excellent seedling vigor and produces higher yields, better forage and larger seeds than Madrid. Seed matures two weeks later than Madrid.

'Madrid' was introduced from Spain to North America in 1910 by the USDA Division of Plant Introduction. This variety has good seedling vigor, frost resistance and seed production.

'Norgold' is a low-coumarin variety released by Agriculture Canada in 1981. Norgold has lower spring vigor than other yellow sweetclover releases and yields less forage.

'Polara' is a low-coumarin variety of white sweetclover from Agriculture Canada. It was released in 1970.

'Yukon' was released in 1970 from Agriculture Canada from selections made from Madrid. Yukon produces equal to or higher yields than Madrid and is more winter hardy.

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Prepared By
Derek Tilley, USDA NRCS Plant Materials Center, Aberdeen, ID

Dan Ogle, USDA NRCS Idaho State Office, Boise, ID

Loren St. John, USDA NRCS Plant Materials Center, Aberdeen, ID

Species Coordinator
Dan Ogle, USDA NRCS Idaho State Office, Boise, ID

Published October, 2008

Edited: 22Oct08djt; 20Oct08lsj; 22Oct08dgo

Citation
Ogle, D., St, John, L., Tilley, D. 2008. Plant Guide for yellow sweetclover (*Melilotus officinalis* (L.) Lam. And white sweetclover (*M. alba* Medik. USDA-Natural Resources Conservation Service, Idaho Plant Materials Center, Aberdeen, ID. 83210

For more information about this and other plants, please contact your local NRCS field office or Conservation District at http://www.nrcs.usda.gov/ and visit the PLANTS Web site at http://plants.usda.gov/ or the Plant Materials Program Web site http://plant-materials.nrcs.usda.gov.

Appendix I [Soil Loss Tables]

Soil loss one week after implementation

Marker	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
1a	0	Totally covered	0	Slightly covered	Totally covered	0
1b	0	0	0	0	0	0
2a	0	0	Slightly covered	0	0	0
2b	0	0	0	0	0	0
3a	0	0	Slightly covered	0	Totally covered	0
3b	0	0	0	0	0	0
4a	0	0	Slightly covered	Slightly covered	0	0
4b	0	0	Totally covered	Half covered	0	0
Average	**0**	**0**	**0**	**0**	**0**	**0**

Soil loss three weeks after implementation

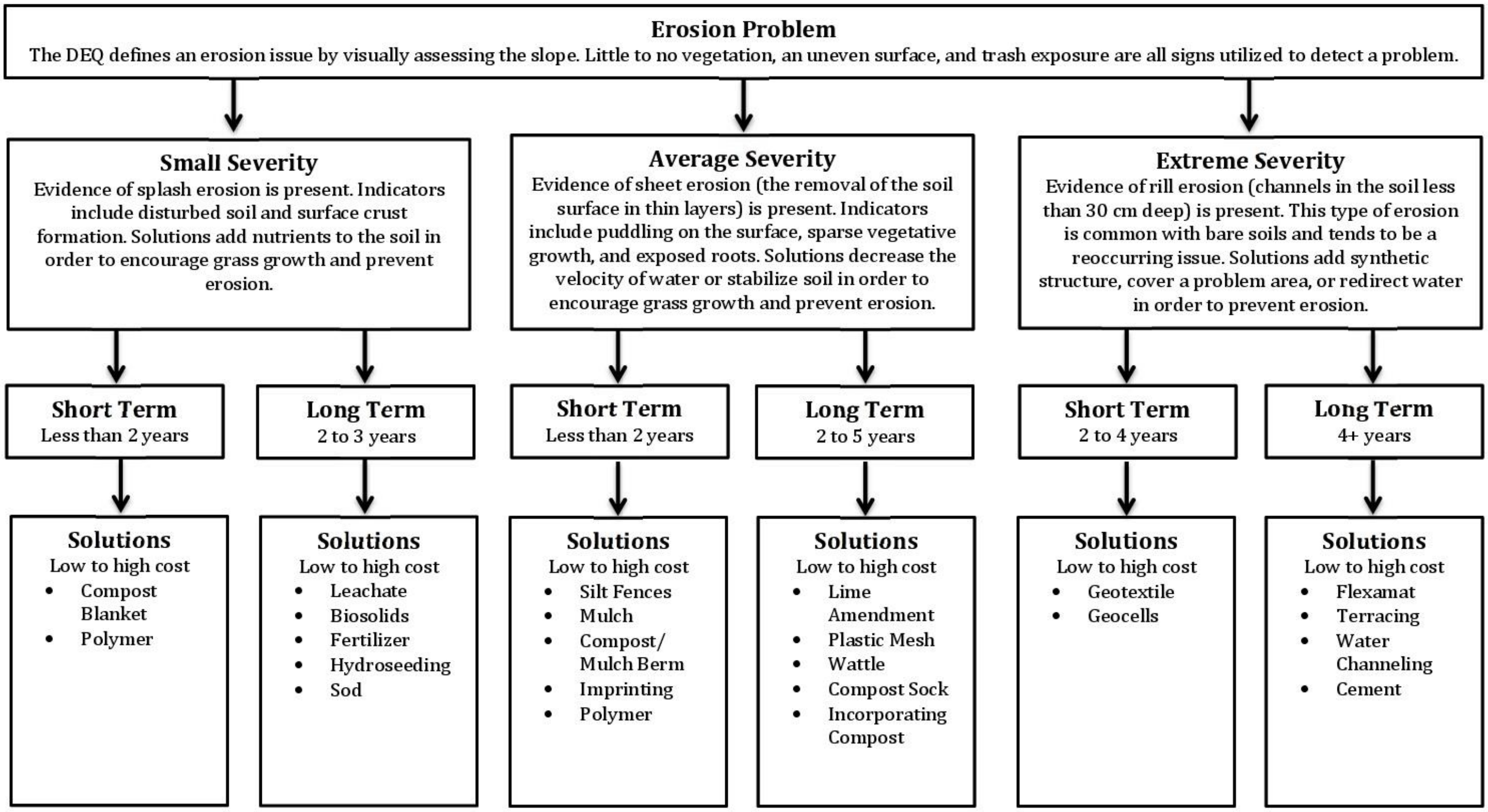
Marker	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
1a	0	0	0	0	0	0
1b	0	0	Half covered	0	0	0
2a	0	0	Totally covered	0	0	0.7
2b	0	Slightly covered	0	0.8	0	0
3a	0	0	0	0	0.4	0.6
3b	0	0	Totally covered	0.7	0	1
4a	0	0.5	0	0.5	0.4	0
4b	0	0	0	0	0	0
Average	**0.0**	**0.1**	**0.0**	**0.3**	**0.1**	**0.3**

Soil loss six weeks after implementation

Marker	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
1a	0.9	0.6	0.9	0.9	0.5	0.4
1b	0.6	1.0	0.8	1.2	0	0
2a	Slightly covered	0	Totally covered	1.0	1.0	1.0
2b	0.5	Totally covered	1.0	2.0	0	0
3a	0	1.0	1.9	1.4	1.3	0
3b	Slightly covered	Slightly covered	1.2	0.6	0	0.5
4a	Slightly covered	1.0	1.5	0.3	0	0
4b	0.5	1.4	1.2	0.4	1.0	0
Average	**0.5**	**0.8**	**1.2**	**1.0**	**0.5**	**0.2**

Appendix J [Design Solution Menu]

Landfill Erosion Control Menu



BIOSOLIDS

Wastewater biosolids can be utilized as a fertilizer. A combination of biosolids and mulch is more effective as a fertilizer and soil stabilizer than either used individually. The biosolids provide a quick release of essential nutrients and organic material for vegetation to be established. Activated sludge can be stabilized with lime, which kills pathogens and creates soil structure. If mulch is also added, it provides a slow release of nutrients while decreasing the nitrogen mineralization rate of the biosolids. The use of on-site mulch and local biosolids is encouraged.

CEMENT

Erosion on landfill slopes is rarely fixed with concrete, but concrete blankets and shotcrete solutions exist for difficult areas. Concrete cloth can be rolled out on a slope and hydrated to cure. Shotcrete is normally used on hard to reach areas and extremely steep slopes. Cement can provide a low maintenance permanent cover.

COMPOST BLANKET

A compost blanket is a layer of loose compost applied to the soil surface. The compost can fill in rills or erosion prone areas to prevent channelized flow and protect the surface from splash erosion. It improves the soil structure and nutrient levels to enhance vegetation establishment. The use of a compost blanket is an especially attractive solution due to their absorbent properties, as they may be able to sorb 80-100% of a 4-inch rainfall event (Filtrexx, 2017). A confinement method (mesh) is required for slopes greater than 1:1, and the compost must be high in nutrients and within EPA regulations to be effective. It is suggested to use about 1 to 3 inch layer of compost material.

COMPOST SOCK

A compost filter sock is a permeable sleeve filled with compost to filter and slow storm water and trap sediment. It's easy to install on severely compacted soils because no incorporation is necessary. Socks are simply staked into place on the surface. Eventually, grass will grow around and over the socks, creating natural berms perpendicular to the slope.

COMPOST/MULCH BERM

A filter berm is a trapezoidal-shaped pile of material placed perpendicular to the sheet flow. The berm can consist of an array of materials such as compost, mulch, municipal solid waste, or feedstock. The berm can trap sediment and pollutants that would otherwise transport down the length of the slope while still allowing water flow through it. Compost also provides a nutrient-rich amendment for nearby soils for vegetative growth. Mulch does not provide nutrients, but it does not degrade quickly. Berms can be used on steeper slopes if they are placed closely together or reinforced with mesh netting. They are not suitable for high velocity flows greater than 1 cubic foot per second.

FERTILIZER

Vegetative cover is one of the most effective methods for controlling erosion and covering landfills. It can be maintained by monitoring necessary nutrient levels. Based on the soil test results, specific nitrogen, phosphorus, and potassium amounts can be recommended to improve the quality of the plant growth.

FLEXAMAT®

This product is a high-strength, interconnected concrete mat system with a customizable underlayment. It conforms to the terrain to stabilize the soil surface, protecting it from rainfall runoff and encouraging grass growth between the concrete blocks. This low-maintenance product is applicable for steep slopes, drainage channels, and maintenance roadways to prevent erosion. It can also be manufactured on the landfill site.

GEOCELLS

Geocells are geometric soil containers typically made of high-density polyethylene and structured like a sheet of honeycomb. The cells can conform to any terrain and be filled with concrete, aggregates, or soil to increase resistance to rainfall runoff or improve soil stabilization for vegetative cover. They can be installed below the topsoil or made level with the soil surface. They can also be stacked to create terraces or placed on slopes up to 45°. TYPAR® GeoCells can be used as berms or impact distributors. Another product, EnviroGrid, can give slope soils a higher angle of repose and stabilize root systems.

GEOTEXTILES (WOVEN & UNWOVEN)

Woven Geotextiles are durable fabrics designed to permanently stabilize soil and increase ground support. Woven geotextiles are mostly made from high-strength polypropylene fibers to allow for maximum slope support, stabilization, and erosion control. Woven geotextile fabric is best for applications in road construction, heavy erosion, embankments, and steep slopes. Nonwoven Geotextile fabrics provide a solution for drainage, filtration and stabilization. They are lightweight, so the fabric is commonly used as both a filter and a stabilization mechanism for construction sites or in other areas with high runoff levels. Coconut Coir Mats are a biodegradable geotextile fabric. Coir mats are available in a wide range of strengths to accommodate low level, medium or steep slopes. The mats stabilize steep slopes long enough for vegetation to fully take root. Coir erosion mats can be used for short term, temporary, or semi-permanent applications.

HYDROSEEDING

Hydroseeding is a type of planting that uses a mixture of seed, nutrients, and mulch to fertilize and seed an area. It is often transported as premixed slurry and then sprayed onto the desired land area. Advantages for hydroseeding include quick application for a large area and rapid germination. Often a mixture of seed type is best. There are many seed options. Common grasses used for erosion control include Bermudagrass, blue grama, buffalograss, vetiver grass, and many more. Native grasses are also an option. Native grasses for Oklahoma include bluestem, Japanese brome, Indiangrass, switchgrass, buffalograss, and grama. There are also annual grasses that have a lifecycle of only one year. Annual grasses must be replanted annually for continuous cover.

IMPRINTING

Imprinting is a land-use practice developed to increase storm water infiltration and decrease erosion. It's terracing on a miniature scale. Divots are created in soil using rollers or heavy machinery treads to create tiny hills perpendicular to the slope. The impressions slow the velocity of water and encourage sedimentation. Imprinting could be a great erosion control practice for a temporarily barren landfill road surface.

INCORPORATING COMPOST

Compost can be tilled in or otherwise incorporated to improve the structure and stability of the soil. Research has shown that incorporating 5cm of compost at a depth of 7.6 cm can improve vegetation growth better than straw mats, but not better than surface compost blankets. Unlike a compost blanket, incorporating compost does not require a plastic mesh to hold compost in place, though it may require more machinery and expertise to install. Special caution must be taken on a landfill slope not to disturb the required amount of cover during the dirt work.

LEACHATE

Leachate can be applied as a fertilizer (mostly nitrogen) to improve soil characteristics and encourage vegetative growth. The salinity and toxicity of the leachate can be concerns, though. It must usually be treated or diluted first to be beneficial to plant growth and test within EPA guidelines of contaminant levels.

LIME AMENDMENT

Lime can be added to soils to improve the workability of silt and clay-based soils. By adding lime, the mechanical properties are also strengthened. Additional benefits of adding lime include increased nutrient availability, improved soil structure, and increased rates of infiltration. Lime application is commonly used in road and highway construction to improve the stability of clay soils.

MULCH

Mulch is composed of chipped tree branches and other yard waste. It protects the soil surface from splash erosion, retains moisture, and improves soil structure while vegetative cover begins to take root. As the organic matter slowly degrades, it releases nutrients to the soil for grass growth. Mulch mixed with biosolids has proven to be an effective combination (see biosolids).

PLASTIC MESH

Plastic mesh can help evenly distribute water over a surface and hold sediment in place. It can also protect grass from the stress of foot and vehicle traffic. Most meshes must be secured with stakes or pins. Many plastic meshes are available on the market, including TYPAR® GRASSPROTECTA, TYPAR® TURFPROTECTA, and TYPAR® BODPAVE PAVERS. Each product is optimized for a specific use.

POLYMER

Polymers are soil adhesion products that can be used to stabilize the soil particles. There are many different chemical mixtures to create a variety of products. The GRT 9000 polymer soil stabilization provides a chemical solution to improve soil conditions. Using on-site materials, GRT 9000 is used to create a hard, semi-flexible and water impermeable surface. The mixture helps prevent surface degradation, and can be used to treat materials such as clays, silts and sands. GRT products are non-toxic, have a low carbon footprint, and use in-situ materials. Another option is GRT-ENVIRO. This product for soil binding and erosion control is an organic soil conditioner based on a water-soluble polymer. This product can be added to irrigation water to reduce soil erosion by agglomerating fine particles that otherwise would be carried away by surface water runoff. Some of the noted benefits are: sediment reduction of up to 95% by increasing cohesion between soils particles, improved water infiltration, reduced leachate in the runoff water, improved germination rate of plants, and up to 30% in water savings.

SILT FENCE

Silt fence is a vertical barrier of water permeable fabric, staked into the ground perpendicular to the slope. Its main purpose is to pond water so that sediment will have time to settle out. This treatment may be effective at reducing soil loss and the silting in of nearby water bodies if installed near the bottom of a landfill slope. Silt fence needs to be maintained after intense rainfall events.

SOD

Sod is turf grass and the soil held by its roots. It is sold in rolls to lay out over soil. It must be well irrigated after installation. Sod is a good solution for level and un-vegetated areas, but it will not fix rill areas.

TERRACING

Terracing is a soil conservation practice applied to prevent rainfall runoff on slopes from accumulating speed and washing away soil. Terraces are stair-step ridges and channels constructed perpendicular to the slope. When water hits a terrace, it slows and sediment falls out. These structures can be earthen or built with gabions or geocells. Earthen terraces are normally a part of the original landfill design because of the risk of exposing trash during dirt work. Compost socks or wattles installed on the surface can create pseudo-terraces. Gabions are versatile wire mesh baskets typically filled with rock and stacked to create barriers or steps. They are fairly easy to install and do not require skilled laborers. Likewise, geocells can be stacked to create terraces. For a cost-effective solution, gabion baskets and geocells can be filled with material that is already on site.

WATER CHANNELING

To prevent erosion on a slope, sometimes water can be re-routed over a slope through a more stable channel or through a pipe. Water is directed to the reinforced channel by the grade of the slope. Gabion baskets can reinforce a channel. Gabions are rock-filled wire mesh baskets that are fairly easy to install and do not require skilled laborers. In addition, gabion baskets can be filled with material that is already on site. Riprap is also an available product to use in water channeling. Riprap is a permanent, erosion-resistant ground cover of large, loose, angular stone used to slow the flow of water. The size of rock varies. This may also be good to install at the bottom of a slope or along a road to the top of the landfill.

WATTLE

A wattle consists of tubular netting filled with absorbent material such as mulch or straw that slows runoff and settles sediment. Straw wattles are light and therefore must be staked. They are prone to floating. Mulch wattles are heavier and therefore prevent sediment loss more effectively. Both wattle types must be placed perpendicularly on the eroding slope. Wattles can also be filled with cost-effective on-site materials.

Appendix K [Fall Senior Design Report]

Sustainable Solutions

Fall Design Report 2016

Hannah Blankenship | Amethyst Kelly | Christian Ley | Katie Schlotthauer

Prepared for:

City of Enid Municipal Landfill

Oklahoma Department of Environmental Quality

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Introduction

The Oklahoma Department of Environmental Quality (DEQ) is responsible for enforcing environmental laws and regulations. Partnering with the DEQ has provided Sustainable Solutions with the opportunity to aid the City of Enid Municipal Landfill with its current erosion problem. Attention was directed to an erosion concern on the north facing slope. These concerns include sediment deposition at the base of the slope, potential trash exposure, rill formation, scarce vegetative growth, and contamination of the on-site stormwater pond.

Some current low-cost solutions on existing landfills around the state have been ineffective in solving the erosion problem long-term. Previously at the City of Enid Municipal Landfill, sections of the north facing slope have been hydroseeded with an ADC machine, covered with mulch, and sprigged and seeded. Other landfill erosion control methods include layering straw and topsoil on the slopes. Many solutions have succeeded for a time, but the erosion problem persists. Therefore, more sustainable designs must be implemented in order to prevent detrimental impacts to the environment. The EPA requires certain standards to be maintained for the on-site stormwater pond, runoff, and groundwater (DEQ, 2016).

Enid's composting program operates on the premises of the landfill. Therefore, yard waste compost and mulch are available for use as soil amendments. A stormwater detention pond nearby could also be utilized for irrigation. If on-site resources are successfully utilized to control the erosion concerns, a similar design could be applied at other erosion-prone sites with the potential to incorporate sustainable local resources.

Mission Statement

Designing green solutions for soil and water related problems.

Problem Statement

Determine viable solutions for mitigating erosion on the north facing slope of the Enid Municipal Landfill.

Customer Requirements

The project requirements provided by the Oklahoma Department of Environmental Quality are as follows:

- Cover all bare soil surfaces on the north slope with vegetation to reduce erosion
- Determine the feasibility of using on-site resources like compost and mulch
- Reduce sedimentation at the base of the slope and silting in the pond
- Provide a model site for other Oklahoma landfills

Additionally, due to the limited availability of government funds, the City of Enid would like Sustainable Solutions to present low and high cost design alternatives.

Project Scope

Sustainable Solutions will design a menu containing effective strategies to reduce erosion on the north facing slope of the Enid landfill. The menu will contain solutions organized by their cost, effectiveness, time commitment for upkeep, and length of solution. The feasibility of using onsite resources such as soil, compost, leachate, and stormwater will be determined. Different erosion control designs will first be evaluated with computer modeling to reduce the options. A full scale experiment will then take place on the landfill slope to determine to most viable solutions.

Deliverables

Proven design solutions will be presented in the form of a menu. Solutions will be judged on the following criteria:

Coverage: Coverage success will be determined by measuring the percentage of surface area in a plot protected by vegetation, as wells as the maximum height of the vegetation over a certain period of time.

Cost: This criterion compares an estimated prediction of all installation costs and maintenance expenses. Cost includes project resource expenses such as equipment, expertise, manpower, and maintenance costs related to additional applications, professional assistance, or monitoring.

Longevity: The effectiveness of each solution over a certain period of time will be taken into account. Data for this criterion will be based largely on research.

Type of Erosion: If a design solution option is best suited for a certain type of erosion, it will also be specified on the menu.

Work Breakdown Structure

1. Research
    - 1.1. Preliminary Web Research
    - 1.2. Technical Literature Review & Patent Analysis
        - 1.2.1. Erosion
        - 1.2.2. Hydroseeding
        - 1.2.3. Compost & Alternative Cover
        - 1.2.4. Alternative Fertilizers
            - 1.2.4.1. On-site Leachate Composition
            - 1.2.4.2. Wastewater Sludge Composition
        - 1.2.5. Cover Management
        - 1.2.6. Support Practices

1.3. Soil & Water Analysis

1.3.1. Web Soil Survey

1.3.2. Soil, Water, and Forage Analysis Lab (SWFAL)

1.3.2.1. Cover Soil

1.3.2.2. Slope Soil

1.3.2.3. Compost

1.3.2.4. Con Cover™

1.3.2.5. Stormwater

2. Design and Model

2.1. Alternative Design Options

2.2. RUSLE2 Simulations

3. Test

3.1. Test for Effectiveness

3.1.1. Rill Erosion Solutions

3.1.2. Sheet Erosion Solutions

3.1.3. Short-term Solutions

3.1.4. Long-term Solutions

4. Deliverables

4.1. Final Report

4.1.1. Erosion Control Menu

4.1.1.1. Effective Solutions

4.1.1.2. Alternative Solutions

4.1.1.3. Ineffective Solutions

4.2. Final PowerPoint Presentation

4.2.1. Client Evaluation

Task List

Research Phase

- Research current erosion solutions for steep slopes and low soil quality
  - Research feasibility of alternative slope covers online
  - Review pertinent technical literature and patents
  - Audit Erosion & Sedimentation Control Class
- Research erosion control methods
  - Make an exhaustive list of products
  - Narrow down based on general feasibility
  - Estimate product cost and longevity
- Research vegetation type best suited for current slope and soil composition
  - Determine soil composition
    - Perform soil type analysis from USDA Web Soil Survey
    - Collect soil samples from landfill site
    - Turn into OSU's Soil, Water, and Forage Analytical Lab
    - Interpret results
  - Meet with specialists to discuss vegetative cover options and constraints
- Compare soil amendment options and feasibility of using on-site resources
  - Analyze composition of on-site leachate collection water and wastewater sludge
  - Interpret compost, Con Cover™, and stormwater SWFAL results
  - Research methods for incorporating leachate, sludge, mulch, and compost
- Develop quantitative engineering specifications
  - Obtain a copy of the landfill site plans
  - Determine total surface area within our scope
  - Research RUSLE2 and determine input variables
- Research relevant EPA regulations and DEQ permitting

    - Research water quality, leachate application, and sludge application standards
- Do cost analysis on alternative designs
    - Compare initial costs
    - Compare maintenance costs

Design Phase

- Do computer modeling with RUSLE2
    - Model current Enid Landfill slope conditions
        - Use USDA Soil Web Survey to input soil composition
    - Determine return period of simulated storm based on historical rainfall data
    - Model alternative erosion control methods
- Determine indicator variables of success
    - Design procedure to monitor/quantify vegetation growth
- Finalize design options to test on slope

Testing Phase

- Test two or three model-proven solutions on landfill slope
- Interpret experimental results
    - Arrange solutions into menu of options categorized by:
        - Cost
        - Erosion Type
        - Effectiveness
        - Solution Lifetime

Finalize & Present Results

- Write final report
- Present menu and report to the City of Enid and DEQ

Research

Technical Literature and Patent Review

Sustainable Solutions began its research on landfills and erosion with a web search. It quickly found that landfills are complex systems, but there are many resources at our disposal. The research was focused on four key areas: erosion control, hydroseeding, alternative cover materials and compost, and waste fertilizer materials like leachate and sludge. Figure 1 below gives a view of the problem slope.

Figure 1: View of the North-facing slope of the Enid Landfill

Erosion Control

Soil erosion is not a new problem. It has been researched in depth for many years. The two main types of soil erosion are water erosion and wind erosion. Particularly in Enid, water erosion on slopes is the main concern, though wind erosion may also play a part. Figure 2 below showcases such erosion. Raindrop splash erosion is the main culprit, and research has found that the steep slope of the land intensifies erosion, allowing more than half of the soil involved in raindrop splashes to be carried downhill (Pimentel, Harvey, Resosudarmo, Sinclair, Kurz, McNair, & Blair, 1995). The loss of soil degrades the quality of land and its capacity to produce plants, further intensifying erodibility.

Figure 2: Image of current rill erosion issue

Soil erosion greatly limits the amount of nutrients available to plants. In turn, a lack of root depth and plant growth increases the soil's susceptibility to erosion. However, if plant cover can be established, it can protect the soil from erosion by reducing water runoff and increasing infiltration. Over the long-term, infiltration can increase the structure of a soil, making it easier for even more vegetation to flourish (Zuazo & Pleguezuelo, 2008).

Covered soil is protected from erosion because the overhead plant mass can dissipate the energy of falling raindrops. Many different practices can be employed to prevent erosion, including adding mulch as cover. Most erosion control methods include creating some kind of protective vegetative cover on top of the soil. Aside from cover, the soil texture and structure can affect its erodibility, which is why it's important to test samples and know the quality of the soil of interest (Pimentel et al., 1995).

The type of vegetation growing, or lack thereof, is dependent upon the soil type. The cover soil that the Enid Landfill is currently utilizing is a hard-packed, sticky red clay. Clayey soils discourage root growth because of their small pore size and high bulk density. Both the soil structure and vegetative growth contribute to the erosion rate. The small particle size found in clay should decrease erosion, but the lack of vegetation increases erosion. A study done by Clary, Dunaway, Swanson, &Wendel (1994) tested the combination of these two factors. They found that clay has a net positive effect on erosion. As the percent of clay in a soil increases, erosion increases and the root density decreases (Clary et al., 1994). Therefore the combination of high clay content soil and sparse vegetation perpetuates the cycle of erosion on the slope.

However, solutions can be found. Even small plant life like algae can disrupt erosion. In 1941, Booth studied algal crusts growing on damaged soils in the Great Plains. Soil algae crusts can prevent water and wind erosion on badly damaged soils without decreasing the stormwater infiltration rate. The algae growth on bare soils can also be very beneficial to the future growth of larger plants. Much of this research was done in Oklahoma, so it can be assumed that the addressed soil types are similar to the Enid landfill slope cover and that algal crusts could be formed on the problem slope. Algal crusts can create a higher moisture content in the upper soil profile and greatly reduce the erosion of poor soils (Booth, 1941).

Hydroseeding

Hydroseeding is a viable option for erosion control on the problem slope. There are many scientific articles that support this option. An article by Merlin, Di-Gioria, and Godden (1999) discusses potential agents that assist with adhesion for the hydroseeding process. Their experiment observed that Guar gums and synthetic polymers were not very effective for adhesion, while alginates demonstrated the best adhesion. They also concluded that nutrients were essential for seed germination on marginal soils. Fertilization needs can be determined by analyzing soil samples taken from the landfill site. The average cost of hydroseeding is 18 cents per square foot. Figure 3 illustrates the hydroseeding application method.

Figure 3: Example of hydroseeding application

A compost blanket approach could also be a viable option. The article written by Faucette, Risse, Jordan, Cabrera, Coleman, and West (2006) discusses this option by comparing the compost blanket and hydroseeding approach for erosion control (See Figure 4). This experiment found that the compost blanket treatment was more successful in vegetative cover for the short term (three months), while in the long term (one year) the hydroseeding and compost blanket treatments had the same amount of vegetative cover. Any alteration in the soil condition was not observed at the culmination of the experiment.

Figure 4: Example of compost blanket application (Integrate Erosion Control AU)

Patent Searches

Patents are another great way to gather information on previous uses and successes of hydroseeding. The patent filed by Edward and Terry on December 7, 2010, describes a unique mixture for hydroseeding containing mostly mulch and straw. This could be applicable to the Enid Landfill site due to the immediate on-site and free access of mulch. The mixture used for hydroseeding is important. This is expressed by Cook in the patent filed April 11, 2013, that talks more about the general idea of hydroseeding and the benefits, but also includes biological components in the mixture. We would need to find the optimal mixture for the Enid landfill based on deficient nutrients and cost.

Patents surrounding hydroseeding follow a trend. They mostly include different mixtures or processes of delivery, but the act of hydroseeding remains consistent. There are many patents that claim small adjustments to the mixtures. We would need to narrow down what type we prefer before understanding if such a mixture has already been created.

Alternative Daily Cover

Spray-on alternative daily cover materials are advantageous due to the fact that the materials do not need to be removed after application (Querio, 2016). However, spray-on alternative daily cover materials may not provide complete cover of the waste, and the process requires preparation and application equipment. Alternative daily cover (ADC) materials can be waste-derived materials, including yard waste and recycled paper. Environmental advantages associated with ADC strategies include saving lateral airspace, extending the life of landfill, and minimizing impacts on soil.

Alternative Daily Cover strategies typically apply 6 inches of soil at the end of each day, and must be approved by agency permit approvals. However, it may be advantageous to use manufactured or waste-derived materials in lieu of soil application. Why eliminate soil? ADC materials occupy less airspace, minimize impacts on the soil, utilize leachate and on-site materials, and extend landfill life. Manufactured materials include geotextiles, spray-on materials such as hydro-mulch, spray-on slurry, or Con Cover™, and foam. Waste derived materials can include recycled paper, contaminated soil, and wood.

Evapotranspiration Based Cover

The soil layer stores the water during rain events and the vegetation removes the water from the soil by evaporation and evapotranspiration (Abichou et al., 2015). The plant roots aerate the soil, thus the methane oxidation is improved by the soil structuring processes of vegetation, and this reduces surface greenhouse gas emissions. This process also reduces the amount of water that infiltrates into the landfill, which reduces leachate production.

In the study by Abichou et al. (2015), a model of a landfill was constructed. In the first model site, the top of landfill was modeled according to the suggested RCRA slope of 2-5%. The second model demonstrated the side of the landfill using slope of 25% or 4:1 ratio. Instrumentation included soil moisture probes, water potential sensors at various depths, and a weather station at central location to monitor rainfall. The unsaturated hydraulic properties of the ET cover were determined. This study is fairly similar to our problem; we are trying to utilize vegetation to mitigate water and soil erosion issues. Additionally, this study investigated the usage of plant cover to mitigate landfill gas emissions, which could be especially useful because our client expressed interest in a landfill gas mitigation system. The viability of the design is dependent on soil type, moisture content, density, organic content, nutrient availability, temperature, precipitation, and vegetation type. See figure 5 below.

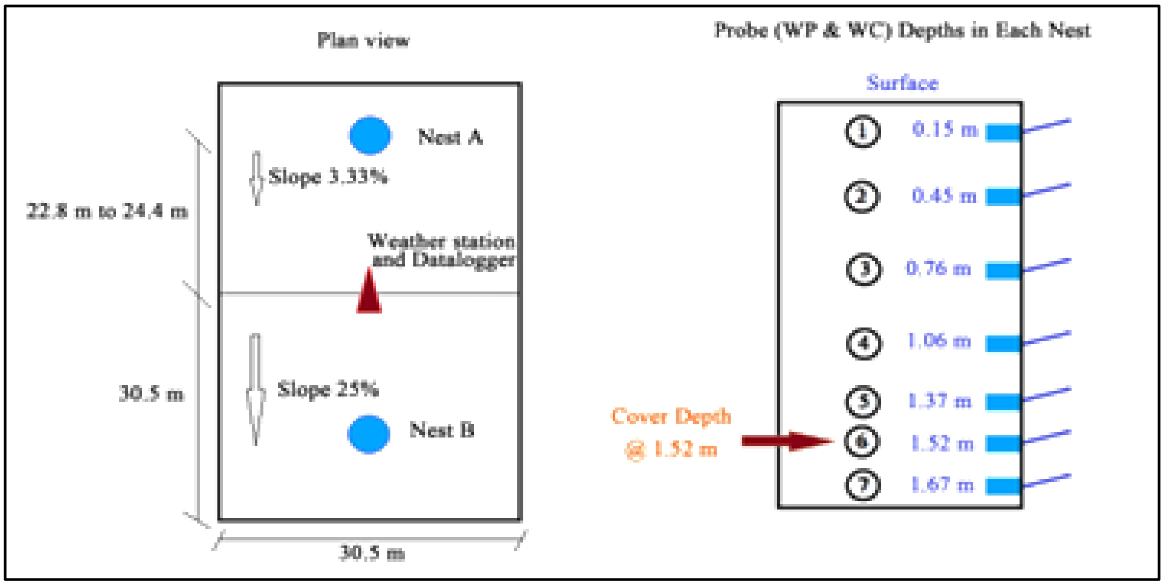


Figure 5: Profile view of instrumentation installed in ET cover (Abichou et al., 2015)

Using Compost as a Landfill Cover

Compost covers have been found to reduce methane emissions from landfills by as much as 100% (EPA, 2002). This solution is a great option for small landfills, where landfill gas collection is not required and where the economics of landfill gas collection systems are too expensive. When the outer layer of compost loses moisture, a barrier is created to prevent temperature loss in the inner compost layer. Compost composition varies greatly and should be carefully considered in the design of the cover. The study suggested that Grade A (high quality) compost is the best type of compost to use as cover material.

The 2002 EPA compost cover study was conducted with three model sites: one on a sloping landfill, one model on flat ground, and a control plot. The cover of the two experimental test sites consisted of 3 layers: a 6-inch thick layer of clay; a 4-6 inch layer of tire chips to distribute the methane; and 36- 40 inches of yard waste compost on the top. The control plot was simply covered with a clay cover 36 inches deep.

Throughout the duration of the experiment, the landfill gas emissions were monitored. The effectiveness of the design was evaluated by conducting erosion tests, which would identify potential problems, such as whether the cover would remain stable with steep slopes or poor weather. The type of vegetation needs to be chosen carefully, so that the plant will grow and stabilize the slope to prevent erosion. The results of this study indicated that the emission reductions exceed that of a landfill gas recovery system, which typically collect about 70-85 percent of the total landfill gas generated.

Landfill owners considering compost cover need to ensure that their cover complies with regulations on cover performance and maintenance of the cover during the closure and post-closure periods. To use an alternative cover, the landfill operator will need specific approval of the Department of Environmental Quality State Director.

Bulk Material Cover Compositions and Methods of Applying

An alternate daily cover material for landfill and a method for applying the cover material are disclosed in Patent US 8946324 (Hansen, 2015). The cover composition includes liquid, cement and/or fly ash, fiber, water dispersible polymer, and acid. Typically, most landfills are covered by spreading a layer of dirt over the exposed portions of the waste piles. For example, a waste pile that is to be covered for a short period of time may require a six-inch layer. This strategy requires a large amount of soil to cover the waste. To maximize the volume available for waste, there are two main options: 1.) reduce the amount of soil necessary for covering the waste piles or 2.) provide a cover material that substitutes for the dirt. In this patent, several spray-on coatings were developed to provide an effective cover to waste piles. These cover materials typically comprise a mixture of water, mineral binder (cement kiln dust), and fibers (both cellulose and synthetic) that can be sprayed onto a waste pile and allowed to set to provide an effective cover. These mineral-based covers have proven to provide effective covers to landfills and other waste piles.

Possible Issues with Fiber-Based Covers

Fiber-based covers do not adhere well to low friction surfaces like plastic containers, typically found in landfills. The fiber-based covers tend to coagulate, so it is difficult to pump and spray these fiber-containing products evenly. This patented invention attempts to solve this problem by improving the application methods of the fiber cover. The adhesion to landfill materials is improved and the materials are easier to apply. The patent provides an improved cover material and method for applying the cover material to a pile by including fly ash in the cover.

In-Situ Fertilizer Application

Leachate

One possible fertilizer source is the on-site landfill leachate. The leachate can be diluted and applied as irrigation water for plants. A couple of studies that were researched showed increased concentrations of available nutrients, organic compounds, and microorganisms in the soil for plants. There are concerns, though, about the impacts that the metals and other contaminate might have on the environment (Wong & Leung, 1989; Bowman, Clune, & Sutton, 2002). Grass cover is used to uptake available forms of nitrogen and mitigate these effects. The Bowman et. al. (2002) research focused on bioremediation of landfill leachate with a turf grass cover. The leachate contained high salt and sodium concentrations which adversely affected the soil structure and grass growth. Therefore, the capacity of the soil to uptake nitrogen decreased with the increased salinity of the soil. The study done by Wong and Leung (1989) also observed detrimental effects of increased salinity soil, as well other contaminants present in the leachate. Upon further investigation, optimal dilution rates could be found to make leachate irrigation an appealing fertilizer. Although, if the issues presented in both studies occur for all soil types or conditions, leaching of nitrogen or other contaminants may prevent the feasibility of using on-site leachate on the problem slope of the Enid Landfill. Investigation of various dilution rates using Enid's landfill leachate may determine the feasibility.

Sludge

Sludge is another possible fertilizer option to improve soil quality. One experiment by Cogliastro, Domon, & Daigle (2001) explored the use of wastewater sludge and woodchip combinations as a soil amendment and fertilizer. "Stabilized" sludge and woodchip combinations have great advantages such as releasing nutrients, like nitrogen, slowly over time as plants need it in a way that sludge or wood chips by themselves would not. The test plots were grown on a flat field with high clay content and poor drainage. The growth of saplings in differing combinations of sludge and woodchip concentrations were observed and analyzed. Results showed minimal plant growth in the first year, but the availability of several essential nutrients increased (some decreased though) over the two year experimentation time to provide necessary nutrients for growth. The smallest sludge application seemed to allow for a release of nutrients over a longer time period, with less nitrogen mineralization in the first year of testing. Successful land rehabilitation needs several years to establish soil physical, chemical, and biological properties essential for stable grass cover.

It is pertinent to know that "waste activated sludge" that is produced from the secondary wastewater treatment process contains harmful pathogens and viruses. This sludge must be deactivated, or stabilized, before applying it to land (National Research Council, 1996). Class B biosolids contain detectable levels of pathogens that must be handled safely. A factsheet provided by the EPA (2000) outlines the stabilization process through cost-effective measures. The pH must be raised to intolerable levels for microorganisms. This can be achieved by mixing Quicklime into the solid sludge and raising the temperature for a certain time through a composting process. Increasing the pH can actually improve the soil conditions and reduce mobilization of metals. Cost for Class A biosolid stabilization is estimated around $139 to $312 per dry ton (EPA, 2000). Stabilization of Class B biosolids may require additional lime that reaches the upper boundary of the cost estimation.

Sludge also contains a high quantity of heavy metals that may be detrimental to plant growth and can pose environmental risks. An experiment performed by Labrecque, Teodorescu, and Daigle (1994) sought to assess the total biomass production as well as plants' ability to bioaccumulate heavy metals with differing wastewater sludge concentrations applied. The highest concentration of sludge applied provided the optimal nutrient requirements and conditions for the trees grown. Although, sludge would most likely need to be reapplied in a few years after initial growth. It was also found that the trees grown did not show detrimental effects from the absorption of heavy metals. This characteristic could be very valuable for the project. Leaching or solubility of metals potentially creates adverse environmental effects, especially in surface water systems. The landfill site contains a stormwater reservoir directly south of the problem slope that must maintain DEQ water quality requirements (DEQ, 2016). Providing a grass or other plant cover could mitigate potential environmental impacts from the application of sludge.

Regulations and Permits

If the leachate collection water or the wastewater sludge are found to be viable fertilizer amendments, applicable regulations and standards will be investigated.

Wastewater Sludge

The City of Enid municipal wastewater plant is currently using Element 2 permit for municipal solid waste landfill disposal. Permit is in accordance with The Department of Environmental Quality Management of Solid Waste guidelines in OAC 252: 515-3-41. 120 days' notice is required before any planned change in sewage disposal (Landfill Permit No. 3524006) per OK DEQ (Oklahoma Department of Environmental Quality, 2016).

Leachate

OAC 252:515 Subchapter 13 gives guidelines on leachate collection and management. A plan for leachate irrigation by the DEQ must be approved (Oklahoma Department of Environmental Quality, 2016).

Soil and Water Analysis

The research phase came to life during a second site visit to Enid. Five different soil samples were taken in order to determine the nutrient availability of the cover topsoil, cover subsoil, grassy slope, mulched slope, and bare slope. See Figures 5 and 6 below for the sampling process. Reference Appendix D for the official OSU soil and water sampling procedures.

Figure 6: Sampling the cover topsoil

Figure 7: Sampling the cured compost

On-site compost, Con Cover™, and stormwater were also sampled to determine their usefulness in amending the soil or irrigating. Samples were taken according to standards set by the Soil Water Forage Analytical Laboratory (SWFAL) at Oklahoma State University (Zhang & Arnall). The samples were analyzed by SWFAL, and the results are show below in Table 1, Table 2, and Table 3.

Table 1: NPK requirements of soil samples (SWFAL)

Soil Description	N (lbs / A)	P (lbs / A)	K (lbs / A)
Cover topsoil	39	48	489
Cover subsoil	1	23	356
Bare slope	6	34	541
Mulch slope	1	35	671
Grassy slope	4	35	450

Overall, the landfill cover and slope soils have plenty of potassium but lack nitrogen and phosphorous. Amending the soil with fertilizers could increase the potential for a healthy vegetative cover to establish. Unfortunately, the results of the compost sampling show that the nitrogen levels of the compost are also low. Though adding compost to the slope would still be beneficial for soil structure and stability, the nutrients will need to come from an outside source.

Table 2: Bar graph of cover topsoil NPK (SWFAL)

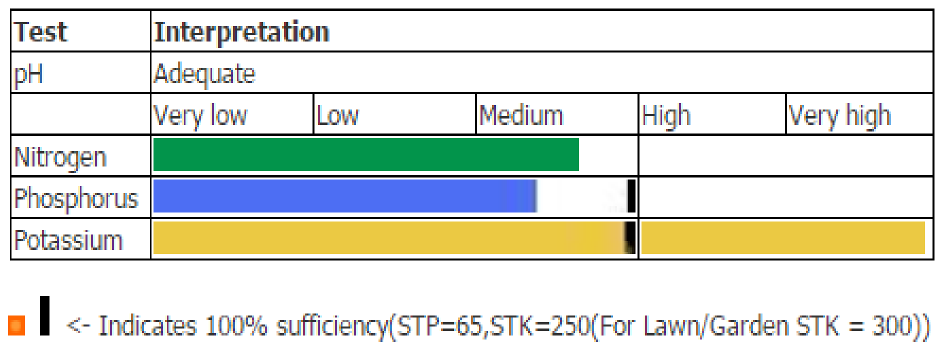
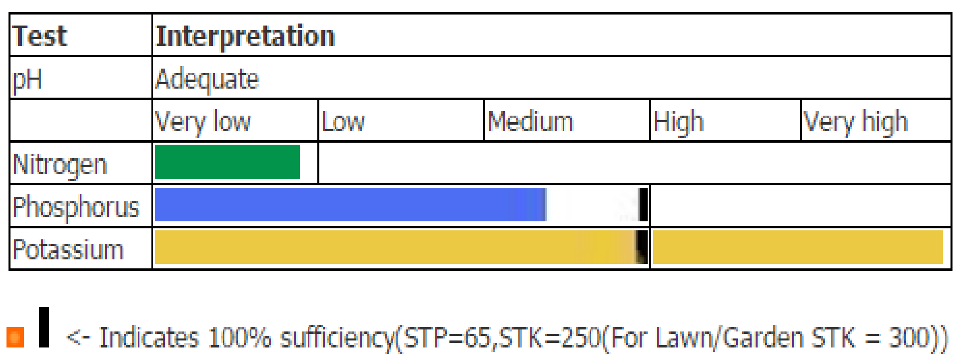


Table 3: Bar graph of cover subsoil NPK (SWFAL)



As expected, the cover topsoil was much higher in nutrients than the cover subsoil. In the future, as new cover soil plots are opened, the topsoil should be set aside and used intentionally on permanent slopes to take better advantage of the available nutrients. Additionally, the tests revealed that the stormwater is safe to use for irrigation if necessary (See Table 4).

Table 4: Results of water sampling (SWFAL)

Test Results For **Irrigation Water**

-----Cations-----		-----Anions-----		-----Other-----	
Sodium (ppm)	32.5	NO_3-N (ppm)	< DL *	pH	8.1
Calcium (ppm)	52.9	Chloride (ppm)	54.1	EC (µS/cm)	712
Magnesium (ppm)	19.9	Sulfate (ppm)	56.2		
Potassium (ppm)	64	Boron (ppm)	0.2		
		Bicarbonate (ppm)	255		

---Derived Values---		--Derived Values(Cont'd)--	
Total Dissolved Salts (TDS in ppm)	535.0	Hardness	214.0
Sodium Adsorption Ratio (SAR)	1.0	Hardness Class	Very Hard
Potassium Adsorption Ratio (PAR)	1.1	Alkalinity (ppm as $CaCO_3$)	209.2
Residual Carbonates (meq)			
Sodium Percentage	24.8%		

Freshmen Involvement

Figure 8: Freshmen field work

Sustainable Solutions had the opportunity to direct two freshman teams throughout the fall semester. These two teams worked on different sections of the senior design project. Working with the senior team gave the freshman experience in large-scale projects and insight into their own scholastic future. The Sustainable Solutions team gained extra manpower and fresh views of the problem. It was a mutually beneficial relationship that led to immense learning.

The first freshman team worked on soil and water analysis. This team was comprised of Elizabeth Alder, Kimberly Guthrie, Morgan McDougal, and Godwin Shokoya. They traveled with the Sustainable Solutions team to the Enid landfill to collect samples. Later they interpreted the test results to determine the deficiencies of the onsite materials. Their final step was to create poster outlining their recommended additives to improve the quality of the soil.

The second freshman team created a small-scale lab testing experiment designed to test erosion scenarios. This team was comprised of Barry Bachman, Tucker Cogburn, Abbey Gray, and Ashton Lofquist. The Sustainable Solutions team gave them a general idea of an experimental setup. The freshman team then created a time frame, budget, and final setup of an experiment to test erosion of different vegetative covers for the slope. The second team also created a poster displaying their experimental setup.

The freshman teams were a valuable resource. Each team presented an intelligent take on their individual projects. Their results were considered in the preliminary narrowing of design concepts.

Product Analysis

After meeting with Dr. Jason Vogel and attending his Erosion and Sediment Control Class, research expanded beyond on-site materials. The brainstorming process created a giant list of design solutions. Proven products on the market and best practices were arranged into the categories of cover management and support practices.

Cover Management

Cover management designs prevent soil erosion by diminishing the effects of erosive activities. These design solutions include but are not limited to practices that will improve vegetative cover.

Woven Geotextiles

Figure 9: Woven textile fabric application (US Fabrics)

Woven Geotextiles are durable fabrics designed to stabilize soil and increase ground support. Woven geotextiles are mostly made from high-strength polypropylene fibers, to allow for maximum slope support, stabilization and erosion control (Woven & Nonwoven Geotextile Fabric, n.d.).

- Predicted cost: $0.05/sq.ft ($85-$100 per 4ft x 500ft Roll)
- Longevity: Unknown

Nonwoven Geotextiles

Figure 10: Nonwoven textile fabric application (Layfield Construction Products)

Nonwoven Geotextile fabrics provide a solution for drainage, filtration and stabilization. They are lightweight, so the fabric is commonly used as both a filter and a stabilization mechanism for construction sites or in other areas with high runoff levels (Woven & Nonwoven Geotextile Fabric, n.d.).

- Predicted Cost: $0.06/sq.ft ($70 per 4ft x 300ft Roll)
- Longevity: Unknown

Coir Erosion Control Mats

Figure 11: Coir textile fabric application (Bender)

Coconut Coir Mats are a biodegradable geotextile fabric. Coir mats are available in a wide range of strengths to accommodate low level, medium or steep slopes. The average longevity for coconut fiber products is from 2 to 5 years. This provides enough to time for steep areas to be stabilized, while vegetation is allowed to fully take root. Also, the longevity of the material on dependent on location and water flow in the area (Coir Products for Erosion Control, n.d.).

- Predicted Cost: $0.91/sq.ft ($80-100/ 3 ft x 33ft Roll)
- Longevity: 2-5 years

Steel Plates Alternative Daily Cover

Figure 12: Landfill steel plates (Solid Waste Association of North America, 2015)

The Revelstoke Iron Grizzly cover system consists of a series of steel panels that provides coverage in active landfill slopes. Each steel plate is constructed with a vector belt along the length which conforms to the uneven surface of the waste. The belts overlap the panel eliminating gaps in the cover which prevents disease vectors from entering the waste cell (Revelstoke Iron Grizzly, n.d.).

- Predicted Cost: High
- Longevity: Long-term

Electro-Osmosis Soil Treatment

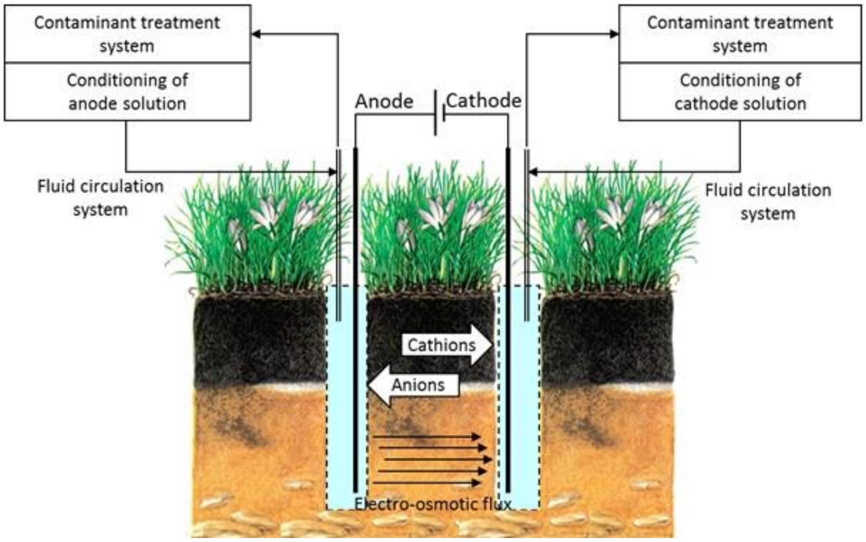


Figure 13: Diagram of electro-osmosis (Geoengineer)

The use of electro-osmosis for treatment of soft clay soils is a common ground improvement technique. Electro-osmotic soil treatment involves the application of an electric field to the soil to initiate flow of water through a clay-water system. Through a series of electrical pathways, electro-osmotic flow appears as plug flow through the pores of soil. Electro-osmosis can cause a significant increase in the settlement and undrained strength of the soil (Estabragh, Naseh, & Javadi, 2014).

- Predicted Cost: High
- Longevity: Unknown

Polymer Soil Stabilization: GRT 9000

Figure 14: Soil stabilizing polymer, GRT9000 (GRT)

GRT 9000 polymer soil stabilization provides a chemical solution to improve soil conditions. Using onsite materials, GRT 9000 is used to create a hard, semi-flexible and water impermeable pavement. The mixture helps prevent surface degradation, and can be used to treat materials such as clays, silts and sands. Environmental protection benefits – GRT products are non-toxic, have a low carbon footprint and use in-situ materials (GRT:9000 Polymer Soil Stabilization, n.d.).

- Predicted Cost: Unknown
- Longevity: Short-term

Soil Binder & Erosion Control: GRT ENVIRO

Figure 15: GRT-Enviro soil binder and erosion control (GRT)

GRT-ENVIRO SOIL BINDER & EROSION CONTROL is an organic soil conditioner based on a water-soluble polymer. This product can be added to irrigation water to reduce soil erosion by agglomerating fine particles that otherwise would be carried away by surface water runoff. Some of the noted benefits are: Sediment reduction of up to 95% by increasing cohesion between soils particles, improves water infiltration, reduced leachate in the runoff water, improved germination rate of plants, and saves up to 30% water. Environmental protection benefits – GRT products are non-toxic, have a low carbon footprint and use in-situ materials (GRT-Enviro Soil Binder & Erosion Control, n.d.).

- Predicted Cost: Unknown

- Longevity: Short-term

Fertilizer Application to Improve Vegetative Cover

Figure 16: Example of large-scale fertilizer application (Corn & Soybean Digest)

Vegetative cover is one of the most commonly used methods for controlling erosion and covering landfills. Based on the soil test results, specific nitrogen, phosphorus, and potassium recommendations can be made to improve the quality of the plant growth.

- Predicted Cost: Low
- Longevity: Varies depending on erosion control methods, precipitation, and climate

Lime Amendment for Soil Stabilization

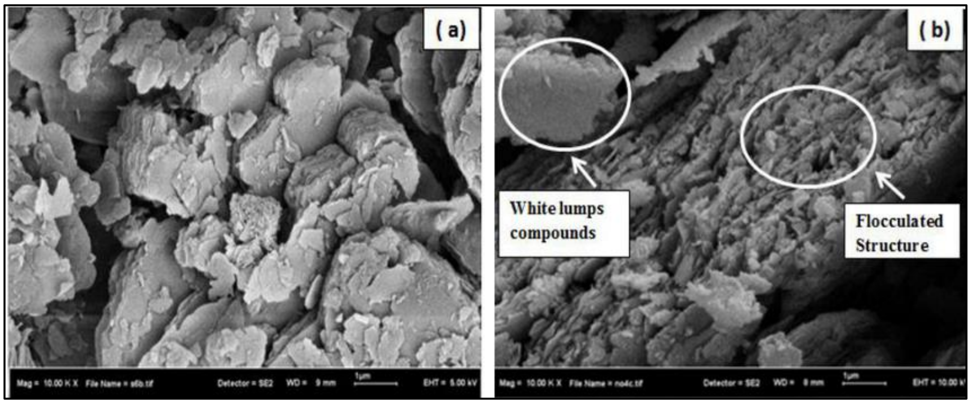


Figure 17: Image of (a) untreated clay soil and (b) lime treated clay (Saeed, 2015)

Lime can be added to soils is to improve the workability of silt and clay-based soils. By adding lime, the mechanical properties are also strengthened. Lime application is commonly used in road and highway construction to improve the stability of clay soils (Herrier, et al., 2012; Saeed, Kassim, Yunus, & Nur, 2015).

- Predicted Cost: Low
- Longevity: Varies

TYPAR® Geocells

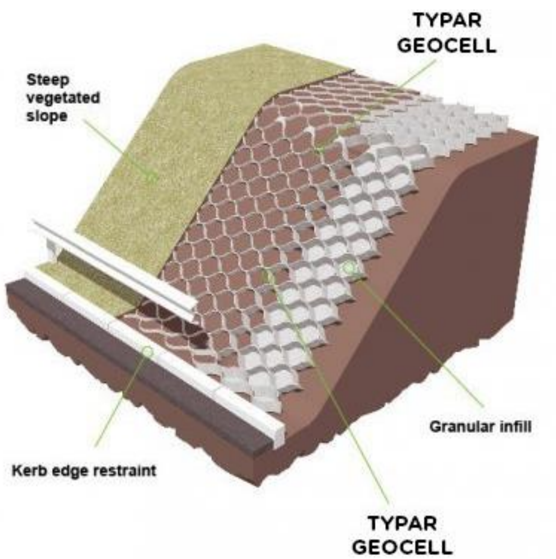


Figure 18: TYPAR® geocell diagram (TYPAR)

Geocells are typically made of high-density polyethylene and structured like a sheet of honeycomb. They can be used on top of slopes to hold rocks and soil or underneath vegetative cover to help stabilize soil. UV protected for >2yrs under soil. Will be installed for basically forever if we put them in. Maintenance supposedly easy in patches (TYPAR Geocell - Slope Protection, n.d.).

- Predicted Cost: Medium
- Longevity: 2+ years

Sod

Figure 19: Example of sod application (Green Valley Turf Co.)

Sod is turf grass and the soil held by its roots, and it is sold in rolls to roll out over soil. On the landfill's steep slope, it will most likely need to be staked. It must be well irrigated after installation. Sod is a good solution for flat and unvegetated areas but will not fix rill areas.

- Predicted Cost: $0.40-$0.90/sq.ft (Sod Types and Prices - Buy Online, n.d.)
- Longevity: Long-term

Incorporating Compost

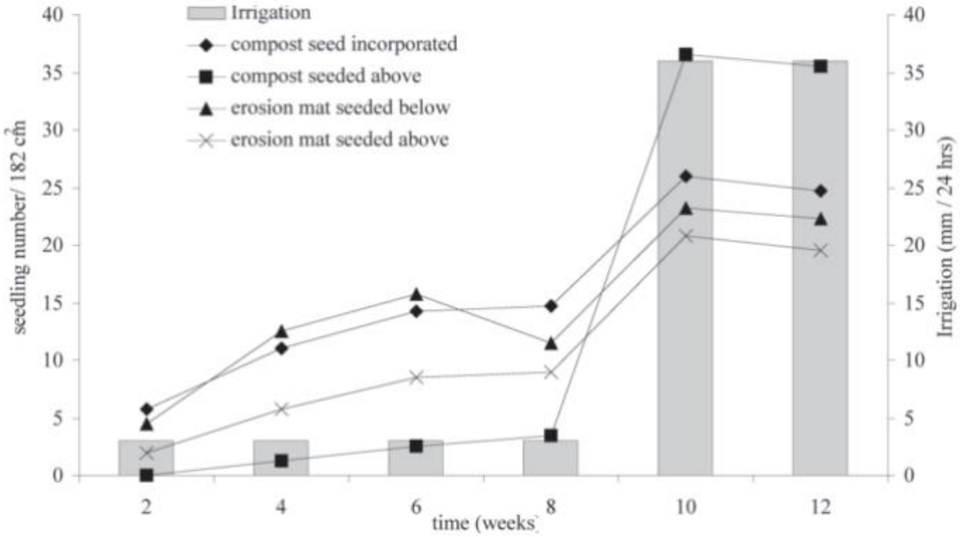


Figure 20: Graph of germination study (Harrell and Miller, 2005)

Compost can be tilled in or otherwise incorporated to improve the structure and stability of the soil. Research has shown that incorporating 5cm of compost at depth of 7.6 cm can improve vegetation growth better than straw mats, but not better than surface compost blankets (Li, Hanlon, O'Connor, Chen, & Silveira, 2010; Reinsch, Admiraal, Dvorak, & Cecrle, 2007; US Composting Council).

- Predicted Cost: $10-$25 per cubic yard, labor only
- Longevity: Two or three seasons

Mulch

Figure 21: Current mulch use existing at the Enid Municipal Landfill

Mulch is composed of decaying chipped tree branches and other woody plants. It can protect the soil and improve its structure while waiting for vegetative cover to take root (Osborne & Gilbert, 1976).

- Predicted Cost: Low
- Longevity: Short-term

Flexamat®

Figure 22: Flexamat® rolled soil stabilizer (Flexamat)

This product is a high strength interconnected concrete mat system with a wood excelsior. It stabilizes the soil surface, protecting it from rainfall runoff and encouraging grass growth. Flexamat® Plus uses 100% recycled plastic. This product is applicable for steep slopes, drainage canals, and maintenance roadways to prevent erosion. It can be manufactured on site and the manufacturer claims it is less expensive than other conventional products (Customize Flexamat, n.d.).

- Predicted Cost: $5.65/ sq.ft (with Curlex®)
- Longevity: Long-term

Compost Blanket

Figure 23: Example of compost blanket application (Integrate Erosion Control AU)

A compost blanket is a layer of loose compost applied to the soil surface. The compost can fill in rills or erosion prone areas to protect it to prevent channelized flow and even splash erosion. It improves the soil structure, CEC, and nutrient levels to create a place for vegetation to be established. A confinement method (mesh) is required for slopes greater than 1:1 and the compost must be high in nutrients and within EPA regulations to be effective. It is suggested to use about 1 to 3 inch layer of compost material (McCoy, 2005; National Pollutant Discharge Elimination System).

- Predicted Cost: $0.11-0.12/sq.ft. (1 in-deep)
- Longevity: Short-term

Typar® GRASSPROTECTA

Figure 24: GrassProtecta grass reinforcement mesh (TYPAR)

This dense plastic mesh can provide slope stabilization and vegetated erosion control. This product is delivered in a roll that can be laid out and staked down for a permanent solution. Light vehicle use is recommended (GrassProtecta grass reinforcement mesh, n.d.).

- Predicted Cost: $2.60/sq.ft
- Longevity: Varies

Typar® TURFPROTECTA

Figure 25: TurfProtecta turf reinforcement mesh (TYPAR)

This is a lightweight plastic mesh roll used as grass protection layer. This product could be used to stabilize the soil surface to allow a strong vegetative cover to grow on the slope. Vehicles can still drive over this material (TurfProtecta turf reinforcement mesh, n.d.).

- Predicted Cost: Unknown
- Longevity: Varies

Typar® BODPAVE Pavers

Figure 26: BODPAVE porous paving grids (TYPAR)

These pavers are made of a durable plastic made to withstand heavy machinery. The grids can be interconnected and filled with gravel or soil to provide a protected surface for grass growth. A proper drainage system must be implemented in conjunction with these pavers (BodPave 85 porous paving grids, n.d.).

- Predicted Cost: $4.44/sq.ft ($12 per 2.7 sq.ft Paver)
- Longevity: Long-term

EnviroGrid™ –cellular confinement

Figure 27: EnviroGrid ™ cellular confinement grids (EnviroGrid)

EnviroGridTM geocells are a confinement system for soil stabilization and erosion control. The cells can be filled with gravel, soil, cement, vegetation, etc. on almost any grade of slope. The grid system reduces rainfall impact and rainwater runoff velocity. This product could also be stacked to create terraces. Multiple size options are available (EnviroGrid, n.d.).

- Predicted Cost: $0.31-$1/sq.ft
- Longevity: Long-term

Adding Leachate

Figure 28: Enid Municipal Landfill leachate collection tank

Using the on-site leachate collection water could be cost effective if pretreatment is not required. Leachate could be applied as a fertilizer to improve soil characteristics and encourage vegetative growth. Environmental concerns and permitting should be highly considered (Wong & Leung, 1989).

- Predicted Cost: Low. Equipment cost or treatment cost could be expensive.
- Longevity: 2-3 years. Until cover is established.

Adding Wastewater Sludge

Figure 29: Example of biosolid land application (Michigan DEQ)

Wastewater sludge could be a great soil amendment as it contains essential nutrients and organic material for plant growth. Biosolid stabilization with lime can further increase the soil structure (see lime fertilizer section). The wastewater biosolids must be treated first and EPA standards must be taken into high consideration (EPA, 2000; EPA, 2016).

- Predicted Cost: Low
- Longevity: 2-3 years

Adding Sludge and Mulch

Figure 30: Example of composted mulch and biosolids (WEF Highlights)

It has been proven that a wastewater sludge and mulch combination is more effective than either used by themselves. The sludge is able to release nutrients quickly for vegetation to be established and the mulch provides a slow release of nutrients (Cogliatro, Domon, & Daigle, 2001). Sludge stabilization and EPA requirements must be taken into high consideration (see wastewater sludge section).

- Predicted Cost: Low
- Longevity: 3-5 years

Hydroseeding

Figure 31: Example of hydroseeding (BAI Environmental Services)

Hydroseeding is a type of planting that uses a mixture of seed, nutrients, and mulch to fertilize and seed an area. It is often transported as a premixed slurry and then sprayed onto the desired land area. Advantages for hydroseeding include quick application for a large area and rapid germination. Often a mixture of seed type is best, but a few categories for consideration are listed below. Cost for dispersal equipment will not be included because the landfill site already owns an ADC machine (Hydroseeding & Soil Stabilization Methods, 2016).

- Predicted cost: \$0.18/sq.ft (includes seed, fertilizer, and stabilizer)
- Longevity: Long-term

Hydroseeding Common Grasses

Figure 32: Example of Bermuda grass (The Grass Patch)

Common grasses used for erosion control include Bermudagrass, blue grama, buffalograss, vetiver grass, and many more. The cost and availability will be considered for use in the design.

- Predicted cost: \$0.01/sq.ft (Bermuda seed only) (Lowe's, n.d.)
- Longevity: Long-term

Hydroseeding Native Grasses

Figure 33: Example of Buffalo grass (Hillerman)

Native grasses for Oklahoma include bluestem, Japanese brome, Indiangrass, switchgrass, buffalograss, grama, and many more. The cost and availability will be considered for use in the design.

- Predicted cost: $0.05/sq.ft (Buffalograss seed only) (Lowe's, n.d.)
- Longevity: Long-term

Hydroseeding Annual Grasses

Figure 34: Example of annual Ryegrass (University of Missouri)

Annual grasses are grasses that only have a lifecycle of one year. This deficiency can be compensated for by the seed dispersal of the grass before the end of its lifecycle, starting a new yearly cycle.

- Predicted cost: $0.01/sq.ft (Ryegrass or Wildflower seed only) (Lowe's, n.d.)
- Longevity: Varies

Hydroseeding Vine/Ground Cover

Figure 35: Example of Rose Moss Cover (ASPCA)

Vine cover includes a variety of plant that grows on top of, and over the ground. Kudzu was considered but not recommended due to its invasive nature.

- Predicted cost: $0.05/sq.ft (Rose moss seed only) (Lowe's, n.d.)
- Longevity: Varies

Support Practices

Support designs for erosion control prevent erosion by controlling runoff; these solutions include terracing, silt fences, and other runoff interceptors.

Cement

Figure 36: Example of concrete blanket effects (Milliken Infrastructure)

Erosion on landfill slopes is rarely fixed with concrete. Concrete blankets and shotcrete solutions exist for difficult areas, but these solutions don't seem appropriate for the Enid Landfill. (Concrete Cloth Erosion Control/Slope Protection, n.d.; Shotcrete, n.d.)

- Predicted Cost: High. $5/sq.ft for slab and shotcrete.
- Longevity: Long-term

Wattle

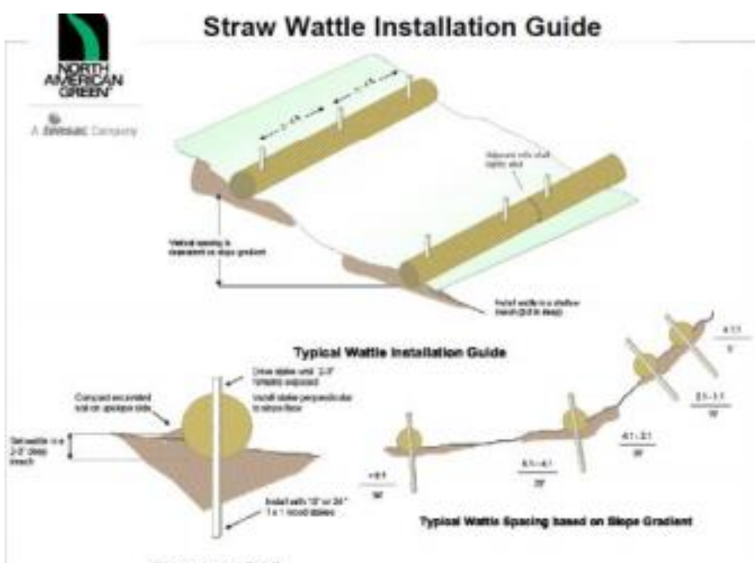


Figure 37: Straw wattle installation diagram (North American Green)

A wattle is tubular netting filled with absorbent material to slow runoff and settle sediment. Straw wattles are light and therefore must be staked. They are prone to floating. Mulch wattles are heavier and therefore prevent sediment loss more effectively (Quadel Industries, 2011; Texas Sustainable Industries, LLC, n.d.) We should look into buying biodegradable netting to fill with Enid's mulch.

- Predicted Cost: $1.00-$2.00/ft
- Longevity: 3-5 years. Netting will degrade in 20-36 months.

Compost Sock

Figure 38: Compost sock terraces (USDA NRCS)

A compost filter sock is a permeable sleeve filled with compost to filter stormwater and trap sediment. It's easy to install on severely compacted soils because no incorporation is necessary. Grass will eventually grow on and over the socks, creating natural berms perpendicular to the landfill slope (Archuleta & Faucette, 2011).

- Predicted Cost: Varies
- Longevity: Unknown

Silt Fence

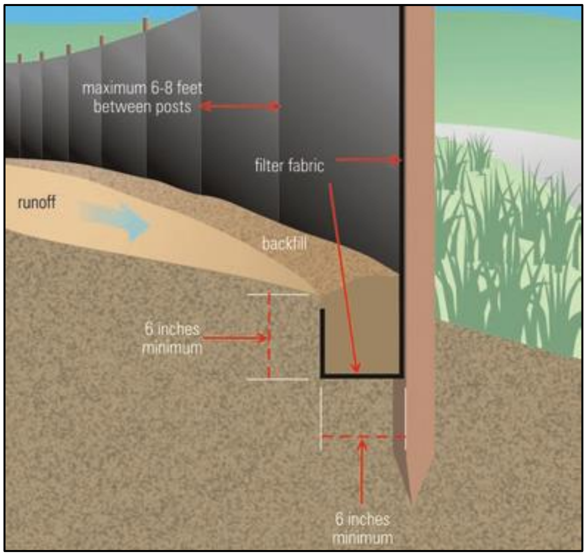


Figure 39: Silt fence installation diagram (Vogel)

Silt fence is water permeable, and its main purpose is to pond water so that sediment will settle out. This treatment may be effective at the bottom of our landfill slope (National Pollutant Discharge Elimination System; Silt Fence, 2003).

- Predicted Cost: $0.48 per ft ($48/100ft)
- Longevity: 5 to 8 months. Maintenance after every intense rainfall event

Gabion Baskets

Figure 40: Example of Gabion baskets (Site Supply, Inc.)

Gabions are rock-filled wire mesh baskets that can be placed on slopes for erosion protection. They can be used to solve a variety of erosion issues due to their flexibility and unique design characteristics. According to the manufacturer, they are fairly easy to install and do not require skilled laborers. In addition, gabion baskets can be filled with material that is already on site (Gabions Confine Stone for Erosion Protection and Retaining Soil, 2016).

- Predicted Cost: Varies based on materials used
- Longevity: Long-term

Terracing

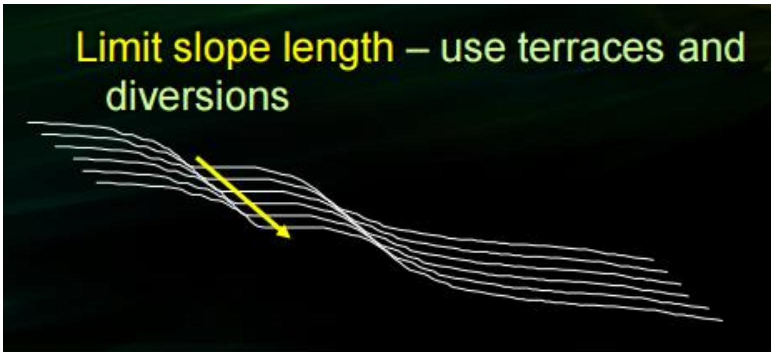


Figure 41: Diagram of slope terracing (Vogel)

Terracing is a soil conservation practice applied to prevent rainfall runoff on sloping land from accumulating and causing serious erosion (Wheaton & Monke, 2001). Terraces consist of ridges and channels constructed across-the-slope. The regrading involved with terracing would limit the practice of terracing to new cells of the landfill because of the risk of exposing trash (Widomski, 2011).

- Predicted Cost: High
- Longevity: Terraces must be maintained over the years but can last forever.

Riprap

Figure 42: Example of riprap channel protection (Anne Arundel County, Maryland)

Riprap is a permanent, erosion-resistant ground cover of large, loose, angular stone used to slow the flow of water (Riprap). The size of the rocks varies. This may be good to install in the ditch at the bottom of our slope or along the road.\

- Predicted Cost: $1/sq.ft (assuming $20 per ton avg.) (Coverage Charts, 2016)
- Longevity: Long-term. Low annual maintenance, will last forever.

Channel Water Over the Slope

Figure 43: Example of water channeling (Stormwater Solutions)

To prevent erosion on a slope, sometimes water can be rerouted over a slope through a more stable channel or through a pipe (Vogel, 2016).

- Predicted Cost: High
- Longevity: Long-term

Imprinting

Figure 44: Example of imprinting a slope (The Imprinting Foundation)

Imprinting is a land-use practice developed to increase stormwater infiltration and decrease erosion. Divots are created in soil using rollers or heavy machinery treads to create tiny hills perpendicular to the slope. The Enid Landfill may already employ machinery with useful treads, meaning that this could be a very viable short-term/daily cover solution (Dixon & Carr, 2003).

- Predicted Cost: Low
- Longevity: Short-term

Compost Berm

Figure 45: Example of compost berm implementation (EPA)

The compost filter berm method consist of a trapezoidal-shaped pile placed perpendicular to the sheet flow. The berm can consist of an array of materials such as mulch, municipal solid waste, and feedstock. The berm can trap sediment and pollutants that would otherwise transport down the length of the slope while still allowing water flow through it. The compost also allows for a nutrient rich amendment for vegetative growth. Berms can be used on steeper slopes if they are placed closely together or in combination with other products. They are not suitable for high velocity flows greater than 1 cfs (National Pollutant Discharge Elimination System).

- Predicted Cost: $1.90-3.00/ft. (McCoy, 2005)
- Longevity: Short-term unless permanent vegetative cover established

The table below gives a summary of the potential design solutions. This list is based upon preliminary brainstorming. More in-depth product analysis will take place in the Spring Semester to narrow down feasible options.

Table 5: Comparison chart of potential design solutions

Design Solution	Cost Estimate	Longevity
Woven Geotextiles	\$0.05/sq.ft	unknown
Nonwoven Geotextiles	\$0.06/sq.ft	unknown
Coir Erosion Control Mats	\$0.91/sq.ft	2-5 years
Steel Plates Alternative Daily Cover	high	long-term
Electro-Osmosis Soil Treatment	high	unknown
Polymer Soil Stabilization: GRT 9000	unknown	short-term
Soil Binder & Erosion Control: GRT ENVIRO	unknown	short-term
Fertilizer Application to Improve Vegetative Cover	low	varies
Lime Amendment for Soil Stabilization	low	varies
TYPAR® Geocells	medium	2+ years
Sod	\$0.40-\$0.90/sq.ft	long-term
Incorporating Compost	\$0.04-\$0.09/cubic ft	2-3 years
Mulch	low	short-term
Flexamat ®	\$5.65/sq.ft	long-term
Compost Blanket	\$0.11-\$0.12/sq.ft	short-term
Typar® GRASSPROTECTA	\$2.60/sq.ft	varies
Typar® TURFPROTECTA	unknown	varies
Typar® BODPAVE Pavers	\$4.44/sq.ft	long-term
EnviroGrid™ –cellular confinement	\$0.31-\$1.00/sq.ft	long-term
Adding Leachate	low	2-3 years
Adding Wastewater Sludge	low	2-3 years
Adding Sludge and Mulch	low	3-5 years
Hydroseeding	\$0.18/sq.ft	long-term
Common Grasses	\$0.01/sq.ft	long-term
Native Grasses	\$0.05/sq.ft	long-term
Annual Grasses	\$0.01/sq.ft	varies
Vine/Ground Cover	\$0.05/sq.ft	varies

Design

Engineering Specifications

Calculations for the slope area were computed using specifications from the Enid Landfill and the site plans. The slope severity of 4:1 and the height range of 60-80 ft. were given by contacts at the Enid Landfill. The base length of 1,950 ft. was determined from the site plans and verified in scale using Google Earth (Figure 46). A slope length range of 240-320 ft. was calculated using the slope. The final slope surface area was calculated to be between 468,000 sq. ft. and 624,000 sq. ft. Sustainable solutions will use the rough estimate of 500,000 sq. ft. to represent the entire North-facing slope. About half of the slope is already covered with vegetation, so the value of 250,000 sq. ft. will be used to calculate the cost evaluations of our future design solutions. This is because the design solution will only be applied to the area where bare soil is exposed. Reference Appendix C for the full landfill site plans.

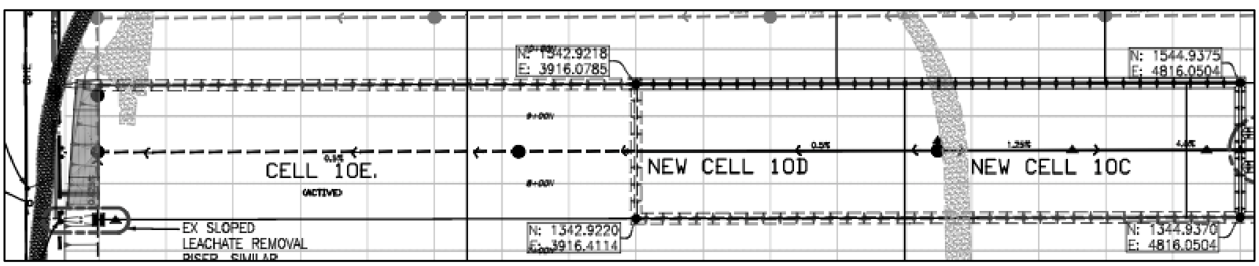


Figure 46: Engineering site plan top view of North Slope (City of Enid)

Erosion Modeling Software

RUSLE2 is a computer modeling software that estimates total soil loss with the Universal Soil Loss Equation (USLE). Users can customize the model using site-specific variables such as rainfall, slope, soil type, etc. (USDA, 2008).

The USLE is written in the form:

$$A = RKLSCP \qquad [1]$$

Where:

A = net detachment (mass/unit area)

R = erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = supporting practices factor

1.0 Proposed Methodology

The RUSLE2 model will be used to predict which erosion mitigation strategies will be most effective for the prevention of erosion in the Enid Landfill. To further assess the erosion mitigation strategies, each of the proposed solutions will be categorized into one of two categories. The categories include cover management and support practices. Cover management practices prevent soil erosion by diminishing the effects of erosive activities. These practices include practices that will improve vegetative cover and enhance soil cohesiveness. Support practices for erosion control prevent erosion by controlling runoff; these solutions include terracing, silt fences, and other runoff interceptors. After each erosion solution is categorized into one of the two aforementioned categories, the solutions will be further ranked and assessed based on the longevity, economic feasibility, and sustainability of each proposed design. The four highest ranking solutions will be tested on-site at the Enid Landfill.

1.1.0 Revised Universal Soil Loss Equation (RUSLE) Modeling

RUSLE is an erosion prediction model that uses the Universal Soil Loss Equation (USLE) and a computer interface. RUSLE models are constructed with physical input values that are widely available in existing databases or can be easily measured (USDA, 2008). According to the USDA, RUSLE2 is a practical erosion prediction model that can be easily learned by new users and can be downloaded at no cost.

1.1.1 RUSLE Model Components

RUSLE includes a computer program and database that connects USLE equations with a database of erosion input data values. The user is able to select a specific set of field conditions to analyze a variety of erosion situations. The mathematical equations and technical advice in the model are based on conservation of mass and USLE principles.

1.1.2 RUSLE Quantifies and Predicts Erosion

The model accounts for both rill and interrill erosion associated with rainfall and flow (USDA, 2008). Rill and interrill erosion are affected by four main factors: climate, soil, topography, and land use. The combination of these four factors are used to compute the expected degree of erosion. Users are not required to collect physical data related to plant yield, canopy cover, surface roughness, mechanical soil disturbance, and amount of biomass; these factors are built into the model's database. The program can be used to model any location where soil may be impacted by rainfall and surface runoff, including construction sites and landfills. Erosion effects are further quantified by considering climate, soil, topography, and land use factors. Climate variables vary by region, and include temperature, precipitation, and erosivity factors. The model addresses variations in topography by accounting for slope length, steepness, and slope. Land use factors are the most important factor affecting erosion, due to the fact that erosion can easily be mitigated by altering the land use conditions (USDA, 2008).

On-site Testing Procedure

Four separate test plots will be chosen on the eroding slope. These plots will be determined by the current type and severity of erosion. The four highest ranking erosion mitigation solutions, as determined by RUSLE2 modeling, will be implemented and tested in the individual test plots. The efficacy of the designs will be quantified by evaluating the total surface area covered by vegetation as well as average height of the grass. Throughout the growth period, the condition of each sub-plot will be visually inspected to account for rill and sheet erosion factors.

Budget

Table 5 below is the budget for the Fall Semester. The costs that were incurred account for two trips to the Enid Municipal Landfill as well as the soil and water analyses performed by OSU's Soil, Water, and Forage Analytical Lab.

Table 6: Fall Semester budget

Item	Number of Items	Itemized Cost ($)	Total Cost ($)	Source
Travel- Sedan rental	2 trips at 140 miles/ trip	$32/day +$0.23 / mile	$128.00	OSU Motorpool
Soil Analysis Fee	5 soil tests 2 compost tests 1 irrigation water test	$10/soil test +$20/ compost test + $15/irrigation test	$105	SWFAL
Total Cost:			$233	

Table 6 below is the proposed budget for the Spring Semester. Fixed costs accounts for known costs for the semester, while uncertain costs accounts for the projected costs of products. Since materials for on-site testing will be decided upon after the computer modeling phase is complete, the budget consists of proposed preliminary design solution costs.

Table 7: Spring Semester budget

Design Solution	Item	Number of Items	Itemized Cost ($)	Total Cost ($)	Source
All	Travel- Sedan rental	3 trips at 140 miles/ trip	$32/day +$0.23 / mile	$256.80	OSU Motorpool
All	Time Lapse Camera	1 Bushnell Trophy Cam HD	$99.20	$99.20	https://www.amazon.com/Bushnell-Trophy-Essential-Trail-Camera/dp/B01CQBYU1U/ref=sr_1_2?s=sporting-goods&ie=UTF8&qid=1480433153&sr=1-2&keywords=Bushnell+Trophy+Cam+HD
All	Johnston Co. Native Grass Seed Mix	(5 lb/acre) x (3 acres)	$40 / 5 lb bag	$120.00	http://www.jeinc.com/seed
All	Soil Analysis Fee	1 compost test	$20/ compost test	$ 20.00	SWFAL
Fertilizer	Scotts 5,000-sq ft. Lawn Fertilizer	(1 acre)x(43560 sq ft/acre)x(1 bag/ 5000 sq ft) = 9 bags/ acre	$21.44/bag	$ 211.86	Lowes.com
Class B Biosolids Stabilization	Lime Application and Drying	5 bags	$ 4 /bag	$20.00	Lowes.com
Nonwoven Geotextile	Nonwoven Drainage Material (6'X100')	(300 ft/plot) x (2 plots)	$90 / roll	$270.00	AgricultureSoultions.com
Wattles, Compost Sock	Compost Sock (8" X 10')	4 Socks	$26/ sock	$104.00	https://www.amazon.com/SCS-LLC-Grow-Sock-8x10/dp/B00ON9MY6M/ref=sr_1_1?ie=UTF8&qid=1479776718&sr=8-1&keywords=compost+sock
Wattles, Compost Sock	DIY Wattles Netting Roll (7' X 20')	12 Wattles / Roll	$10 / Roll	$10.00	https://www.amazon.com/Easy-Gardener-604-BirdBlock-20-Foot/dp/B00004RA0P/ref=sr_1_fkmr1_1?ie=UTF8&qid=1479778528&sr=8-1-fkmr1&keywords=wattle+netting
Wattles, Compost Sock	Rubber Mallet	1 Mallet	$12.86	$12.86	https://www.amazon.com/TEKTON-30603-Fiberglass-Handle-16-Ounce/dp/B00KX4KB5M/ref=pd_sim_86_72?_encoding=UTF8&pd_rd_i=B00KX4KB5M&pd_rd_r=W71609T6MK09G4X2C5F3&pd_rd_w=1qUvU&pd_rd_wg=2ccwR&psc=1&refRID=W71609T6MK09G4X2C5F3
Wattles, Compost Sock	U-Shaped Sod Staples	100 Staples / Pack	$12. 95 / pack	$12.95	https://www.amazon.com/GardenMate-100-Pack-HEAVY-DUTY-U-Shaped-Securing/dp/B00LQZB9F8/ref=pd_sim_86_2/166-0902316-5158943?_encoding=UTF8&pd_rd_i=B00LQZB9F8&pd_rd_r=1EXCTQXPRQ2CZY4SAF7N&pd_rd_w=xj9nL&pd_rd_wg=y99lA&psc=1&refRID=1EXCTQXPRQ2CZY4SAF7N
Silt Fence	Silt Fence Roll (2' X 100')	1 Roll	$20	$20.00	https://www.lowes.com/pd/2-x-100-Silt-Fence-Roll/1112447
Wattles, Compost Sock	Zip Ties	100 Zip Ties	$6 / Package	$6.00	https://www.amazon.com/Dxg-150mm-Self-locking-Nylon-Cable/dp/B01FMHYOZW/ref=sr_1_1?ie=UTF8&qid=1479778943&sr=8-1-spons&keywords=zip+ties&psc=1
Typar BODPAVE Pavers	Typar BODPAVE Pavers	50 sq. ft.	$4.44/sq.ft	$222.00	http://www.typargeosynthetics.com/products/porous-paving/bodpave-85-porous-pavers.html
Total Cost:				$1,385.67	

Conclusion

Impacts and Sustainability

The versatility of the erosion control menu may extend its useful life indefinitely. While certain products may be discontinued over time, many solutions will remain viable. Depending on how frequently the menu is updated and how well it is maintained, it could serve as a resource for municipal landfills for years to come.

Vegetative cover is one of the menu items that may require the least amount of updating. Unless a new type of grass is proven more suitable or the landfill cover soil composition changes drastically, the grasses recommended by the menu will not change.

The menu's soil amendment options will vary on a case-by-case basis depending on accessibility of resources. The nutrient availability of the compost may vary widely, the leachate may not always be in compliance for irrigation, and it may not always be economically feasible to treat the wastewater sludge. Additionally, if the amount and composition of these amendments are not monitored closely, contaminated runoff can pose a serious threat to the environment and human health.

Lastly, production of specific products like wattles and Rolled Erosion Control Products on the erosion control menu could be discontinued over the years. The market should always contain similar or improved products to keep the menu up to date.

Landfills are continuously expanding to keep pace with the inflow of trash. Thus, bare soil surfaces prone to erosion and sediment loss are a perpetual issue. The City of Enid Municipal Landfill is currently preparing a new cell adjacent to the focus slope of Sustainable Solutions. An erosion control menu will not only provide solutions for the already-existing slopes but also provide proactive erosion control techniques and products to implement while building the new cell, preventing the severity of erosion problem that Sustainable Solutions has been tasked with solving and ultimately saving taxpayer dollars.

Safety Considerations

Safety considerations must be taken into account when implementing new designs. Sustainable Solutions' design concepts for the Enid Landfill project contain potential risks that must be noted and addressed. The wastewater sludge that is discussed as a potential soil amendment contains harmful pathogens classified as class B biosolids that can cause illness to surrounding citizens. The pathogens can be transmitted through soil, animal, and water movement. The sludge must be pretreated with the addition of lime to destroy the pathogens before use. Other safety procedures for handling the sludge must be strictly adhered to as well.

Many of the design concepts include the use of new machinery or equipment such as hydroseeding or the pneumatic system used to spread a compost blanket. Unfamiliar equipment can cause unintended accidents. The situation is further exacerbated by the use of the equipment on a steep slope. Employees expected to use the equipment will need to be adequately educated on the operation process and accompanying machinery safety. The possibility of unearthing trash during the implementation of some menu design solutions also causes concern. The unearthing allows for contaminates to be spread and garbage to blow out of the landfill. Caution must be exercised during all design solutions to maintain continuity of the outer soil layer.

The application of soil additives, such as the on-site leachate water, also poses a threat to surrounding land and water. If a nutrient is applied in excess it can cause overgrowth of plants or eutrophication in surrounding bodies of water. These undesired effects can be avoided with careful calculations before application or with the use of solutions to minimize runoff.

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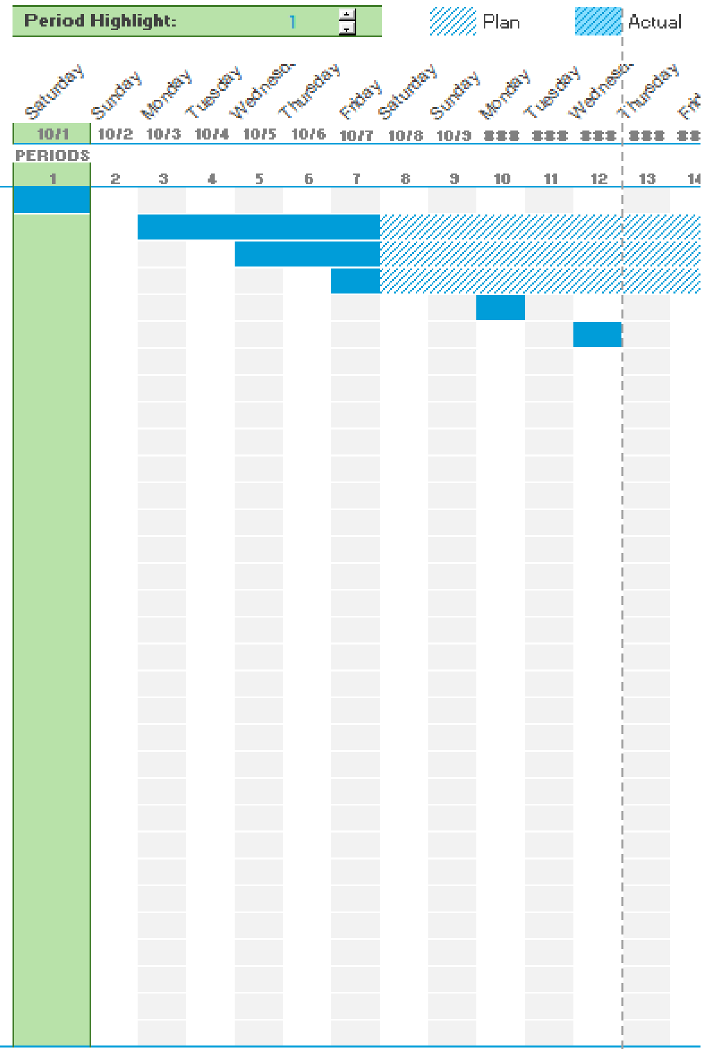
Appendices

Appendix A [Gantt Chart]

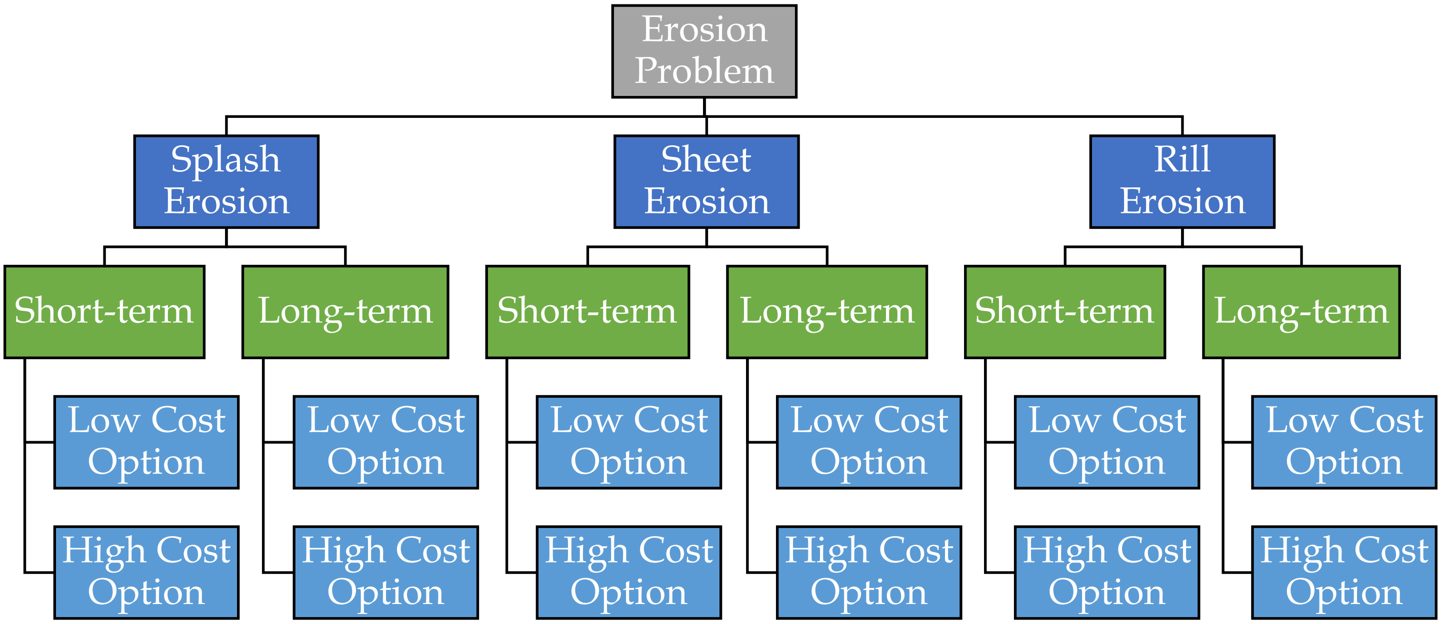
Sustainable Solutions

Design Schedule

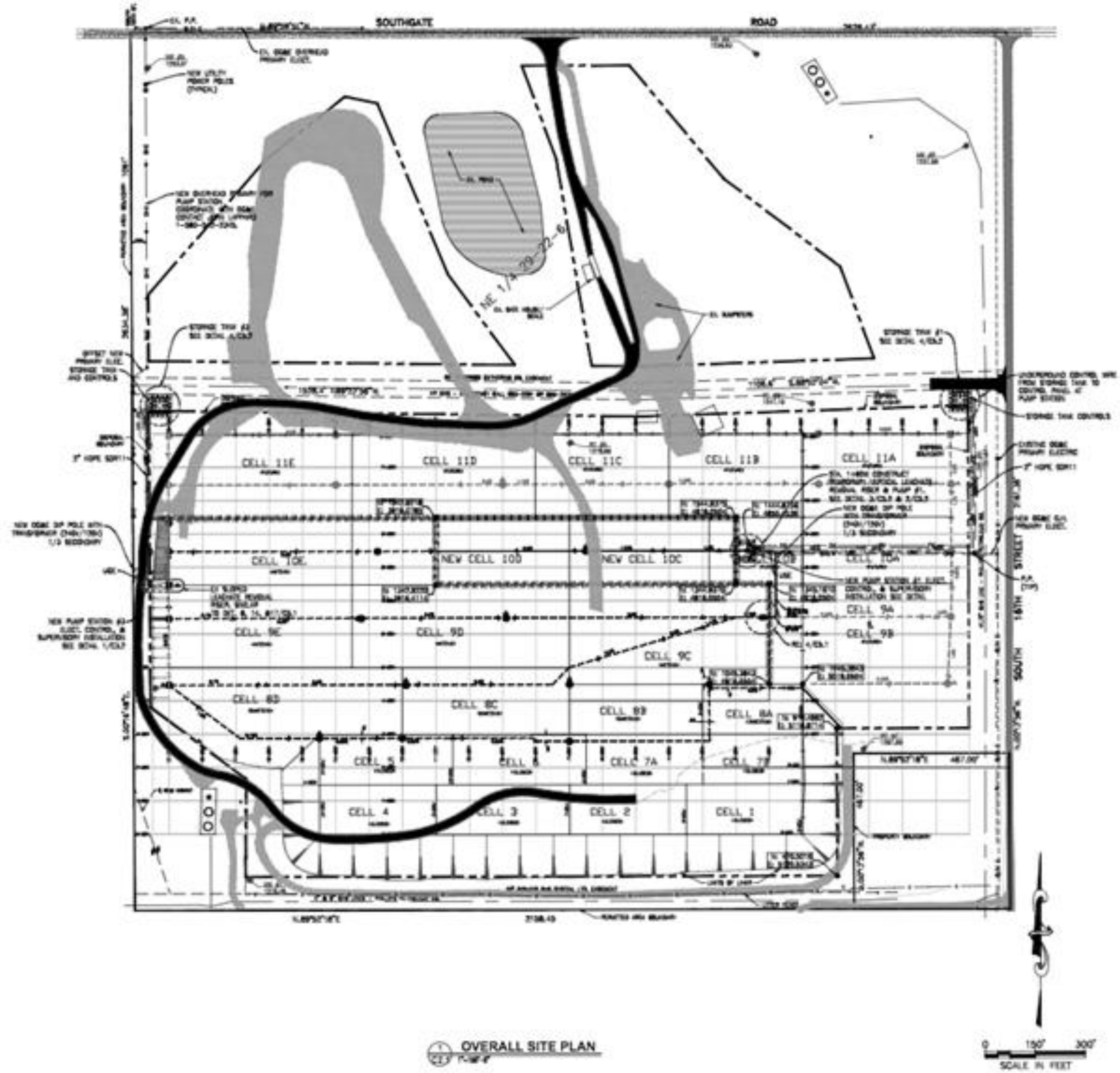
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Collect water and soil samples from Enid	1	1	1	1	100%
Analyze soil and water samples	3	12	3	5	100%
Develop Preliminary design concepts	5	17	5	3	100%
Analyze leachate and sludge data	7	8	7	1	100%
Meet with Freshmen Teams	10	1	10	1	100%
Team Planning Meeting	12	1	12	1	100%
Meeting with Kelly Dillow	19	1	27	1	100%
Team Planning Meeting	26	1	26	1	100%
Write Report First Draft	26	10	26	3	100%
Meet with Freshmen Teams	31	1	31	1	100%
Team Planning Meeting	33	1	33	1	100%
Obtain site plans	36	1	28	1	100%
Write Fall Report Final Draft	38	5	52		25%
Develop Final Fall Presentation	40	10	40	10	100%
Team Planning Meeting	52	1	52	1	100%
Work on web page layout	52	15	52		5%
Peer Evaluations Fall	63	1			
Computer Modeling	109	28			
Computer Modeling Data Analysis	137	14			
Team Planning Meeting	151	1			
On-site Testing Design Plan	151	7			
On-site Testing	158	35			
On-site Testing Analysis	193	7			
Team Planning Meeting	199	1			
Preliminary Menu	200	5			
Write Final Report Draft	200	14			
Create Final Presentation	205	7			
Final Menu	206	3			
Team Planning Meeting	212	1			
Give Final Presentation	213	1			
Peer Evaluations	215	1			
Complete Final Report	216	5			



Appendix B [Preliminary Menu Design]



Appendix C [City of Enid Municipal Landfill Site Plans]



1 OVERALL SITE PLAN
C2.1

LEGEND

1260.0	PROP. TOP OF CLAY LINER CONTOUR
1260.0	EX. CONTOUR
1252.0	GROUNDWATER CONTOUR
■	EXISTING/PROPOSED/FUTURE LEACHATE COLLECTION SUMP
●	EXISTING/PROPOSED/FUTURE LEACHATE CLEANOUT RISER
	EXISTING/PROPOSED/FUTURE FLOWLINE IN LEACHATE TRENCH & LOCATION OF CHANGE OF GRADE
	MW OR PZ W/ GROUND WATER ELEVATION USED FOR CONTOURING
	LEACHATE COLLECTION TRENCH WITH DIRECTION AND SLOPE OF FLOW OF LEACHATE
	EXISTING TOP OF CLAY LINER ELEVATIONS
	EXISTING LEACHATE PERFORATED PIPING (8" SCH 80 PVC) WITH FLOWLINE OF PIPE
	PROPOSED TOP OF CLAY LINER ELEVATIONS
	PROPOSED LEACHATE PERFORATED PIPING (8" SCH 80 PVC) WITH FLOWLINE OF PIPE
	PROPOSED LEACHATE FLOWLINE
	FUTURE TOP OF CLAY LINER ELEVATIONS
	FUTURE LEACHATE PERFORATED PIPING (8" SCH 80 PVC) WITH FLOWLINE OF PIPE
OHE	OVERHEAD PRIMARY ELECTRICAL UTILITY (OG&E)
UGE	UNDERGROUND SECONDARY ELECTRICAL UTILITY (OG&E)
UGC	UNDERGROUND CONTROL CABLE
FM	3" HDPE SDR11 (160 PSI) FORCE MAIN
	LOCAL LANDFILL COORDINATES
FML	FLEXIBLE MEMBRANE LINER
RCL	RECONSTRUCTED CLAY LINER
LCS	LEACHATE COLLECTION SYSTEM
	MONITORING WELL W/ HIGH WATER LEVEL
	PIEZOMETER W/ HIGH WATER LEVEL

ENID MUNICIPAL LANDFILL
CONSTRUCT CELLS 10C & 10D
PROJECT NO. M-1207B

BRUEGGEMANN ENGINEERING

ENID MUNICIPAL LANDFILL
RECONSTRUCTED CLAY LINER FML & LCS INSTALL.
CELLS 10C & 10D

OVERALL SITE PLAN

C2.1
of
10

Appendix D [Oklahoma State University Soil Sampling Guide]

How to Get a Good Soil Sample

Hailin Zhang
Director, Soil, Water and Forage Analytical laboratory

Brian Arnall
Nutrient Management Specialist

Soil tests provide a scientific basis for evaluating available plant nutrients in cropland, pastures, lawns, and gardens. Analyses of soil samples can help farmers and homeowners fine-tune nutrient applications from fertilizers, biosolids, and animal manure. Properly managing the amount of nutrients added to the soil can save money and protect the environment.

Soil nutrients vary by location, slope, soil depth, soil texture, organic matter content, and past management practices, so getting a good soil sample stands out as a major factor affecting the accuracy and usefulness of soil testing. This fact sheet outlines some specific considerations which should be taken into account to get the greatest benefit from soil testing.

Sample Soil at the Right Time

Fields used for production of cultivated crops may be sampled any time after harvest or before planting. Generally, two weeks should be allowed for mailing, analysis, and reporting of results. Additional time may need to be allotted for ordering and application of fertilizers, manure, or lime materials. Noncultivated fields should be sampled during the dormant season. In either case, do not sample immediately after lime, fertilizer, or manure applications because those samples do not represent the true soil fertility.

Fields should be tested annually to measure the available nitrogen pool or as frequently as necessary to gain an understanding of how soil properties may be changing in relation to cultural practices and crop production.

Collect a Representative Sample

Getting a representative sample is simple, but not easy. Research at OSU and other universities has clearly shown that a minimum of 20 cores or small samples taken randomly from the field or area of interest are necessary to obtain a sample which will represent an average of the soil in the field (Figure 1). These cores should be collected in a clean plastic bucket (to avoid metal contamination) and mixed thoroughly by hand. The sample bag should be filled from the mixture. A one pint (OSU soil sample bag full) sample is usually adequate for all tests which might be required. If the sample is too wet to mix, it should be spread out to dry some and then mixed, or sampling should be delayed until the field is drier.

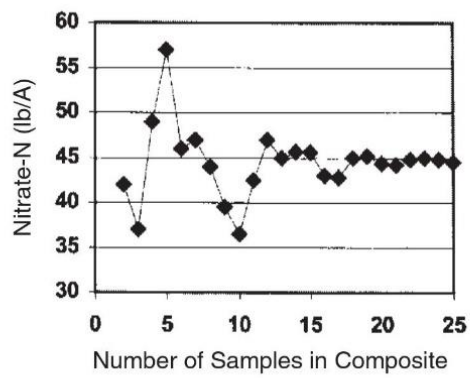


Figure 1. The minimum number of core samples needed to make a representative composite sample is about 20.

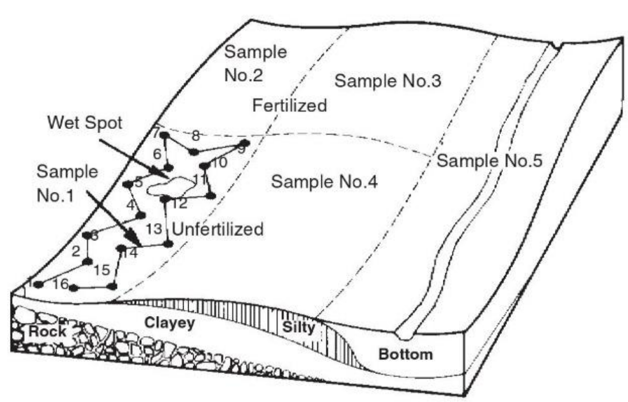


Figure 2. Divide field into uniform sampling areas and follow a random pattern when sampling. Avoid unusual spots and try to obtain a representative sample.

It is important to remember that the sample obtained by the above procedure will be an average of the area sampled. If the area sampled is extremely variable in the soil properties which are going to be tested, then it may be better to separate the field into smaller areas, and get a representative (20 cores) sample from each of these areas in order to determine how variable the field is (Figure 2). In this way, it may be possible to treat some areas of the field differently from others and remove variability so that the field can be sampled and treated as a unit in the future. Variability in a field can often be noted by differences in surface soil color and crop growth or yield.

Using only one sample for a large variable field can be very costly. Since the sample represents an average of the soil in that field, recommendations based on the soil test will likely cause the field to be overfertilized on some parts and underfertilized on other parts. Failure to obtain uniform response to treatments based on a soil test is frequently a result of one sample being used to represent a large variable field.

An example of field variability is shown in Table 1. The range of test values was obtained by testing 40 individual cores taken at random from an "apparently uniform " 80-acre field. The variation is great enough so that for some analyses the average is not a good representation of the field. Areas of the field with the lowest pH, phosphorus, and potassium values will not receive adequate lime or fertilizer if recommendations are based on the average test values.

A single core sample, or spadeful, is extremely risky because it may test anywhere in the range shown for each of the analyses. For example, deficiencies for wheat could range from zero to 37 pounds of P_2O_5 and zero to 34 pounds of K_2O. For alfalfa, which has much greater nutrient requirements, deficiencies could range from zero to 94 pounds of P_2O_5 and zero to 120 pounds of K_2O. This would also affect the amount of nitrogen and lime required. Obviously, unless the 80 acres is divided into less variable units for testing, some areas of the field will receive either too much or too little fertilizer and lime.

In deciding how large an area can be represented by one composite sample (20 cores), the determining factor is not the number of acres involved, but rather, the variability of the area. Some large, uniform fields can be represented well by a single 20-core sample, while some highly variable fields need to be split into two or more smaller areas for testing. Regardless of the field size or main area being sampled, unusual spots in the field (salty or wet spots) should be avoided during the initial random sampling. When unusual spots make up a significant area, they should be sampled separately.

Sampling Where Nutrients are Banded

It is a challenge to sample fields where fertilizers have been band applied. Research has shown that soil test P values are not increased beyond 2 inches from the band of fertilizer placement. If a soil sample is collected from the banding zone, it has the risk to greatly skew the results of a soil test, ultimately leading to under-fertilization and yield loss. Some soils through, have very high P fixing capabilities, and the amount of available P is very small a year after application. This is commonly seen in soils with very low or high soil pH. In these conditions, where row spacing is less than 12 inches (e.g., winter wheat), it is not necessary to change sampling procedures discussed earlier.

Table 1. Variability of an 80 Acre Field Based on Soil Tests of 40 Individual Soil Cores .

	Soil Test Values	
Analysis	Range	Average
pH	4.9-6.3	5.6
Buffer Index	7.1-7.4	7.3
Nitrogen	1-34	11
Phosphorus	23-114	36
Potassium	149-770	306

The primary concern with banding fertilizer is with no-till production of row crops. There are three situations you may encounter: 1) planting over existing rows, 2) knowing the location of rows but not planting over them, and 3) previous rows are unknown. All three situations require a different sampling strategy. When you are planting over past rows, it is important to know the residual of past bandings, so it is recommended to sample in the area around the rows.

When sampling where band location is known, but new row placement is unknown, there is a sampling scheme that can be used to give a more accurate result. A minimum number of sub-samples are required from the area between two bands for every one sub-sample collected from the band. Table 2 shows how many sub-samples between bands need to be collected for one sub-sample from the band for different row spacing.

Table 2. The number of sub-samples to collect from between bands for each sub-sample within band.

Band spacing (in)	*Sub-samples between bands*
15	10
24	16
30	20
40	27

When collecting soil samples from a field where previous bands are unknown, the common recommendation is that for every core taken, collect an extra sample half the distance of the row spacing away from the first core. For example, sampling a field that was previously in corn on 30-inch row spacing, when you collect one core sample, move over 15 inches and collect a second sample before moving on. Therefore, instead of 15 cores total, you need to collect 15 pairs, or 30 cores to make a composite sample. This method has shown to improve the accuracy of the soil sample greatly. The most important thing to keep in mind is that the greatest error occurs when too few samples are taken. By increasing the number of soil samples collected per composite the accuracy of the soil test results are improved.

Sample at Proper Depth

Cultivated Fields

For most soil tests the sampling depth is the tillage depth. The reason for this is because most crops have their greatest root activity in the tillage depth. Obtaining a representative sample with regard to depth means that each of the 20 cores taken from an area should be from similar depth, tillage, or six inches. Soil tests are generally calibrated on the basis of an acre furrow slice, approximately two million pounds of soil in the top six inches.

For deep-rooted nonlegumes such as wheat, bermudagrass, sorghum, and cotton, a separate sample representative of the subsoil should be taken in addition to the tillage depth or six-inch sample. This subsoil sample should represent the layer of soil from 6 to 18 inches below the surface. Because nitrate-nitrogen is mobile in the soil, a test of available nitrogen (and/or chloride and sulfate) in the subsoil sample will provide a more complete picture of available mobile nutrients for these crops (Figure 3) and can save fertilizer expenses.

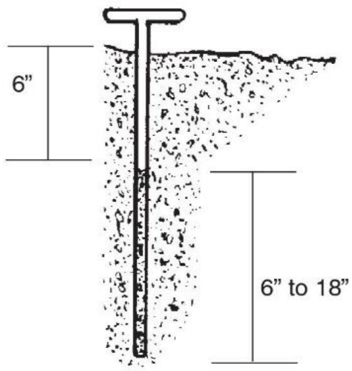


Figure 3. A soil probe is a good tool for obtaining soil samples. Push the tube to the six-inch depth and remove the core. Then take the 6- to 18-inch core through the same hole for the subsoil test.

No-till Fields

Noncultivated fields should be sampled to a depth of six inches, again because this is the effective depth of most treatments and the depth of most root activity. Nutrients from fertilizer, animal manure, and lime can be accumulated on the surface if they are surface applied without incorporation. A set of samples from the top two inches will help identify stratification of nutrients and is especially important for pH determination for no-till fields. If nutrient loss in runoff is the main concern, the two-inch sample is better than a six-inch sample because only the surface inch or two is in direct contact with surface runoff.

Salinity Diagnosis

When salt accumulation is suspected as a cause of poor stand establishment and the sample is being taken after planting, then the depth of sampling should approximate the seeding depth (one to three inches). This is especially important when conditions have been favorable for soluble salts to move upward and accumulate near the surface after planting. Since excess salts are most harmful to germination and seedling vigor, it is this shallow depth which should be tested. At other times during the year, a sample of the entire tillage depth may be most useful to test for salt accumulation.

Send Samples for Analysis

Soil sample bags are available at local county Extension offices. Extension offices will mail your samples to the OSU Soil, Water and Forage Analytical Laboratory and assist you to interpret test results.

Sustainable Solutions

Senior Design Presentation
May 4, 2017

Sustainable Solutions

The Team

Katie Schlotthauer, Christian Ley, Amethyst Kelly, Hannah Blankenship

Mission Statement

Designing green solutions for soil and water related problems.

The Problem

Sustainable Solutions

The City of Enid Municipal Landfill has erosion problems on its north-facing exterior slope.

The Problem

Severe Erosion
Rill Formation

Sparse
Vegetation

The Problem

No Vegetative Cover

The Problem

Risk of Trash Exposure

Poor Soil Quality

The Plan

Sustainable Solutions

Problem Statement

- Research and organize erosion strategies applicable to Oklahoma landfills
- Recommend a design solution to mitigate erosion on the north-facing slope of the City of Enid (COE) Municipal Landfill

Customer Requirements

- Develop a solution that covers all bare soil surfaces with vegetation
- Organize erosion control methods as a reference for other landfills
- Determine the feasibility of using on-site resources

Project Overview

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Research

- Erosion Control Product List
- Soil and Water Analysis

Modeling

- RUSLE2 Computer Simulation
- On-Site Testing

Solution

- Site-Specific
- Erosion Control Menu

The Plan

Project Scope

Erosion control designs were evaluated through

- Research
- Computer modeling
- On-site testing

Deliverables

COE Recommendation

- Site specific
- On-site resources

Design Solution Menu

- Severity / Type of Erosion
- Longevity
- Cost

Research - Soil Analysis

Soil Description	N (lbs /A)	P (lbs /A)	K (lbs /A)
Cover topsoil	39	48	489
Cover subsoil	1	23	356
Bare slope	6	34	541
Mulch slope	1	35	671
Grassy slope	4	35	450

Soil Description	Total C (%)	Total (%N)
Compost	10.1	1.26

- Soil conditions varied slightly by location
- All presented nitrogen and phosphorous deficiencies
- Compost nutrient levels low

Research - Erosion

- Types and impacts of erosion were researched

- Need to reduce runoff and increase infiltration

- Most erosion control methods include creating some kind of protective vegetative cover

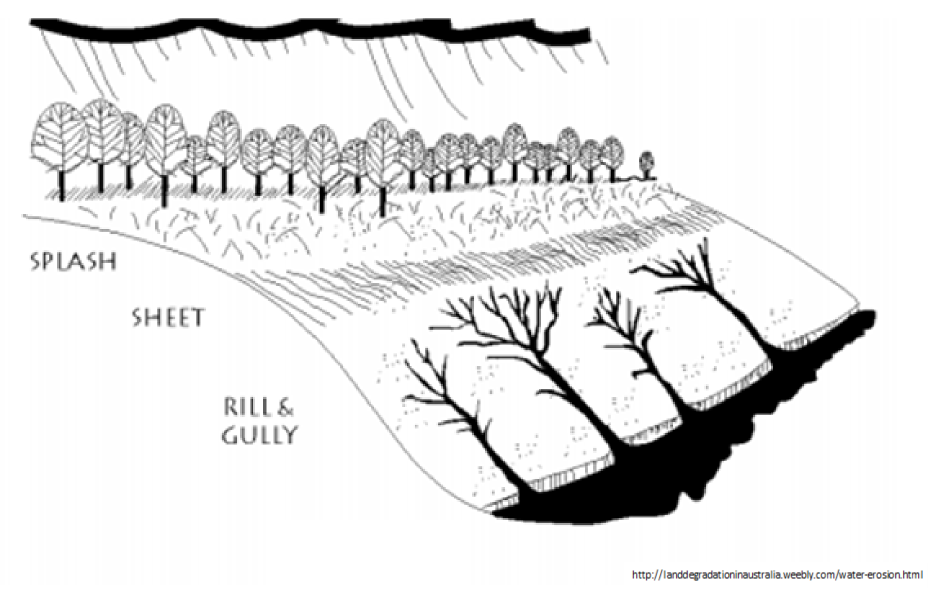

Diagram of erosion types

Research - Erosion Control

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Cover Management

Soil cohesiveness
Rolled products
Vegetative cover

Support Practices

Natural materials
Synthetic material
Water diversion

RUSLE2 Modeling

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The Universal Soil Loss Equation (USLE)

A = RKLSCP

Where:

A = net detachment (mass/unit area)
R = erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = supporting practices factor

Erosion Modeling Software

- RUSLE2 is a computer software that estimates total soil loss with the Universal Soil Loss Equation (USLE).
- The mathematical equations and technical advice in the model are based on conservation of mass and USLE principles.

USDA NRCS
U.S. Department of Agriculture
Natural Resources Conservation Service

RUSLE2 Modeling

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Constant Inputs:

- Slope Characteristics
  - length
  - steepness
- Climate Characteristics
  - precipitation
  - temperature
- Soil Characteristics
  - soil type/texture

Variable Inputs:

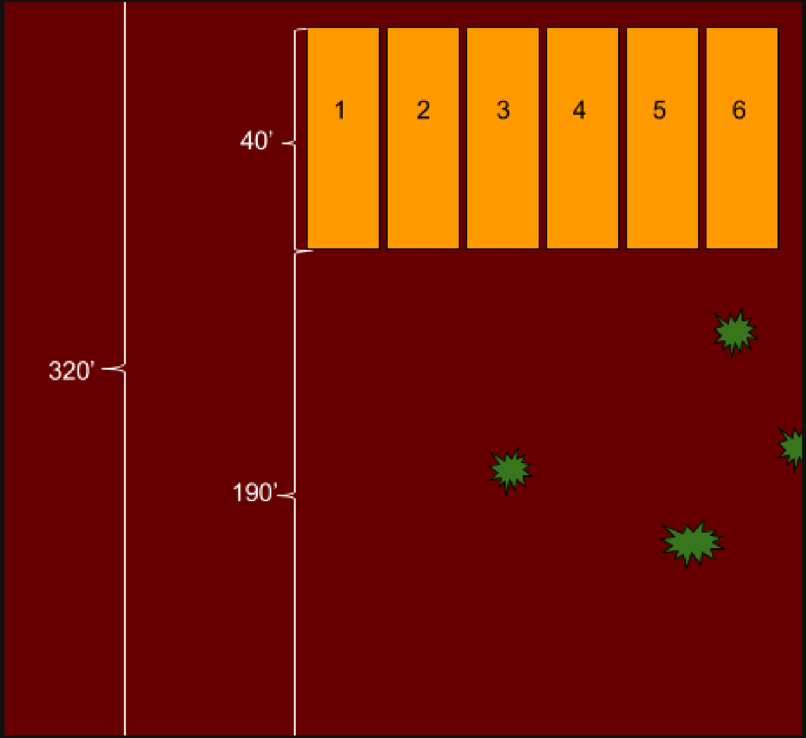
- Ground Cover
  - bare soil
  - grass cover
- Soil Conservation Structure
  - mulch berm
  - compost socks
  - wattles

RUSLE2 Modeling Results

Conservation Operation	Soil Loss (t/ac/yr)	Soil Loss (lb/yr)
None (Bare Ground)	167.00	4676000
Poor Grass Cover	3.000	84000
Moderate Grass Cover	0.320	8960
Mulch Berm	0.071	1988
6" Wattles (4)	0.062	1736
8" Compost Socks (4)	0.055	1540
Grass Cover (Bermudagrass)	0.048	1344

On-Site Testing

- 6 plots
- 10 ft x 40 ft
- Hand-seeded with Johnston Seed Co. mix
- No fertilizer or irrigation water added
- 5 gallon buckets and front end loader for measuring and transporting
- March 3 - April 14



On-Site Testing:
Erosion Evaluation

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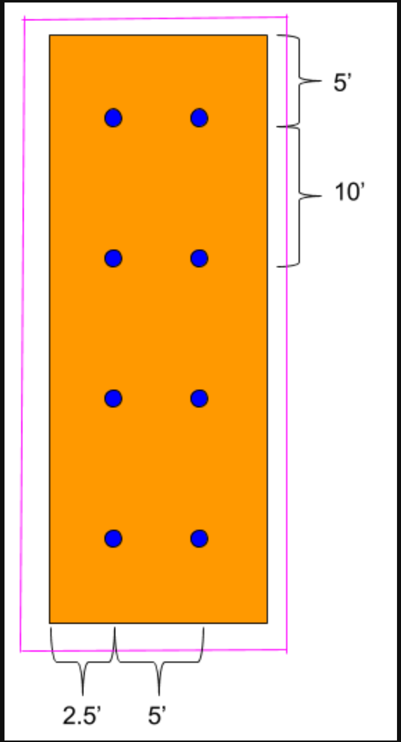
Soil Loss:

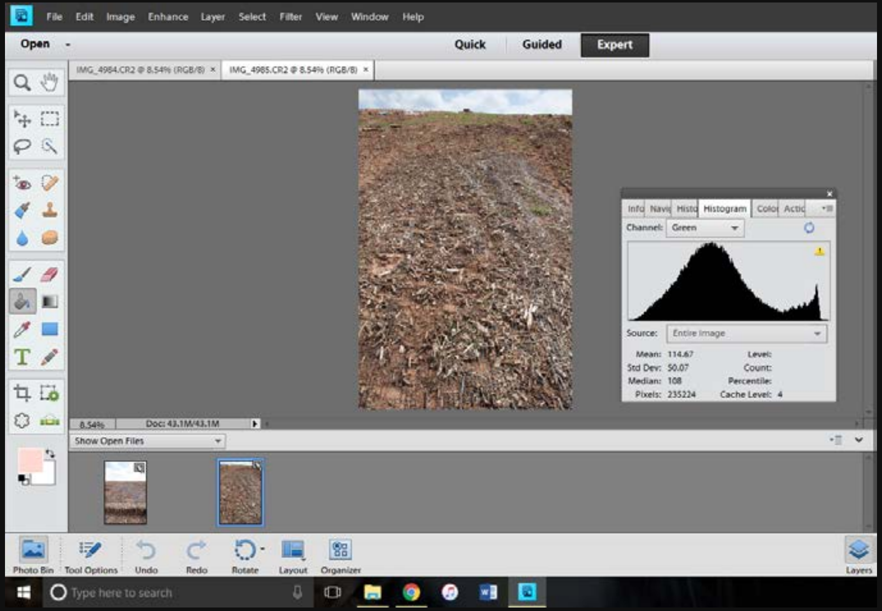
- Evaluated severity of sheet erosion by quantifying total soil loss
- Metal garden stakes placed in 2 x 4 grid even with surface
- Measurements taken with ruler



On-Site Testing: Vegetation Evaluation

Vegetative Cover:

- Estimated total percentage of vegetative cover
- Photographs taken of top and bottom half of plot
- RGB values analyzed to count total pixels and total green pixels



On-Site Testing: Compost Blanket

- Hand-seeded first
- On-site compost spread to 1.5 inch thickness
- Netting installed 5 feet above and below plot
- Netting secured with 4 inch garden staples around edges

On-Site Testing: Control

- Hand-seeded
- Left bare

On-Site Testing: Manufactured Compost Socks

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- Hand-seeded
- 40 feet of 8 inch diameter compost sock provided by Minick Materials
- Placed at 10 ft intervals with one at top from RUSLE2 modeling
- Staked with 2 ft wooden stakes at each end

On-Site Testing:
Homemade Compost Socks

- Hand-seeded
- Same netting filled with on-site compost
- Same procedure as manufactured compost sock plot

On-Site Testing: Wattles

Sustainable Solutions

- Hand-seeded
- Netting provided by ASP Enterprises and cut to 10 ft sections
- Filled with on-site woodchips to fit 6 inch diameter
- Placed 13.3 ft and 26.6 ft from top
- Staked on both sides at angle

On-Site Testing: Biosolids and Woodchips

- Composted biosolids provided by Midwest City Compost Facility
- Biosolids mixed with on-site woodchips and grass seed and raked evenly
- Netting staked around edges
- Mulch berm constructed at base of plot

On-Site Testing:
Biosolids and Woodchips

- Amount of biosolids based upon total nitrogen content of 34 lb N/ ton and 75 lb N/acre
- 36% mineralization assumed to give 60 lb total
- 107 gallons of woodchips and 25 gallons of soil used

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Budget

Item	Cost
Travel (7 trips)	517.45
Stakes	48.69
Pins	49.66
Zip Ties	11.96
Netting	147.42
Biosolids (1 yd^3)	21.64
Spray Paint	4.48
Twine	13.94
Buckets (6)	19.38
Total:	**834.62**

- Allocated $2400 for reimbursement by DEQ
- Actual expense total: $834.62
- Difference due to donations of seed, socks, and wattles
- The largest recurring cost was travel expense

Results:
Compost Blanket

- Vegetative Cover - Highest surface area vegetative coverage
- Soil Loss - Mild soil loss and sedimentation above and below netting
- No rills coming out of base
- Insect population present in nutrient supplemented plots

Results:
Control Plot

- Vegetative Cover - Very little vegetative cover
- Soil Loss - Even distribution of soil loss
- Single rill coming from base of plot

Results:
Manufactured Compost Socks

- Vegetative Cover - Grass growing on surfaces between socks
- Soil Loss - High degree of sedimentation
- Composition inside sock changed
- Rills forming on either side of plot

Results:
Homemade Compost Socks

- Vegetative Cover - Grass growing on step surfaces between socks
- Soil Loss - High degree of sedimentation
- Compost in socks covered by a layer of sediment
- Undercutting under one sock
- Rills forming on either side of plot

Results:
Homemade Wattles

- Vegetative cover - Taller grass growth than control
- Even distribution of growth
- Soil loss - Socks trapped sediment
- Similar but smaller terracing effect

Results:
Biosolids and Woodchips

- Vegetative Cover - Good variety of grass growth
- Mature plants
- Even distribution of soil loss
- Soil Loss - Homemade mulch berm caught a lot of sediment

Results:
Biosolids and Woodchips

Sustainable Solutions

Results:
Sediment Loss (cm)

	Average sediment loss in cm			
Plot	**Week 1**	**Week 3**	**Week 6**	**Cumulative**
Compost Blanket	0.0	0.0	0.5	**0.5**
Control	0.0	0.1	0.8	**0.9**
Manufactured Compost Socks	0.0	0.0	1.2	**1.2**
Homemade Compost Socks	0.0	0.3	1.0	**1.3**
Homemade Wattles	0.0	0.1	0.5	**0.6**
Biosolids and Woodchips	0.0	0.3	0.2	**0.5**

- Plots with both nutrient addition (compost) and structure (netting) had the least sediment loss
- Error in unidentical plots, no way to quantify soil addition

Results:
Vegetative Cover

Plot 1 Compost Blanket	Plot 2 Control Plot	Plot 3 Manufactured Compost Socks	Plot 4 Homemade Compost Socks	Plot 5 Homemade Wattles	Plot 6 Biosolids & Mulch
1.67%	0.86%	0.84%	0.86%	0.84%	1.02%

- Plots with both nutrient addition (compost) and structure (netting) had the best comparative grass coverage

Troubleshooting & Obstacles

Sustainable Solutions

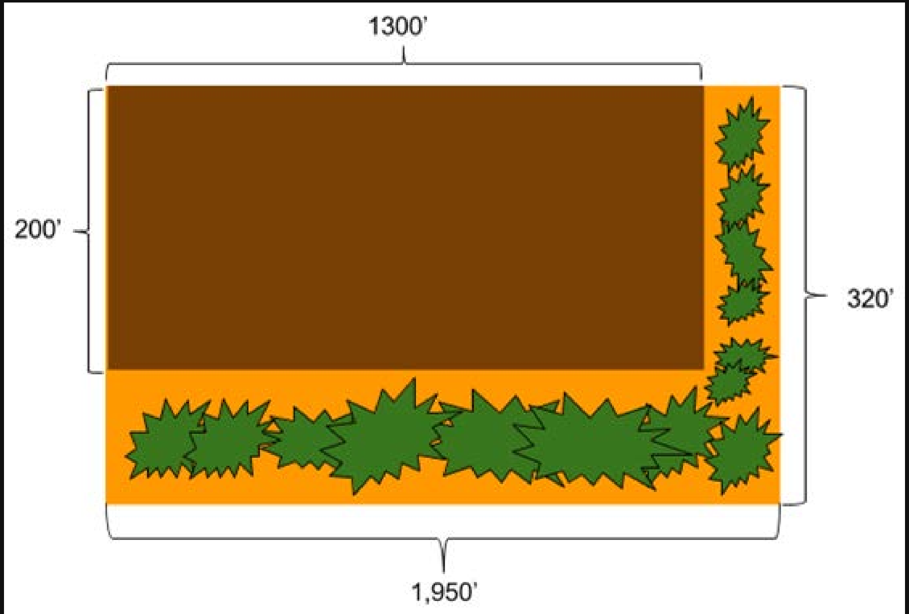
- Communication and chain of command
- Biosolids permitting process
- Inoperable hydroseeding machinery
- Weather limitations
- Distance and time constraints

Recommendation

- Integrated solution - nutrient addition and support practice
- Compost Blanket
- Homemade Mulch Berm

Cost Analysis

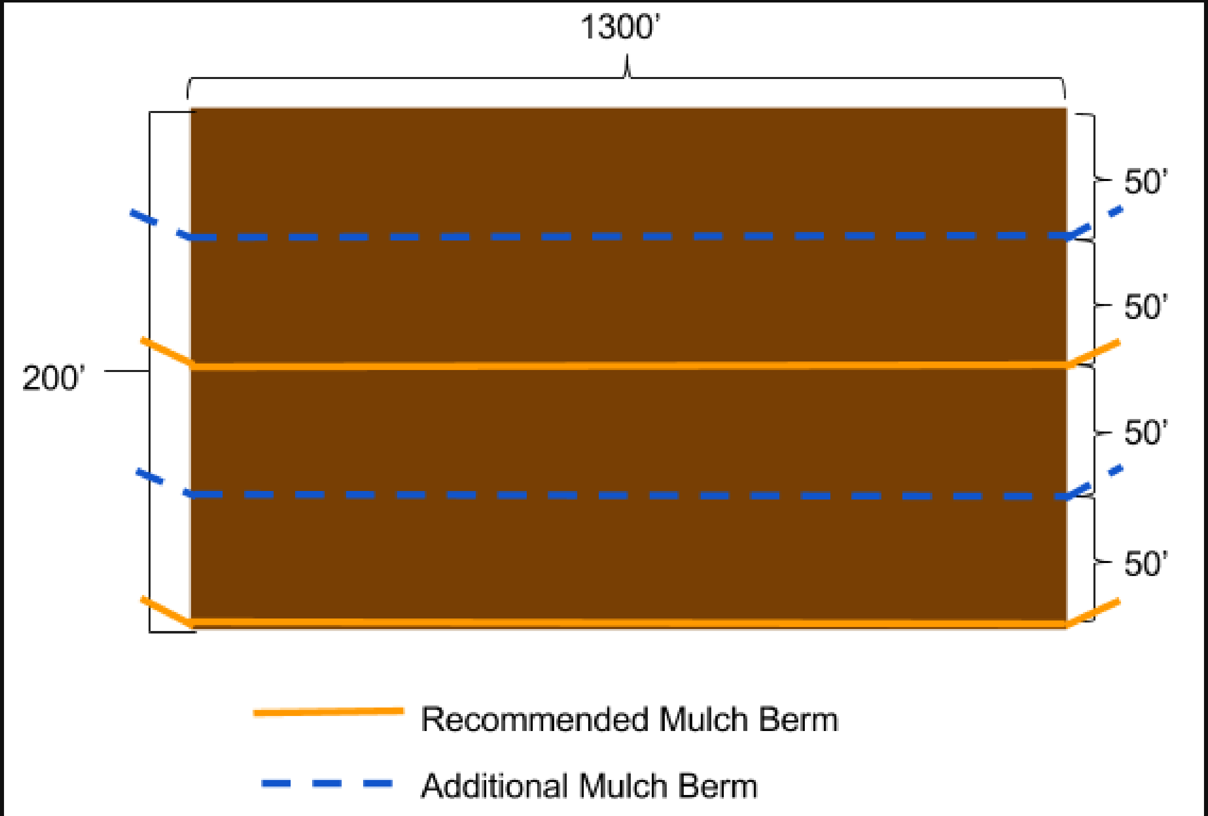
- Based on bare slope area of 260,000 sq ft (6 acres)
- No labor costs included
- The Do-Nothing Option
    - o Amber Edwards, DEQ Solid Waste Compliance Manager
    - o $500 - $1000 monthly fine



Critical Area

Critical Area

- First two homemade mulch berms placed at 100 ft and 200 ft from top of slope
- After evaluation, additional mulch berms can be placed at 50 ft and 150 ft from top of slope



Cost Analysis-Seed

Recommend critical site application rate

Seeding Rate	Seeding Rate (lbs PLS/acre)	Cost/Acre	Cost
Landscape	11.7	$51.00	$306.00
Critical	26.1	$104.00	$624.00

Cost Analysis-Nutrient Blanket

Cost Level	Supply	Cost / yd^3	Total Material Cost
High	Purchased Compost	$30	$24,120
Medium	Purchased Biosolids	$20	$16,080
Low	On-site Compost	$0	$0

Cost Analysis-Support Practice

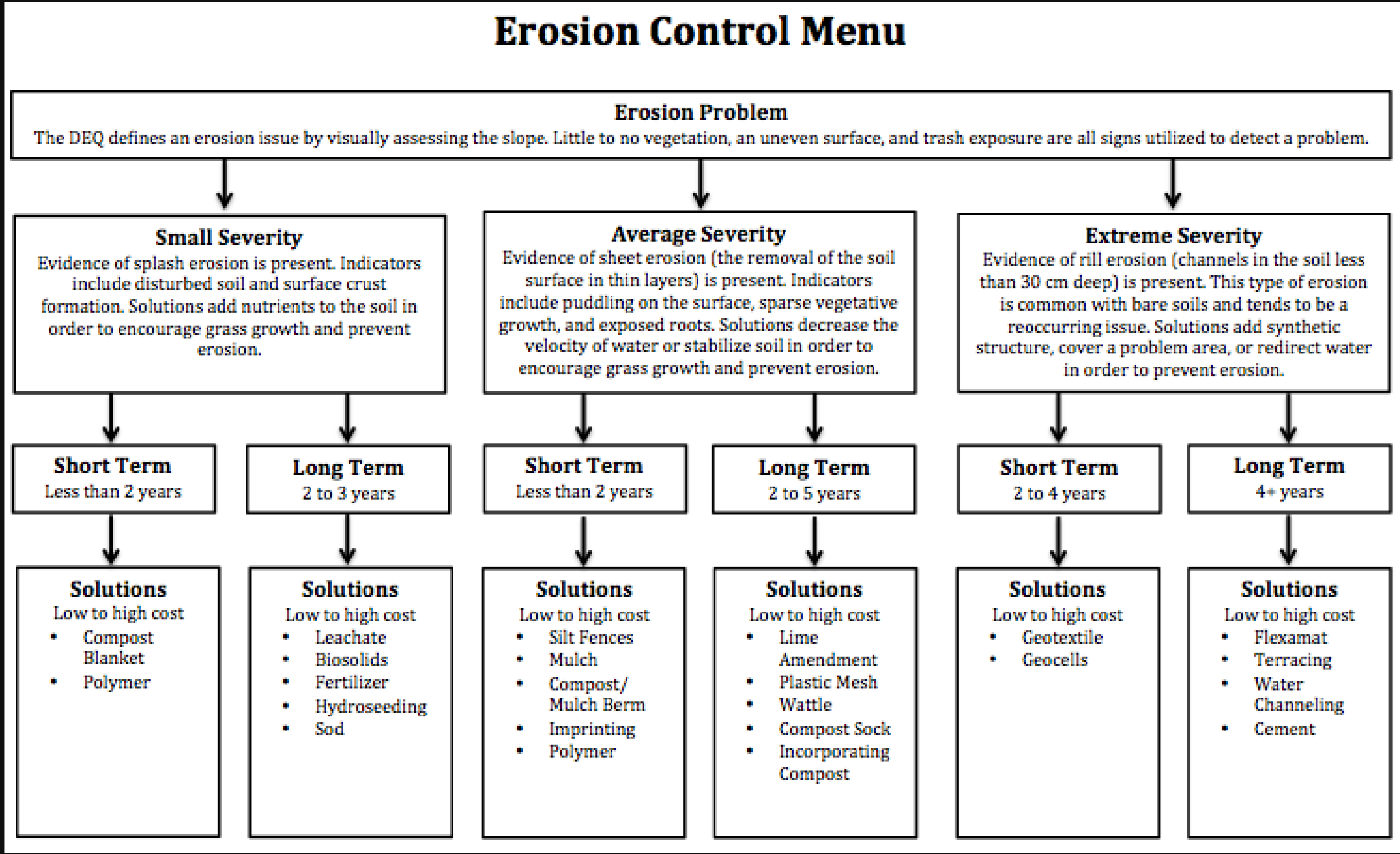
Homemade Mulch Berm

Item	Unit	Unit Cost	Number	Cost
12" netting	150' roll	$25.50	18	$460.00
24" stake	pack of 6	$5.00	87	$435.00
8" zip tie	pack of 100	$7.00	11	$77.00
			Total:	$972.00

Manufactured Wattles

Item	Unit	Unit Cost	Number	Cost
8" wattle	25' length	$25.00	104	$2600.00

Erosion Control Menu



Erosion Control Menu - Low Severity

Sustainable Solutions

- Evidence of splash erosion: disturbed soil and surface crust formation
- Solution: add nutrients to encourage grass growth and prevent rainfall impact

Short Term- less than 2 years

- Compost Blanket
- Polymer

Long Term- 2 to 3 years

- Leachate
- Biosolids
- Fertilizer
- Hydroseeding
- Sod

Erosion Control Menu - Average Severity

Sustainable Solutions

- Evidence of sheet erosion: sparse vegetative growth, exposed roots/trash
- Solution: decrease the velocity of water or stabilize soil

Short Term - less than 2 years

- Silt Fence
- Mulch
- Compost / Mulch Berm
- Imprinting
- Polymer

Long Term - 2 to 5 years

- Lime Amendment
- Plastic Mesh
- Wattle
- Compost Sock
- Incorporating Compost

Erosion Control Menu - Extreme Severity

Sustainable Solutions

- Evidence of rill erosion: channels in the soil less than 30 cm deep
- Solution: add synthetic structure, cover a problem area, or redirect water to prevent channeling

Short Term - 2 years or less

- Geotextiles
- Geocells

Long Term - 2 to 3 years

- Flexamat
- Terracing
- Water Channeling
- Cement

Impacts and Sustainability

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The erosion control menu:

- Provides solutions for already-existing slopes
- Provides proactive techniques for the construction of new cells
- Prevents the increasing severity of erosion problems
- Ultimately saving taxpayer dollars

Future Erosion Work

- Continuously evaluate test solutions left on-site
- Plan for erosion control before construction begins
  - Store topsoil for exterior slope
  - Incorporate compost into cover soil before spreading
- Look into stabilizing biosolids on-site for future use and revenue
- Keep menu updated with trending effective solutions

Thank You!

Sustainable Solutions

A special thanks to those who provided guidance along the way:

- Barry Brummit, Environmental Specialist, City of Enid
- David Cates, Oklahoma Dept. of Environmental Quality
- David Cross, Landfill Manager, City of Enid
- Louis Mintz, Director of Public Utilities, City of Enid
- Kelly Dillow, Oklahoma Dept. of Environmental Quality
- Amber Edwards, Oklahoma Dept. of Environmental Quality
- Dr. Jason Vogel, OSU Dept. of Biosystems Engineering
- Dr. Paul Weckler, OSU Dept. of Biosystems Engineering

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Acknowledgements

DEQ
OKLAHOMA
DEPARTMENT OF ENVIRONMENTAL QUALITY

CITY OF Enid
OKLAHOMA

MINICK MATERIALS
SINCE 1958
SOIL · STONE · SERVICE

JOHNSTON
SEED COMPANY

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

ASP
ENTERPRISES

Sustainable Solutions

Fall Design Report 2016

Hannah Blankenship | Amethyst Kelly | Christian Ley | Katie Schlotthauer

Prepared for:

City of Enid Municipal Landfill

Oklahoma Department of Environmental Quality

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Introduction

The Oklahoma Department of Environmental Quality (DEQ) is responsible for enforcing environmental laws and regulations. Partnering with the DEQ has provided Sustainable Solutions with the opportunity to aid the City of Enid Municipal Landfill with its current erosion problem. Attention was directed to an erosion concern on the north facing slope. These concerns include sediment deposition at the base of the slope, potential trash exposure, rill formation, scarce vegetative growth, and contamination of the on-site stormwater pond.

Some current low-cost solutions on existing landfills around the state have been ineffective in solving the erosion problem long-term. Previously at the City of Enid Municipal Landfill, sections of the north facing slope have been hydroseeded with an ADC machine, covered with mulch, and sprigged and seeded. Other landfill erosion control methods include layering straw and topsoil on the slopes. Many solutions have succeeded for a time, but the erosion problem persists. Therefore, more sustainable designs must be implemented in order to prevent detrimental impacts to the environment. The EPA requires certain standards to be maintained for the on-site stormwater pond, runoff, and groundwater (DEQ, 2016).

Enid's composting program operates on the premises of the landfill. Therefore, yard waste compost and mulch are available for use as soil amendments. A stormwater detention pond nearby could also be utilized for irrigation. If on-site resources are successfully utilized to control the erosion concerns, a similar design could be applied at other erosion-prone sites with the potential to incorporate sustainable local resources.

Mission Statement

Designing green solutions for soil and water related problems.

Problem Statement

Determine viable solutions for mitigating erosion on the north facing slope of the Enid Municipal Landfill.

Customer Requirements

The project requirements provided by the Oklahoma Department of Environmental Quality are as follows:

- Cover all bare soil surfaces on the north slope with vegetation to reduce erosion
- Determine the feasibility of using on-site resources like compost and mulch
- Reduce sedimentation at the base of the slope and silting in the pond
- Provide a model site for other Oklahoma landfills

Additionally, due to the limited availability of government funds, the City of Enid would like Sustainable Solutions to present low and high cost design alternatives.

Project Scope

Sustainable Solutions will design a menu containing effective strategies to reduce erosion on the north facing slope of the Enid landfill. The menu will contain solutions organized by their cost, effectiveness, time commitment for upkeep, and length of solution. The feasibility of using onsite resources such as soil, compost, leachate, and stormwater will be determined. Different erosion control designs will first be evaluated with computer modeling to reduce the options. A full scale experiment will then take place on the landfill slope to determine to most viable solutions.

Deliverables

Proven design solutions will be presented in the form of a menu. Solutions will be judged on the following criteria:

Coverage: Coverage success will be determined by measuring the percentage of surface area in a plot protected by vegetation, as wells as the maximum height of the vegetation over a certain period of time.

Cost: This criterion compares an estimated prediction of all installation costs and maintenance expenses. Cost includes project resource expenses such as equipment, expertise, manpower, and maintenance costs related to additional applications, professional assistance, or monitoring.

Longevity: The effectiveness of each solution over a certain period of time will be taken into account. Data for this criterion will be based largely on research.

Type of Erosion: If a design solution option is best suited for a certain type of erosion, it will also be specified on the menu.

Work Breakdown Structure

1. Research
    1.1. Preliminary Web Research
    1.2. Technical Literature Review & Patent Analysis
        1.2.1. Erosion
        1.2.2. Hydroseeding
        1.2.3. Compost & Alternative Cover
        1.2.4. Alternative Fertilizers
            1.2.4.1. On-site Leachate Composition
            1.2.4.2. Wastewater Sludge Composition
        1.2.5. Cover Management
        1.2.6. Support Practices

1.3. Soil & Water Analysis

1.3.1. Web Soil Survey

1.3.2. Soil, Water, and Forage Analysis Lab (SWFAL)

1.3.2.1. Cover Soil

1.3.2.2. Slope Soil

1.3.2.3. Compost

1.3.2.4. Con Cover™

1.3.2.5. Stormwater

2. Design and Model

2.1. Alternative Design Options

2.2. RUSLE2 Simulations

3. Test

3.1. Test for Effectiveness

3.1.1. Rill Erosion Solutions

3.1.2. Sheet Erosion Solutions

3.1.3. Short-term Solutions

3.1.4. Long-term Solutions

4. Deliverables

4.1. Final Report

4.1.1. Erosion Control Menu

4.1.1.1. Effective Solutions

4.1.1.2. Alternative Solutions

4.1.1.3. Ineffective Solutions

4.2. Final PowerPoint Presentation

4.2.1. Client Evaluation

Task List

Research Phase

- Research current erosion solutions for steep slopes and low soil quality
    - Research feasibility of alternative slope covers online
    - Review pertinent technical literature and patents
    - Audit Erosion & Sedimentation Control Class
- Research erosion control methods
    - Make an exhaustive list of products
    - Narrow down based on general feasibility
    - Estimate product cost and longevity
- Research vegetation type best suited for current slope and soil composition
    - Determine soil composition
        - Perform soil type analysis from USDA Web Soil Survey
        - Collect soil samples from landfill site
        - Turn into OSU's Soil, Water, and Forage Analytical Lab
        - Interpret results
    - Meet with specialists to discuss vegetative cover options and constraints
- Compare soil amendment options and feasibility of using on-site resources
    - Analyze composition of on-site leachate collection water and wastewater sludge
    - Interpret compost, Con Cover™, and stormwater SWFAL results
    - Research methods for incorporating leachate, sludge, mulch, and compost
- Develop quantitative engineering specifications
    - Obtain a copy of the landfill site plans
    - Determine total surface area within our scope
    - Research RUSLE2 and determine input variables
- Research relevant EPA regulations and DEQ permitting

    - Research water quality, leachate application, and sludge application standards
- Do cost analysis on alternative designs
    - Compare initial costs
    - Compare maintenance costs

Design Phase

- Do computer modeling with RUSLE2
    - Model current Enid Landfill slope conditions
        - Use USDA Soil Web Survey to input soil composition
    - Determine return period of simulated storm based on historical rainfall data
    - Model alternative erosion control methods
- Determine indicator variables of success
    - Design procedure to monitor/quantify vegetation growth
- Finalize design options to test on slope

Testing Phase

- Test two or three model-proven solutions on landfill slope
- Interpret experimental results
    - Arrange solutions into menu of options categorized by:
        - Cost
        - Erosion Type
        - Effectiveness
        - Solution Lifetime

Finalize & Present Results

- Write final report
- Present menu and report to the City of Enid and DEQ

Research

Technical Literature and Patent Review

Sustainable Solutions began its research on landfills and erosion with a web search. It quickly found that landfills are complex systems, but there are many resources at our disposal. The research was focused on four key areas: erosion control, hydroseeding, alternative cover materials and compost, and waste fertilizer materials like leachate and sludge. Figure 1 below gives a view of the problem slope.

Figure 1: View of the North-facing slope of the Enid Landfill

Erosion Control

Soil erosion is not a new problem. It has been researched in depth for many years. The two main types of soil erosion are water erosion and wind erosion. Particularly in Enid, water erosion on slopes is the main concern, though wind erosion may also play a part. Figure 2 below showcases such erosion. Raindrop splash erosion is the main culprit, and research has found that the steep slope of the land intensifies erosion, allowing more than half of the soil involved in raindrop splashes to be carried downhill (Pimentel, Harvey, Resosudarmo, Sinclair, Kurz, McNair, & Blair, 1995). The loss of soil degrades the quality of land and its capacity to produce plants, further intensifying erodibility.

Figure 2: Image of current rill erosion issue

Soil erosion greatly limits the amount of nutrients available to plants. In turn, a lack of root depth and plant growth increases the soil's susceptibility to erosion. However, if plant cover can be established, it can protect the soil from erosion by reducing water runoff and increasing infiltration. Over the long-term, infiltration can increase the structure of a soil, making it easier for even more vegetation to flourish (Zuazo & Pleguezuelo, 2008).

Covered soil is protected from erosion because the overhead plant mass can dissipate the energy of falling raindrops. Many different practices can be employed to prevent erosion, including adding mulch as cover. Most erosion control methods include creating some kind of protective vegetative cover on top of the soil. Aside from cover, the soil texture and structure can affect its erodibility, which is why it's important to test samples and know the quality of the soil of interest (Pimentel et al., 1995).

The type of vegetation growing, or lack thereof, is dependent upon the soil type. The cover soil that the Enid Landfill is currently utilizing is a hard-packed, sticky red clay. Clayey soils discourage root growth because of their small pore size and high bulk density. Both the soil structure and vegetative growth contribute to the erosion rate. The small particle size found in clay should decrease erosion, but the lack of vegetation increases erosion. A study done by Clary, Dunaway, Swanson, &Wendel (1994) tested the combination of these two factors. They found that clay has a net positive effect on erosion. As the percent of clay in a soil increases, erosion increases and the root density decreases (Clary et al., 1994). Therefore the combination of high clay content soil and sparse vegetation perpetuates the cycle of erosion on the slope.

However, solutions can be found. Even small plant life like algae can disrupt erosion. In 1941, Booth studied algal crusts growing on damaged soils in the Great Plains. Soil algae crusts can prevent water and wind erosion on badly damaged soils without decreasing the stormwater infiltration rate. The algae growth on bare soils can also be very beneficial to the future growth of larger plants. Much of this research was done in Oklahoma, so it can be assumed that the addressed soil types are similar to the Enid landfill slope cover and that algal crusts could be formed on the problem slope. Algal crusts can create a higher moisture content in the upper soil profile and greatly reduce the erosion of poor soils (Booth, 1941).

Hydroseeding

Hydroseeding is a viable option for erosion control on the problem slope. There are many scientific articles that support this option. An article by Merlin, Di-Gioria, and Godden (1999) discusses potential agents that assist with adhesion for the hydroseeding process. Their experiment observed that Guar gums and synthetic polymers were not very effective for adhesion, while alginates demonstrated the best adhesion. They also concluded that nutrients were essential for seed germination on marginal soils. Fertilization needs can be determined by analyzing soil samples taken from the landfill site. The average cost of hydroseeding is 18 cents per square foot. Figure 3 illustrates the hydroseeding application method.

Figure 3: Example of hydroseeding application

A compost blanket approach could also be a viable option. The article written by Faucette, Risse, Jordan, Cabrera, Coleman, and West (2006) discusses this option by comparing the compost blanket and hydroseeding approach for erosion control (See Figure 4). This experiment found that the compost blanket treatment was more successful in vegetative cover for the short term (three months), while in the long term (one year) the hydroseeding and compost blanket treatments had the same amount of vegetative cover. Any alteration in the soil condition was not observed at the culmination of the experiment.

Figure 4: Example of compost blanket application (Integrate Erosion Control AU)

Patent Searches

Patents are another great way to gather information on previous uses and successes of hydroseeding. The patent filed by Edward and Terry on December 7, 2010, describes a unique mixture for hydroseeding containing mostly mulch and straw. This could be applicable to the Enid Landfill site due to the immediate on-site and free access of mulch. The mixture used for hydroseeding is important. This is expressed by Cook in the patent filed April 11, 2013, that talks more about the general idea of hydroseeding and the benefits, but also includes biological components in the mixture. We would need to find the optimal mixture for the Enid landfill based on deficient nutrients and cost.

Patents surrounding hydroseeding follow a trend. They mostly include different mixtures or processes of delivery, but the act of hydroseeding remains consistent. There are many patents that claim small adjustments to the mixtures. We would need to narrow down what type we prefer before understanding if such a mixture has already been created.

Compost and Alternative Cover

Alternative Daily Cover

Spray-on alternative daily cover materials are advantageous due to the fact that the materials do not need to be removed after application (Querio, 2016). However, spray-on alternative daily cover materials may not provide complete cover of the waste, and the process requires preparation and application equipment. Alternative daily cover (ADC) materials can be waste-derived materials, including yard waste and recycled paper. Environmental advantages associated with ADC strategies include saving lateral airspace, extending the life of landfill, and minimizing impacts on soil.

Alternative Daily Cover strategies typically apply 6 inches of soil at the end of each day, and must be approved by agency permit approvals. However, it may be advantageous to use manufactured or waste-derived materials in lieu of soil application. Why eliminate soil? ADC materials occupy less airspace, minimize impacts on the soil, utilize leachate and on-site materials, and extend landfill life. Manufactured materials include geotextiles, spray-on materials such as hydro-mulch, spray-on slurry, or Con Cover™, and foam. Waste derived materials can include recycled paper, contaminated soil, and wood.

Evapotranspiration Based Cover

The soil layer stores the water during rain events and the vegetation removes the water from the soil by evaporation and evapotranspiration (Abichou et al., 2015). The plant roots aerate the soil, thus the methane oxidation is improved by the soil structuring processes of vegetation, and this reduces surface greenhouse gas emissions. This process also reduces the amount of water that infiltrates into the landfill, which reduces leachate production.

In the study by Abichou et al. (2015), a model of a landfill was constructed. In the first model site, the top of landfill was modeled according to the suggested RCRA slope of 2-5%. The second model demonstrated the side of the landfill using slope of 25% or 4:1 ratio. Instrumentation included soil moisture probes, water potential sensors at various depths, and a weather station at central location to monitor rainfall. The unsaturated hydraulic properties of the ET cover were determined. This study is fairly similar to our problem; we are trying to utilize vegetation to mitigate water and soil erosion issues. Additionally, this study investigated the usage of plant cover to mitigate landfill gas emissions, which could be especially useful because our client expressed interest in a landfill gas mitigation system. The viability of the design is dependent on soil type, moisture content, density, organic content, nutrient availability, temperature, precipitation, and vegetation type. See figure 5 below.

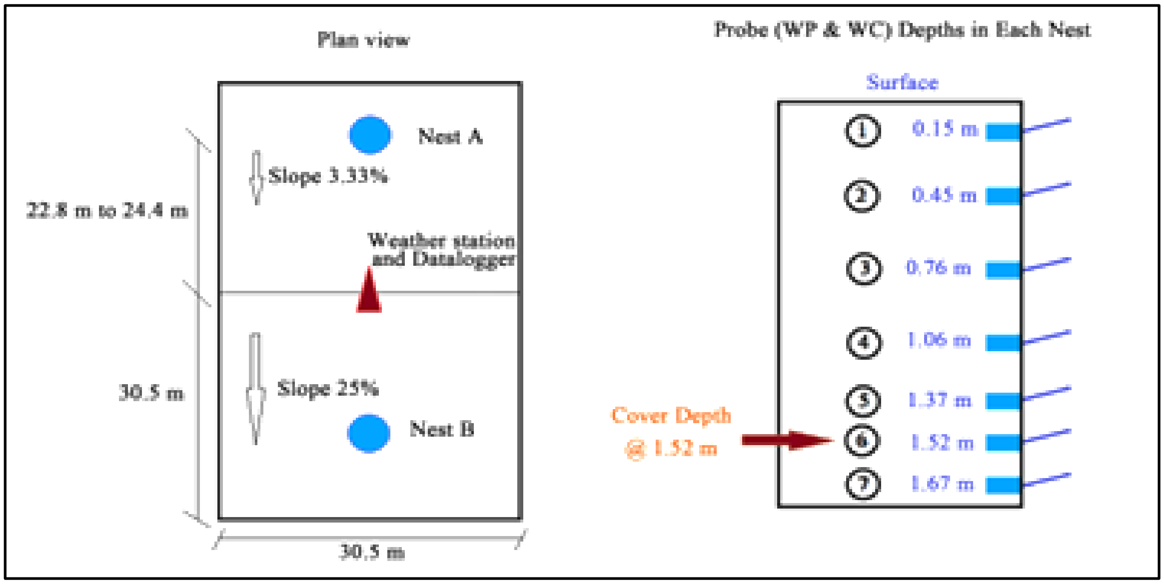


Figure 5: Profile view of instrumentation installed in ET cover (Abichou et al., 2015)

Using Compost as a Landfill Cover

Compost covers have been found to reduce methane emissions from landfills by as much as 100% (EPA, 2002). This solution is a great option for small landfills, where landfill gas collection is not required and where the economics of landfill gas collection systems are too expensive. When the outer layer of compost loses moisture, a barrier is created to prevent temperature loss in the inner compost layer. Compost composition varies greatly and should be carefully considered in the design of the cover. The study suggested that Grade A (high quality) compost is the best type of compost to use as cover material.

The 2002 EPA compost cover study was conducted with three model sites: one on a sloping landfill, one model on flat ground, and a control plot. The cover of the two experimental test sites consisted of 3 layers: a 6-inch thick layer of clay; a 4-6 inch layer of tire chips to distribute the methane; and 36- 40 inches of yard waste compost on the top. The control plot was simply covered with a clay cover 36 inches deep.

Throughout the duration of the experiment, the landfill gas emissions were monitored. The effectiveness of the design was evaluated by conducting erosion tests, which would identify potential problems, such as whether the cover would remain stable with steep slopes or poor weather. The type of vegetation needs to be chosen carefully, so that the plant will grow and stabilize the slope to prevent erosion. The results of this study indicated that the emission reductions exceed that of a landfill gas recovery system, which typically collect about 70-85 percent of the total landfill gas generated.

Landfill owners considering compost cover need to ensure that their cover complies with regulations on cover performance and maintenance of the cover during the closure and post-closure periods. To use an alternative cover, the landfill operator will need specific approval of the Department of Environmental Quality State Director.

Bulk Material Cover Compositions and Methods of Applying

An alternate daily cover material for landfill and a method for applying the cover material are disclosed in Patent US 8946324 (Hansen, 2015). The cover composition includes liquid, cement and/or fly ash, fiber, water dispersible polymer, and acid. Typically, most landfills are covered by spreading a layer of dirt over the exposed portions of the waste piles. For example, a waste pile that is to be covered for a short period of time may require a six-inch layer. This strategy requires a large amount of soil to cover the waste. To maximize the volume available for waste, there are two main options: 1.) reduce the amount of soil necessary for covering the waste piles or 2.) provide a cover material that substitutes for the dirt. In this patent, several spray-on coatings were developed to provide an effective cover to waste piles. These cover materials typically comprise a mixture of water, mineral binder (cement kiln dust), and fibers (both cellulose and synthetic) that can be sprayed onto a waste pile and allowed to set to provide an effective cover. These mineral-based covers have proven to provide effective covers to landfills and other waste piles.

Possible Issues with Fiber-Based Covers

Fiber-based covers do not adhere well to low friction surfaces like plastic containers, typically found in landfills. The fiber-based covers tend to coagulate, so it is difficult to pump and spray these fiber-containing products evenly. This patented invention attempts to solve this problem by improving the application methods of the fiber cover. The adhesion to landfill materials is improved and the materials are easier to apply. The patent provides an improved cover material and method for applying the cover material to a pile by including fly ash in the cover.

In-Situ Fertilizer Application

Leachate

One possible fertilizer source is the on-site landfill leachate. The leachate can be diluted and applied as irrigation water for plants. A couple of studies that were researched showed increased concentrations of available nutrients, organic compounds, and microorganisms in the soil for plants. There are concerns, though, about the impacts that the metals and other contaminate might have on the environment (Wong & Leung, 1989; Bowman, Clune, & Sutton, 2002). Grass cover is used to uptake available forms of nitrogen and mitigate these effects. The Bowman et. al. (2002) research focused on bioremediation of landfill leachate with a turf grass cover. The leachate contained high salt and sodium concentrations which adversely affected the soil structure and grass growth. Therefore, the capacity of the soil to uptake nitrogen decreased with the increased salinity of the soil. The study done by Wong and Leung (1989) also observed detrimental effects of increased salinity soil, as well other contaminants present in the leachate. Upon further investigation, optimal dilution rates could be found to make leachate irrigation an appealing fertilizer. Although, if the issues presented in both studies occur for all soil types or conditions, leaching of nitrogen or other contaminants may prevent the feasibility of using on-site leachate on the problem slope of the Enid Landfill. Investigation of various dilution rates using Enid's landfill leachate may determine the feasibility.

Sludge

Sludge is another possible fertilizer option to improve soil quality. One experiment by Cogliastro, Domon, & Daigle (2001) explored the use of wastewater sludge and woodchip combinations as a soil amendment and fertilizer. "Stabilized" sludge and woodchip combinations have great advantages such as releasing nutrients, like nitrogen, slowly over time as plants need it in a way that sludge or wood chips by themselves would not. The test plots were grown on a flat field with high clay content and poor drainage. The growth of saplings in differing combinations of sludge and woodchip concentrations were observed and analyzed. Results showed minimal plant growth in the first year, but the availability of several essential nutrients increased (some decreased though) over the two year experimentation time to provide necessary nutrients for growth. The smallest sludge application seemed to allow for a release of nutrients over a longer time period, with less nitrogen mineralization in the first year of testing. Successful land rehabilitation needs several years to establish soil physical, chemical, and biological properties essential for stable grass cover.

It is pertinent to know that "waste activated sludge" that is produced from the secondary wastewater treatment process contains harmful pathogens and viruses. This sludge must be deactivated, or stabilized, before applying it to land (National Research Council, 1996). Class B biosolids contain detectable levels of pathogens that must be handled safely. A factsheet provided by the EPA (2000) outlines the stabilization process through cost-effective measures. The pH must be raised to intolerable levels for microorganisms. This can be achieved by mixing Quicklime into the solid sludge and raising the temperature for a certain time through a composting process. Increasing the pH can actually improve the soil conditions and reduce mobilization of metals. Cost for Class A biosolid stabilization is estimated around $139 to $312 per dry ton (EPA, 2000). Stabilization of Class B biosolids may require additional lime that reaches the upper boundary of the cost estimation.

Sludge also contains a high quantity of heavy metals that may be detrimental to plant growth and can pose environmental risks. An experiment performed by Labrecque, Teodorescu, and Daigle (1994) sought to assess the total biomass production as well as plants' ability to bioaccumulate heavy metals with differing wastewater sludge concentrations applied. The highest concentration of sludge applied provided the optimal nutrient requirements and conditions for the trees grown. Although, sludge would most likely need to be reapplied in a few years after initial growth. It was also found that the trees grown did not show detrimental effects from the absorption of heavy metals. This characteristic could be very valuable for the project. Leaching or solubility of metals potentially creates adverse environmental effects, especially in surface water systems. The landfill site contains a stormwater reservoir directly south of the problem slope that must maintain DEQ water quality requirements (DEQ, 2016). Providing a grass or other plant cover could mitigate potential environmental impacts from the application of sludge.

Regulations and Permits

If the leachate collection water or the wastewater sludge are found to be viable fertilizer amendments, applicable regulations and standards will be investigated.

Wastewater Sludge

The City of Enid municipal wastewater plant is currently using Element 2 permit for municipal solid waste landfill disposal. Permit is in accordance with The Department of Environmental Quality Management of Solid Waste guidelines in OAC 252: 515-3-41. 120 days' notice is required before any planned change in sewage disposal (Landfill Permit No. 3524006) per OK DEQ (Oklahoma Department of Environmental Quality, 2016).

Leachate

OAC 252:515 Subchapter 13 gives guidelines on leachate collection and management. A plan for leachate irrigation by the DEQ must be approved (Oklahoma Department of Environmental Quality, 2016).

Soil and Water Analysis

The research phase came to life during a second site visit to Enid. Five different soil samples were taken in order to determine the nutrient availability of the cover topsoil, cover subsoil, grassy slope, mulched slope, and bare slope. See Figures 5 and 6 below for the sampling process. Reference Appendix D for the official OSU soil and water sampling procedures.

Figure 6: Sampling the cover topsoil

Figure 7: Sampling the cured compost

On-site compost, Con Cover™, and stormwater were also sampled to determine their usefulness in amending the soil or irrigating. Samples were taken according to standards set by the Soil Water Forage Analytical Laboratory (SWFAL) at Oklahoma State University (Zhang & Arnall). The samples were analyzed by SWFAL, and the results are show below in Table 1, Table 2, and Table 3.

Table 1: NPK requirements of soil samples (SWFAL)

Soil Description	N (lbs / A)	P (lbs / A)	K (lbs / A)
Cover topsoil	39	48	489
Cover subsoil	1	23	356
Bare slope	6	34	541
Mulch slope	1	35	671
Grassy slope	4	35	450

Overall, the landfill cover and slope soils have plenty of potassium but lack nitrogen and phosphorous. Amending the soil with fertilizers could increase the potential for a healthy vegetative cover to establish. Unfortunately, the results of the compost sampling show that the nitrogen levels of the compost are also low. Though adding compost to the slope would still be beneficial for soil structure and stability, the nutrients will need to come from an outside source.

Table 2: Bar graph of cover topsoil NPK (SWFAL)

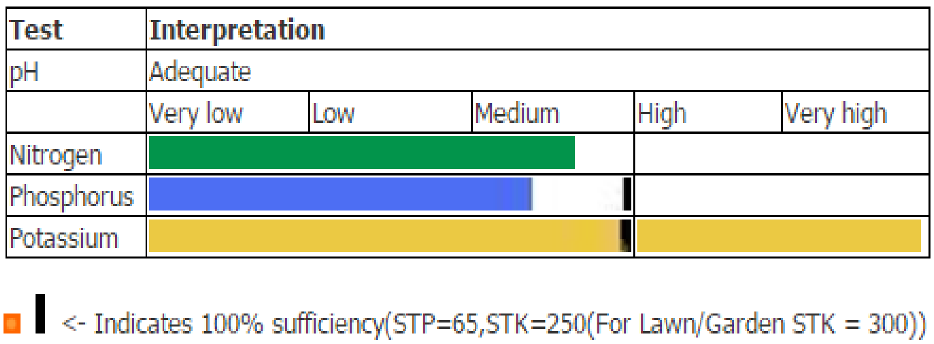
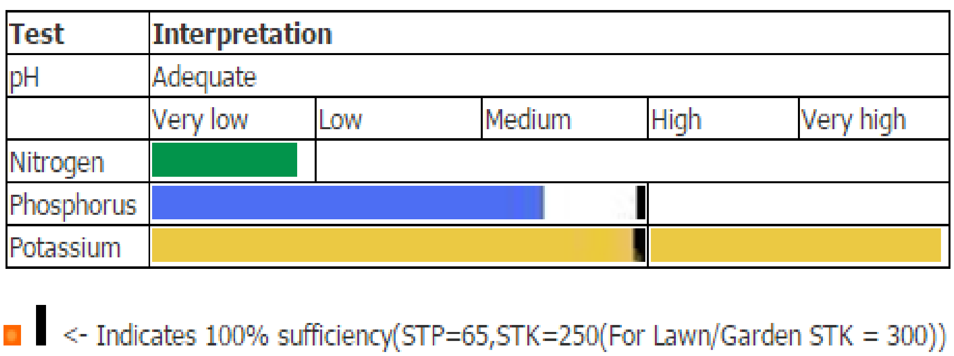


Table 3: Bar graph of cover subsoil NPK (SWFAL)



As expected, the cover topsoil was much higher in nutrients than the cover subsoil. In the future, as new cover soil plots are opened, the topsoil should be set aside and used intentionally on permanent slopes to take better advantage of the available nutrients. Additionally, the tests revealed that the stormwater is safe to use for irrigation if necessary (See Table 4).

Table 4: Results of water sampling (SWFAL)

Test Results For **Irrigation Water**

-----Cations-----		-----Anions-----		-----Other-----	
Sodium (ppm)	32.5	NO_3-N (ppm)	< DL *	pH	8.1
Calcium (ppm)	52.9	Chloride (ppm)	54.1	EC (µS/cm)	712
Magnesium (ppm)	19.9	Sulfate (ppm)	56.2		
Potassium (ppm)	64	Boron (ppm)	0.2		
		Bicarbonate (ppm)	255		

---Derived Values---		--Derived Values(Cont'd)--	
Total Dissolved Salts (TDS in ppm)	535.0	Hardness	214.0
Sodium Adsorption Ratio (SAR)	1.0	Hardness Class	Very Hard
Potassium Adsorption Ratio (PAR)	1.1	Alkalinity (ppm as $CaCO_3$)	209.2
Residual Carbonates (meq)			
Sodium Percentage	24.8%		

Freshmen Involvement

Figure 8: Freshmen field work

Sustainable Solutions had the opportunity to direct two freshman teams throughout the fall semester. These two teams worked on different sections of the senior design project. Working with the senior team gave the freshman experience in large-scale projects and insight into their own scholastic future. The Sustainable Solutions team gained extra manpower and fresh views of the problem. It was a mutually beneficial relationship that led to immense learning.

The first freshman team worked on soil and water analysis. This team was comprised of Elizabeth Alder, Kimberly Guthrie, Morgan McDougal, and Godwin Shokoya. They traveled with the Sustainable Solutions team to the Enid landfill to collect samples. Later they interpreted the test results to determine the deficiencies of the onsite materials. Their final step was to create poster outlining their recommended additives to improve the quality of the soil.

The second freshman team created a small-scale lab testing experiment designed to test erosion scenarios. This team was comprised of Barry Bachman, Tucker Cogburn, Abbey Gray, and Ashton Lofquist. The Sustainable Solutions team gave them a general idea of an experimental setup. The freshman team then created a time frame, budget, and final setup of an experiment to test erosion of different vegetative covers for the slope. The second team also created a poster displaying their experimental setup.

The freshman teams were a valuable resource. Each team presented an intelligent take on their individual projects. Their results were considered in the preliminary narrowing of design concepts.

Product Analysis

After meeting with Dr. Jason Vogel and attending his Erosion and Sediment Control Class, research expanded beyond on-site materials. The brainstorming process created a giant list of design solutions. Proven products on the market and best practices were arranged into the categories of cover management and support practices.

Cover Management

Cover management designs prevent soil erosion by diminishing the effects of erosive activities. These design solutions include but are not limited to practices that will improve vegetative cover.

Woven Geotextiles

Figure 9: Woven textile fabric application (US Fabrics)

Woven Geotextiles are durable fabrics designed to stabilize soil and increase ground support. Woven geotextiles are mostly made from high-strength polypropylene fibers, to allow for maximum slope support, stabilization and erosion control (Woven & Nonwoven Geotextile Fabric, n.d.).

- Predicted cost: $0.05/sq.ft ($85-$100 per 4ft x 500ft Roll)
- Longevity: Unknown

Nonwoven Geotextiles

Figure 10: Nonwoven textile fabric application (Layfield Construction Products)

Nonwoven Geotextile fabrics provide a solution for drainage, filtration and stabilization. They are lightweight, so the fabric is commonly used as both a filter and a stabilization mechanism for construction sites or in other areas with high runoff levels (Woven & Nonwoven Geotextile Fabric, n.d.).

- Predicted Cost: $0.06/sq.ft ($70 per 4ft x 300ft Roll)
- Longevity: Unknown

Coir Erosion Control Mats

Figure 11: Coir textile fabric application (Bender)

Coconut Coir Mats are a biodegradable geotextile fabric. Coir mats are available in a wide range of strengths to accommodate low level, medium or steep slopes. The average longevity for coconut fiber products is from 2 to 5 years. This provides enough to time for steep areas to be stabilized, while vegetation is allowed to fully take root. Also, the longevity of the material on dependent on location and water flow in the area (Coir Products for Erosion Control, n.d.).

- Predicted Cost: $0.91/sq.ft ($80-100/ 3 ft x 33ft Roll)
- Longevity: 2-5 years

Steel Plates Alternative Daily Cover

Figure 12: Landfill steel plates (Solid Waste Association of North America, 2015)

The Revelstoke Iron Grizzly cover system consists of a series of steel panels that provides coverage in active landfill slopes. Each steel plate is constructed with a vector belt along the length which conforms to the uneven surface of the waste. The belts overlap the panel eliminating gaps in the cover which prevents disease vectors from entering the waste cell (Revelstoke Iron Grizzly, n.d.).

- Predicted Cost: High
- Longevity: Long-term

Electro-Osmosis Soil Treatment

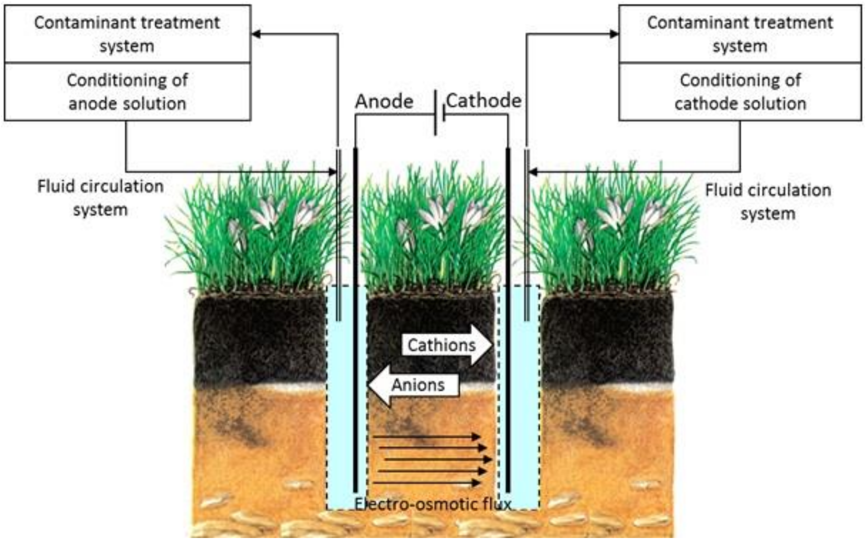


Figure 13: Diagram of electro-osmosis (Geoengineer)

The use of electro-osmosis for treatment of soft clay soils is a common ground improvement technique. Electro-osmotic soil treatment involves the application of an electric field to the soil to initiate flow of water through a clay-water system. Through a series of electrical pathways, electro-osmotic flow appears as plug flow through the pores of soil. Electro-osmosis can cause a significant increase in the settlement and undrained strength of the soil (Estabragh, Naseh, & Javadi, 2014).

- Predicted Cost: High
- Longevity: Unknown

Polymer Soil Stabilization: GRT 9000

Figure 14: Soil stabilizing polymer, GRT9000 (GRT)

GRT 9000 polymer soil stabilization provides a chemical solution to improve soil conditions. Using onsite materials, GRT 9000 is used to create a hard, semi-flexible and water impermeable pavement. The mixture helps prevent surface degradation, and can be used to treat materials such as clays, silts and sands. Environmental protection benefits – GRT products are non-toxic, have a low carbon footprint and use in-situ materials (GRT:9000 Polymer Soil Stabilization, n.d.).

- Predicted Cost: Unknown
- Longevity: Short-term

Soil Binder & Erosion Control: GRT ENVIRO

Figure 15: GRT-Enviro soil binder and erosion control (GRT)

GRT-ENVIRO SOIL BINDER & EROSION CONTROL is an organic soil conditioner based on a water-soluble polymer. This product can be added to irrigation water to reduce soil erosion by agglomerating fine particles that otherwise would be carried away by surface water runoff. Some of the noted benefits are: Sediment reduction of up to 95% by increasing cohesion between soils particles, improves water infiltration, reduced leachate in the runoff water, improved germination rate of plants, and saves up to 30% water. Environmental protection benefits – GRT products are non-toxic, have a low carbon footprint and use in-situ materials (GRT-Enviro Soil Binder & Erosion Control, n.d.).

- Predicted Cost: Unknown

- Longevity: Short-term

Fertilizer Application to Improve Vegetative Cover

Figure 16: Example of large-scale fertilizer application (Corn & Soybean Digest)

Vegetative cover is one of the most commonly used methods for controlling erosion and covering landfills. Based on the soil test results, specific nitrogen, phosphorus, and potassium recommendations can be made to improve the quality of the plant growth.

- Predicted Cost: Low
- Longevity: Varies depending on erosion control methods, precipitation, and climate

Lime Amendment for Soil Stabilization

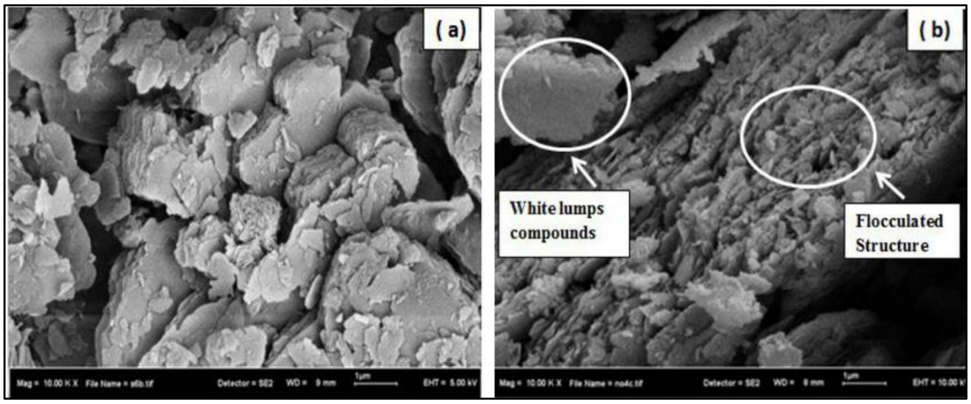


Figure 17: Image of (a) untreated clay soil and (b) lime treated clay (Saeed, 2015)

Lime can be added to soils is to improve the workability of silt and clay-based soils. By adding lime, the mechanical properties are also strengthened. Lime application is commonly used in road and highway construction to improve the stability of clay soils (Herrier, et al., 2012; Saeed, Kassim, Yunus, & Nur, 2015).

- Predicted Cost: Low
- Longevity: Varies

TYPAR® Geocells

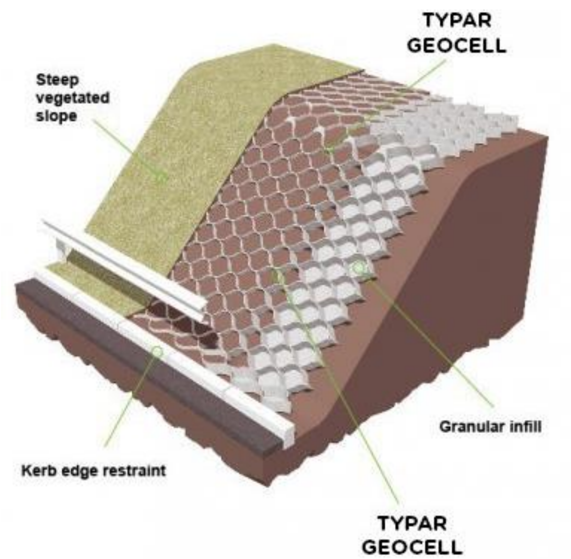


Figure 18: TYPAR® geocell diagram (TYPAR)

Geocells are typically made of high-density polyethylene and structured like a sheet of honeycomb. They can be used on top of slopes to hold rocks and soil or underneath vegetative cover to help stabilize soil. UV protected for >2yrs under soil. Will be installed for basically forever if we put them in. Maintenance supposedly easy in patches (TYPAR Geocell - Slope Protection, n.d.).

- Predicted Cost: Medium
- Longevity: 2+ years

Sod

Figure 19: Example of sod application (Green Valley Turf Co.)

Sod is turf grass and the soil held by its roots, and it is sold in rolls to roll out over soil. On the landfill's steep slope, it will most likely need to be staked. It must be well irrigated after installation. Sod is a good solution for flat and unvegetated areas but will not fix rill areas.

- Predicted Cost: \$0.40-\$0.90/sq.ft (Sod Types and Prices - Buy Online, n.d.)
- Longevity: Long-term

Incorporating Compost

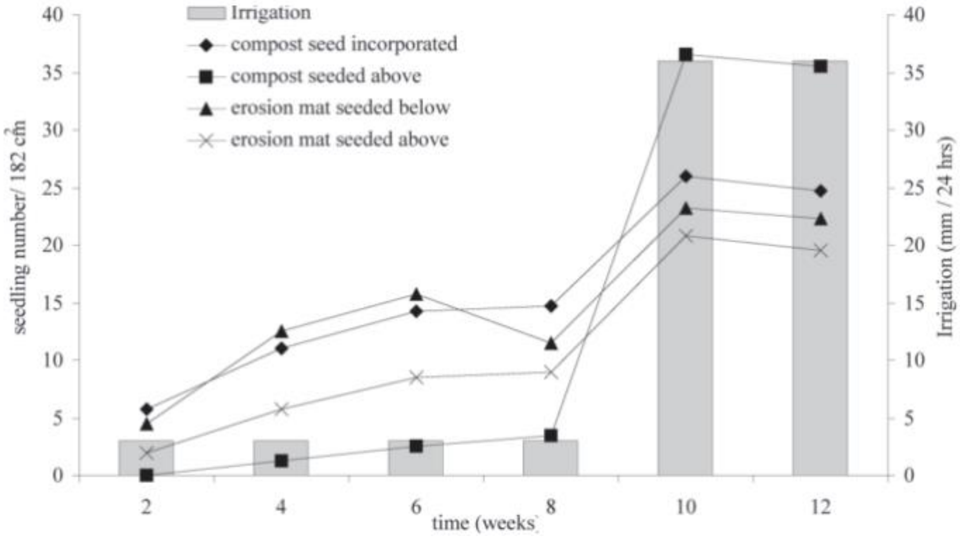


Figure 20: Graph of germination study (Harrell and Miller, 2005)

Compost can be tilled in or otherwise incorporated to improve the structure and stability of the soil. Research has shown that incorporating 5cm of compost at depth of 7.6 cm can improve vegetation growth better than straw mats, but not better than surface compost blankets (Li, Hanlon, O'Connor, Chen, & Silveira, 2010; Reinsch, Admiraal, Dvorak, & Cecrle, 2007; US Composting Council).

- Predicted Cost: $10-$25 per cubic yard, labor only
- Longevity: Two or three seasons

Mulch

Figure 21: Current mulch use existing at the Enid Municipal Landfill

Mulch is composed of decaying chipped tree branches and other woody plants. It can protect the soil and improve its structure while waiting for vegetative cover to take root (Osborne & Gilbert, 1976).

- Predicted Cost: Low
- Longevity: Short-term

Flexamat®

Figure 22: Flexamat® rolled soil stabilizer (Flexamat)

This product is a high strength interconnected concrete mat system with a wood excelsior. It stabilizes the soil surface, protecting it from rainfall runoff and encouraging grass growth. Flexamat® Plus uses 100% recycled plastic. This product is applicable for steep slopes, drainage canals, and maintenance roadways to prevent erosion. It can be manufactured on site and the manufacturer claims it is less expensive than other conventional products (Customize Flexamat, n.d.).

- Predicted Cost: $5.65/ sq.ft (with Curlex®)
- Longevity: Long-term

Compost Blanket

Figure 23: Example of compost blanket application (Integrate Erosion Control AU)

A compost blanket is a layer of loose compost applied to the soil surface. The compost can fill in rills or erosion prone areas to protect it to prevent channelized flow and even splash erosion. It improves the soil structure, CEC, and nutrient levels to create a place for vegetation to be established. A confinement method (mesh) is required for slopes greater than 1:1 and the compost must be high in nutrients and within EPA regulations to be effective. It is suggested to use about 1 to 3 inch layer of compost material (McCoy, 2005; National Pollutant Discharge Elimination System).

- Predicted Cost: $0.11-0.12/sq.ft. (1 in-deep)
- Longevity: Short-term

Typar® GRASSPROTECTA

Figure 24: GrassProtecta grass reinforcement mesh (TYPAR)

This dense plastic mesh can provide slope stabilization and vegetated erosion control. This product is delivered in a roll that can be laid out and staked down for a permanent solution. Light vehicle use is recommended (GrassProtecta grass reinforcement mesh, n.d.).

- Predicted Cost: $2.60/sq.ft
- Longevity: Varies

Typar® TURFPROTECTA

Figure 25: TurfProtecta turf reinforcement mesh (TYPAR)

This is a lightweight plastic mesh roll used as grass protection layer. This product could be used to stabilize the soil surface to allow a strong vegetative cover to grow on the slope. Vehicles can still drive over this material (TurfProtecta turf reinforcement mesh, n.d.).

- Predicted Cost: Unknown
- Longevity: Varies

Typar® BODPAVE Pavers

Figure 26: BODPAVE porous paving grids (TYPAR)

These pavers are made of a durable plastic made to withstand heavy machinery. The grids can be interconnected and filled with gravel or soil to provide a protected surface for grass growth. A proper drainage system must be implemented in conjunction with these pavers (BodPave 85 porous paving grids, n.d.).

- Predicted Cost: $4.44/sq.ft ($12 per 2.7 sq.ft Paver)
- Longevity: Long-term

EnviroGrid™ –cellular confinement

Figure 27: EnviroGrid ™ cellular confinement grids (EnviroGrid)

EnviroGridTM geocells are a confinement system for soil stabilization and erosion control. The cells can be filled with gravel, soil, cement, vegetation, etc. on almost any grade of slope. The grid system reduces rainfall impact and rainwater runoff velocity. This product could also be stacked to create terraces. Multiple size options are available (EnviroGrid, n.d.).

- Predicted Cost: $0.31-$1/sq.ft
- Longevity: Long-term

Adding Leachate

Figure 28: Enid Municipal Landfill leachate collection tank

Using the on-site leachate collection water could be cost effective if pretreatment is not required. Leachate could be applied as a fertilizer to improve soil characteristics and encourage vegetative growth. Environmental concerns and permitting should be highly considered (Wong & Leung, 1989).

- Predicted Cost: Low. Equipment cost or treatment cost could be expensive.
- Longevity: 2-3 years. Until cover is established.

Adding Wastewater Sludge

Figure 29: Example of biosolid land application (Michigan DEQ)

Wastewater sludge could be a great soil amendment as it contains essential nutrients and organic material for plant growth. Biosolid stabilization with lime can further increase the soil structure (see lime fertilizer section). The wastewater biosolids must be treated first and EPA standards must be taken into high consideration (EPA, 2000; EPA, 2016).

- Predicted Cost: Low
- Longevity: 2-3 years

Adding Sludge and Mulch

Figure 30: Example of composted mulch and biosolids (WEF Highlights)

It has been proven that a wastewater sludge and mulch combination is more effective than either used by themselves. The sludge is able to release nutrients quickly for vegetation to be established and the mulch provides a slow release of nutrients (Cogliatro, Domon, & Daigle, 2001). Sludge stabilization and EPA requirements must be taken into high consideration (see wastewater sludge section).

- Predicted Cost: Low
- Longevity: 3-5 years

Hydroseeding

Figure 31: Example of hydroseeding (BAI Environmental Services)

Hydroseeding is a type of planting that uses a mixture of seed, nutrients, and mulch to fertilize and seed an area. It is often transported as a premixed slurry and then sprayed onto the desired land area. Advantages for hydroseeding include quick application for a large area and rapid germination. Often a mixture of seed type is best, but a few categories for consideration are listed below. Cost for dispersal equipment will not be included because the landfill site already owns an ADC machine (Hydroseeding & Soil Stabilization Methods, 2016).

- Predicted cost: $0.18/sq.ft (includes seed, fertilizer, and stabilizer)
- Longevity: Long-term

Hydroseeding Common Grasses

Figure 32: Example of Bermuda grass (The Grass Patch)

Common grasses used for erosion control include Bermudagrass, blue grama, buffalograss, vetiver grass, and many more. The cost and availability will be considered for use in the design.

- Predicted cost: $0.01/sq.ft (Bermuda seed only) (Lowe's, n.d.)
- Longevity: Long-term

Hydroseeding Native Grasses

Figure 33: Example of Buffalo grass (Hillerman)

Native grasses for Oklahoma include bluestem, Japanese brome, Indiangrass, switchgrass, buffalograss, grama, and many more. The cost and availability will be considered for use in the design.

- Predicted cost: $0.05/sq.ft (Buffalograss seed only) (Lowe's, n.d.)
- Longevity: Long-term

Hydroseeding Annual Grasses

Figure 34: Example of annual Ryegrass (University of Missouri)

Annual grasses are grasses that only have a lifecycle of one year. This deficiency can be compensated for by the seed dispersal of the grass before the end of its lifecycle, starting a new yearly cycle.

- Predicted cost: $0.01/sq.ft (Ryegrass or Wildflower seed only) (Lowe's, n.d.)
- Longevity: Varies

Hydroseeding Vine/Ground Cover

Figure 35: Example of Rose Moss Cover (ASPCA)

Vine cover includes a variety of plant that grows on top of, and over the ground. Kudzu was considered but not recommended due to its invasive nature.

- Predicted cost: $0.05/sq.ft (Rose moss seed only) (Lowe's, n.d.)
- Longevity: Varies

Support Practices

Support designs for erosion control prevent erosion by controlling runoff; these solutions include terracing, silt fences, and other runoff interceptors.

Cement

Figure 36: Example of concrete blanket effects (Milliken Infrastructure)

Erosion on landfill slopes is rarely fixed with concrete. Concrete blankets and shotcrete solutions exist for difficult areas, but these solutions don't seem appropriate for the Enid Landfill. (Concrete Cloth Erosion Control/Slope Protection, n.d.; Shotcrete, n.d.)

- Predicted Cost: High. $5/sq.ft for slab and shotcrete.
- Longevity: Long-term

Wattle

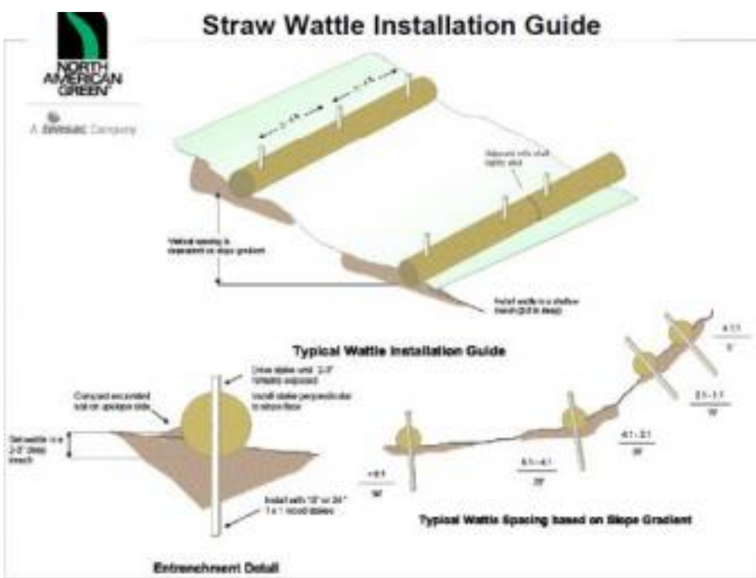


Figure 37: Straw wattle installation diagram (North American Green)

A wattle is tubular netting filled with absorbent material to slow runoff and settle sediment. Straw wattles are light and therefore must be staked. They are prone to floating. Mulch wattles are heavier and therefore prevent sediment loss more effectively (Quadel Industries, 2011; Texas Sustainable Industries, LLC, n.d.) We should look into buying biodegradable netting to fill with Enid's mulch.

- Predicted Cost: $1.00-$2.00/ft
- Longevity: 3-5 years. Netting will degrade in 20-36 months.

Compost Sock

Figure 38: Compost sock terraces (USDA NRCS)

A compost filter sock is a permeable sleeve filled with compost to filter stormwater and trap sediment. It's easy to install on severely compacted soils because no incorporation is necessary. Grass will eventually grow on and over the socks, creating natural berms perpendicular to the landfill slope (Archuleta & Faucette, 2011).

- Predicted Cost: Varies
- Longevity: Unknown

Silt Fence

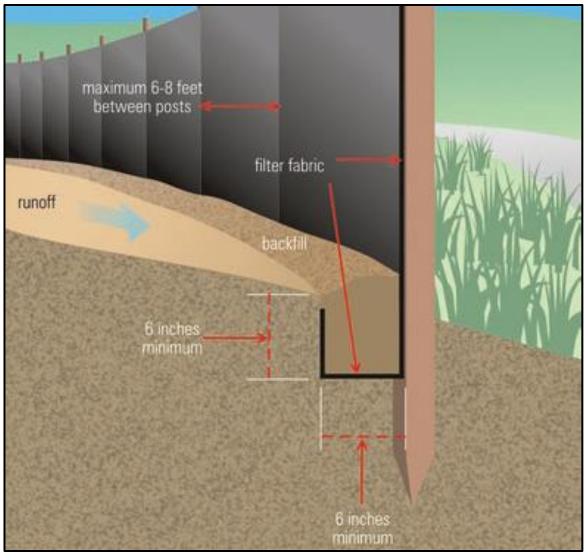


Figure 39: Silt fence installation diagram (Vogel)

Silt fence is water permeable, and its main purpose is to pond water so that sediment will settle out. This treatment may be effective at the bottom of our landfill slope (National Pollutant Discharge Elimination System; Silt Fence, 2003).

- Predicted Cost: $0.48 per ft ($48/100ft)
- Longevity: 5 to 8 months. Maintenance after every intense rainfall event

Gabion Baskets

Figure 40: Example of Gabion baskets (Site Supply, Inc.)

Gabions are rock-filled wire mesh baskets that can be placed on slopes for erosion protection. They can be used to solve a variety of erosion issues due to their flexibility and unique design characteristics. According to the manufacturer, they are fairly easy to install and do not require skilled laborers. In addition, gabion baskets can be filled with material that is already on site (Gabions Confine Stone for Erosion Protection and Retaining Soil, 2016).

- Predicted Cost: Varies based on materials used
- Longevity: Long-term

Terracing

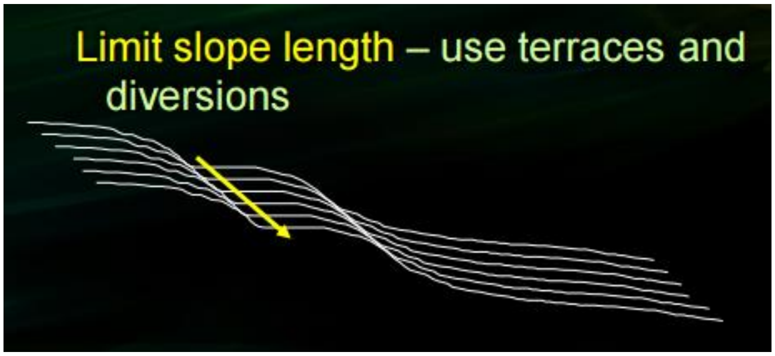


Figure 41: Diagram of slope terracing (Vogel)

Terracing is a soil conservation practice applied to prevent rainfall runoff on sloping land from accumulating and causing serious erosion (Wheaton & Monke, 2001). Terraces consist of ridges and channels constructed across-the-slope. The regrading involved with terracing would limit the practice of terracing to new cells of the landfill because of the risk of exposing trash (Widomski, 2011).

- Predicted Cost: High
- Longevity: Terraces must be maintained over the years but can last forever.

Riprap

Figure 42: Example of riprap channel protection (Anne Arundel County, Maryland)

Riprap is a permanent, erosion-resistant ground cover of large, loose, angular stone used to slow the flow of water (Riprap). The size of the rocks varies. This may be good to install in the ditch at the bottom of our slope or along the road.\

- Predicted Cost: $1/sq.ft (assuming $20 per ton avg.) (Coverage Charts, 2016)
- Longevity: Long-term. Low annual maintenance, will last forever.

Channel Water Over the Slope

Figure 43: Example of water channeling (Stormwater Solutions)

To prevent erosion on a slope, sometimes water can be rerouted over a slope through a more stable channel or through a pipe (Vogel, 2016).

- Predicted Cost: High
- Longevity: Long-term

Imprinting

Figure 44: Example of imprinting a slope (The Imprinting Foundation)

Imprinting is a land-use practice developed to increase stormwater infiltration and decrease erosion. Divots are created in soil using rollers or heavy machinery treads to create tiny hills perpendicular to the slope. The Enid Landfill may already employ machinery with useful treads, meaning that this could be a very viable short-term/daily cover solution (Dixon & Carr, 2003).

- Predicted Cost: Low
- Longevity: Short-term

Compost Berm

Figure 45: Example of compost berm implementation (EPA)

The compost filter berm method consist of a trapezoidal-shaped pile placed perpendicular to the sheet flow. The berm can consist of an array of materials such as mulch, municipal solid waste, and feedstock. The berm can trap sediment and pollutants that would otherwise transport down the length of the slope while still allowing water flow through it. The compost also allows for a nutrient rich amendment for vegetative growth. Berms can be used on steeper slopes if they are placed closely together or in combination with other products. They are not suitable for high velocity flows greater than 1 cfs (National Pollutant Discharge Elimination System).

- Predicted Cost: $1.90-3.00/ft. (McCoy, 2005)
- Longevity: Short-term unless permanent vegetative cover established

The table below gives a summary of the potential design solutions. This list is based upon preliminary brainstorming. More in-depth product analysis will take place in the Spring Semester to narrow down feasible options.

Table 5: Comparison chart of potential design solutions

Design Solution	Cost Estimate	Longevity
Woven Geotextiles	\$0.05/sq.ft	unknown
Nonwoven Geotextiles	\$0.06/sq.ft	unknown
Coir Erosion Control Mats	\$0.91/sq.ft	2-5 years
Steel Plates Alternative Daily Cover	high	long-term
Electro-Osmosis Soil Treatment	high	unknown
Polymer Soil Stabilization: GRT 9000	unknown	short-term
Soil Binder & Erosion Control: GRT ENVIRO	unknown	short-term
Fertilizer Application to Improve Vegetative Cover	low	varies
Lime Amendment for Soil Stabilization	low	varies
TYPAR® Geocells	medium	2+ years
Sod	\$0.40-\$0.90/sq.ft	long-term
Incorporating Compost	\$0.04-\$0.09/cubic ft	2-3 years
Mulch	low	short-term
Flexamat®	\$5.65/sq.ft	long-term
Compost Blanket	\$0.11-\$0.12/sq.ft	short-term
Typar® GRASSPROTECTA	\$2.60/sq.ft	varies
Typar® TURFPROTECTA	unknown	varies
Typar® BODPAVE Pavers	\$4.44/sq.ft	long-term
EnviroGrid™ –cellular confinement	\$0.31-\$1.00/sq.ft	long-term
Adding Leachate	low	2-3 years
Adding Wastewater Sludge	low	2-3 years
Adding Sludge and Mulch	low	3-5 years
Hydroseeding	\$0.18/sq.ft	long-term
Common Grasses	\$0.01/sq.ft	long-term
Native Grasses	\$0.05/sq.ft	long-term
Annual Grasses	\$0.01/sq.ft	varies
Vine/Ground Cover	\$0.05/sq.ft	varies

Design

Engineering Specifications

Calculations for the slope area were computed using specifications from the Enid Landfill and the site plans. The slope severity of 4:1 and the height range of 60-80 ft. were given by contacts at the Enid Landfill. The base length of 1,950 ft. was determined from the site plans and verified in scale using Google Earth (Figure 46). A slope length range of 240-320 ft. was calculated using the slope. The final slope surface area was calculated to be between 468,000 sq. ft. and 624,000 sq. ft. Sustainable solutions will use the rough estimate of 500,000 sq. ft. to represent the entire North-facing slope. About half of the slope is already covered with vegetation, so the value of 250,000 sq. ft. will be used to calculate the cost evaluations of our future design solutions. This is because the design solution will only be applied to the area where bare soil is exposed. Reference Appendix C for the full landfill site plans.

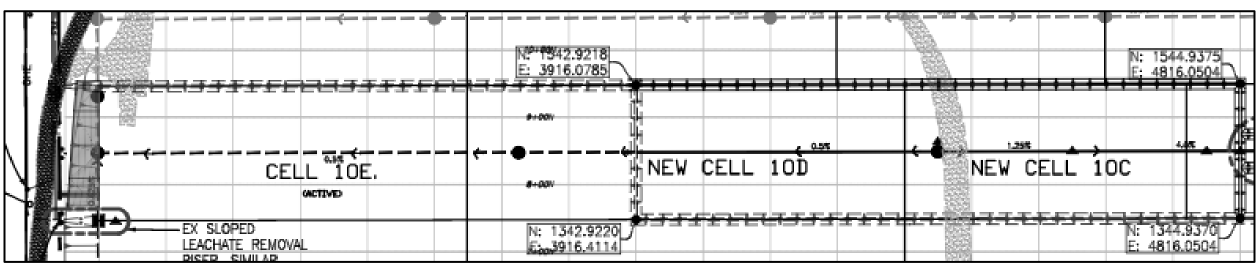


Figure 46: Engineering site plan top view of North Slope (City of Enid)

Erosion Modeling Software

RUSLE2 is a computer modeling software that estimates total soil loss with the Universal Soil Loss Equation (USLE). Users can customize the model using site-specific variables such as rainfall, slope, soil type, etc. (USDA, 2008).

The USLE is written in the form:

$$A = RKLSCP \qquad [1]$$

Where:

A = net detachment (mass/unit area)

R = erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = supporting practices factor

1.0 Proposed Methodology

The RUSLE2 model will be used to predict which erosion mitigation strategies will be most effective for the prevention of erosion in the Enid Landfill. To further assess the erosion mitigation strategies, each of the proposed solutions will be categorized into one of two categories. The categories include cover management and support practices. Cover management practices prevent soil erosion by diminishing the effects of erosive activities. These practices include practices that will improve vegetative cover and enhance soil cohesiveness. Support practices for erosion control prevent erosion by controlling runoff; these solutions include terracing, silt fences, and other runoff interceptors. After each erosion solution is categorized into one of the two aforementioned categories, the solutions will be further ranked and assessed based on the longevity, economic feasibility, and sustainability of each proposed design. The four highest ranking solutions will be tested on-site at the Enid Landfill.

1.1.0 Revised Universal Soil Loss Equation (RUSLE) Modeling

RUSLE is an erosion prediction model that uses the Universal Soil Loss Equation (USLE) and a computer interface. RUSLE models are constructed with physical input values that are widely available in existing databases or can be easily measured (USDA, 2008). According to the USDA, RUSLE2 is a practical erosion prediction model that can be easily learned by new users and can be downloaded at no cost.

1.1.1 RUSLE Model Components

RUSLE includes a computer program and database that connects USLE equations with a database of erosion input data values. The user is able to select a specific set of field conditions to analyze a variety of erosion situations. The mathematical equations and technical advice in the model are based on conservation of mass and USLE principles.

1.1.2 RUSLE Quantifies and Predicts Erosion

The model accounts for both rill and interrill erosion associated with rainfall and flow (USDA, 2008). Rill and interrill erosion are affected by four main factors: climate, soil, topography, and land use. The combination of these four factors are used to compute the expected degree of erosion. Users are not required to collect physical data related to plant yield, canopy cover, surface roughness, mechanical soil disturbance, and amount of biomass; these factors are built into the model's database. The program can be used to model any location where soil may be impacted by rainfall and surface runoff, including construction sites and landfills. Erosion effects are further quantified by considering climate, soil, topography, and land use factors. Climate variables vary by region, and include temperature, precipitation, and erosivity factors. The model addresses variations in topography by accounting for slope length, steepness, and slope. Land use factors are the most important factor affecting erosion, due to the fact that erosion can easily be mitigated by altering the land use conditions (USDA, 2008).

On-site Testing Procedure

Four separate test plots will be chosen on the eroding slope. These plots will be determined by the current type and severity of erosion. The four highest ranking erosion mitigation solutions, as determined by RUSLE2 modeling, will be implemented and tested in the individual test plots. The efficacy of the designs will be quantified by evaluating the total surface area covered by vegetation as well as average height of the grass. Throughout the growth period, the condition of each sub-plot will be visually inspected to account for rill and sheet erosion factors.

Budget

Table 5 below is the budget for the Fall Semester. The costs that were incurred account for two trips to the Enid Municipal Landfill as well as the soil and water analyses performed by OSU's Soil, Water, and Forage Analytical Lab.

Table 6: Fall Semester budget

Item	Number of Items	Itemized Cost ($)	Total Cost ($)	Source
Travel- Sedan rental	2 trips at 140 miles/ trip	$32/day +$0.23 / mile	$128.00	OSU Motorpool
Soil Analysis Fee	5 soil tests 2 compost tests 1 irrigation water test	$10/soil test +$20/ compost test + $15/irrigation test	$105	SWFAL
Total Cost:			$233	

Table 6 below is the proposed budget for the Spring Semester. Fixed costs accounts for known costs for the semester, while uncertain costs accounts for the projected costs of products. Since materials for on-site testing will be decided upon after the computer modeling phase is complete, the budget consists of proposed preliminary design solution costs.

Table 7: Spring Semester budget

Design Solution	Item	Number of Items	Itemized Cost ($)	Total Cost ($)	Source
All	Travel- Sedan rental	3 trips at 140 miles/ trip	$32/day +$0.23 / mile	$256.80	OSU Motorpool
All	Time Lapse Camera	1 Bushnell Trophy Cam HD	$99.20	$99.20	https://www.amazon.com/Bushnell-Trophy-Essential-Trail-Camera/dp/B01CQBYU1U/ref=sr_1_2?s=sporting-goods&ie=UTF8&qid=1480433153&sr=1-2&keywords=Bushnell+Trophy+Cam+HD
All	Johnston Co. Native Grass Seed Mix	(5 lb/acre) x (3 acres)	$40 / 5 lb bag	$120.00	http://www.jeinc.com/seed
All	Soil Analysis Fee	1 compost test	$20/ compost test	$ 20.00	SWFAL
Fertilizer	Scotts 5,000-sq ft. Lawn Fertilizer	(1 acre)x(43560 sq ft/acre)x(1 bag/ 5000 sq ft) = 9 bags/ acre	$21.44/bag	$ 211.86	Lowes.com
Class B Biosolids Stabilization	Lime Application and Drying	5 bags	$ 4 /bag	$20.00	Lowes.com
Nonwoven Geotextile	Nonwoven Drainage Material (6'X100')	(300 ft/plot) x (2 plots)	$90 / roll	$270.00	AgricultureSoultions.com
Wattles, Compost Sock	Compost Sock (8" X 10')	4 Socks	$26/ sock	$104.00	https://www.amazon.com/SCS-LLC-Grow-Sock-8x10/dp/B00ON9MY6M/ref=sr_1_1?ie=UTF8&qid=1479776718&sr=8-1&keywords=compost+sock
Wattles, Compost Sock	DIY Wattles Netting Roll (7' X 20')	12 Wattles / Roll	$10 / Roll	$10.00	https://www.amazon.com/Easy-Gardener-604-BirdBlock-20-Foot/dp/B00004RA0P/ref=sr_1_fkmr1_1?ie=UTF8&qid=1479778528&sr=8-1-fkmr1&keywords=wattle+netting
Wattles, Compost Sock	Rubber Mallet	1 Mallet	$12.86	$12.86	https://www.amazon.com/TEKTON-30603-Fiberglass-Handle-16-Ounce/dp/B00KX4KB5M/ref=pd_sim_86_72?_encoding=UTF8&pd_rd_i=B00KX4KB5M&pd_rd_r=W71609T6MK09G4X2C5F3&pd_rd_w=1qUvU&pd_rd_wg=2ccwR&psc=1&refRID=W71609T6MK09G4X2C5F3
Wattles, Compost Sock	U-Shaped Sod Staples	100 Staples / Pack	$12. 95 / pack	$12.95	https://www.amazon.com/GardenMate-100-Pack-HEAVY-DUTY-U-Shaped-Securing/dp/B00LQZB9F8/ref=pd_sim_86_2/166-0902316-5158943?_encoding=UTF8&pd_rd_i=B00LQZB9F8&pd_rd_r=1EXCTQXPRQ2CZY4SAF7N&pd_rd_w=xj9nL&pd_rd_wg=y99lA&psc=1&refRID=1EXCTQXPRQ2CZY4SAF7N
Silt Fence	Silt Fence Roll (2' X 100')	1 Roll	$20	$20.00	https://www.lowes.com/pd/2-x-100-Silt-Fence-Roll/1112447
Wattles, Compost Sock	Zip Ties	100 Zip Ties	$6 / Package	$6.00	https://www.amazon.com/Dxg-150mm-Self-locking-Nylon-Cable/dp/B01FMHYOZW/ref=sr_1_1?ie=UTF8&qid=1479778943&sr=8-1-spons&keywords=zip+ties&psc=1
Typar BODPAVE Pavers	Typar BODPAVE Pavers	50 sq. ft.	$4.44/sq.ft	$222.00	http://www.typargeosynthetics.com/products/porous-paving/bodpave-85-porous-pavers.html
Total Cost:				$1,385.67	

Conclusion

Impacts and Sustainability

The versatility of the erosion control menu may extend its useful life indefinitely. While certain products may be discontinued over time, many solutions will remain viable. Depending on how frequently the menu is updated and how well it is maintained, it could serve as a resource for municipal landfills for years to come.

Vegetative cover is one of the menu items that may require the least amount of updating. Unless a new type of grass is proven more suitable or the landfill cover soil composition changes drastically, the grasses recommended by the menu will not change.

The menu's soil amendment options will vary on a case-by-case basis depending on accessibility of resources. The nutrient availability of the compost may vary widely, the leachate may not always be in compliance for irrigation, and it may not always be economically feasible to treat the wastewater sludge. Additionally, if the amount and composition of these amendments are not monitored closely, contaminated runoff can pose a serious threat to the environment and human health.

Lastly, production of specific products like wattles and Rolled Erosion Control Products on the erosion control menu could be discontinued over the years. The market should always contain similar or improved products to keep the menu up to date.

Landfills are continuously expanding to keep pace with the inflow of trash. Thus, bare soil surfaces prone to erosion and sediment loss are a perpetual issue. The City of Enid Municipal Landfill is currently preparing a new cell adjacent to the focus slope of Sustainable Solutions. An erosion control menu will not only provide solutions for the already-existing slopes but also provide proactive erosion control techniques and products to implement while building the new cell, preventing the severity of erosion problem that Sustainable Solutions has been tasked with solving and ultimately saving taxpayer dollars.

Safety Considerations

Safety considerations must be taken into account when implementing new designs. Sustainable Solutions' design concepts for the Enid Landfill project contain potential risks that must be noted and addressed. The wastewater sludge that is discussed as a potential soil amendment contains harmful pathogens classified as class B biosolids that can cause illness to surrounding citizens. The pathogens can be transmitted through soil, animal, and water movement. The sludge must be pretreated with the addition of lime to destroy the pathogens before use. Other safety procedures for handling the sludge must be strictly adhered to as well.

Many of the design concepts include the use of new machinery or equipment such as hydroseeding or the pneumatic system used to spread a compost blanket. Unfamiliar equipment can cause unintended accidents. The situation is further exacerbated by the use of the equipment on a steep slope. Employees expected to use the equipment will need to be adequately educated on the operation process and accompanying machinery safety. The possibility of unearthing trash during the implementation of some menu design solutions also causes concern. The unearthing allows for contaminates to be spread and garbage to blow out of the landfill. Caution must be exercised during all design solutions to maintain continuity of the outer soil layer.

The application of soil additives, such as the on-site leachate water, also poses a threat to surrounding land and water. If a nutrient is applied in excess it can cause overgrowth of plants or eutrophication in surrounding bodies of water. These undesired effects can be avoided with careful calculations before application or with the use of solutions to minimize runoff.

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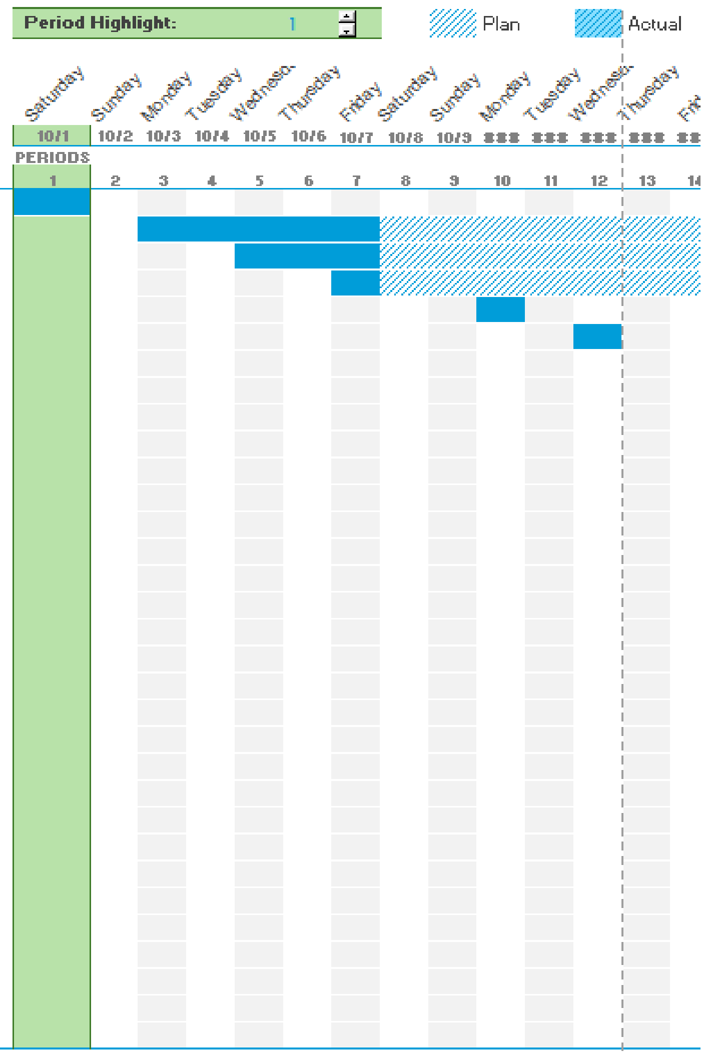
Appendices

Appendix A [Gantt Chart]

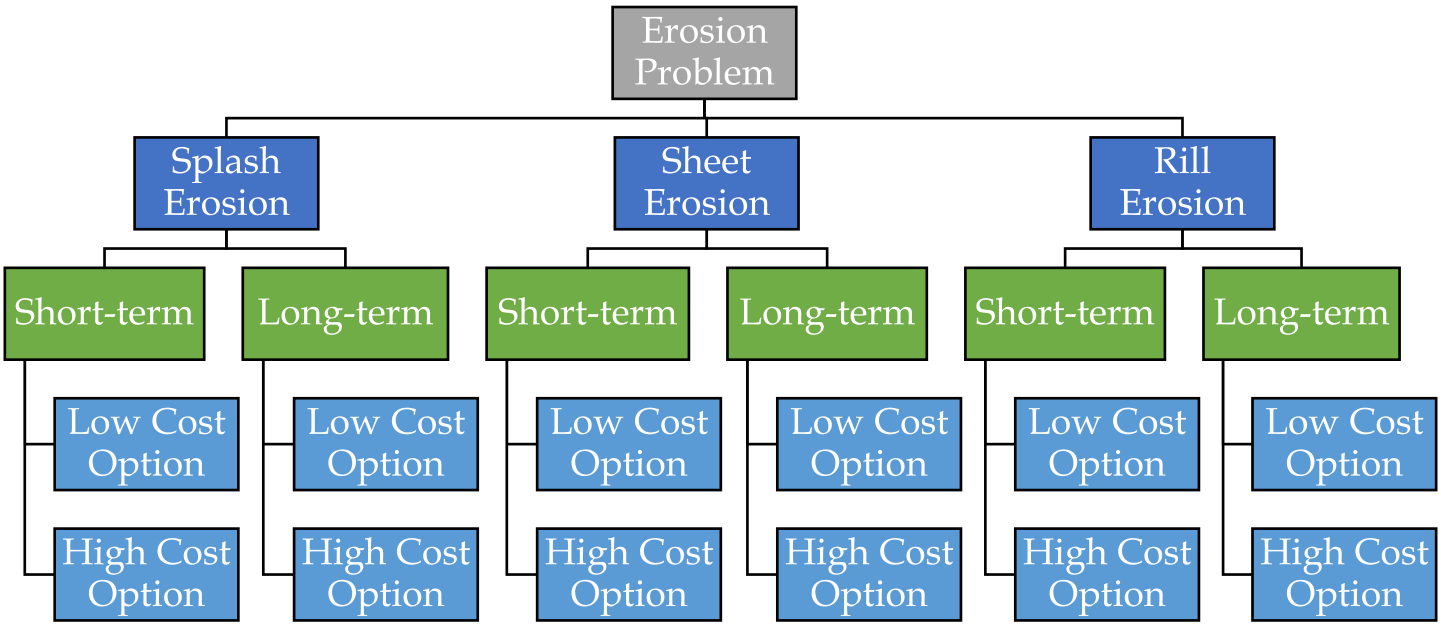
Sustainable Solutions

Design Schedule

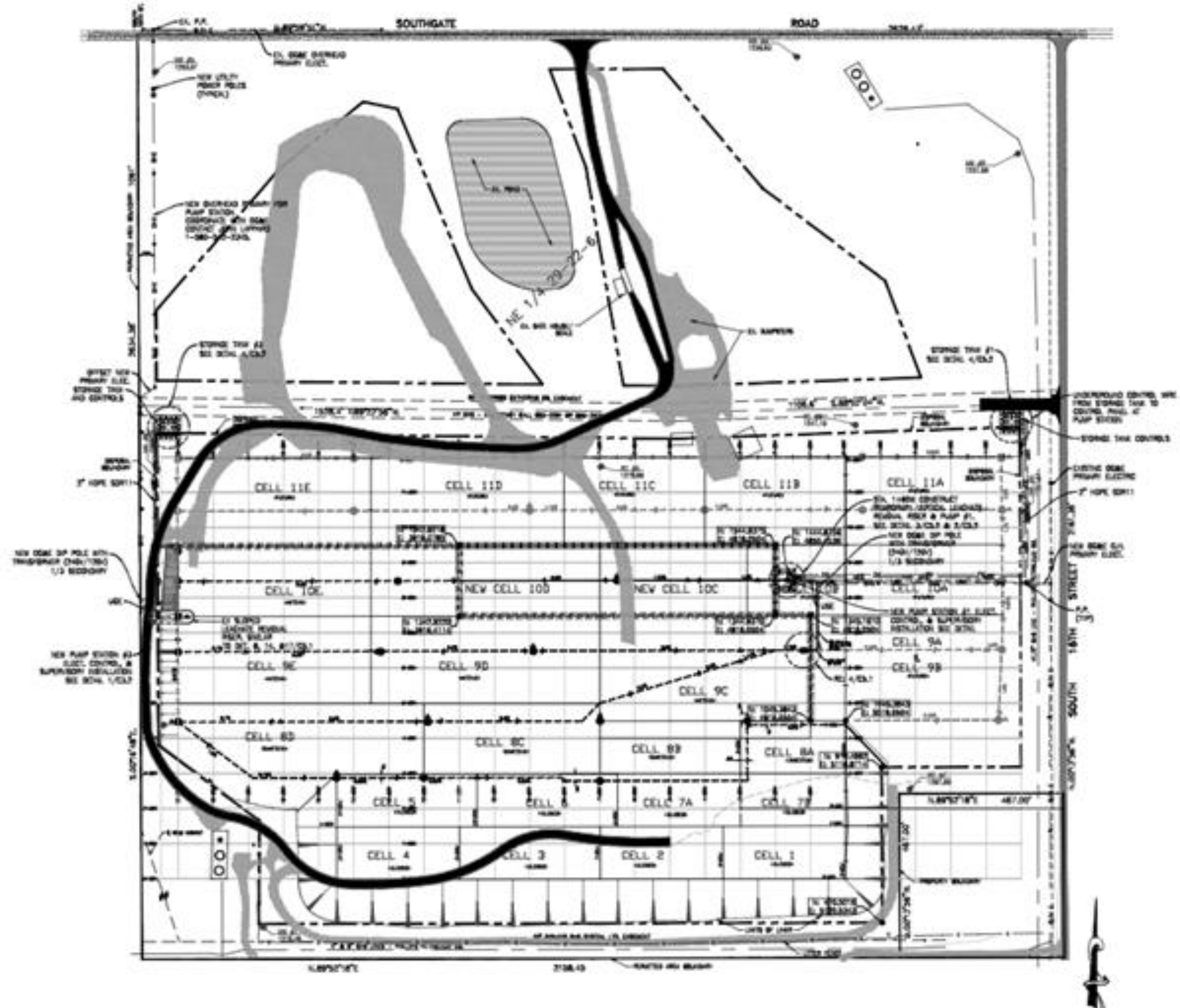
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Collect water and soil samples from Enid	1	1	1	1	100%
Analyze soil and water samples	3	12	3	5	100%
Develop Preliminary design concepts	5	17	5	3	100%
Analyze leachate and sludge data	7	8	7	1	100%
Meet with Freshmen Teams	10	1	10	1	100%
Team Planning Meeting	12	1	12	1	100%
Meeting with Kelly Dillow	19	1	27	1	100%
Team Planning Meeting	26	1	26	1	100%
Write Report First Draft	26	10	26	3	100%
Meet with Freshmen Teams	31	1	31	1	100%
Team Planning Meeting	33	1	33	1	100%
Obtain site plans	36	1	28	1	100%
Write Fall Report Final Draft	38	5	52		25%
Develop Final Fall Presentation	40	10	40	10	100%
Team Planning Meeting	52	1	52	1	100%
Work on web page layout	52	15	52		5%
Peer Evaluations Fall	63	1			
Computer Modeling	109	28			
Computer Modeling Data Analysis	137	14			
Team Planning Meeting	151	1			
On-site Testing Design Plan	151	7			
On-site Testing	158	35			
On-site Testing Analysis	193	7			
Team Planning Meeting	199	1			
Preliminary Menu	200	5			
Write Final Report Draft	200	14			
Create Final Presentation	205	7			
Final Menu	206	3			
Team Planning Meeting	212	1			
Give Final Presentation	213	1			
Peer Evaluations	215	1			
Complete Final Report	216	5			



Appendix B [Preliminary Menu Design]



Appendix C [City of Enid Municipal Landfill Site Plans]



OVERALL SITE PLAN

0 150' 300'
SCALE IN FEET

LEGEND

- PROP. TOP OF CLAY LINER CONTOUR
- EX. CONTOUR
- GROUNDWATER CONTOUR
- EXISTING/PROPOSED/FUTURE LEACHATE COLLECTION SUMP
- EXISTING/PROPOSED/FUTURE LEACHATE CLEANOUT RISER
- EXISTING/PROPOSED/FUTURE FLOWLINE IN LEACHATE TRENCH & LOCATION OF CHANGE OF GRADE
- MW OR PZ W/ GROUND WATER ELEVATION USED FOR CONTOURING
- LEACHATE COLLECTION TRENCH WITH DIRECTION AND SLOPE OF FLOW OF LEACHATE
- EXISTING TOP OF CLAY LINER ELEVATIONS
- EXISTING LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- PROPOSED TOP OF CLAY LINER ELEVATIONS
- PROPOSED LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- PROPOSED LEACHATE FLOWLINE
- FUTURE TOP OF CLAY LINER ELEVATIONS
- FUTURE LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- OHE — OVERHEAD PRIMARY ELECTRICAL UTILITY (OG&E)
- UGE — UNDERGROUND SECONDARY ELECTRICAL UTILITY (OG&E)
- UGC — UNDERGROUND CONTROL CABLE
- FM — 3" HDPE SDR11 (160 PSI) FORCE MAIN
- LOCAL LANDFILL COORDINATES
- FML — FLEXIBLE MEMBRANE LINER
- RCL — RECONSTRUCTED CLAY LINER
- LCS — LEACHATE COLLECTION SYSTEM
- MONITORING WELL W/ HIGH WATER LEVEL
- PIEZOMETER W/ HIGH WATER LEVEL

ENID MUNICIPAL LANDFILL
CONSTRUCT CELLS 10C & 10D
PROJECT NO. M-1207B

BRUEGGEMANN ENGINEERING

ENID MUNICIPAL LANDFILL
RECONSTRUCTED CLAY LINER FML & LCS INSTALL.
CELLS 10C & 10D

OVERALL SITE PLAN

C2.1
of
10

Appendix D [Oklahoma State University Soil Sampling Guide]

How to Get a Good Soil Sample

Hailin Zhang
Director, Soil, Water and Forage Analytical laboratory

Brian Arnall
Nutrient Management Specialist

Soil tests provide a scientific basis for evaluating available plant nutrients in cropland, pastures, lawns, and gardens. Analyses of soil samples can help farmers and homeowners fine-tune nutrient applications from fertilizers, biosolids, and animal manure. Properly managing the amount of nutrients added to the soil can save money and protect the environment.

Soil nutrients vary by location, slope, soil depth, soil texture, organic matter content, and past management practices, so getting a good soil sample stands out as a major factor affecting the accuracy and usefulness of soil testing. This fact sheet outlines some specific considerations which should be taken into account to get the greatest benefit from soil testing.

Sample Soil at the Right Time

Fields used for production of cultivated crops may be sampled any time after harvest or before planting. Generally, two weeks should be allowed for mailing, analysis, and reporting of results. Additional time may need to be allotted for ordering and application of fertilizers, manure, or lime materials. Noncultivated fields should be sampled during the dormant season. In either case, do not sample immediately after lime, fertilizer, or manure applications because those samples do not represent the true soil fertility.

Fields should be tested annually to measure the available nitrogen pool or as frequently as necessary to gain an understanding of how soil properties may be changing in relation to cultural practices and crop production.

Collect a Representative Sample

Getting a representative sample is simple, but not easy. Research at OSU and other universities has clearly shown that a minimum of 20 cores or small samples taken randomly from the field or area of interest are necessary to obtain a sample which will represent an average of the soil in the field (Figure 1). These cores should be collected in a clean plastic bucket (to avoid metal contamination) and mixed thoroughly by hand. The sample bag should be filled from the mixture. A one pint (OSU soil sample bag full) sample is usually adequate for all tests which might be required. If the sample is too wet to mix, it should be spread out to dry some and then mixed, or sampling should be delayed until the field is drier.

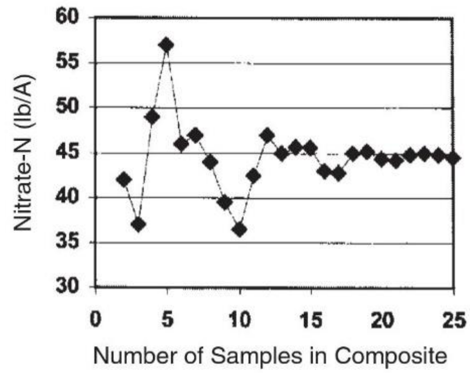


Figure 1. The minimum number of core samples needed to make a representative composite sample is about 20.

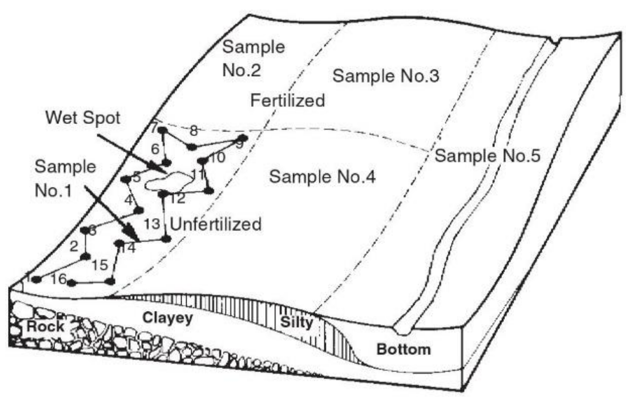


Figure 2. Divide field into uniform sampling areas and follow a random pattern when sampling. Avoid unusual spots and try to obtain a representative sample.

It is important to remember that the sample obtained by the above procedure will be an average of the area sampled. If the area sampled is extremely variable in the soil properties which are going to be tested, then it may be better to separate the field into smaller areas, and get a representative (20 cores) sample from each of these areas in order to determine how variable the field is (Figure 2). In this way, it may be possible to treat some areas of the field differently from others and remove variability so that the field can be sampled and treated as a unit in the future. Variability in a field can often be noted by differences in surface soil color and crop growth or yield.

Using only one sample for a large variable field can be very costly. Since the sample represents an average of the soil in that field, recommendations based on the soil test will likely cause the field to be overfertilized on some parts and underfertilized on other parts. Failure to obtain uniform response to treatments based on a soil test is frequently a result of one sample being used to represent a large variable field.

An example of field variability is shown in Table 1. The range of test values was obtained by testing 40 individual cores taken at random from an "apparently uniform " 80-acre field. The variation is great enough so that for some analyses the average is not a good representation of the field. Areas of the field with the lowest pH, phosphorus, and potassium values will not receive adequate lime or fertilizer if recommendations are based on the average test values.

A single core sample, or spadeful, is extremely risky because it may test anywhere in the range shown for each of the analyses. For example, deficiencies for wheat could range from zero to 37 pounds of P_2O_5 and zero to 34 pounds of K_2O. For alfalfa, which has much greater nutrient requirements, deficiencies could range from zero to 94 pounds of P_2O_5 and zero to 120 pounds of K_2O. This would also affect the amount of nitrogen and lime required. Obviously, unless the 80 acres is divided into less variable units for testing, some areas of the field will receive either too much or too little fertilizer and lime.

In deciding how large an area can be represented by one composite sample (20 cores), the determining factor is not the number of acres involved, but rather, the variability of the area. Some large, uniform fields can be represented well by a single 20-core sample, while some highly variable fields need to be split into two or more smaller areas for testing. Regardless of the field size or main area being sampled, unusual spots in the field (salty or wet spots) should be avoided during the initial random sampling. When unusual spots make up a significant area, they should be sampled separately.

Sampling Where Nutrients are Banded

It is a challenge to sample fields where fertilizers have been band applied. Research has shown that soil test P values are not increased beyond 2 inches from the band of fertilizer placement. If a soil sample is collected from the banding zone, it has the risk to greatly skew the results of a soil test, ultimately leading to under-fertilization and yield loss. Some soils through, have very high P fixing capabilities, and the amount of available P is very small a year after application. This is commonly seen in soils with very low or high soil pH. In these conditions, where row spacing is less than 12 inches (e.g., winter wheat), it is not necessary to change sampling procedures discussed earlier.

Table 1. Variability of an 80 Acre Field Based on Soil Tests of 40 Individual Soil Cores .

	Soil Test Values	
Analysis	Range	Average
pH	4.9-6.3	5.6
Buffer Index	7.1-7.4	7.3
Nitrogen	1-34	11
Phosphorus	23-114	36
Potassium	149-770	306

The primary concern with banding fertilizer is with no-till production of row crops. There are three situations you may encounter: 1) planting over existing rows, 2) knowing the location of rows but not planting over them, and 3) previous rows are unknown. All three situations require a different sampling strategy. When you are planting over past rows, it is important to know the residual of past bandings, so it is recommended to sample in the area around the rows.

When sampling where band location is known, but new row placement is unknown, there is a sampling scheme that can be used to give a more accurate result. A minimum number of sub-samples are required from the area between two bands for every one sub-sample collected from the band. Table 2 shows how many sub-samples between bands need to be collected for one sub-sample from the band for different row spacing.

Table 2. The number of sub-samples to collect from between bands for each sub-sample within band.

Band spacing (in)	*Sub-samples between bands*
15	10
24	16
30	20
40	27

When collecting soil samples from a field where previous bands are unknown, the common recommendation is that for every core taken, collect an extra sample half the distance of the row spacing away from the first core. For example, sampling a field that was previously in corn on 30-inch row spacing, when you collect one core sample, move over 15 inches and collect a second sample before moving on. Therefore, instead of 15 cores total, you need to collect 15 pairs, or 30 cores to make a composite sample. This method has shown to improve the accuracy of the soil sample greatly. The most important thing to keep in mind is that the greatest error occurs when too few samples are taken. By increasing the number of soil samples collected per composite the accuracy of the soil test results are improved.

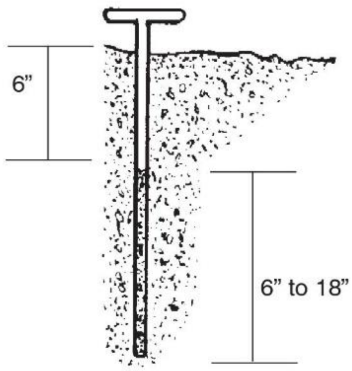
Sample at Proper Depth

Cultivated Fields

For most soil tests the sampling depth is the tillage depth. The reason for this is because most crops have their greatest root activity in the tillage depth. Obtaining a representative sample with regard to depth means that each of the 20 cores taken from an area should be from similar depth, tillage, or six inches. Soil tests are generally calibrated on the basis of an acre furrow slice, approximately two million pounds of soil in the top six inches.

For deep-rooted nonlegumes such as wheat, bermudagrass, sorghum, and cotton, a separate sample representative of the subsoil should be taken in addition to the tillage depth or six-inch sample. This subsoil sample should represent the layer of soil from 6 to 18 inches below the surface. Because nitrate-nitrogen is mobile in the soil, a test of available nitrogen (and/or chloride and sulfate) in the subsoil sample will provide a more complete picture of available mobile nutrients for these crops (Figure 3) and can save fertilizer expenses.

Figure 3. A soil probe is a good tool for obtaining soil samples. Push the tube to the six-inch depth and remove the core. Then take the 6- to 18-inch core through the same hole for the subsoil test.



No-till Fields

Noncultivated fields should be sampled to a depth of six inches, again because this is the effective depth of most treatments and the depth of most root activity. Nutrients from fertilizer, animal manure, and lime can be accumulated on the surface if they are surface applied without incorporation. A set of samples from the top two inches will help identify stratification of nutrients and is especially important for pH determination for no-till fields. If nutrient loss in runoff is the main concern, the two-inch sample is better than a six-inch sample because only the surface inch or two is in direct contact with surface runoff.

Salinity Diagnosis

When salt accumulation is suspected as a cause of poor stand establishment and the sample is being taken after planting, then the depth of sampling should approximate the seeding depth (one to three inches). This is especially important when conditions have been favorable for soluble salts to move upward and accumulate near the surface after planting. Since excess salts are most harmful to germination and seedling vigor, it is this shallow depth which should be tested. At other times during the year, a sample of the entire tillage depth may be most useful to test for salt accumulation.

Send Samples for Analysis

Soil sample bags are available at local county Extension offices. Extension offices will mail your samples to the OSU Soil, Water and Forage Analytical Laboratory and assist you to interpret test results.

Fall Design Report

November 18, 2016

Prepared For:

The City of Enid

Department of Environmental Quality

- **Christian Ley:** Bioprocessing and Biotechnology Option
- **Katie Schlotthauer:** Environmental and Natural Resources Option
- **Hannah Blankenship:** Environmental and Natural Resources Option
- **Amethyst Kelly:** Environmental and Natural Resources Option

Mission Statement:

Designing green solutions for soil and water related problems.

Overview

- Problem Defined
- Customer Requirements
- Project Scope
- Design Approach
- Work Breakdown Structure
- Deliverables
- Technical Specifications
- Technical Research
- Product Research
- Soil and Water Analysis
- Erosion Modeling Software
- On-Site Testing Design
- Safety and Regulation Research
- Design Solution Examples
- Preliminary Menu Design
- Conclusion

Problem Defined

- The City of Enid Municipal Landfill currently has erosion problems on its north-facing exterior slope.
  - rill formation
  - sediment deposition
  - sparse vegetative growth


North-Facing Exterior Slope

Problem Defined


Rill formation


Sparse vegetation

Problem Statement:
Determine suitable design solutions for mitigating erosion on the slope with modeling software and on-site testing.

Customer Requirements

- Project requirements provided by the Oklahoma Department of Environmental Quality:
  - Cover bare soil surfaces on slope with vegetation
  - Reduce sedimentation at the base of the slope and silting in the pond
  - Determine the feasibility of using on-site resources
  - Provide a model site for other Oklahoma landfills

Project Scope

- Design a menu containing effective strategies to reduce erosion
- Determine feasibility of using on-site resources:
  - borrow pit soil
  - compost
  - leachate
  - stormwater
  - wastewater sludge
- Model designs with computer software to narrow down the options
- On-site experiment to determine to most viable solutions

Design Approach

Brainstorm

- Define project scope
- Soil and Water Analysis

Modeling

- Computer Simulation
- On-Site Testing

Analysis

- Cost analysis and site evaluation
- Prepare menu of final solutions

Work Breakdown Structure

1. **Research**
   1.1. Preliminary Web Research
   1.2. Technical Literature Review & Patent Analysis
      1.2.1. Erosion
      1.2.2. Hydroseeding
      1.2.3. Compost & Alternative Cover
      1.2.4. Alternative Fertilizers
         1.2.4.1. On-site Leachate Composition
         1.2.4.2. Wastewater Sludge Composition
      1.2.5. Cover Management
      1.2.6. Support Practices
   1.3. Soil & Water Analysis
      1.3.1. Web Soil Survey
      1.3.2. Soil, Water, and Forage Lab Analysis(SWAFL)
         1.3.2.1. Cover Soil
         1.3.2.2. Slope Soil
         1.3.2.3. Compost
         1.3.2.4. Con Cover
         1.3.2.5. Stormwater

2. **Design and Model**
   2.1. Alternative Design Options
   2.2. RUSLE2 Simulations

3. **Test**
   3.1. Test for Effectiveness
      3.1.1. Rill Erosion Solutions
      3.1.2. Sheet Erosion Solutions
      3.1.3. Short-term Solutions
      3.1.4. Long-term Solutions

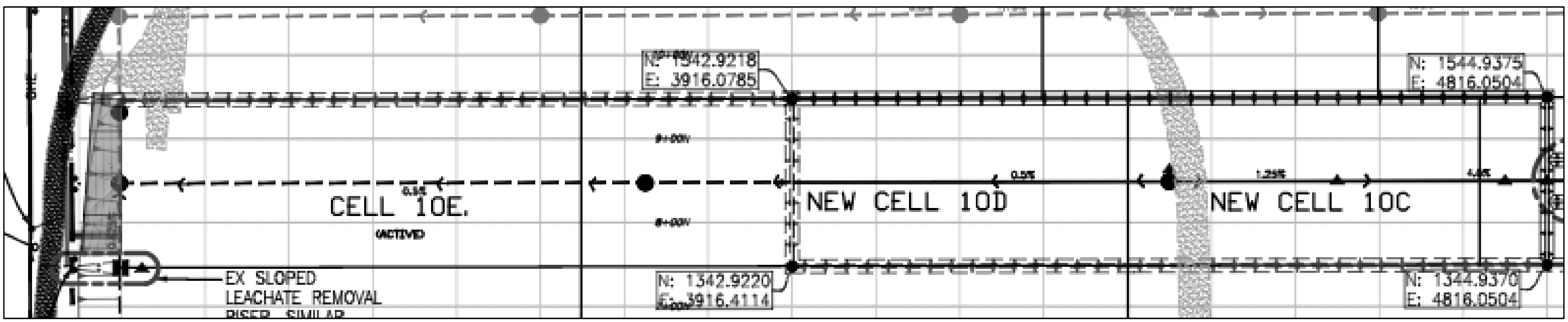
4. **Deliverables**
   4.1. Final Report
      4.1.1. Erosion Control Menu
         4.1.1.1. Effective Solutions
         4.1.1.2. Alternative Solutions
         4.1.1.3. Ineffective Solutions
   4.2. Final Powerpoint Presentation
      4.2.1. Client Evaluation

Deliverables

- Solutions will be judged on the following criteria and presented in a menu form:
  - **Coverage:** percentage of surface area protected by vegetation and max height of vegetation
  - **Cost:** installation, maintenance, and resource expenses
  - **Longevity:** lifetime and predicted maintenance
  - **Type of Erosion:** specify rill, splash, or sheet erosion

Technical Specifications

- Design Plan Calculations
  - Slope: 4:1
  - Base Length: 1,950 ft.
  - Height: 60-80 ft.
  - Slope Length: 240 – 320 ft.
  - Slope Surface Area: 468,000 – 624,000 sq.ft.
  - Assume slope surface area of 250,000 sq. ft.
  - Roughly half of slope bare



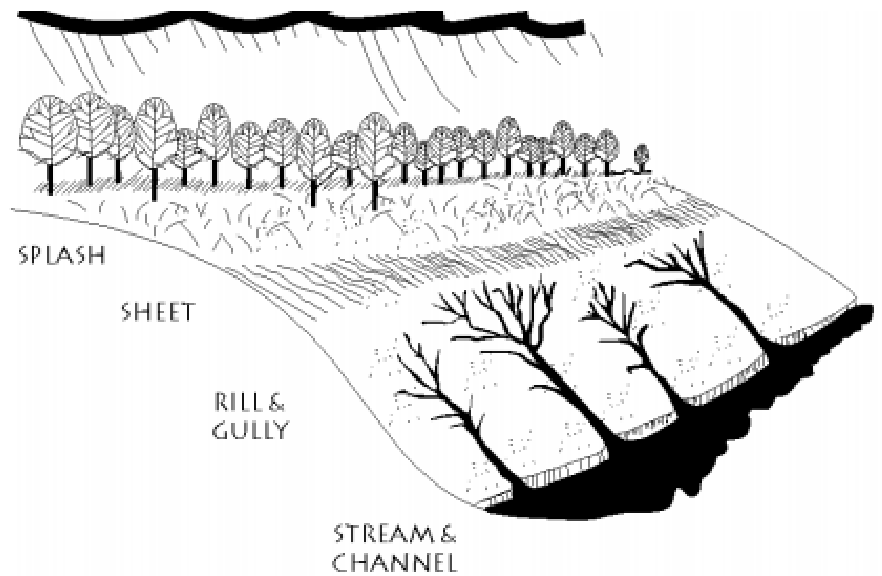
Engineering site plan top view of north slope (City of Enid)

Technical Research

- Began with a general web search in four areas:
  - erosion control
  - hydroseeding
  - alternative cover methods and compost
  - leachate and wastewater sludge soil amendments
- This was based on utilizing on-site materials or easily attainable products.
- Once scope was more defined, search was widened to include cover management practices and support materials.

Erosion Control

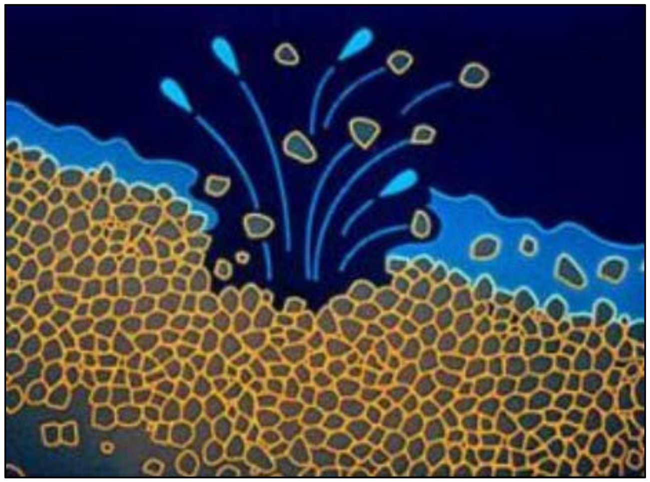
- Types and impacts of erosion were researched.
- Need to reduce runoff and increase infiltration. Most erosion control methods include creating some kind of protective vegetative cover.[1]
- As the percent of clay in a soil increases, erosion increases and the root density decreases.[2]
- Even small plant life like algae can disrupt erosion.[3]



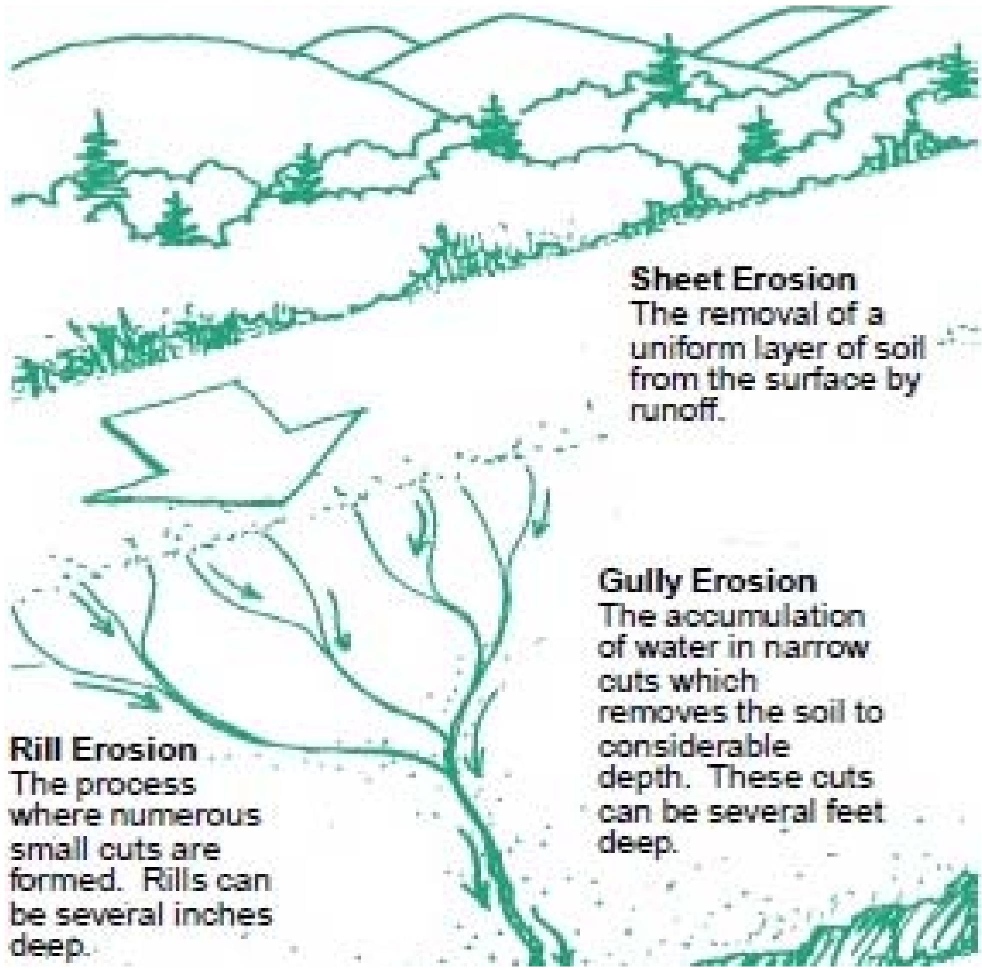
http://landdegradationinaustralia.weebly.com/water-erosion.html

Diagram of erosion types

Types of Erosion



Example of splash erosion



Source: http://www.fairfaxcounty.gov/nvswcd/drainageproblem/glossary.htm

Hydroseeding

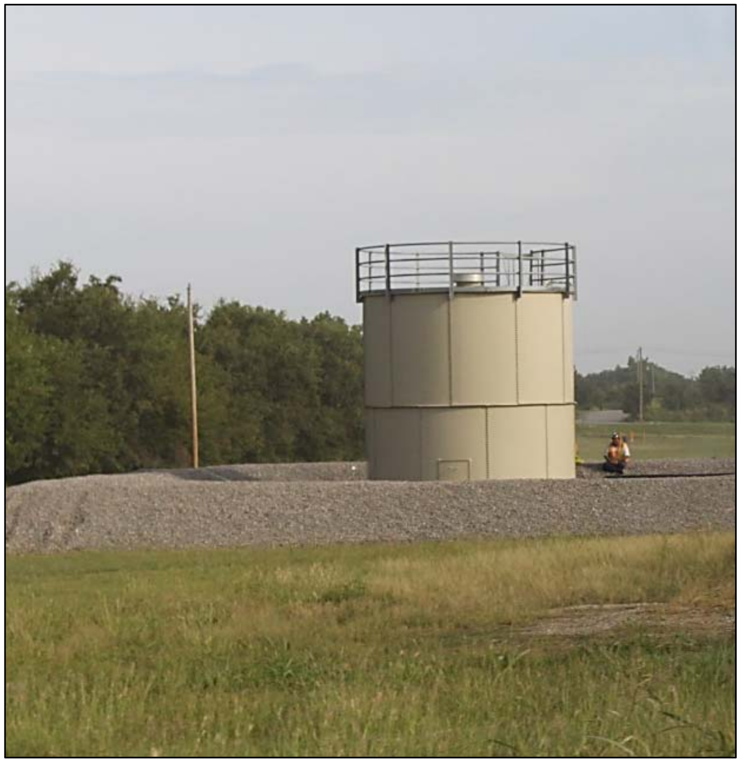
- Fertilizer is essential for germination on marginal soils. Compost blankets and hydroseeding are an effective combination.[4]
- Patents:
  - Hydroseeding with mulch and straw to deliver nutrients.[5]
  - Most of the patents reviewed consistently use similar techniques of applying seed but differ greatly on composition.

Compost and Alternative Cover

- Spray-on daily cover can consist of natural or manufactured materials. These are applied to the active face of the landfill.[7]
- Environmental advantages associated with alternative daily cover (ADC) strategies include:
  - saving lateral airspace
  - extending landfill life
  - minimizing impacts on soil[7]

In-Situ Fertilizer Application

- **Leachate Collection Water:**
  - Leachate can be applied as irrigation water to provide nutrients for the soil.
  - High metal concentrations may adversely affect plant life.
  - Leachate is usually high in salts and sodium that can prevent good soil structure and root growth.[7,8]
  - Leachate can be diluted to make leachate irrigation an attractive resource.[8]



Enid landfill leachate collection tank

In-Situ Fertilizer Application

- **Municipal Wastewater Sludge:**
  - Wastewater sludge in combination with woodchips allows for a slow release of nutrients like nitrogen as plants need them.[9]
  - It is pertinent to know that "waste activated sludge" contains harmful pathogens and viruses. This sludge must be deactivated before applying it to land.[10]
  - Cost-effective measures can be taken to stabilize the sludge by adding lime.[11]
  - Wastewater sludge can contain high quantities of heavy metals, but a study done showed no detrimental effects from absorption of heavy metals.[12]

Cover Management and Support Practices

- **Cover management designs** protect the soil surface and diminish the effects of erosive activity. These practices can involve improving soil cohesiveness, encouraging vegetative cover, or reducing rainfall impact to the soil.

- **Support practices** focus on controlling runoff. Flow is concentrated or detained to reduce velocity and erosive effects.

Cover Management

- **Soil Cohesiveness:**
  - Electro-osmosis treatment
  - Polymer soil stabilization
  - Lime for soil stabilization
  - Imprinting
  - Compost and mulch

- **Rolled Products:**
  - Woven geotextiles
  - Nonwoven geotextiles
  - Coir erosion control mats
  - Flexamat

- **Vegetative Cover:**
  - Fertilizer application
  - Sludge or leachate on the surface
  - Hydroseeding or sod
  - Compost blanket

Support Practices

- **Natural materials:**
  - Gabion baskets
  - Riprap
  - Wattle
  - Compost sock or berm

- **Synthetic materials:**
  - Geocells
  - Mesh grass protection
  - Steel plated cover
  - Cement
  - Silt fence

- **Water Diversion:**
  - Terracing
  - Channeling water over the slope

Soil and Water Analysis

Table 1: Web Soil Descriptions [13]

Garfield County, Oklahoma (OK047)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
Ec	Masham clay, 3 to 12 percent slopes	7.0	3.7%
GaC2	Grant silt loam, 3 to 5 percent slopes, eroded	61.5	32.9%
KrB	Kirkland-Renfrow complex, 1 to 3 percent slopes	35.7	19.1%
RvC2	Renthin-Masham complex, 3 to 5 percent slopes, eroded	11.5	6.2%
VcC2	Grainola-Masham complex, 3 to 5 percent slopes, eroded	32.0	17.1%
VrD	Grainola-Masham-Ironmound complex, 5 to 12 percent slopes	39.1	20.9%
Totals for Area of Interest		**186.8**	**100.0%**

USDA Web Soil Survey Soil Map [13]

Freshman Teams

- Soil Sampling Team
  - Analyzed on-site samples

- Lab-Scale Testing Team
  - Experiment Design
  - Grass Seed

Soil Sampling


Cover material topsoil sample collection


Cover material subsoil sample collection

Soil Sampling

Bare soil sample collection

Grass covered soil sample collection

Soil Sampling

Mulch covered soil sample collection

Compost sample collection

Soil Analysis

Table 2: Current soil conditions reported by SWAFL [14]

Soil Description	N (lbs / A)	P (lbs / A)	K (lbs / A)
Cover topsoil	39	48	489
Cover subsoil	1	23	356
Bare slope	6	34	541
Mulch slope	1	35	671
Grassy slope	4	35	450

Table 3: Amendment requirements based on grass type [14]

Possible grasses	N (lbs/ A)	P (lbs/ A)	K (lbs/ A)
Cool Season Grasses	60	30	0
Weeping Lovegrass	35	20	0
Bluestem	35	20	0
Bermuda grass	50	20	0

Conclusion

- Analyzed soil for nutrient deficiencies
- Soil samples are low in nitrogen and phosphorus

Compost Analysis

Table 4: Current Compost Conditions reported by SWAFL [14]

Sample No.	Soil Description	Moisture (%)	Dry Matter (%)	pH	EC (µS)	Dissolved Salts (ppm)	P_2O_5 (%)	Calcium (%)	K_2O (%)
6	Compost	23.3	76.7	8.3	2940	1970	0.42	1.1	0.96
7	Con Cover	7.3	92.7	8	278	186	0.03	0.73	0.02

Sample No.	Magnesium (%)	Sodium (%)	Sulfur (%)	Iron (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Total C (%)	Total N (%)
6	0.37	0.04	0.16	9008	81.7	15.4	232.6	10.1	1.26
7	0.03	0.09	0.1	218.6	29.4	36	27.9	44.1	0.21

Conclusion:

- The compost may not be suitable to improve the nutrient levels
- Compost may be better suited to enhance soil cohesion

Soil Analysis

Table 5: Cover topsoil conditions [14]

Test	Interpretation				
pH	Adequate				
	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					

<- Indicates 100% sufficiency(STP=65,STK=250(For Lawn/Garden STK = 300))

Table 6: Cover subsoil conditions [14]

Test	Interpretation				
pH	Adequate				
	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					

<- Indicates 100% sufficiency(STP=65,STK=250(For Lawn/Garden STK = 300))

Soil Analysis

Table 7: Bare slope soil conditions [14]

Test	**Interpretation**				
pH	Adequate				
	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					

<- Indicates 100% sufficiency(STP=65,STK=250(For Lawn/Garden STK = 300))

Table 8: Mulched slope soil conditions [14]

Test	**Interpretation**				
pH	Adequate				
	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					

<- Indicates 100% sufficiency(STP=65,STK=250(For Lawn/Garden STK = 300))

Table 9: Grassy slope soil conditions [14]

Test	**Interpretation**				
pH	Adequate				
	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					

<- Indicates 100% sufficiency(STP=65,STK=250(For Lawn/Garden STK = 300))

Water Analysis

Stormwater Sample:

- Suitable for use on most crops under most conditions
- A problem may arise with continued use of this water on heavy soils where no leaching occurs.
- If rainfall is sufficient, it will dilute the salts and reduce the hazard
- (SWAFL, OSU)

Table 10: Stormwater conditions reported by SWAFL [14]

Test Results For **Irrigation Water**

-----**Cations**-----		-----**Anions**-----		-----**Other**-----	
Sodium (ppm)	32.5	NO_3-N (ppm)	< DL *	pH	8.1
Calcium (ppm)	52.9	Chloride (ppm)	54.1	EC (µS/cm)	712
Magnesium (ppm)	19.9	Sulfate (ppm)	56.2		
Potassium (ppm)	64	Boron (ppm)	0.2		
		Bicarbonate (ppm)	255		

---**Derived Values**---		--**Derived Values(Cont'd)**--	
Total Dissolved Salts (TDS in ppm)	535.0	Hardness	214.0
Sodium Adsorption Ratio (SAR)	1.0	Hardness Class	Very Hard
Potassium Adsorption Ratio (PAR)	1.1	Alkalinity (ppm as $CaCO_3$)	209.2
Residual Carbonates (meq)			
Sodium Percentage	24.8%		

RUSLE2 Hydrologic Modeling

The USLE is written in the form [15]:

$$A = RKLSCP \qquad [1]$$

Where:

A = net detachment (mass/unit area)

R = erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = supporting practices factor

- Estimates total soil loss with the Universal Soil Loss Equation (USLE).
- RUSLE2 user describes the specific field conditions

RUSLE2 Hydrologic Modeling

- Effectiveness of erosion control practices will be compared:
  - Vegetation types
  - Application of surface and buried materials (mulch)
  - Increasing random roughness
  - Contouring
  - Strip systems: Buffer, filter, strip cropping, barriers
  - Terracing
  - Organic material

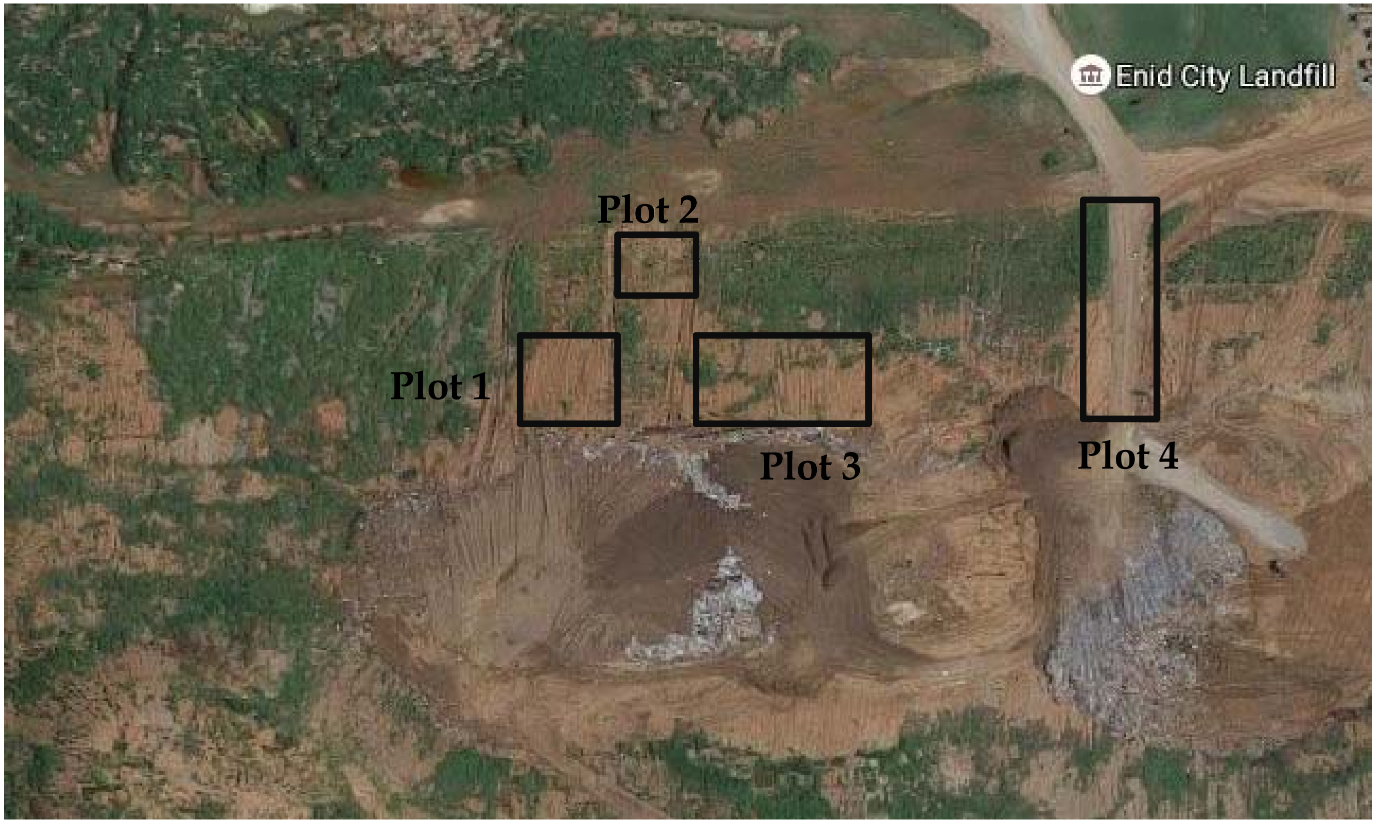
- Soil loss, deposition, and sediment yield for each profile will be ranked

On-Site Testing

Example of possible test site

- 2-4 plots on slope of the Enid Landfill
- Different design solution or combination tested on each plot
- Plot location will be based on type of erosion and severity
- Set up the experiment in March 2017

On-Site Testing



Performance Testing

"Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Ability to Encourage Seed Germination and Plant Growth" [16]

ASTM D-7322:

1. Inclined (4:1) slopes divided into sub-sections: 1 control + 3 replicate plots
2. Soil plots will be seeded and then covered with an RECP
3. Germination rates will be measured periodically throughout the test
4. Test sets are designed to evaluate an RECP's ability to enhance the rate and quantity of germination

Impacts and Sustainability

- The versatility of the erosion control menu may extend well into the future.
- Menu products can be maintained to serve as a resource for municipal landfills throughout the state for years to come.
- Items such as soil amendments must be handled based on the composition of material and the site's soil nutrient requirements, so specific recommendations will not be made.
- Discontinued products or more effective products can be added or can replace other products on the list.

Safety Considerations

- **Wastewater Sludge**
  - The municipal wastewater sludge from Stover Group is classified as Class B Biosolids, meaning there are detectable levels of fecal coliforms.[17]
  - The biosolids can be stabilized, but they must be handled with caution.[18]
- **Leachate Collection Water**
  - Contaminants in leachate could runoff and cause adverse effects in the stormwater pond and groundwater.[19]
- **Heavy Machinery**
  - Designs should consider any potential harm of equipment on the steep slope.
  - Make special note to ensure trash is not exposed during construction.

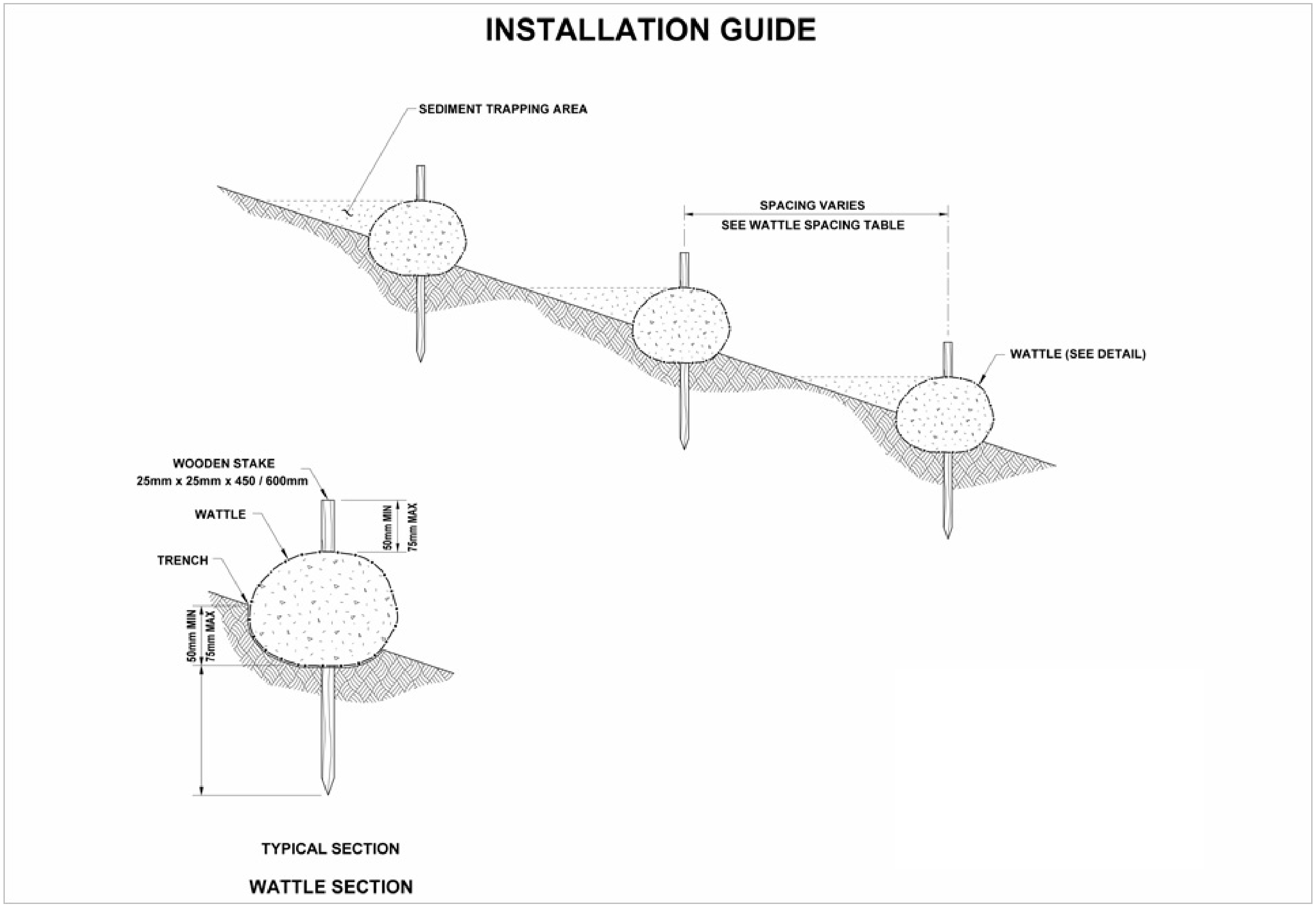
Permits and Regulations

- More in depth investigation of applicable standards and permits will be done if use of leachate or biosolids is found viable.
- **Wastewater Sludge**
  - The City of Enid municipal wastewater plant is currently using Element 2 permit for municipal solid waste landfill disposal. **Permit is in accordance with OAC 252: 515-3-41.**
  - 120 days notice is required before any planned change in sewage disposal (Landfill Permit No. 3524006) per OK DEQ.
- **Landfill Leachate**
  - OAC 252:15 Subchapter 13 gives guidelines on leachate collection and management. A plan for leachate irrigation by the DEQ must be approved.

Wattle

- Long, tubular netting filled with absorbent material to slow runoff and settle soil particles[20].
- Cost: $1.00-$2.00/ft
- Longevity: 3-5 years
- RUSLE2: Yes

Wattle


INSTALLATION GUIDE
SEDIMENT TRAPPING AREA
SPACING VARIES
SEE WATTLE SPACING TABLE
WATTLE (SEE DETAIL)
WOODEN STAKE
25mm x 25mm x 450 / 600mm
WATTLE
TRENCH
50mm MIN
75mm MAX
50mm MIN
75mm MAX
TYPICAL SECTION
WATTLE SECTION

Compost Sock

- Permeable sleeve filled with compost to filter stormwater and trap sediment.[21]
- Cost: $2.00-$4.00/ft
- Longevity: Unknown
- RUSLE2: Yes

Compost Sock

Compost Sock Terraces[20]

Hydroseeding

- Type of planting in which a premixed slurry of seed, nutrients, and mulch are sprayed into the desired land area.[22]
- Cost: $0.18/sq.ft
- Longevity: Re-apply only as needed.
- RUSLE2: Yes

Compost Blanket

- One to three inch layer of loose compost applied to the soil surface to prevent channelized erosion and improve soil structure.[23]
- Cost: $0.11/sq.ft
- Longevity: Short-term. Permanent vegetative cover must overtake.
- RUSLE2: Yes

Coir Matting

- Biodegradable geotextile fabric that stabilizes steep slopes to allow vegetation time to take root.[24]
- Cost: $0.91/sq.ft
- Longevity: 2-5 years
- RUSLE2: Yes

Coir Matting

Preliminary Menu Design

- Erosion Problem
  - Splash Erosion
    - Short-term
      - Low Cost
      - High Cost
    - Long-term
      - Low Cost
      - High Cost
  - Sheet Erosion
    - Short-term
      - Low Cost
      - High Cost
    - Long-term
      - Low Cost
      - High Cost
  - Rill Erosion
    - Short-term
      - Low Cost
      - High Cost
    - Long-term
      - Low Cost
      - High Cost

Conclusions

- Continue to narrow list of feasible design options
- Begin RUSLE2 modeling in January
- Begin on-site testing in March
- Exemplary Site

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