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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.

![North-facing problem slope](image)

**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:

$$ A = RKLSCP $$ \hspace{1cm} [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.
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 Co. seed mix tag](image)

**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.
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](image)

**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.
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.

![Image of installed homemade compost sock plot](image)

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 10 feet 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
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).

\[
lbs \text{ of biosolids} = \frac{75 \text{ lb} \ N}{\text{acre}} \times \frac{0.01 \text{ acre}}{\text{plot}} \times \frac{\text{dry ton}}{34.0 \text{ lb} \ N} \times \frac{2000 \text{ lb}}{\text{ton}} = 44 \text{ lb!}
\]

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 200 m$^3$/hectare. However, the compost provided by Midwest City contained a high (and unknown) proportion of woodchipped yard waste, so we divided in half the amount of recommended wood chips added to the plot.

$$\text{gallons woodchips} = \frac{200 \text{ m}^3}{\text{ha}} \times \frac{\text{ha}}{2.47 \text{ acres}} \times \frac{264.2 \text{ gal}}{\text{m}^3} \times \frac{0.01 \text{ acre}}{\text{plot}} \times \frac{1}{2} \Rightarrow 107 \text{ gallons!}$$

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**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel (7 trips)</td>
<td>517.45</td>
</tr>
<tr>
<td>Stakes</td>
<td>48.69</td>
</tr>
<tr>
<td>Pins</td>
<td>49.66</td>
</tr>
<tr>
<td>Zip Ties</td>
<td>11.96</td>
</tr>
<tr>
<td>Netting</td>
<td>147.42</td>
</tr>
<tr>
<td>Biosolids</td>
<td>21.64</td>
</tr>
<tr>
<td>Spray Paint</td>
<td>4.48</td>
</tr>
<tr>
<td>Twine</td>
<td>13.94</td>
</tr>
<tr>
<td>Buckets</td>
<td>19.38</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>834.62</strong></td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Conservation Operation</th>
<th>Sediment Delivery (t/ac/yr)</th>
<th>Soil Loss (t/ac/yr)</th>
<th>Event Runoff (inch/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Ground</td>
<td>170.000</td>
<td>167.000</td>
<td>7.7</td>
</tr>
<tr>
<td>Woodchips Berm</td>
<td>0.073</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>Bermudagrass</td>
<td>0.048</td>
<td>0.048</td>
<td>2.9</td>
</tr>
<tr>
<td>Cool-season grass:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Strong growth</td>
<td>0.071</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>- Moderate stand</td>
<td>0.322</td>
<td>0.320</td>
<td>3</td>
</tr>
<tr>
<td>- Poor stand</td>
<td>3.050</td>
<td>3.000</td>
<td>4</td>
</tr>
<tr>
<td>8” Compost Sock:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 1 Compost Socks (Top)</td>
<td>0.072</td>
<td>0.055</td>
<td>2.7</td>
</tr>
<tr>
<td>- 2 Compost Socks (Bottom and 50%)</td>
<td>0.074</td>
<td>0.074</td>
<td>2.7</td>
</tr>
<tr>
<td>- 4 Compost Socks (Top, 75%, 50%, 25%)</td>
<td>0.075</td>
<td>0.055</td>
<td>2.8</td>
</tr>
<tr>
<td>Silt Fence:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Base of slope</td>
<td>0.071</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>- 2 Silt Fences</td>
<td>0.071</td>
<td>0.071</td>
<td>2.8</td>
</tr>
<tr>
<td>- 4 Silt Fences</td>
<td>0.069</td>
<td>0.062</td>
<td>2.8</td>
</tr>
<tr>
<td>Wattle:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 inch- 1 per plot (Bottom)</td>
<td>0.073</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>6 inch- 2 per plot (Bottom and 50%)</td>
<td>0.074</td>
<td>0.067</td>
<td>2.7</td>
</tr>
<tr>
<td>6 inch- 4 per plot (Bottom, 75%, 50%, 25%)</td>
<td>0.076</td>
<td>0.062</td>
<td>2.8</td>
</tr>
<tr>
<td>Conservation Operation</td>
<td>Sediment Delivery (t/ac/yr)</td>
<td>Soil Loss (t/ac/yr)</td>
<td>Event Runoff (inch/yr)</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>--------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>9 inch - 1 per plot (Bottom)</td>
<td>0.073</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>9 inch - 2 per plot (Bottom and 50%)</td>
<td>0.074</td>
<td>0.067</td>
<td>2.7</td>
</tr>
<tr>
<td>9 inch - 4 per plot (Bottom, 75%, 50%, 25%)</td>
<td>0.076</td>
<td>0.062</td>
<td>2.8</td>
</tr>
<tr>
<td>12 inch - 1 per plot (Bottom)</td>
<td>0.073</td>
<td>0.071</td>
<td>2.7</td>
</tr>
<tr>
<td>12 inch - 2 per plot (Bottom and 50%)</td>
<td>0.074</td>
<td>0.067</td>
<td>2.8</td>
</tr>
<tr>
<td>12 inch - 4 per plot (Bottom, 75%, 50%, 25%)</td>
<td>0.076</td>
<td>0.062</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**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
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 19: Image of changed composition in manufactured compost sock
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](image)

**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.

![Image of biosolids and woodchip plot at week 6](image)

**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

<table>
<thead>
<tr>
<th></th>
<th>Average sediment loss in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 1</td>
</tr>
<tr>
<td>Compost Blanket</td>
<td>0.0</td>
</tr>
<tr>
<td>Control</td>
<td>0.0</td>
</tr>
<tr>
<td>Manufactured Compost Socks</td>
<td>0.0</td>
</tr>
<tr>
<td>Homemade Compost Socks</td>
<td>0.0</td>
</tr>
<tr>
<td>Homemade Wattles</td>
<td>0.0</td>
</tr>
<tr>
<td>Biosolids and Woodchips</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Plot</th>
<th>Percent Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost Blanket</td>
<td>1.67%</td>
</tr>
<tr>
<td>Control</td>
<td>0.86%</td>
</tr>
<tr>
<td>Manufactured Compost Socks</td>
<td>0.84%</td>
</tr>
<tr>
<td>Homemade Compost Socks</td>
<td>0.86%</td>
</tr>
<tr>
<td>Homemade Wattles</td>
<td>0.84%</td>
</tr>
<tr>
<td>Biosolids and Woodchips</td>
<td>1.02%</td>
</tr>
</tbody>
</table>
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.
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).

![Image of compost blanket netting](image)

**Figure 25:** Image of compost blanket netting
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).
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>
<thead>
<tr>
<th>Condition</th>
<th>Seeding Rate (lbs PLS/acre)</th>
<th>Cost/Acre</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landscape</td>
<td>11.68</td>
<td>$51.00</td>
<td>$306.00</td>
</tr>
<tr>
<td>Critical</td>
<td>26.1</td>
<td>$104.00</td>
<td>$624.00</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Cost Level</th>
<th>Material</th>
<th>Cost/yd³</th>
<th>Cost to cover slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Purchased Compost</td>
<td>$30.00</td>
<td>$24,120.00</td>
</tr>
<tr>
<td>Medium</td>
<td>Purchased Biosolids</td>
<td>$20.00</td>
<td>$16,080.00</td>
</tr>
<tr>
<td>Low</td>
<td>On-site Compost</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

_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**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Unit Cost</th>
<th>Number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot; netting</td>
<td>150' roll</td>
<td>$25.50</td>
<td>18</td>
<td>$460.00</td>
</tr>
<tr>
<td>24&quot; stake</td>
<td>pack of 6</td>
<td>$5.00</td>
<td>87</td>
<td>$435.00</td>
</tr>
<tr>
<td>8&quot; zip tie</td>
<td>pack of 100</td>
<td>$7.00</td>
<td>11</td>
<td>$77.00</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Unit Cost</th>
<th>Number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>8&quot; wattle</td>
<td>1 feet</td>
<td>$1</td>
<td>2600</td>
<td>$2,600</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Unit Cost</th>
<th>Number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7' netting</td>
<td>100' roll</td>
<td>$14.98</td>
<td>377</td>
<td>$5,647.46</td>
</tr>
<tr>
<td>4&quot; pin</td>
<td>pack of 75</td>
<td>$9.98</td>
<td>23</td>
<td>$229.54</td>
</tr>
</tbody>
</table>

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.
References


EPA. (1993). The standards for the use or disposal of sewage sludge (Title 40 of the code of federal regulations, Part 503). US Environmental Protection Agency. Retrieved from: https://www.ecfr.gov/cgi-bin/text-idx?SID=320c6d636bc6d1c43802ad010efee4e8&amp;mc=true&amp;node=pt40.32.503&amp;rgn=div5


Appendices
Appendix A [Project Schedule]
<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 31</td>
<td>Computer Modeling</td>
</tr>
<tr>
<td>Feb 1</td>
<td>Computer Modeling</td>
</tr>
<tr>
<td>Feb 2</td>
<td>Computer Modeling</td>
</tr>
<tr>
<td>Feb 3</td>
<td>Finish Computer Modeling, Finalize On-site Test Choices</td>
</tr>
<tr>
<td>Feb 6</td>
<td>Work on Menu, Finalize On-site Test Choices</td>
</tr>
<tr>
<td>Feb 7</td>
<td>Work on Menu</td>
</tr>
<tr>
<td>Feb 8</td>
<td>Work on Menu</td>
</tr>
<tr>
<td>Feb 9</td>
<td>Work on Menu</td>
</tr>
<tr>
<td>Feb 10</td>
<td>Enid Trip, stake &amp; size test plots</td>
</tr>
<tr>
<td>Feb 13</td>
<td>Order All Products</td>
</tr>
<tr>
<td>Feb 14</td>
<td>Work on Menu, On-site Design</td>
</tr>
<tr>
<td>Feb 15</td>
<td>Work on Menu, On-site Design</td>
</tr>
<tr>
<td>Feb 16</td>
<td>Work on Menu, On-site Design</td>
</tr>
<tr>
<td>Feb 17</td>
<td>Work on Menu, On-site Design</td>
</tr>
<tr>
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<td>On-site Design</td>
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<td>On-site Design</td>
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<td>Feb 22</td>
<td>On-site Design</td>
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<tr>
<td>Feb 23</td>
<td>On-site Design</td>
</tr>
<tr>
<td>Feb 24</td>
<td>On-site Design</td>
</tr>
<tr>
<td>Feb 27</td>
<td>On-site Design</td>
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<tr>
<td>Feb 28</td>
<td>On-site Design</td>
</tr>
<tr>
<td>Mar 1</td>
<td>Finalize On-site Procedure, all products obtained</td>
</tr>
<tr>
<td>Mar 2</td>
<td>On-site Design</td>
</tr>
<tr>
<td>Mar 3</td>
<td>Enid Trip, assemble &amp; begin recording data</td>
</tr>
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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]
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<th>Sediment Loss</th>
<th>% Vegetative Cover</th>
<th>Vegetative Health</th>
<th>Total</th>
<th>% Rank</th>
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<td>7</td>
<td>7</td>
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<tr>
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<td>Erosion Control- Handmade Wattle</td>
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<td>8</td>
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<td>9</td>
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<td>1</td>
<td>26</td>
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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  

<table>
<thead>
<tr>
<th>Name</th>
<th>CITY Of MWC</th>
<th>Lab ID No.:</th>
<th>829426</th>
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<td></td>
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<tr>
<th>TEST</th>
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<th>As Received lbs/ton</th>
<th>Dry Basis lbs/ton</th>
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<tr>
<td>Dry Matter</td>
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<tr>
<td>pH</td>
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<td>EC</td>
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<tr>
<td>Soluble Salts</td>
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<tr>
<td>Total N</td>
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<tr>
<td>Phosphorus</td>
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<td>K2O</td>
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<td>Iron (Fe)</td>
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<td>Zinc (Zn)</td>
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<td>Copper (Cu)</td>
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<td>Manganese (Mn)</td>
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Ray Ridlen
Signature
Appendix G [Johnston Co. Grass Mix Composition]
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|       | 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: CALIF NRCS Plant Materials Program

Description
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, or state natural resource or agriculture department regarding its status and use. More information is also available from the PLANTS Web site at plants.usda.gov.

Adaptation and Distribution
Alfalfa grows best on loamy, well-drained, fertile soils. Land subject to frequent submergence or high water tables are unsuitable for alfalfa. The pH of the soil should be 5.5 to 7.5.

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 drainage. 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 1/2-inch deep on adapted, properly prepared sites will produce adequate stands. A combination drill and packer is desirable.

Plant Materials <http://plant-materials.nrcs.usda.gov/>
National Plant Data Center <http://nptc.usda.gov>
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 warrant 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
Italian ryegrass, *Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot

**Description**

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
BERMUDAGRASS
Cynodon dactylon (L.) Pers.
Plant Symbol = CNVD

Caution: This plant is considered invasive in several states and is subject to control measures. Please check with the local NRCS Plant Health Service for updated information. If necessary, consult with your local NRCS Plant Health Service for additional information. Please consult with your local NRCS Plant Health Service for additional information.

Description: Bermudagrass is a warm-season, grassy, flowering plant native to South America. It grows in clumps and is commonly found in disturbed areas, such as roadsides, parking lots, and golf courses.

Use: Bermudagrass is used as a turf grass, especially in warm climates. It is also used for erosion control and soil stabilization.

Adaptation and Distribution: Bermudagrass is adapted to warm, humid climates and is commonly found in the southeastern United States. It is also found in other warm regions around the world.

Invasive Species: Bermudagrass is considered an invasive species in many areas. It can quickly spread and take over native vegetation, leading to the decline of native plant species.

Control Measures: Control measures for Bermudagrass include mechanical methods, such as mowing, and chemical methods, such as herbicides. Control measures should be implemented by licensed professionals.

Note: Please consult the PLANTS Web site and your State Department of Natural Resources for the latest information on the status of this plant.

References:

Plants Materials: [http://plantmaterials.ars.usda.gov/]

Plant Fact Sheet: [http://plants.usda.gov/hs/hs coordinators.html]

Plant Health: [http://planthealth.ars.usda.gov/]

Plant Nutrition: [http://plants.usda.gov/]

Plant Pest: [http://plantpest.ars.usda.gov/]

Plant Diseases: [http://plantedis.ars.usda.gov/]

PLANTS Web site: [http://plants.usda.gov/]

Bermudagrass: [http://plants.usda.gov/hs/bermudagrass.html]
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 to 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', 'Tifturf', 'Tufcot', '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>
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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 buffalo grass, western wheatgrass, needlegrass and in some areas the bluegrasses.

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 'Livingston' (NM), 'Hayden' (NM), and 'Alma' (NM) and the upland rice release Bad River Ecotype (SD). Seeds are available at most commercial seed sources.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program

For more information about this and other plans, please contact your local NRCS Field Office or Conservation District and visit the PLANTS Web site at http://plants.usda.gov or the Plant Materials Program Web site at http://plants.nrcs.usda.gov.

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Visit the NRCS Rights Act Web site at the Natural Resources Conservation Service.
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 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.
Taproot is distributed throughout the majority of the United States. For a current distribution map, please visit the Plants of North America website.

Establishment

Taproot is established by seeds. Seeds are dispersed by wind and can remain viable for several years. Seedling emergence is best in late spring and early summer. Seedling growth can be slow, and plants may take several years to reach a flowering stage.

Management

While taproot is considered a weed and can be harmful to crops, it is also considered an important species of blackberries. It is important to monitor the population levels of this species and to take appropriate steps to control it. Taproot can be controlled using herbicides such as 2,4-D or glyphosate. In fact, these herbicides are frequently used to control taproot in commercial settings.

Cultivars, Propagation, and Selection Materials used

Several cultivars are recommended for the Northeast for their resistance to various environmental factors. For the best results, it is recommended to select cultivars that are adapted to the local climate and soil conditions. Selection of the best cultivars for the Northeast can be found in the Plant Materials Handbook (http://www.plantmaterialshandbook.org/).

Proposed By & Species Coordinator:

(First Name Last Name, Plant Materials Program)

For more information about the project, please contact the Northeast Regional Plant Materials Program at (508) 465-3500 or visit their website at http://www.plantmaterialshandbook.org/.

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GREEN SPRANGLETOP
Leptochloa dubia (Kunth) Nees

Plant Symbol: LEDU

Contributed By: USDA NRCS National Plant Data Center

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 legume concentrate. It is used in range seeding mixtures. When this grass is a key management species, as more than 50 percent of current growth by weight should be removed at any season. Summer and fall grazing deferments of at least 60 days improve vigor, increase seed production, and provide forage for winter use. The seedhead turns brown and drops 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 rain. 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 state of its range. It is seldom found on deep clay or deep sandy soils in the western part of its range.

Cultivar, Improved and Selected Materials / area of origin
Please contact your local NRCS Field Office.

Reference

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

Date: 13May1892, rec: 15Jul1893, rev: 26Aug1893

For more information on this and other plants, please consult www.ars.usda.gov/Services/docs.htm?docid=2703 & 1165. For assistance, please contact your local NRCS Field Office (http://planrepository.nrcs.gov) for the Plant-Biosecurity Program Web site (http://planrepository.nrcs.gov).

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

Description
LITTLE BLUESTEM is a tall, coarse grass that is readily identified in the prairie. It is one of the most common and widespread grasses in the prairie, occurring from Minnesota to Texas and west to Colorado. The plant has a dense, tufted growth habit, with long, slender, bluish-green tillers. The leaves are narrow, long, and比较长，brown, and tend to arch or bend over. The plant grows in open areas and along roadsides.

Adaptation
LITTLE BLUESTEM is adapted to various ranges of soil conditions. It tolerates a wide range of soil moisture, from dry to wet, and can thrive in both sandy and clayey soils. It is also adapted to a variety of soil pH levels, ranging from acidic to alkaline.

Uses
LITTLE BLUESTEM is a valuable forage for livestock, providing excellent quality and quantity. The plant is also used in erosion control, as it helps to stabilize soil and reduce water runoff. Additionally, it is used in wildlife habitat, providing food and cover for a variety of animals.

Notes
LITTLE BLUESTEM is an important part of the prairie ecosystem, providing habitat and food for a wide range of species. It is an excellent example of a native, prairie plant and serves as a model for the importance of maintaining and protecting our natural habitats.

Distribution
LITTLE BLUESTEM is found throughout the Great Plains and is also found in the Midwest and Midwest. It is found in a variety of habitats, including prairies, fields, and along roadsides.
Little Bluestem is relatively resistant to fire under moist conditions. The growing point (apical meristem) is slightly more than an inch above the soil surface (Ludlow, 1989). Little Bluestem in the immature growth phase is considered an nutritious, palatable grass for all classes of livestock; in late summer and early fall it is found 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 important 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 ensure stand longevity. Although not usually recommended for hay production, little bluestem can make a fine good hay with part of a native hayland mixture (Sundvor et al., 2000). It is a popular species to include in prairie restoration seedings because of its wide adaptation and high wildlife value. Plants self-retainers from the center out-in the champ if the plants become too dry. Harvest at the opportune time can help to reduce the population of cool-season competion vegetation, as well as grassy species.

Fries and Potential Problems
A leaf spot disease was found to be widespread in a little bluestem meadow established at Mandan, North Dakota; from plants collected in North Dakota, South Dakota, and Minnesota. P. lindemuthianum is the species is consistently found from leaves showing leaf spot symptoms. The fungus was also isolated from native prairie grasses. The fungus was also isolated from native prairie grasses. The fungus was also isolated from native prairie grasses. The fungus was also isolated from native prairie grasses.

Environmental Concerns
This grass is primarily a forage that will spread most by seed. The seed is light and fluffy and it will move to adjacent areas. Fire will allow the grass to spread; thus 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 specialists to learn what weeds are in your area and how to use it safely. Always read and follow instructions for each control method. Trade names and control measures appear in this document only to provide specific information. USEF 505C does not guarantee or warranty the products and control methods named, and other products may be equally effective.

Seed and Plant Production
Seed is a free seed after maturity. It is a solid seed (1 inches or less in shape) or approximately 4.5 liters per acre. 450 seeds per linear foot of row, or 15 seeds per linear foot of row, or 15 seeds per linear foot of row. 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 debeader 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., 1980).

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

<table>
<thead>
<tr>
<th>Cultivar/Type</th>
<th>Year</th>
<th>Origin</th>
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<tbody>
<tr>
<td>Coastal Plains Germplasm</td>
<td>2016</td>
<td>TX</td>
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<tr>
<td>STN-176 Germplasm*</td>
<td>2015</td>
<td>TX</td>
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<td>STN-461 Germplasm*</td>
<td>2015</td>
<td>TX</td>
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<td>Ozark Germplasm</td>
<td>2010</td>
<td>MO</td>
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<tr>
<td>Suther Germplasm</td>
<td>2008</td>
<td>NC</td>
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<tr>
<td>Prairie View Indiana Germplasm</td>
<td>2005</td>
<td>IN</td>
</tr>
<tr>
<td>OK Select Germplasm</td>
<td>2003</td>
<td>OK</td>
</tr>
<tr>
<td>Spirit Ecorvar (Canada)</td>
<td>2003</td>
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<td>Southlow Michigan Germplasm</td>
<td>2001</td>
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<td>Itasca Germplasm</td>
<td>2001</td>
<td>ND, SD, MN</td>
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<td>Taylor Ecorvar (Canada)</td>
<td>2000</td>
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<tr>
<td>&quot;Aldous&quot;</td>
<td>1966</td>
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**Literature Cited**


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Mace, E. 1987. Little barley. Hort. Newsletter, Univ. of Wisconsin, Madison, WI.


Western Cooperative Extension Service, Fargo, ND.


Citation


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Edited: May 2013

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SIDEOATS GRAMA
Bouteloua curtipendula
(Michx.) Torr.
Plant Symbol = BOCU

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 broad-grown spike, sometimes with a purplish cast (especially in the spring), and leaves to a reddish-brown or russet color. Leaves are coarser than other species of grama, straight, comparatively stiff, and mostly basal. Ten to thirty small, pan-like spikes are borne merely along one side of each central seed stalk. These spikes drop when mature, having a long silky 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 rows, resultant seedheads at the rate of 5 to 7 pounds per acre to provide good seed per acre. Protect from grazing from date of seeding through the second growing season. Seeding 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. Reduces fire production, carrying capacity, and hay in cattle weight in a direct result of overgrazing. Sideoats grama is a normal component of a large number of range sites. The grass longhairs
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
COMPOSITE DROPSEED
Sporobolus compositus (Poir.) Merr., var. compositus
Plant Symbol – SPDC02

Contributed by: USDA NRCS Valentine Plant Materials Center and the National Plant Germplasm Center

Description:
Sporobolus compositus is a grass that grows in a wide range of soil types and is adapted to a variety of environments. It is characterized by its fluffy, light-colored fruit heads that appear in late summer. The plant is vigorous and can grow to a height of 2-3 feet. The leaves are narrow and green, and the plant has a coarse texture.

Habitat:
Sporobolus compositus is found in a wide range of habitats, including prairies, meadows, and open fields. It is tolerant of both drought and moderate grazing pressures. This species is well-adapted to a variety of soil types, including sandy and clay soils.

Adaptation:
Sporobolus compositus is a hardy species that can tolerate a wide range of conditions. It is drought-tolerant and can grow in areas with limited water availability. It is also resistant to many common diseases and pests, making it a popular choice for landscaping and restoration projects.

Note:
Sporobolus compositus is a valuable species for wildlife habitat and erosion control. It provides food and habitat for a variety of birds and small mammals, and its fluffy fruit heads are a favorite food source for many birds and mammals.
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 ashei*) 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 a 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*), Indian grass (*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.

**References**


http://nativetulip.gardens.sabah.edu.my/PLANT


Prepared By
USDA-NRCS, Elkharty Plant Materials Center and James Blanton, National Plant Data Center

Species Coordinator
USDA-NRCS, Elkharty Plant Materials Center, Elkharty, Missouri

Start: 22Mar2006

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTNET Web site (http://plants.usda.gov/) or the Plant Materials Program Web site at http://plants.missouri.edu/PLANTNET/.

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YELLOW SWEETCLOVER & WHITE SWEETCLOVER

Melilotus officinalis (L.) Lam. & M. albus Medik

Plant Invasive - NOCP, AILS A1.2

Contributed by Adele HRC3 State Office and Missouri 911 Plant Materials Center

Adaptively Tolerant

Resistant to drought, frost, and alkaline soils

Type

BROADLEAF

Resources to provide food and cover to ecoregions of birds and mammals. The short and low canopy of yellow sweetclover can be cut for hay or unusual events. The low and dense mat of white sweetclover can be cut for pasture throughout the year (O'Neal et al., 1973).

Description:

The plants become coarse, mat-like and less predictable late in the season.

Resources are improved by hays in over-run and leaf. White sweetclover provides excellent hay yields, produces a high-quality forage, and can improve range quality for pasture improvement and forage production. Yellow sweetclover is a good material for hay and pasture use, providing good hay yields and high-quality forage for livestock and wildlife.

Morphology:

Resistant to drought, frost, and alkaline soils. The plants become coarse, mat-like, and less predictable late in the season.

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Green manure crops, such as sweetclover, 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 synonymizing the two species under *M. officinalis* may be warranted.

Yellow sweetclover is reported to be shorter growing, more widely branching, finerstemmed, 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 seedlings 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 (Baldrige 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).

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 (Baldrige 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

Pests and Potential Problems
Sweetclover plants contain coumarin, which is the cause of sweetclover bleeding disease. Coumarin breaks down to dicoumarol 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).
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.

References
Appendix I [Soil Loss Tables]
Soil loss one week after implementation

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Appendix J [Design Solution Menu]
Landfill Erosion Control Menu

Erosion Problem
The DEQ defines an erosion issue by visually assessing the slope. Little to no vegetation, an uneven surface, and trash exposure are all signs utilized to detect a problem.

Small Severity
Evidence of splash erosion is present. Indicators include disturbed soil and surface crust formation. Solutions add nutrients to the soil in order to encourage grass growth and prevent erosion.

- Short Term
  - Less than 2 years

  Solutions
  - Low to high cost
    - Compost
    - Blanket
    - Polymer

- Long Term
  - 2 to 3 years

  Solutions
  - Low to high cost
    - Leachate
    - Biosolid
    - Fertilizer
    - Hydromulding
    - Seed

Average Severity
Evidence of sheet erosion (the removal of the soil surface in thin layers) is present. Indicators include puddling on the surface, sparse vegetative growth, and exposed roots. Solutions decrease the velocity of water or stabilize soil in order to encourage grass growth and prevent erosion.

- Short Term
  - Less than 2 years

  Solutions
  - Low to high cost
    - Silk Fences
    - Mulch
    - Compost/Mulch/Progress
    - Imprinting
    - Polymer

- Long Term
  - 2 to 5 years

  Solutions
  - Low to high cost
    - Lime
    - Amendment
    - Plastic Mesh
    - Wattle
    - Compost Sock
    - Incorporating Compost

Extreme Severity
Evidence of rill erosion (channels in the soil less than 30 cm deep) is present. This type of erosion is common with bare soils and tends to be a recurring issue. Solutions add synthetic structure, cover a problem area, or redirect water in order to prevent erosion.

- Short Term
  - 2 to 4 years

  Solutions
  - Low to high cost
    - Gutterline
    - Gaurcell

- Long Term
  - 4+ years

  Solutions
  - Low to high cost
    - Flexcurtain
    - Terracing
    - Water Channeling
    - Cement
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 (Filtrecx, 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 underlaymen. 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°. TPAR® 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 types is best. There are many seed options. Common grasses used for erosion control include Bermudagrass, blue gamla, 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 to not 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 silty 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 decreasing 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 waffles 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]
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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 well 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. Hydroyseeding
      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](image)

**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.

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.
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 hydroteeding 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 hydroteeding 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.
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 contaminates 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](image)
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 shown below in Table 1, Table 2, and Table 3.

**Table 1: NPK requirements of soil samples (SWFAL)**

<table>
<thead>
<tr>
<th>Soil Description</th>
<th>N (lbs /A)</th>
<th>P (lbs /A)</th>
<th>K (lbs /A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover topsoil</td>
<td>39</td>
<td>48</td>
<td>489</td>
</tr>
<tr>
<td>Cover subsoil</td>
<td>1</td>
<td>23</td>
<td>356</td>
</tr>
<tr>
<td>Bare slope</td>
<td>6</td>
<td>34</td>
<td>541</td>
</tr>
<tr>
<td>Mulch slope</td>
<td>1</td>
<td>35</td>
<td>671</td>
</tr>
<tr>
<td>Grassy slope</td>
<td>4</td>
<td>35</td>
<td>450</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Test</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Adequate</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Very low</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Very high</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Adequate</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Very low</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Very high</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Cations</th>
<th>Freshmen Involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (ppm)</td>
<td>32.5</td>
</tr>
<tr>
<td>Calcium (ppm)</td>
<td>52.9</td>
</tr>
<tr>
<td>Magnesium (ppm)</td>
<td>19.9</td>
</tr>
<tr>
<td>Potassium (ppm)</td>
<td>64.0</td>
</tr>
<tr>
<td><strong>Anions</strong></td>
<td></td>
</tr>
<tr>
<td>NO₃-N (ppm)</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Chloride (ppm)</td>
<td>54.1</td>
</tr>
<tr>
<td>Sulfate (ppm)</td>
<td>56.2</td>
</tr>
<tr>
<td>Boron (ppm)</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>8.1</td>
</tr>
<tr>
<td>EC (μS/cm)</td>
<td>7.12</td>
</tr>
</tbody>
</table>

**Derived Values**

- Total Dissolved Salts (TDS in ppm): 323.0
- Sodium Adsorption Ratio (SAR): 1.0
- Potassium Adsorption Ratio (PARR): 1.1
- Residual Carbonates (meq): 24.8%

**Derived Values (Cont'd)**

- Hardness: 214.0
- Hardness Class: Very Hard
- Alkalinity (ppm as CaCO₃): 209.2

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 a 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 time for steep areas to be stabilized, while vegetation is allowed to fully take root. Also, the longevity of the material depends 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 33 ft Roll)
- Longevity: 2-5 years

*Steel Plates Alternative Daily Cover*

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

The Revelstoke Iron Grizzly cover system consists of a series of steel panels that provide 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

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 13: Diagram of electro-osmosis (Geoengineer)

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](image-url)

**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*

![Image of large-scale fertilizer application](image)

**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*

![Image of untreated clay soil and lime treated clay](image)

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

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](image)

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
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

![GrassProtecta grass reinforcement mesh (TYPAR)](image)

**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

![TurfProtecta turf reinforcement mesh (TYPAR)](image)

**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*

![Typar® BODPAVE Pavers](image)

*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

![EnviroGrid™ cellular confinement grids](image)

**Figure 27: EnviroGrid™ cellular confinement grids (EnviroGrid)**

EnviroGrid™ 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

![Enid Municipal Landfill leachate collection tank](image)

**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*

![Example of biosolid land application (Michigan DEQ)](image)

**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

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

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)](image)

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

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 33: Example of Buffalo grass (Hillerman)

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)](image)

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.
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)](image)

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

![Silt Fence Installation Diagram](image)

**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

![Gabion Baskets](image)

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

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

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)](image)

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
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

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

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:

\[ A = RKLSCP \] \[1\]

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,
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**

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

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

<table>
<thead>
<tr>
<th>Design Solution</th>
<th>Item</th>
<th>Number of Items</th>
<th>Itemized Cost ($)</th>
<th>Total Cost ($)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Travel- Sedan rental</td>
<td>3 trips at 140 miles/ trip</td>
<td>$32/day +$0.23 / mile</td>
<td>$256.80</td>
<td>OSU Motorpool</td>
</tr>
<tr>
<td>All</td>
<td>Time Lapse Camera</td>
<td>1 Bushnell Trophy Cam HD</td>
<td>$99.20</td>
<td>$99.20</td>
<td><a href="https://www.amazon.com/Bushnell-Trophy-Essential-Trail-Camera/dp/B01CQBY1U1/ref=sr_1_2?keywords=Bushnell+Trophy+Cam+HD">https://www.amazon.com/Bushnell-Trophy-Essential-Trail-Camera/dp/B01CQBY1U1/ref=sr_1_2?keywords=Bushnell+Trophy+Cam+HD</a></td>
</tr>
<tr>
<td>All</td>
<td>Johnston Co. Native Grass Seed Mix</td>
<td>(5 lb/acre) x (3 acres)</td>
<td>$40 / 5 lb bag</td>
<td>$120.00</td>
<td><a href="http://www.ajsinc.com/seed">http://www.ajsinc.com/seed</a></td>
</tr>
<tr>
<td>All</td>
<td>Soil Analysis Fee</td>
<td>1 compost test</td>
<td>$20/ compost test</td>
<td>$20.00</td>
<td>SWFAL</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Scotts 5,000-sq ft. Lawn Fertilizer</td>
<td>(1 acre)x(43560 sq ft/acre)(1 bag/ 5000 sq ft) = 9 bags/ acre</td>
<td>$21.44/bag</td>
<td>$211.86</td>
<td>Lowes.com</td>
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<td>Class B Biosolids Stabilization</td>
<td>Lime Application and Drying</td>
<td>5 bags</td>
<td>$4 /bag</td>
<td>$20.00</td>
<td>AgricultureSolutions.com</td>
</tr>
<tr>
<td>Nonwoven Geotextile</td>
<td>Nonwoven Drainage Material (6’X100’)</td>
<td>(300 ft/plot) x (2 plots)</td>
<td>$90 / roll</td>
<td>$270.00</td>
<td></td>
</tr>
<tr>
<td>Watts, Compost Sock</td>
<td>Compost Sock (8’ X 10’)</td>
<td>4 Socks</td>
<td>$26/ sock</td>
<td>$104.00</td>
<td><a href="https://www.amazon.com/SLS-LLC-Grow-Socks-8x10/dp/B0004M9V9M/ref=sr_1_17?ie=UTF8&amp;qid=1479777671&amp;sr=8-1&amp;keywords=compote+sock">https://www.amazon.com/SLS-LLC-Grow-Socks-8x10/dp/B0004M9V9M/ref=sr_1_17?ie=UTF8&amp;qid=1479777671&amp;sr=8-1&amp;keywords=compote+sock</a></td>
</tr>
<tr>
<td>Watts, Compost Sock</td>
<td>Rubber Mallet</td>
<td>1 Mallet</td>
<td>$12.86</td>
<td>$12.86</td>
<td></td>
</tr>
<tr>
<td>Watts, Compost Sock</td>
<td>U-Shaped Sod Staples</td>
<td>100 Staples / Pack</td>
<td>$12.95 / pack</td>
<td>$12.95</td>
<td></td>
</tr>
<tr>
<td>Silt Fence</td>
<td>Silt Fence Roll (2’ X 100’)</td>
<td>1 Roll</td>
<td>$20</td>
<td>$20.00</td>
<td></td>
</tr>
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<td>Watts, Compost Sock</td>
<td>Zip Ties</td>
<td>100 Zip Ties</td>
<td>$6 / Package</td>
<td>$6.00</td>
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<td><strong>Total Cost:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$1,385.67</strong></td>
<td></td>
</tr>
</tbody>
</table>
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.


Appendices
### Appendix A [Gantt Chart]

**Sustainable Solutions**

**Design Schedule**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Plan Start</th>
<th>Plan Duration</th>
<th>Actual Start</th>
<th>Actual Duration</th>
<th>Percent Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect water and soil samples from Enid</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Analyze soil and water samples</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Develop Preliminary design concepts</td>
<td>5</td>
<td>17</td>
<td>5</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Analyze leachate and sledge data</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Meet with freshmen Teams</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Team Planning Meeting</td>
<td>12</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Meeting with Kelly Dillon</td>
<td>19</td>
<td>1</td>
<td>27</td>
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</tr>
<tr>
<td>Team Planning Meeting</td>
<td>26</td>
<td>1</td>
<td>26</td>
<td>1</td>
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</tr>
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Appendix B [Preliminary Menu Design]

Diagram: Erosion Problem

- Splash Erosion
  - Short-term: Low Cost Option, High Cost Option
  - Long-term: Low Cost Option, High Cost Option

- Sheet Erosion
  - Short-term: Low Cost Option, High Cost Option
  - Long-term: Low Cost Option, High Cost Option

- Rill Erosion
  - Short-term: Low Cost Option, High Cost Option
  - Long-term: Low Cost Option, High Cost Option
Appendix C [City of Enid Municipal Landfill Site Plans]
Appendix D [Oklahoma State University Soil Sampling Guide]
How to Get a Good Soil Sample

Hsinlin Zhong
Soil Testing Coordinator

Brian Arrill
Soil Management Specialist

Soil tests provide a scientific basis for evaluating crop
management schemes and improving soil quality.

Sample Soil at the Right Time

Soil samples should be taken at the right time of year and
space to stabilize before shipping. A delay of two weeks
should be allowed for testing. Samples should be stored
in a cool, dry place. Soil samples should be collected
with a drier or preferably a wet sample.

Collect a Representative Sample

A representative sample is one that reflects the
conditions of the soil and the plants growing in it.

Figure 1. The minimum number of core samples needed
to make a representative sample is about 30.

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.

Oklahoma Cooperative Extension Service Fact Sheets
are also available on our website at:
http://oeta.okstate.edu
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 any of the analyses. For example, deficiencies for wheat could range from zero to 37 pounds of P₂O₅ and zero to 34 pounds of K₂O. For alfalfa, which has much greater nutrient requirements, deficiencies could range from zero to 94 pounds of P₂O₅ and zero to 120 pounds of K₂O. 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 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.

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.

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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 apple-farme site, approximately two million pounds of soil in the top six inches.

For deep-rooted nonlegumes such as wheat, barley, oats, 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, some of available nitrogen (total nitrate and sulfate) in the subsoil sample will provide a more complete picture of available nitrogen plus nitrate for these crops (Figure 1) and can save fertilizer expenses.

![Subsoil Sampling Diagram](image)

**Figure 1**. Assay 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.

**Ninety Fields**

Nonlegume 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. Nitrates from fertilizers, animal manure, and lime can be accumulated on the surface if they are surface applied without incorporation. A set of samples from the surface may well help quantify stratification of nutrients and is especially important for pH determination in non-legume 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, the sample should be taken after planting, but the depth of sampling should approximate the seeding depth (one to three inches). This is especially important when conditions are favorable for soluble salts to move upward and accumulate near the surface after planting. Since excessive salts are most harmful to germination and seedling vigor, it is this shallow depth which should be leased. At other times during the year, a sample of the entire tillage depth may be most useful in test for salt accumulation.

**Send Samples for Analysis**

Send samples to your local county Extension office, or mail your samples to the OSU Soil, Water and Forage Analytical Laboratory. Assistance is available to interpret test results.