Sustainable Solutions

Fall Design Report 2016

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Prepared for:

City of Enid Municipal Landfill

Oklahoma Department of Environmental Quality

Table of Contents

List of Figures

List of Tables

Introduction

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

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

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

Mission Statement

Designing green solutions for soil and water related problems.

Problem Statement

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

Customer Requirements

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

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

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

Project Scope

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

Deliverables

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

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

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

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

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

Work Breakdown Structure

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

1.3. Soil & Water Analysis

1.3.1. Web Soil Survey

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

1.3.2.1. Cover Soil

1.3.2.2. Slope Soil

1.3.2.3. Compost

1.3.2.4. Con Cover™

1.3.2.5. Stormwater

2. Design and Model

2.1. Alternative Design Options

2.2. RUSLE2 Simulations

3. Test

3.1. Test for Effectiveness

3.1.1. Rill Erosion Solutions

3.1.2. Sheet Erosion Solutions

3.1.3. Short-term Solutions

3.1.4. Long-term Solutions

4. Deliverables

4.1. Final Report

4.1.1. Erosion Control Menu

4.1.1.1. Effective Solutions

4.1.1.2. Alternative Solutions

4.1.1.3. Ineffective Solutions

4.2. Final PowerPoint Presentation

4.2.1. Client Evaluation

Task List

Research Phase

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

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

Design Phase

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

Testing Phase

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

Finalize & Present Results

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

Research

Technical Literature and Patent Review

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

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

Erosion Control

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

Figure 2: Image of current rill erosion issue

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

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

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

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

Hydroseeding

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

Figure 3: Example of hydroseeding application

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

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

Patent Searches

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

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

Compost and Alternative Cover

Alternative Daily Cover

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

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

Evapotranspiration Based Cover

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

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

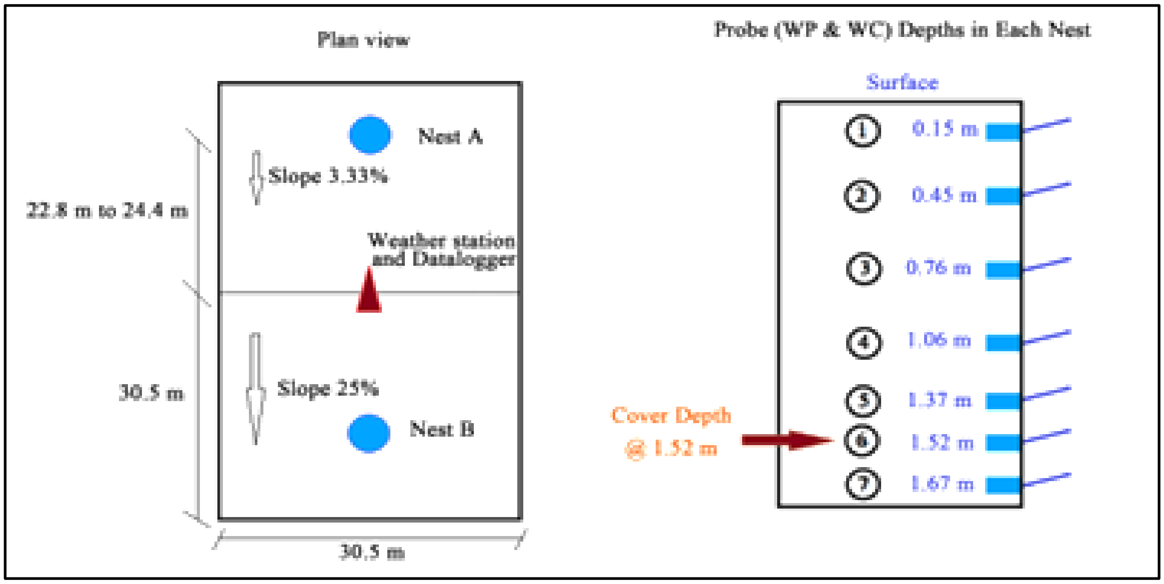


Figure 5: Profile view of instrumentation installed in ET cover (Abichou et al., 2015)

Using Compost as a Landfill Cover

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

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

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

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

Bulk Material Cover Compositions and Methods of Applying

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

Possible Issues with Fiber-Based Covers

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

In-Situ Fertilizer Application

Leachate

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

Sludge

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

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

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

Regulations and Permits

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

Wastewater Sludge

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

Leachate

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

Soil and Water Analysis

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

Figure 6: Sampling the cover topsoil

Figure 7: Sampling the cured compost

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

Table 1: NPK requirements of soil samples (SWFAL)

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

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

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

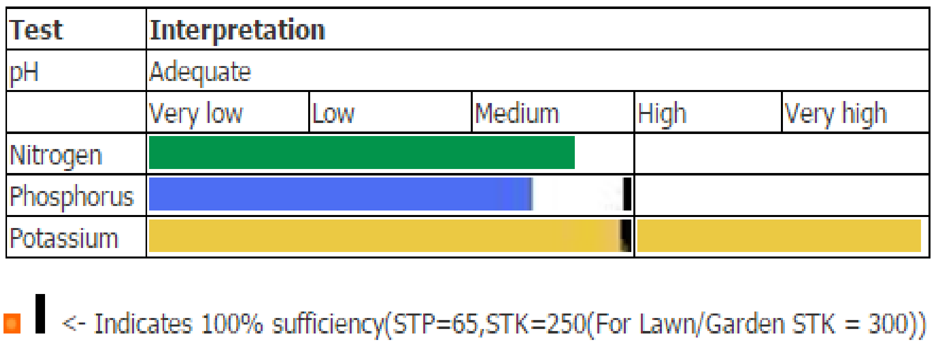
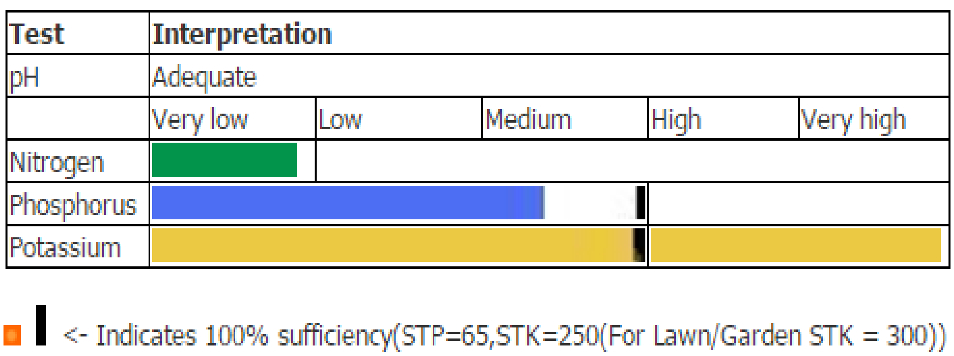


Table 3: Bar graph of cover subsoil NPK (SWFAL)



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

Table 4: Results of water sampling (SWFAL)

Test Results For **Irrigation Water**

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

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

Freshmen Involvement

Figure 8: Freshmen field work

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

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

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

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

Product Analysis

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

Cover Management

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

Woven Geotextiles

Figure 9: Woven textile fabric application (US Fabrics)

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

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

Nonwoven Geotextiles

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

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

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

Coir Erosion Control Mats

Figure 11: Coir textile fabric application (Bender)

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

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

Steel Plates Alternative Daily Cover

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

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

- Predicted Cost: High
- Longevity: Long-term

Electro-Osmosis Soil Treatment

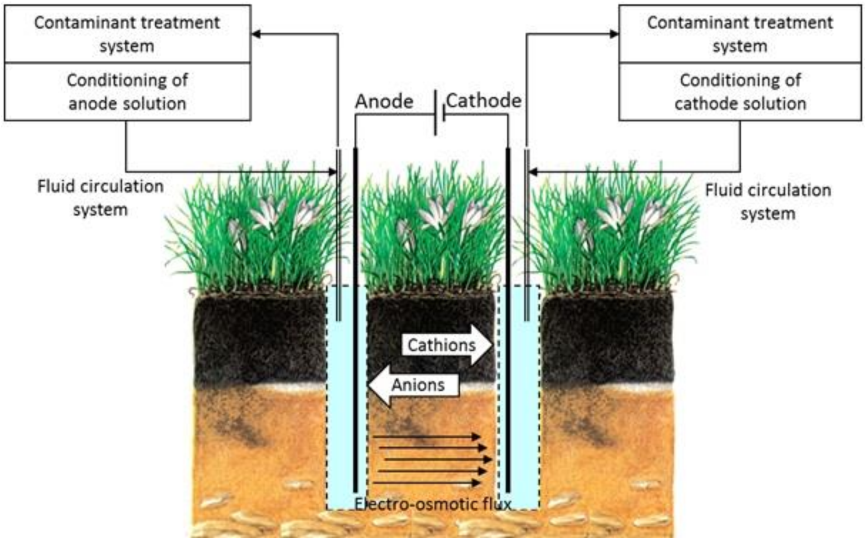


Figure 13: Diagram of electro-osmosis (Geoengineer)

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

- Predicted Cost: High
- Longevity: Unknown

Polymer Soil Stabilization: GRT 9000

Figure 14: Soil stabilizing polymer, GRT9000 (GRT)

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

- Predicted Cost: Unknown
- Longevity: Short-term

Soil Binder & Erosion Control: GRT ENVIRO

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

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

- Predicted Cost: Unknown

- Longevity: Short-term

Fertilizer Application to Improve Vegetative Cover

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

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

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

Lime Amendment for Soil Stabilization

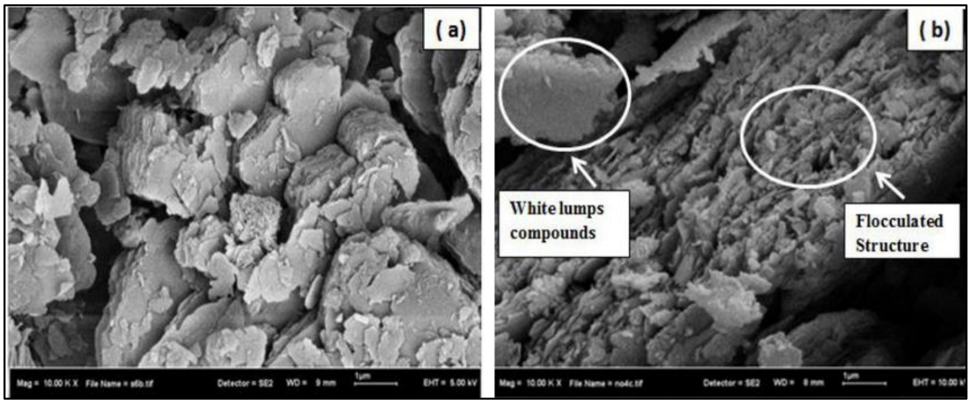


Figure 17: Image of (a) untreated clay soil and (b) lime treated clay (Saeed, 2015)

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

- Predicted Cost: Low
- Longevity: Varies

TYPAR® Geocells

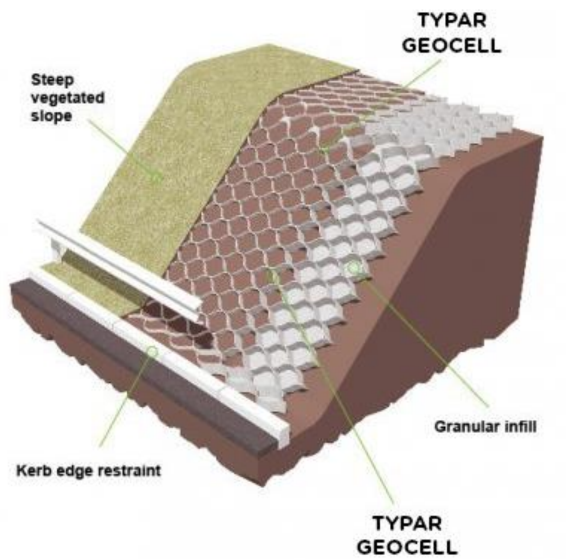


Figure 18: TYPAR® geocell diagram (TYPAR)

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

- Predicted Cost: Medium
- Longevity: 2+ years

Sod

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

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

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

Incorporating Compost

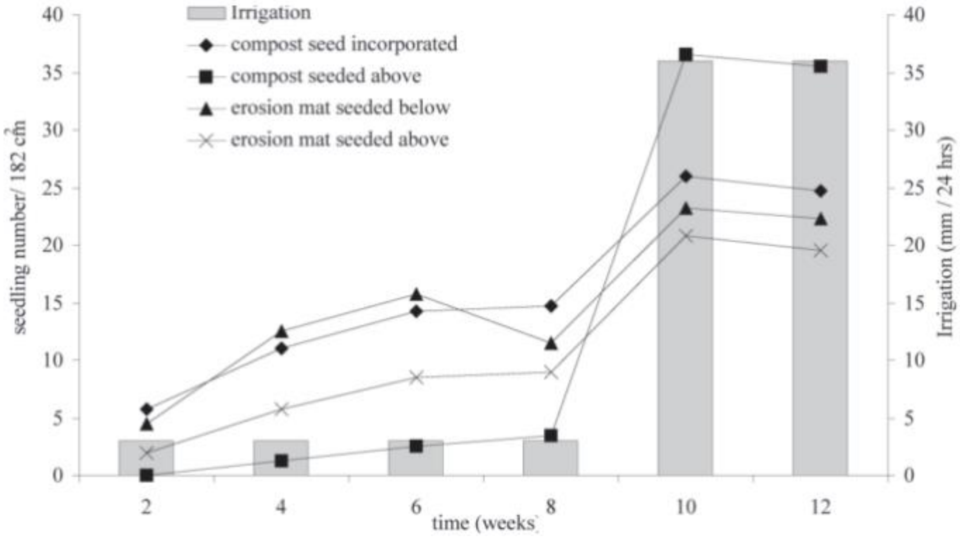


Figure 20: Graph of germination study (Harrell and Miller, 2005)

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

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

Mulch

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

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

- Predicted Cost: Low
- Longevity: Short-term

Flexamat®

Figure 22: Flexamat® rolled soil stabilizer (Flexamat)

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

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

Compost Blanket

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

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

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

Typar® GRASSPROTECTA

Figure 24: GrassProtecta grass reinforcement mesh (TYPAR)

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

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

Typar® TURFPROTECTA

Figure 25: TurfProtecta turf reinforcement mesh (TYPAR)

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

- Predicted Cost: Unknown
- Longevity: Varies

Typar® BODPAVE Pavers

Figure 26: BODPAVE porous paving grids (TYPAR)

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

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

EnviroGrid™ –cellular confinement

Figure 27: EnviroGrid ™ cellular confinement grids (EnviroGrid)

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

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

Adding Leachate

Figure 28: Enid Municipal Landfill leachate collection tank

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

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

Adding Wastewater Sludge

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

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

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

Adding Sludge and Mulch

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

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

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

Hydroseeding

Figure 31: Example of hydroseeding (BAI Environmental Services)

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

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

Hydroseeding Common Grasses

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

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

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

Hydroseeding Native Grasses

Figure 33: Example of Buffalo grass (Hillerman)

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

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

Hydroseeding Annual Grasses

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

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

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

Hydroseeding Vine/Ground Cover

Figure 35: Example of Rose Moss Cover (ASPCA)

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

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

Support Practices

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

Cement

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

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

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

Wattle

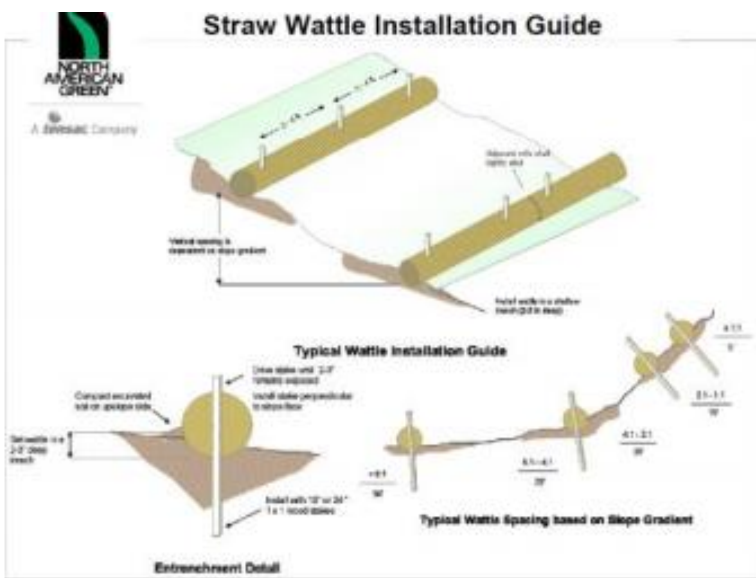


Figure 37: Straw wattle installation diagram (North American Green)

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

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

Compost Sock

Figure 38: Compost sock terraces (USDA NRCS)

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

- Predicted Cost: Varies
- Longevity: Unknown

Silt Fence

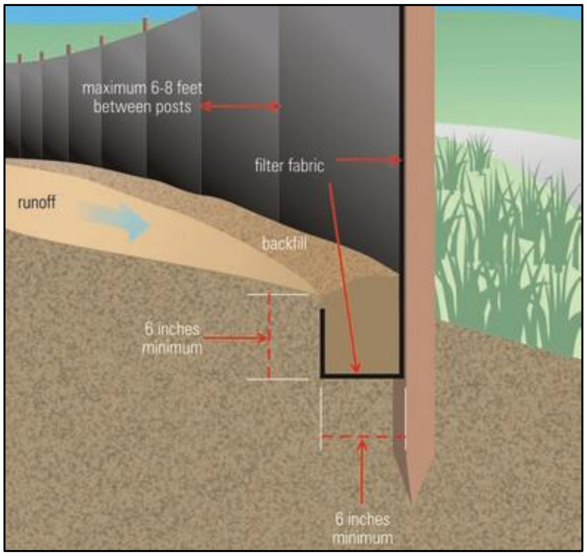


Figure 39: Silt fence installation diagram (Vogel)

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

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

Gabion Baskets

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

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

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

Terracing

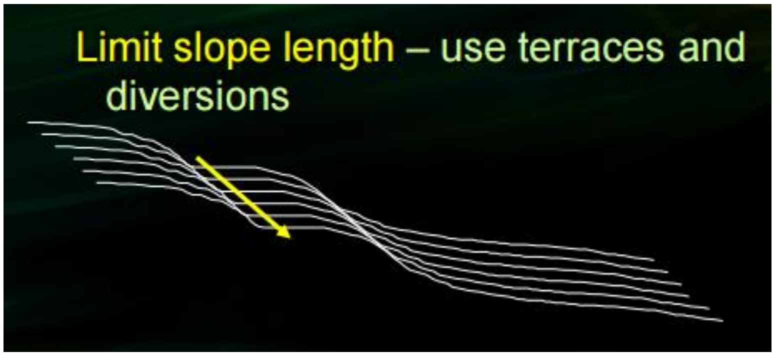


Figure 41: Diagram of slope terracing (Vogel)

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

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

Riprap

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

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

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

Channel Water Over the Slope

Figure 43: Example of water channeling (Stormwater Solutions)

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

- Predicted Cost: High
- Longevity: Long-term

Imprinting

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

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

- Predicted Cost: Low
- Longevity: Short-term

Compost Berm

Figure 45: Example of compost berm implementation (EPA)

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

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

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

Table 5: Comparison chart of potential design solutions

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

Design

Engineering Specifications

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

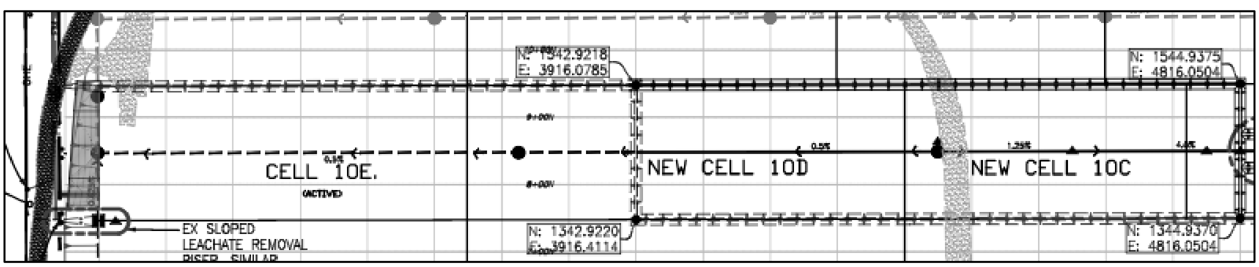


Figure 46: Engineering site plan top view of North Slope (City of Enid)

Erosion Modeling Software

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

The USLE is written in the form:

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

Where:

A = net detachment (mass/unit area)

R = erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = supporting practices factor

1.0 Proposed Methodology

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

1.1.0 Revised Universal Soil Loss Equation (RUSLE) Modeling

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

1.1.1 RUSLE Model Components

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

1.1.2 RUSLE Quantifies and Predicts Erosion

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

On-site Testing Procedure

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

Budget

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

Table 6: Fall Semester budget

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

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

Table 7: Spring Semester budget

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

Conclusion

Impacts and Sustainability

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

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

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

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

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

Safety Considerations

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

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

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

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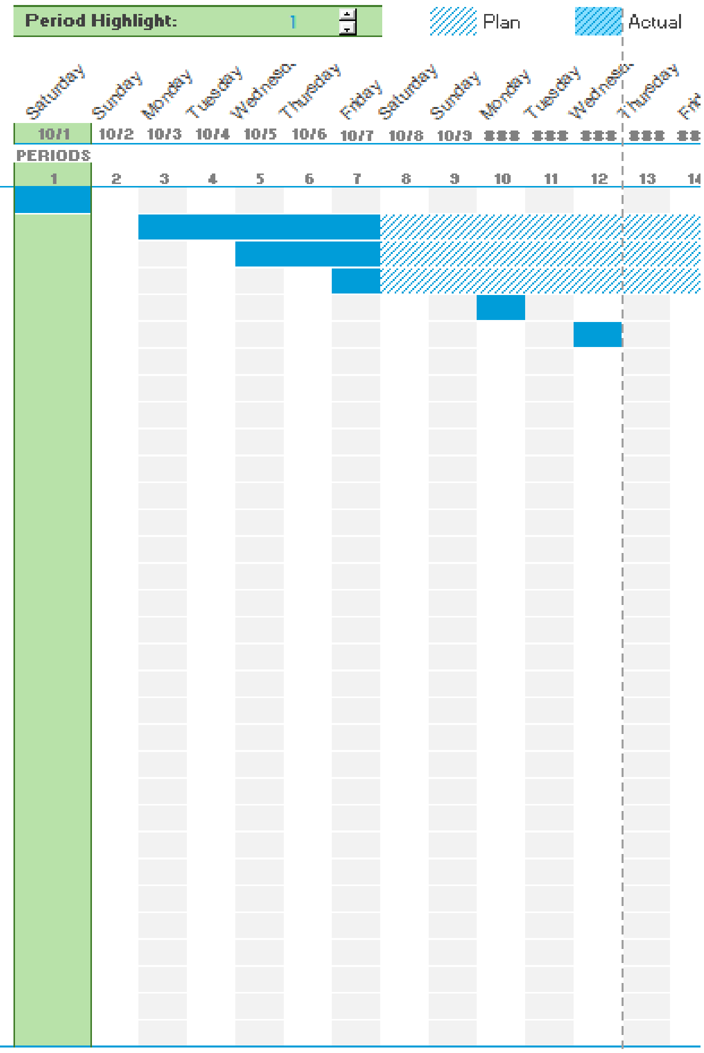
Appendices

Appendix A [Gantt Chart]

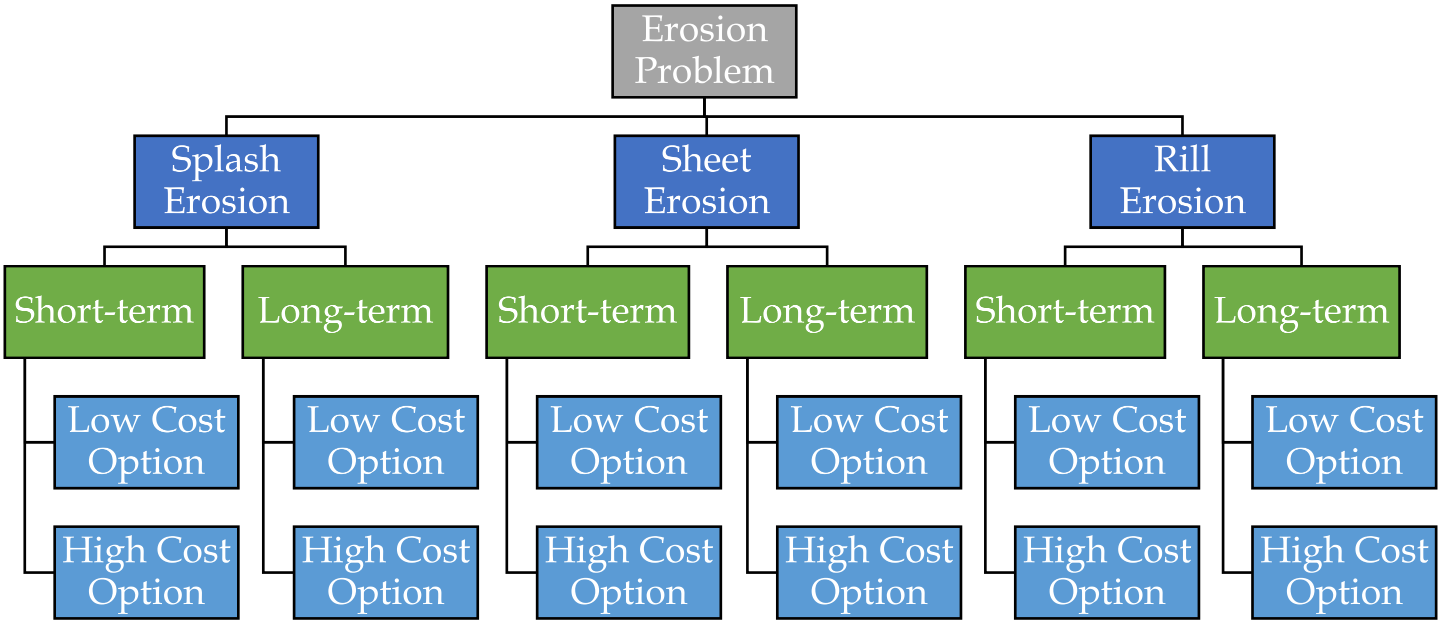
Sustainable Solutions

Design Schedule

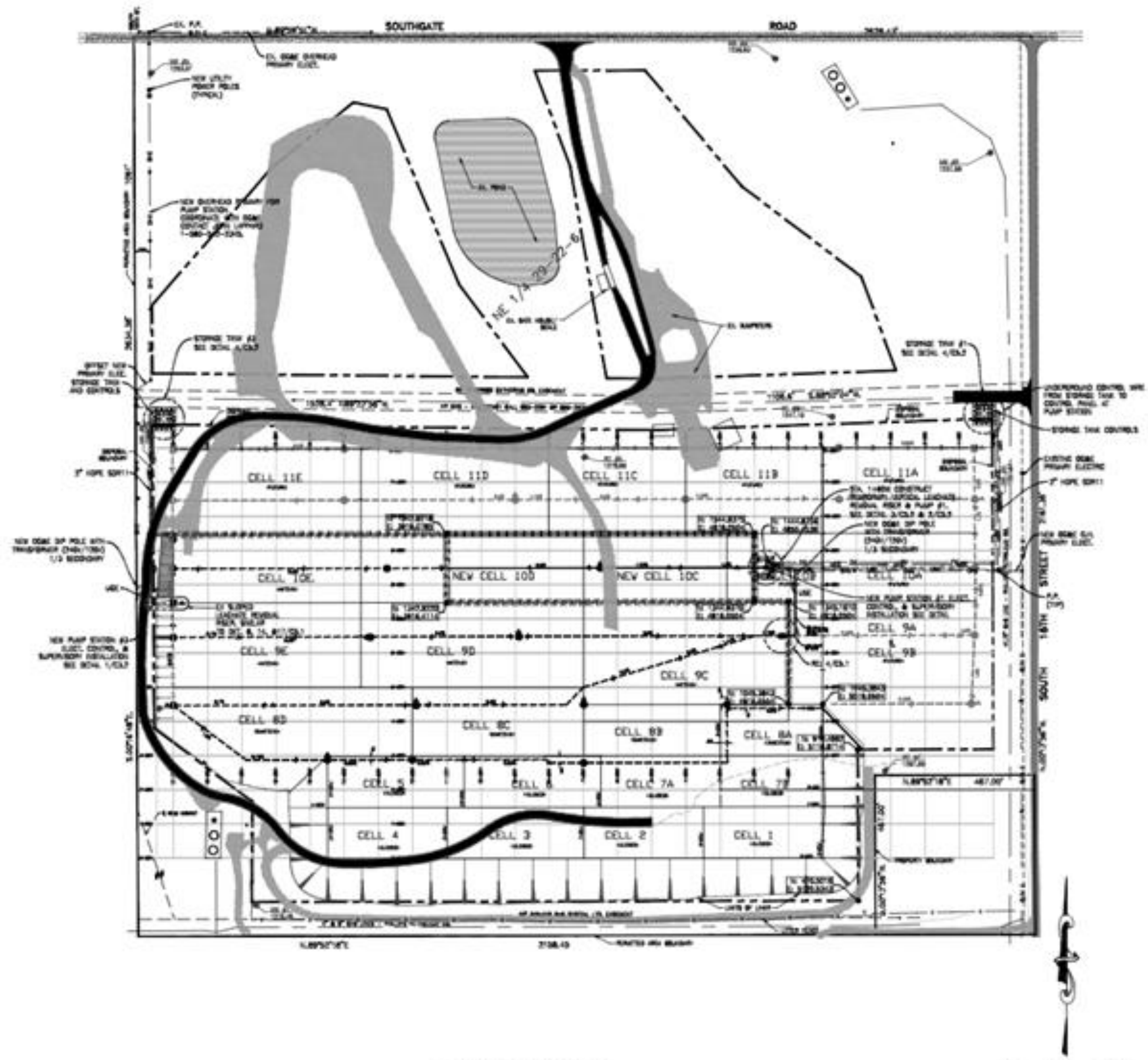
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Collect water and soil samples from Enid	1	1	1	1	100%
Analyze soil and water samples	3	12	3	5	100%
Develop Preliminary design concepts	5	17	5	3	100%
Analyze leachate and sludge data	7	8	7	1	100%
Meet with Freshmen Teams	10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



Appendix B [Preliminary Menu Design]



Appendix C [City of Enid Municipal Landfill Site Plans]



OVERALL SITE PLAN

0 150' 300'
SCALE IN FEET

LEGEND

- PROP. TOP OF CLAY LINER CONTOUR
- EX. CONTOUR
- GROUNDWATER CONTOUR
- EXISTING/PROPOSED/FUTURE LEACHATE COLLECTION SUMP
- EXISTING/PROPOSED/FUTURE LEACHATE CLEANOUT RISER
- EXISTING/PROPOSED/FUTURE FLOWLINE IN LEACHATE TRENCH & LOCATION OF CHANGE OF GRADE
- MW OR PZ W/ GROUND WATER ELEVATION USED FOR CONTOURING
- LEACHATE COLLECTION TRENCH WITH DIRECTION AND SLOPE OF FLOW OF LEACHATE
- EXISTING TOP OF CLAY LINER ELEVATIONS
- EXISTING LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- PROPOSED TOP OF CLAY LINER ELEVATIONS
- PROPOSED LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- PROPOSED LEACHATE FLOWLINE
- FUTURE TOP OF CLAY LINER ELEVATIONS
- FUTURE LEACHATE PERFORATED PIPING (6" SCH 80 PVC) WITH FLOWLINE OF PIPE
- OVERHEAD PRIMARY ELECTRICAL UTILITY (OG&E)
- UNDERGROUND SECONDARY ELECTRICAL UTILITY (OG&E)
- UNDERGROUND CONTROL CABLE
- 3" HDPE SDR11 (160 PSI) FORCE MAIN
- LOCAL LANDFILL COORDINATES
- FML: FLEXIBLE MEMBRANE LINER
- RCL: RECONSTRUCTED CLAY LINER
- LCS: LEACHATE COLLECTION SYSTEM
- MONITORING WELL W/ HIGH WATER LEVEL
- PIEZOMETER W/ HIGH WATER LEVEL

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

BRUEGGEMANN ENGINEERING

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

OVERALL SITE PLAN

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Appendix D [Oklahoma State University Soil Sampling Guide]

How to Get a Good Soil Sample

Hailin Zhang
Director, Soil, Water and Forage Analytical laboratory

Brian Arnall
Nutrient Management Specialist

Oklahoma Cooperative Extension Fact Sheets are also available on our website at:
http://osufacts.okstate.edu

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

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

Sample Soil at the Right Time

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

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

Collect a Representative Sample

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

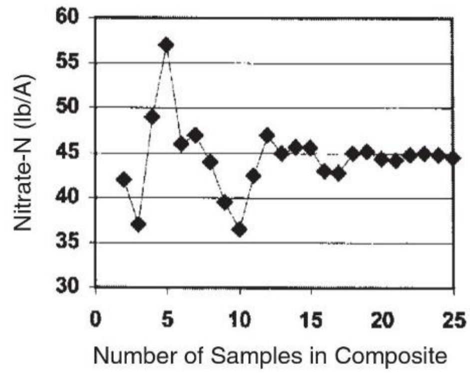

Figure 1. The minimum number of core samples needed to make a representative composite sample is about 20.

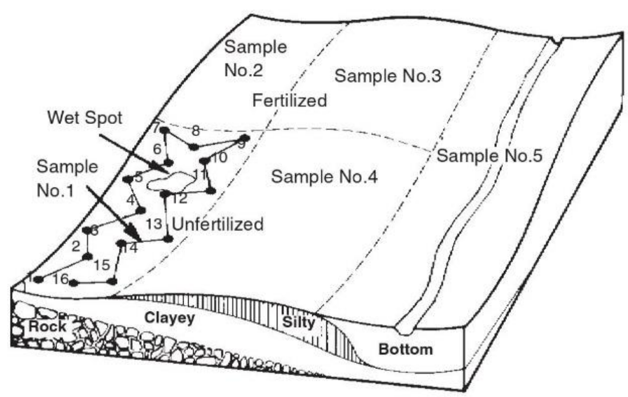

Figure 2. Divide field into uniform sampling areas and follow a random pattern when sampling. Avoid unusual spots and try to obtain a representative sample.

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

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

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

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

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

Sampling Where Nutrients are Banded

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

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

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

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

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

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

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

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

Sample at Proper Depth

Cultivated Fields

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

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

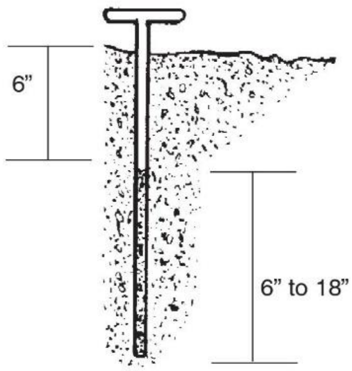

Figure 3. A soil probe is a good tool for obtaining soil samples. Push the tube to the six-inch depth and remove the core. Then take the 6- to 18-inch core through the same hole for the subsoil test.

No-till Fields

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

Salinity Diagnosis

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

Send Samples for Analysis

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