ALTERNATIVE LANDFILL LINER

FINAL REPORT

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Section 1: Acknowledgments

SK Geotechnical company members have taken effort in the landfill liner project. However, it would not have been possible without the kind support and help of many individuals and organizations. SK Geotechnical Company would like to extend their sincere thanks to all of them.

The completion of this project could not have been possible without the expertise of Dr. Wilbert Odem, the Project Supervisor. We would also like to thank Mr. Matthew Morales, the Project Client and Manager, for his help through the project. A debt of gratitude is also owed to Mr. Gerjen Slim, the Technical Advisor, for providing help, and guiding the team through the lab testing. Last but not least, the team would like to express their special thanks to Cinder Lake Landfill company for providing the waste materials to conduct the lab tests.

Sincerely,

SK Geotechnical Company

Section 2: Project Description

2.1 Project Understanding

The purpose of the landfill liner project is to create a liner for Cinder Lake landfill, made out of materials that are entering the landfill. The landfill liner will be designed using cost-effective materials and techniques. The selected materials must withstand shear and hydraulic forces applied on them by the landfill. The team tested samples that include Fly Ash, Paper Pulp Sludge(PPS), Polymers, Soil, Lime, and Bentonite to develop a landfill liner that meets and exceeds the given constraints and criteria. The designed landfill liner will be beneficial because it will be cheaper than the existing liners. This would allow for the landfill to reallocate their cash flow and make improvements to the landfill as a whole. The new liner will use materials currently entering the landfill, which would reduce the amount of materials present in the landfill over time. This would help extend the life of the landfill.

Cinder Lake landfill is a municipal solid waste landfill located approximately 12 miles Northeast of Flagstaff on Highway 89 and Landfill Road in Coconino County, AZ. Figure 1 shows the overhead view of the landfill's location [1].

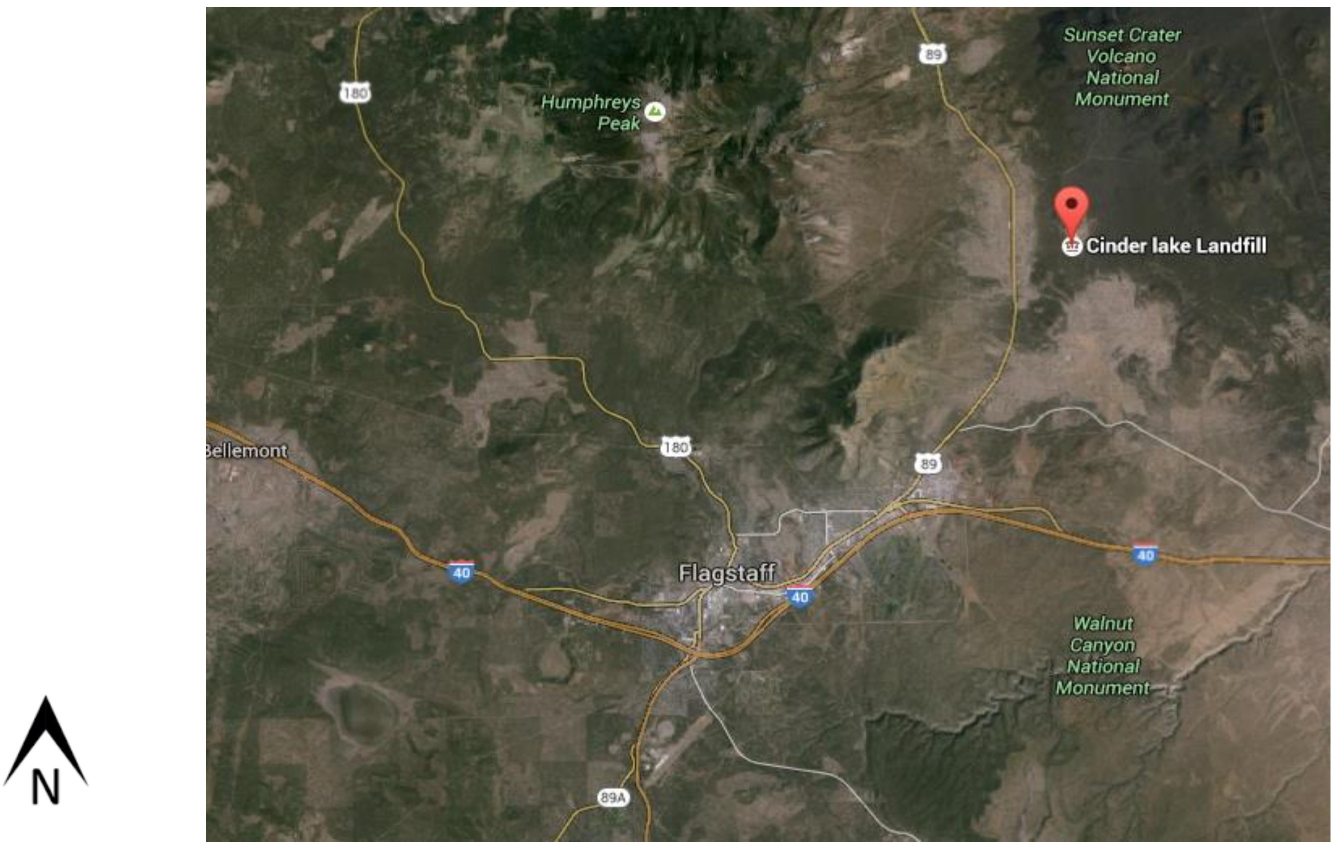

FIGURE 1: CINDER LAKE LANDFILL SITE LOCATION [1].

Cinder Lake Landfill accepts household, commercial, and institutional waste. Furthermore, the landfill accepts paper sludge (PPS) from a local paper recycling plant. The sludge is mixed with wood mulch and used as an alternative daily cover. The landfill receives approximately 122,000 mega grams per day, which is equivalent to approximately 279 tons per day. In the landfill, solid wastes are disposed in layers no thicker than 2 feet. Compacted solid waste are covered with 6-8 inches of alternate daily cover. The landfill serves approximately 17,000 residential and commercial entities in the City of Flagstaff with 70-mile radius around Flagstaff. The total area

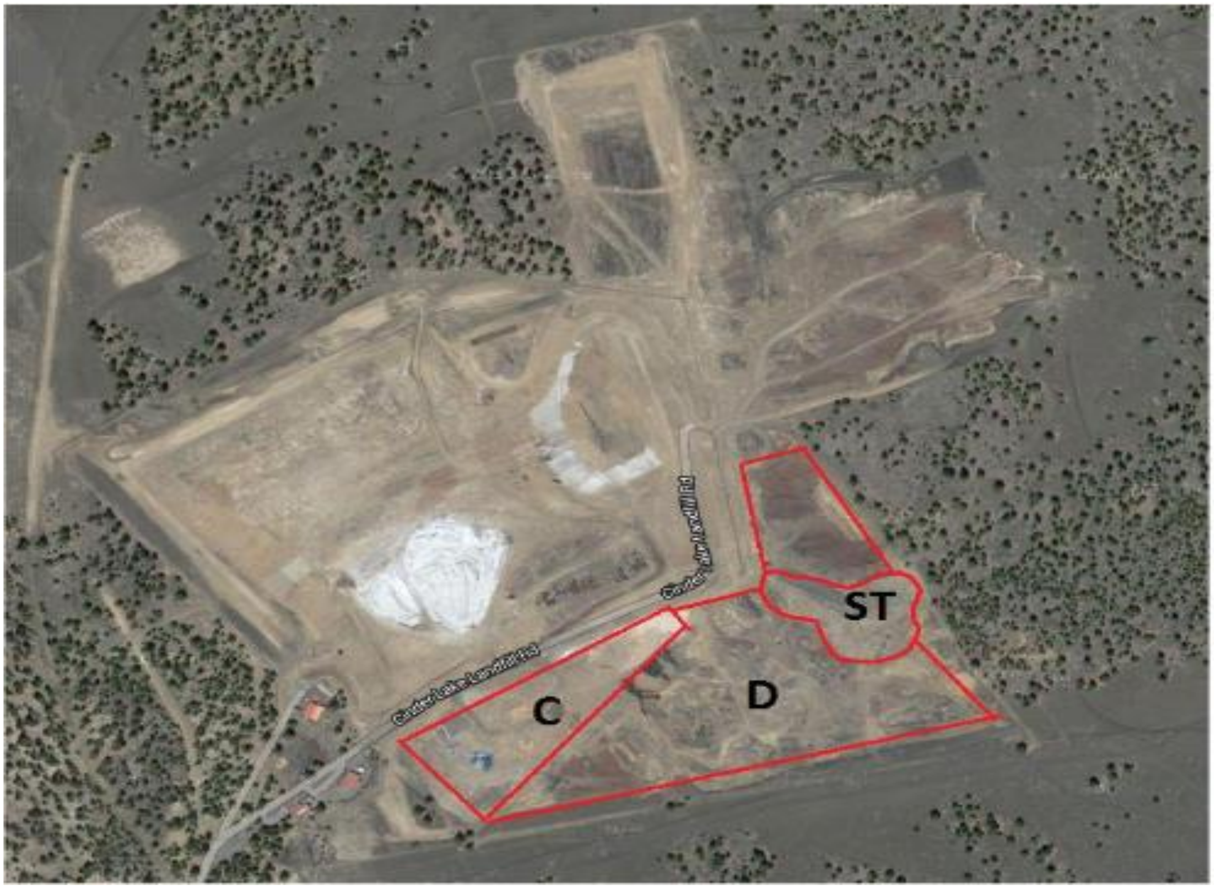

FIGURE 2: THE CURRENT CELL D, CELL C, AND THE SOUTH THUMB (ST) [3].

of the landfill is 343-acre. Figure 2 shows an overview of the landfill [2]. This landfill is ideal for such a project because it is located far above the water table.

Cell C currently contains predominantly construction waste that is approximately 30 years while the South Thumb contains municipal waste that is around 20 years old. Cell D currently has not waste and contains rock and soil. Eventually, Cell D will be expanded so that it has an area of 50 acres. Figure 3 shows the current landfill and the proposed expansion.

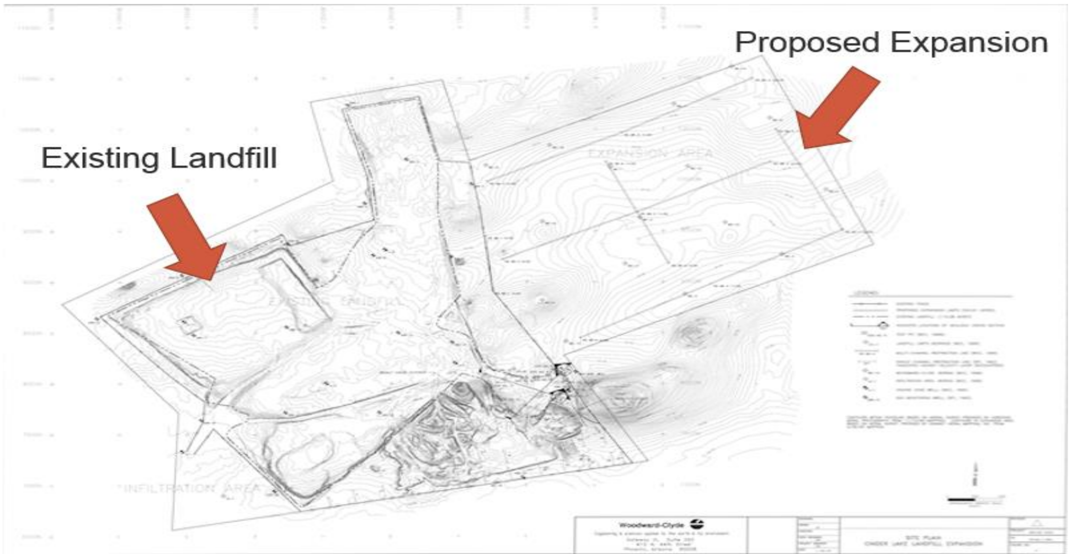

FIGURE 3: CINDER LAKE LANDFILL EXPANSION [3].

2.2 Constraints/Limitations

The designed landfill liner is based on the design criteria from 40 CFR, specifically Section 258.60. The requirements are listed below:

1- Primary criteria: The designed liner must have a permeability less than or equal to the permeability of any bottom liner, or a permeability no greater than 1×10^{-7} cm/sec.

2- Secondary Criteria: The liner must withstand Shear Strength and Proctor Compaction.

3- The designed liner should meet the EPA design regulations.

4- The designed liner should be cost effective.

The project is limited due to several factors such as time and material acquisition/composition. The team is limited with a specific amount of time, which may result in lack of material testing that will affect the final design implementation. The materials will also be provided by Cinder Lake Landfill. That being said, the amount of materials used for testing will be based on the amount the landfill is willing to give away for testing.

2.3 Tasks and Subtasks

This section will list what the team completed throughout the entire project. It will also include a list of services not included in the project. These items cannot be completed due to other factors, one of them being time constraints.

Task 1.0: Health and Safety Protocols

The safety of team members during the duration of the project is extremely important and is a main focus point throughout the entire project. Typical lab safety measures will be implemented to ensure the team's personal safety. No food or water will be allowed in the lab at any time. This will help reduce the amount of sample contaminations while conducting labs.

Task 2.0: Material Preparation

There are five testing materials used for the project. They are as follows: PPS, Fly Ash, Polymers, Soil, and Bentonite. All materials will be delivered to the team through the NAU Facility. The team will gain access to the materials when lab testing begins. Before testing can begin, the materials must first be prepared in certain ways. The following sections will discuss how each material was prepared for testing.

2.1 PPS Preparation

The PPS was delivered to the team in a wet form with the consistency of mud. It was then placed in drying ovens to be air dried for roughly 16 hours to make sure it was dry before conducting any tests. For compaction tests, the PPS was required to be finer than #4 sieve. Once the following steps were completed, the material was ready to be mixed with the Fly Ash.

2.2 Fly Ash Preparation

The Fly Ash was delivered to the lab and does not require further preparation. As soon as the PPS preparation is complete, the two will be mixed together.

2.3 Polymers Preparation

The team tested the mixture of PPS and Fly Ash with 3 different polymers. The polymers were delivered to the lab and did not require further preparation aside from measuring the correct amount needed to complete the tests.

2.4 Soil Preparation

The soil used for lab testing will be taken directly from the Cinder Lakes Landfill. The soil classification was still unknown.

2.5 Bentonite Preparation

The Bentonite will be delivered to the lab and does not require further preparation. The Bentonite will be ready to mix with the PPS after it finished drying.

Task 3.0: Material Testing

Material testing was an essential part of this project. The team will be conducting two geotechnical tests; the Modified Compaction Test (ASTM D1157) and the Permeability Test (ASTM 5084) [4][5].This task also includes gathering all the required testing apparatuses.

3.1 Modified Compaction Test

The modified compaction tests have been conducted to determine the mixture's optimum moisture content. The team completed 45 compaction tests on a variety of different mixtures.

The mixtures consist of the same materials but will be run at different percentages. Along with the optimum moisture content, the compaction test will show how the properties of the mixture act when subjected to an applied load.

3.2 Permeability Test

Permeability tests will be conducted to determine how well a substance flows through another substance. Once the optimum moisture content is obtained from the modified compaction tests, the team will conduct permeability tests. These tests will help the team determine to what extent the proposed liner will allow leachate to infiltrate the subsurface.

Task 4.0: Data Analysis

All raw data collected will be recorded in a single Excel document throughout the duration of lab testing. The team will convert the raw data into useful charts to obtain desired results. The data and the results produced will then be shown in tables and graphs in the report. The data generated will be used to help determine the optimum mixture as well as the final liner recommendation.

Task 5.0: Project Management

This role will be assigned to the team leader. The team leader will be responsible for scheduling team meetings, site visits, and lab times. The leader will also responsible for ensuring every deadline is met as well communication with the client. Wilbert Odem, Matthew Morales, and Gerjen Slim, are all contacts that will be utilized throughout the entirety of the project.

5.1: Team Meetings

The team will meet at their discretion to discuss the project's progression as well as to discuss the raw data obtained from testing. The team will also communicate in such a way to ensure everyone is on the same page.

5.2: TA Meetings

Throughout the entire project, the team will meet with Gerjen Slim, the team's technical advisor. Before each meeting, the team will create a memo that outlines the objectives for the meeting as well as summaries the previous meeting's discussion.

5.3: Website

The team plans to meet with a web design student to work out any bugs before the launch of the website. The website will be designed to direct users to useful information on the project as well as make their visit enjoyable.

5.4: 50% Report

Halfway through the project, the team been creating a 50% report to illustrate the progress made on the project. This report consists of all data completed to that point, including lab data.

5.5: Final report

After the completion of all lab testing and data analysis, the team will produce a final report that includes all relevant Excel spreadsheets generated from lab testing. The report will also discuss what all the data means and how it is applicable. The report will make a final recommendation for the alternate liner.

2.4 Exclusions

The team has identified a few tasks that will not be conducted. The team reserves the right to add to this list as the project progresses. They will not be implementing the final landfill liner design at the landfill. The team also recognizes that not all lab tests will be conducted by them. More lab tests may be requested at a later date during the project.

Section 3: Technical Sections

The following sections will discuss all of the data gathering that is required for this project. I will also show the testing results as well as how the results impact the final design.

3.1 Testing

This section will discuss the tests that will be used to help justify the final design. The tests that will be completed are as follows: Modified Proctor Compaction and Hydraulic Conductivity.

3.1.1 Modified Proctor Compaction

The modified compaction test will be required to find the optimum moisture content for each material that will be used in the final liner design. The optimum moisture content will be different for each design option, because each one of the designs include different percentages of material. The modified proctor compaction test will use a heavier hammer then the standard proctor compaction test. The heavier hammer results in a more compact sample, which is more attractive because it will help reduce hydraulic conductivity. A total of 10 modified compaction tests have been done to determine the optimum moisture content for Fly Ash, Bentonite, Lime, Soil, and the Polymers. The modified compaction tests for Fly Ash, Soil, and Polymers were determined by the previous teams that worked on the project. The optimum moisture content was determined by adding an arbitrary moisture content for each material, starting by 7% moisture content by weight. After each addition, the dry unit weight was calculated. The addition of moisture content increases the dry unit weight until a certain point. The moisture content would peak at a given concentration, then it would start to decrease with the more moisture added. The last point of dry unit weight increment reflects the optimum moisture content of the material. This can be determined by graphing each dry unit weight with its moisture content. The following equations were used to determine the dry unit weight:

$$Dry\ Unit\ Weight = \frac{Unit\ Weight}{1 + Moisture\ Content} \qquad Equation\ 1$$

$$Unit\ Weight = \frac{((Mass\ of\ Compacted\ Soil + Mold) - Mass\ of\ Mold\ ) \times 9.81 \times 1000}{Volume\ of\ Sample} \qquad Equation\ 2$$

Section 3.2.1 will demonstrate the moisture content and dry unit weight graphs for Bentonite, and PPS.

3.1.2 Hydraulic Conductivity

Hydraulic conductivity testing will be required because the selected liner is a municipal landfill liner. In accordance with 40 CFR 258, the desired value for each design must be less than or equal to $1 * 10^{-7}$cm/s. Hydraulic conductivity cannot be tested until the optimum moisture content was found. Once the optimum moisture content was acquired, testing for hydraulic conductivity can begin. Each sample was compacted in the proctor molds after being mixed together with their optimum moisture content. Moisture content was weighted on how much of each ingredient was present in each sample. After compacting each sample, the sample was fully submerged in water for at least 24 hours. After at least 24 hours, the sample was assumed to be fully saturated. The sample was then prepared for testing using the permeameters. The time taken for water to drop 1" was recorded and used to determine the value for hydraulic conductivity. Equation 3 is used to calculate the hydraulic conductivity of each sample:

$$K = \frac{a\,.\,L}{A\,.\,t}\ln\left(\frac{h_1}{h_2}\right) \qquad \textit{Equation } 3$$

Where:

K is the hydraulic conductivity (cm/s)

a is the area of drainage hole (cm^2)

L is the length of the sample (cm)

A is the area of the sample (cm^2)

t is the time water takes to drop 1"(s)

h_1 is the starting head (in)

h_2 is the ending head (in)

Figure 4 shows the permeameters that were used to conduct the test.

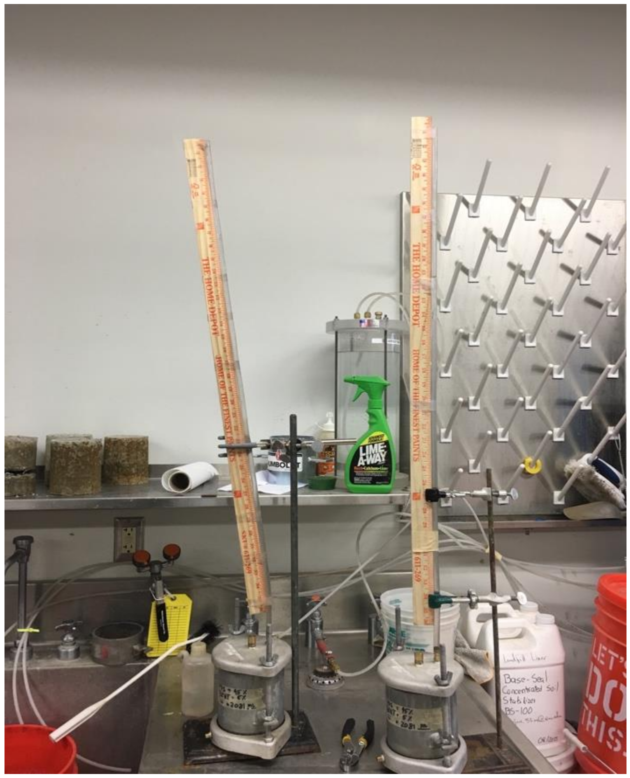

FIGURE 4: PERMEAMETERS FOR HYDRAULIC CONDUCTIVITY TESTING

Section 3.2.2 will represent the hydraulic conductivity results for all mixtures that have been done.

3.2 Analysis

This section will take the data that was gathered from both the modified proctor compaction tests and the hydraulic conductivity tests. The data will be used to produce values for both optimum moisture content and hydraulic conductivity. The hydraulic conductivity will then be compared to 40 CFR Section 258 to determine if the value passes the requirement. A final design will be recommended by using the mixture with a hydraulic conductivity that meets the 40 CFR regulations and is cost effective. Testing is now complete and all data has been finalized. The team did a lot of sieve analysis tests, compaction tests, and permeability tests for many different materials and mixtures. The final materials are selected by their compositions, cost, and material availability.

3.2.1 Sieve Analysis Tests

Sieve Analysis tests have been done for the Burnt PPS. The purpose of completing the Sieve Analysis tests was to classify the unknown materials. As the graph shown below, the Burnt PPS was classified as a silty sand.

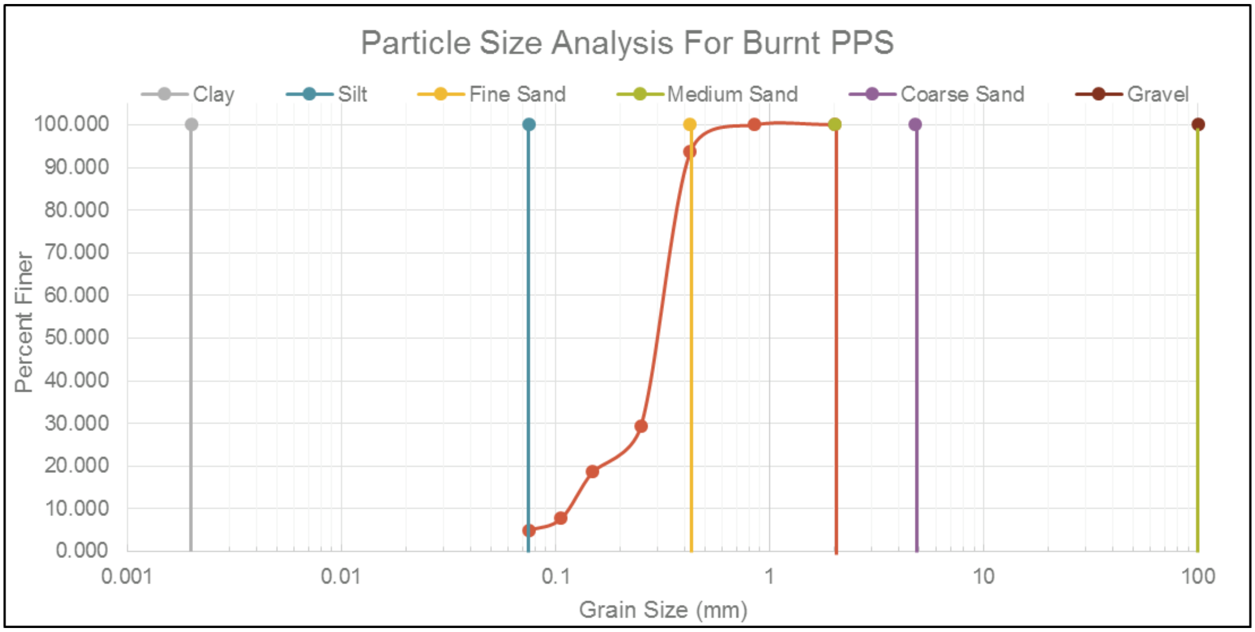

FIGURE 5: BURNT PPS SIEVE ANALYSIS RESULTS

3.2.1 Compaction Tests

The optimum moisture content for Burnt PPS was determined to be 45.48% by weight. Table 1 shows the results of Burnt PPS modified compaction test in terms of dry unit weight and moisture content.

TABLE 1: COMPACTION TEST RESULTS FOR BURNT PPS.

Moisture Content %	Dry Unit Weight (Kn/m^3)
32.26%	9.42
35.36%	9.90
41.33%	10.15
45.48%	10.65
49.07%	10.54
54.77%	10.08

Using the previous table, a moisture content graph was created to determine the peak dry unity weight of the Burnt PPS. Figure 5 shows the moisture content curve that was graphed after the modified compaction test.

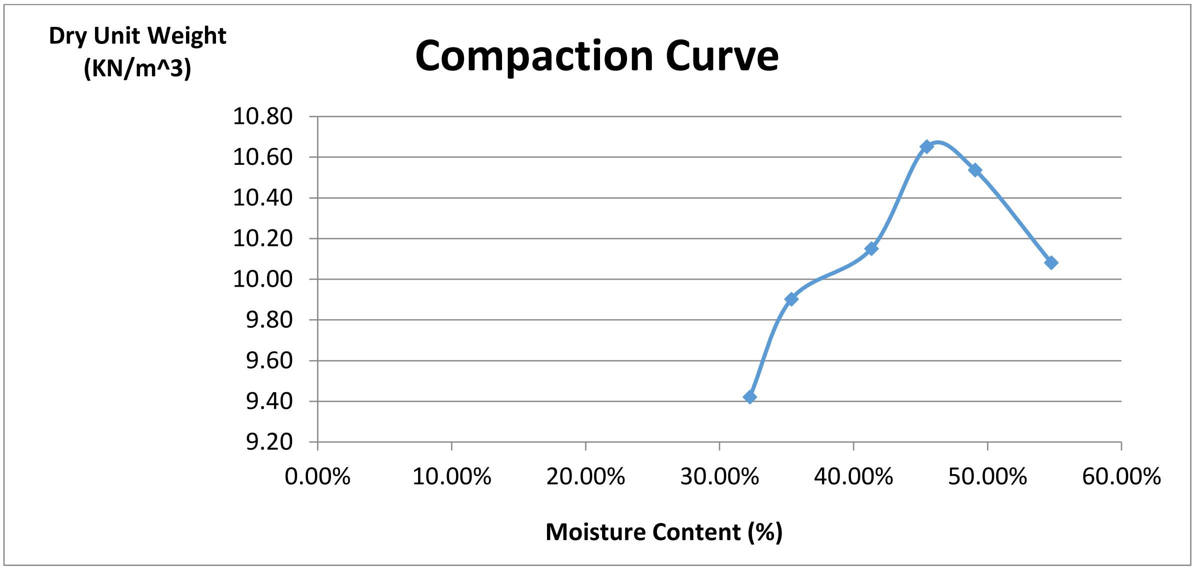

FIGURE 6: BURNT PPS COMPACTION CURVE

FIGURE 4: COMPACTION CURVE FOR BURNT PPS.

It should be noted that the highest dry unit weight for PPS is 10.65 (KN/m^3), which corresponds to a moisture content of 48.45%. For bentonite, the optimum moisture content was determined to be 26.34% by weight. Table 2 shows the modified compaction test results for bentonite.

TABLE 2: COMPACTION TEST RESULTS FOR BENTONITE

Moisture Content %	Dry Unit Weight (KN/m^3)
7.28%	12.76
12.30%	12.91
14.31%	12.97
15.80%	13.08
20.92%	13.78
25.82%	14.09
26.34%	14.15
33.12%	13.65

Using the previous table, a moisture content graph was created for bentonite to determine its optimum moisture content. Figure 5 shows the moisture content graph for bentonite.

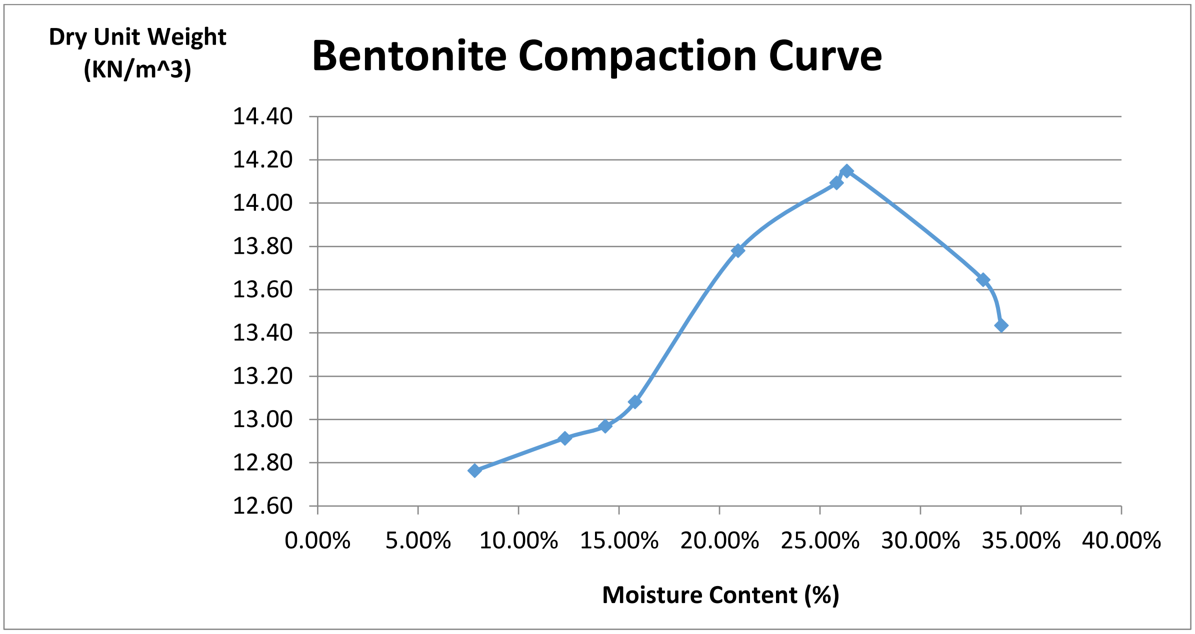

FIGURE 7: COMPACTION CURVE FOR BENTONITE

For Kaolinite, the optimum moisture content has been determined to be 28.15% by weight. Table 3 shows the compaction test results for Kaolinite.

TABLE 3: KAOLINITE COMPACTION RESULTS

Moisture Content %	Dry Unit Weight (KN/m^3)
21.16%	13.46
28.15%	14.08
31.22%	13.80
33.52%	13.16

Using the previous table, a moisture content graph was created for bentonite to determine its optimum moisture content. Figure 8 shows the moisture content graph for bentonite.

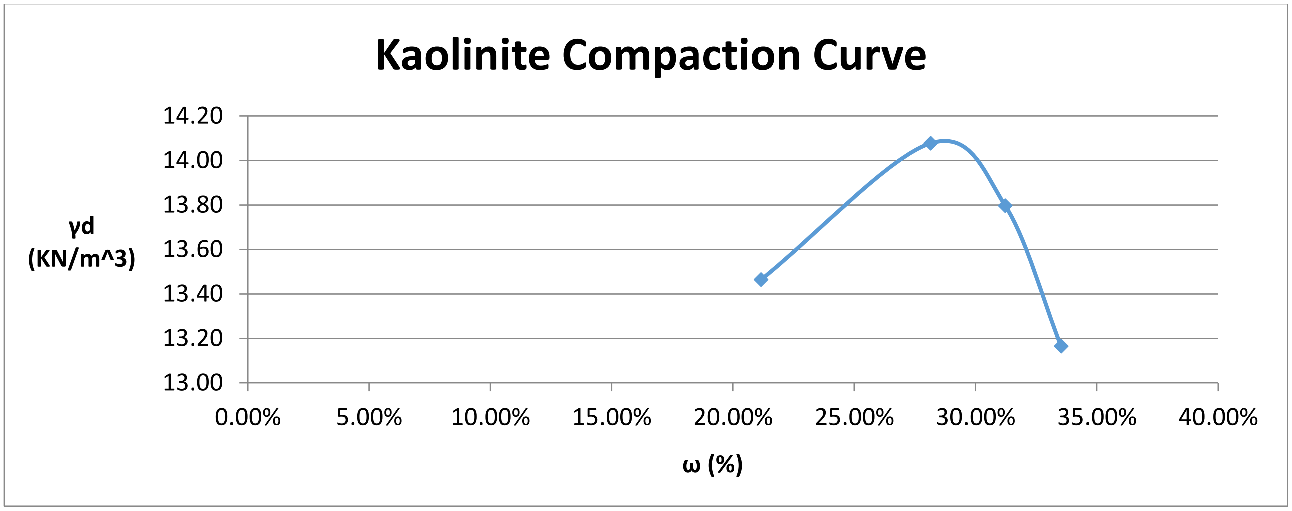

FIGURE 8: KAOLINITE COMPACTION CURVE

Each ingredient was tested by itself, resulting in an optimum moisture content that will be used in future mixtures. These values will be used in samples that contain any mixture of these three ingredients. A weighted moisture content will be assigned to the sample based on how much of each ingredient is present in the mixture.

The optimum moisture content for Fly Ash Class C was not found by running tests. The team obtained the optimum moisture content of 20% from a thesis [6].

The team's Technical Advisor informed the team that lime is ideal for increasing shear strength as well as decreasing hydraulic conductivity. The team was given two types of Fly Ash: Class C and Class F. Class F Fly Ash was tested and classified as poorly graded sand with silt. The team decided to use Class C Fly Ash because it contains lime while Class F Fly Ash does not. The team also found that Class C Fly Ash costs less than Class F Fly Ash.

3.2.2 Hydraulic Conductivity

The team started testing the hydraulic conductivities of mixtures that contain polymers, soil, Fly Ash Class F, and PPS according to the testing plan in Appendix 1. A total of 25 tests were conducted using different ratios of PPS, Fly Ash, and soil. Appendix 1 shows all results of hydraulic conductivities that have been calculated for different mixtures. Table 4 shows the best results that have been obtained, with the materials mixture ratio of each test.

TABLE 4: BEST HYDRAULIC CONDUCTIVITY RESULTS WITH PPS, FLY ASH, SOIL, AND POLYMERS MIXTURES

Mixture (Percentage by Weight)	Hydraulic Conductivity (cm/s)
50% PPS, 50% Fly ash (Class F)	4.59×10^{-5}
47% PPS, 47% Soil, and 4.8% Fly ash (class F), 1.2% Lime.	1.2×10^{-4}
50% PPS, 49% Fly ash (Class F), and 1% Polymers.	4.59×10^{-5}
95% PPS, 5% Polymers.	5.71×10^{-6}

It should be noted that the lowest hydraulic conductivity that has been calculated with a mixtures of PPS, Fly Ash Class F, soil, and polymers is 5.7 x 10^{-6} cm/s. Given the results of the tests, the team found that polymers, along with soil, increase the hydraulic conductivity of the mixture. The team also found that polymers increase the shear stress. Table 4 shows results that have been obtained by using PPS, bentonite, and lime as mixtures.

TABLE 5: HYDRAULIC CONDUCTIVITY

Mixture (Percentage by Weight)	Permeability (cm/s)
80% PPS, 20% Bentonite.	3.27 x 10-8
60% Fly Ash, 40% Lime.	9.01 x 10-7
85% PPS, 15% Bentonite.	2.60 x 10-8
90% PPS, 10% Bentonite.	1.23 x 10-7
95% PPS, 5% Bentonite.	4.18 x 10-6

It should be noted that by replacing polymers and soil with lime, and bentonite, the hydraulic conductivity of the mixture decreased, and started to enter the 40 CFR range (1 x 10^{-7} cm/s). The hydraulic conductivity values for the PPS/Bentonite and Fly Ash/Lime mixtures are by far the most promising.

3.3 Identification of Alternates

When the project first started, the team decided to use Paper Millings (PPS) finer than #4 sieves, Lime, Soil, Fly Ash (Class F), and Polymers as basic materials for creating the liner. Both PPS and soil are environment-friendly materials that can be compacted really well. At the same time, they are both cheap and easily accessible. Because of these features, they were considered to be the main materials for the landfill liner. Lime and Fly Ash are made up of tiny particles that can help fill up the pores found in PPS and soil, which leads to a lower hydraulic conductivity. Polymers help extend the life cycle of the landfill liner. However, the team believed that polymers increase hydraulic conductivity.

After comparing the results of several permeability tests of mixtures made up of PPS and Fly Ash with mixtures made up of PPS, Fly Ash, soil, and polymers, the team found that soil and polymers does increase the hydraulic conductivity. This makes the liner out of 40 CFR regulations. It was found that lime can help decrease the hydraulic conductivity as well as increase shear strength, but the price of lime is pretty high.

It was found that the particle sizes of PPS (finer than #4 sieve) were too big and lead to poor compaction results. Because of this, the team decided to use PPS (finer than 3/8" sieve) for future testing. The tests results that were obtained using the 3/8" sieve were desirable, so the team did not have to select a smaller sieve number. The team also found that Burnt PPS took too long to prepare. They also found that when Burnt PPS is mixed with Fly Ash (Class F), the compaction results were unpredictable and not uniform. Both Kaolinite and Bentonite are good materials to decrease the hydraulic conductivity and increase the shear strength, but the Kaolinite has a higher optimum moisture content than Bentonite.

Bentonite and Kaolinite are the two clays that have been considered to use in the liner. The clay is sticky and will be used as a cementing agent for the mixtures. The team believes that it can help to fill up the pores in the sample, which would make it more permeable. After conducting several compaction tests alternating between Bentonite and Kaolinite, the team found that the properties of Bentonite are better than Kaolinite. Given that information, the team decided to stop all testing with Kaolinite and only use Bentonite. The team is still considering the use of lime, but is reluctant to use it in large quantities because of its expensive price. Fly Ash is a waste that the team highly recommends to be used in the liner, because it is cheap and it helps in making the sample more permeable.

After completing the tests, the team has come to a conclusion and is ready to make final recommendations. The team recommends that the mixture used for the landfill liner be comprised of Fly Ash (Class C), PPS, and Bentonite.

Table 6 shows the four successful mixtures that should be used for the final design for the project. Each of those meets the criteria.

TABLE 6: FINAL DESIGN MIXTURES

Mixture (Percentage by Weight)	Hydraulic Conductivity (cm/s)
80% PPS, 20% Bentonite	3.27×10^{-8}
90% PPS, 10% Bentonite	5.9×10^{-8}
85% PPS, 15% Bentonite	2.59×10^{-8}
80% PPS, 15% Bentonite, 5% Fly Ash (Class C)	4.77×10^{-8}

Section 4: Landfill Liner Design

This section will discuss how the team chose a design for the liner as well as make a final recommendation for the landfill liner.

4.1 Identification of Selected Designs

The team created a schematic for the final design for test cells at the Cinder Lake Landfill with help from their client. The team only came up with one design because it was a modification of what the client gave the team. The design is what the client wants to implement at the landfill, so no other designs were needed.

4.2 Final Design

Figure 9 shows a basic schematic of the designed test cell. The test cell has two liners because the proposed liner contains the mixtures that have not been field tested. The second liner will be the typical landfill liner currently in use at Cinder Lakes Landfill. The team would like to test four mixtures, so the team recommends that four test cells be constructed. The team recommends that the test cells be tested for at least 2 years to determine if they are viable alternative for the clay layer in the common liner. It should be noted that this is a schematic for a test cell, not a common landfill cell. A common cell only has one liner. Because this is a new mixture that has not been field tested, a second liner will be required to catch any leachate that goes through the proposed liner. The proposed liner has been designed so that it should not fail, but the second liner will act as a fail-safe in case it does fail.

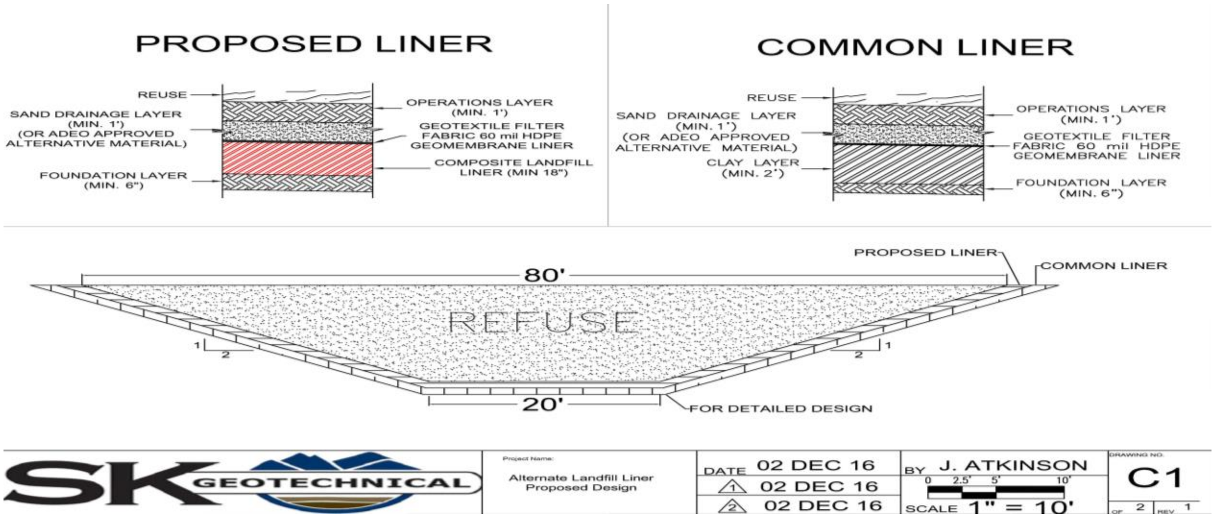

FIGURE 9: TEST CELL FINAL DESIGN

Figure 10 shows a more detailed schematic of the liner's cross-section. Both liners will be required to have two sump pumps located at the bottom of the liner to pump out leachate. Each liner will also have their own leachate collection tank, where the leachate will be collected and sent to a lab for lab testing. The team recommends that the client uses the same pumps already in use at the landfill. These pumps will be powered by solar panels already located on site. The top liner in Figure 10 is the proposed liner while the bottom liner is the common liner.

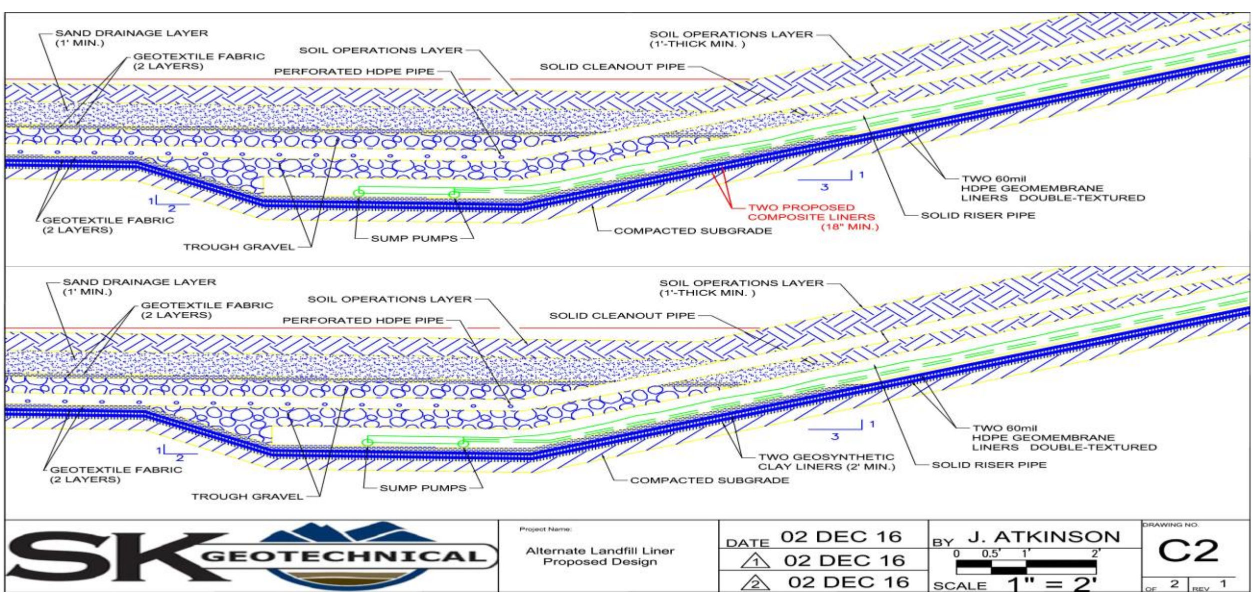

FIGURE 10: DETAILED LINER DESIGN

4.4. Proposed vs. Actual Hours

Tables 7 will show the hours the team listed in the proposal. These hours were estimated at the beginning of the project.

TABLE 7: PROPOSED HOURS

Task	DENG	RENG	LAB	INT
1.0 Health and Safety Protocols.	-	-	12	-
2.0 Material Preparation.	-	2	40	-
3.0 Material Testing.	-	3	300	-
4.0 Data Analysis.	30	-	60	-
5.0 Project Management	10	60	30	40
Subtotal	40	77	430	40
Total Hours + 80 hours researching = 667 hours				

Task	DENG	RENG	LAB	INT
1.0 Health and Safety Protocols.	-	-	12	-
2.0 Material Preparation.	-	2	100	-
3.0 Material Testing.	-	2	400	-
4.0 Data Analysis.	15	-	35	-
5.0 Project Management	5	35	-	50
Subtotal	20	39	547	50
Total Hours = 646 + 10 hours researching = 656 hours				

TABLE 8: ACTUAL HOURS

Table 8 shows the actual hours the team used to complete the entire project. These hours will be multiplied by the SK Geotechnical's hourly rates to obtain the total personnel expenses. The total cost can be found in Table 9.

4.5 Cost of Engineering Services

Table 9 shows the total cost for engineering services. These costs are broken down to show the hours each team member worked along with the position's hourly rate. A lab rental fee was also included because the team was required to do lab testing.

TABLE 9: COST OF ENGINEERING SERVICES

Position	Classification	Hours	Cost
Development Engineer	DENG	20	$ 3300.00
Research Engineer	RENG	39	$ 3500.00
Lab Assistant	LAB	547	$ 32,900.00
Engineering Intern	INT	50	$ 1500.00
Total personnel expenses			$ 41,200.00
Lab rental		240 days	$ 7,200.00
Total Staffing Cost	$ 48,400.00		

4.6 Cost of Implementing the Design

The team researched the prices of the recommended materials. Table 10 shows the cost of each material per two tons [8][9].

TABLE 10: MATERIAL COSTS

Required Materials	Material Cost per 2 Tons including Shipping
Bentonite	$2,240.00
Fly Ash (Class C)	$1,320.00
Paper Pulp Sludge (PPS)	Free

The listed cost includes shipping from Shanghai to Houston to Flagstaff [8]. Table11 shows the team's 4 recommended mixes along with a fifth option. The fifth option (100% Bentonite) is what is already in use in the common liner. It was added to Table 11 to be used as a cost comparison. The four mixtures listed above it show an average savings of about $60,000.00.

TABLE 11: TOTAL LINER COST PER TEST CELL

Material	Required Quantity	Total Cost
80%PPS, 20%Bentonite	65.4 tons	$14,650.00
90%PPS, 10%Bentonite		$7,330.00
85%PPS, 15%Bentonite		$10,990.00
80%PPS, 15% Bentonite, 5% Fly Ash (Class C)		$13,150.00
100% Bentonite		$72,240.00

Section 5: Triple Bottom Line (TBL)

The Triple Bottom Line (TBL) required the team to look into the potential impacts of the implementation of this project. The TBL is made up of three major parts: Environmental impacts, Social impacts, and Economical impacts.

When looking at the environmental impacts of this project, the team will be implementing a composite liner made out of materials entering the waste stream. This liner will be used in place of the existing clay liner, which will reduce the amount of clay required per cell. The liner will also protect the groundwater from the leachate that is produced when the waste decomposes in the cells. The construction of the liner will potentially have a negative effect on the local wildlife living in the area.

Reusing waste materials entering the landfill will reduce the amount of waste entering the landfill, which will make the landfill more eco-friendly because less plastic/clay will have to be shipped to the landfill. This will improve the public's perception of the landfill. The construction of the liner will potentially produce unpleasant odors, which may affect local homes around the landfill. These are the social impacts the team has to consider when implementing the final design.

The implementation of this liner will save the landfill lots of money over time. As shown in Section 4.3, the liner will save the landfill around $60,000 per test cell. The team also believes that the disposal cost for the landfill will drop because there will be more room for waste materials. The only major negative economic impact from this project is that it will require a major initial investment from either the City of Flagstaff or the Federal Government.

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Appendix

Appendix 1: Testing Plan and Results

Sample Name	Paper Millings (%)	Fly Ash (%)	Class C Fly Ash (%)	Lime (%)	CLL Soil (%)	Bentonite (%)	Hydraulic Conductivity (cm/s)
PPS	100	0		0	0	0	
50-50	50	50					2.09E-05
BS1	50	50					4.59E-05
ES3	50	50					4.35E-05
TS5	50	50					5.13E-05
F16-1	47	1.2		4.8	47	0	2.09E-04
F16-2	47	1.8		4.2	47	0	2.01E-04
F16-3	47	2.4		3.6	47	0	2.52E-04
F16-4	47	3		3	47	0	2.25E-04
F16-5	47	3.6		2.4	47	0	1.81E-04
F16-6	47	4.2		1.8	47	0	1.44E-04
F16-7	47	4.8		1.2	47	0	1.20E-04
PPS TA1***	100						4.95E-04
PPS TA2***	100						1.69E-04
PPS TA3***	100						4.78E-05
PPS TA4***	100						1.33E-05
PPS TA5***	100						5.71E-06
80-20 PPS Bentonite	80					20	3.27E-08
80-20 PPS Kaolinite	80						1.53E-06
80-20 PPS Kaolinite	80						2.63E-05
Burnt PPS	100						8.27E-06
Burnt PPS	100						6.48E-05
FA-Lime		60		40			9.01E-07
PPS Bent	85					15	3.24E-08
PPS Bent	90					10	7.57E-08
PPS Bent	95					5	1.39E-06
PPS Bent C	80		10			10	2.55E-07
PPS Bent C	80		15			5	8.10E-06
PPS Bent C	80		5			15	4.77E-08