NORTHERN ARIZONA UNIVERSITY

College of Engineering, Applied Sciences, and Informatics

City of Flagstaff Low Impact Development Bio-remediation Soil Design

CENE 486C:

Final Report

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List of Abbreviations

LID: Low Impact Development
NAU: Northern Arizona University
TLC: The Landscape Connection
SSD: Saturated Soil Dry
WTI: Western Technologies Inc.

Acknowledgements

This project was a continuation of the 2016-2017 NAU City of Flagstaff Low Impact Development (LID) Bio-remediation Soil Design Capstone project. The Spring-Fall 2018 City of Flagstaff Low Impact Development (LID) Bio-remediation Soil Design capstone team would like to thank the previous team's efforts and acknowledge the support and professional help from the 2018 team's grading instructor and client, Mark Lamer. The team would also like to acknowledge the technical help provided by the team's technical advisor, Adam Bringhurst, and Dr. Terry Baxter, who provided laboratory guidance. Significant guidance for the technical LID design and implementation information was provided by The City of Flagstaff Stormwater Management section's LID manual. The team acknowledges the help from capstone graders, Bridget Bero, Dianne McDonnell, Mark Lamer, and William Mancini for their technical and professional advisement throughout the project development. Lastly, the team would like to acknowledge Western Technologies Inc. for allowing the team to use their geotechnical laboratory to test for soil properties along with the extensive knowledge provided by their geotechnical department and The Landscape Connection for providing the team with locally sourced landscape materials.

1.0 Project Introduction

1.1 Project Purpose

Low Impact Development (LID) is a system of stormwater management practices which integrate natural components and work with the existing environment to minimize negative environmental impacts. The City of Flagstaff, Arizona requires Low Impact Development (LID) practices to be implemented on any new development where stormwater retention is required [1]. Advantages of using LID are that stormwater infiltrates locally into the soil, where it is naturally filtered and retained. Groundwater recharge is also facilitated. This reduces the amount of runoff and pollutants that ultimately end up in receiving waters, such as the Rio de Flag.

While LID practices are well-established in Flagstaff, there is not currently a proven method for constructing an appropriate soil matrix for LID using exclusively materials sourced from the state of Arizona. Since sourcing materials locally can reduce both project costs and environmental impacts, it is advantageous to explore design alternatives using only locally available materials. It is also beneficial to assess the efficacy of treating contaminants found in stormwater such as total dissolved solids, coliform, and nutrients such as phosphorus and nitrogen to further understand the environmental benefits of implementing LID. The Northern Arizona University (NAU) 2017 LID capstone team began research on the infiltration and remediation characteristics of different soil matrix combinations, and recommended further research on different topsoil materials and the addition of a top layer with vegetation to improve both infiltration rates and remediation efficacy. The purpose of this project was to design a soil matrix according to City of Flagstaff LID guidelines, using exclusively materials sourced from the state of Arizona, to assess the pollutant remediation efficacy of the design, and the impacts of adding a vegetative layer.

1.2 Project Constraints and Limitations

The City of Flagstaff LID manual specifies that soil media must infiltrate the first 1” of stormwater runoff from all impervious areas of sites requiring stormwater detention at a minimum rate of 1” per hour. In addition to meeting LID guidelines, the soil matrix materials and vegetation had to be sourced exclusively from Arizona. While there are currently no standards or requirements for effective bioremediation, the pollutant reduction efficacy was also assessed.

1.3 Project Objectives

The main objective of LID is to achieve a necessary infiltration rate for a 1” of rainfall and improve the water quality by providing a stormwater treatment system. The project objectives are to select the right soil that provide the required infiltration rate, design a soil matrix that fulfills the project requirements, and assess the bioremediation efficacy of the matrix. A soil identification process is conducted to choose the soil necessary for the project. The soil is to be chosen based on materials sourced from the state of Arizona to reduce the cost of soil materials, and physical properties to achieve the requirements of the project. The soil testing aims to determine the soil porosity, saturation, and specific gravity. The soil matrix design aimed to build different soil matrix and test each matrix for water infiltration. The vegetative coverage test aims to choose a local grass, create a vegetative coverage on the matrix and test the soil matrix. The stormwater testing aims to test the stormwater for pollutants such as fecal coliform, nutrients, and turbidity.

2.0 Soil Identification

2.1 Local Soil Selection

As a continuation of the 2017 NAU LID capstone team's work, it was established that the soil matrix should include four distinct layers including, topsoil, cinders, sand, and rocks. The available material types included: large river rock, red ice cinder rock, grey pea gravel, black pea gravel, red cinders gravel, red cinder sand, brown sand, mulch, and top soil. Based on the infiltration rate testing results performed by the 2017 NAU LID capstone team, the team decided to only obtain materials that tested the highest in infiltration rate when put together as a matrix [2]. Figure 1 and Table 1, obtained from the CENE 486C Sustainable Stormwater Engineering final design report, demonstrate the best matrices and their materials based on their infiltration ability. According to the 2017 LID capstone final design report, the team decided to obtain a topsoil, red cinders, brown sand, and river rock to compose the matrix. Since the team will be incorporating grass into the topsoil for further infiltration testing, it was decided to exclude a mulch layer from the matrix.

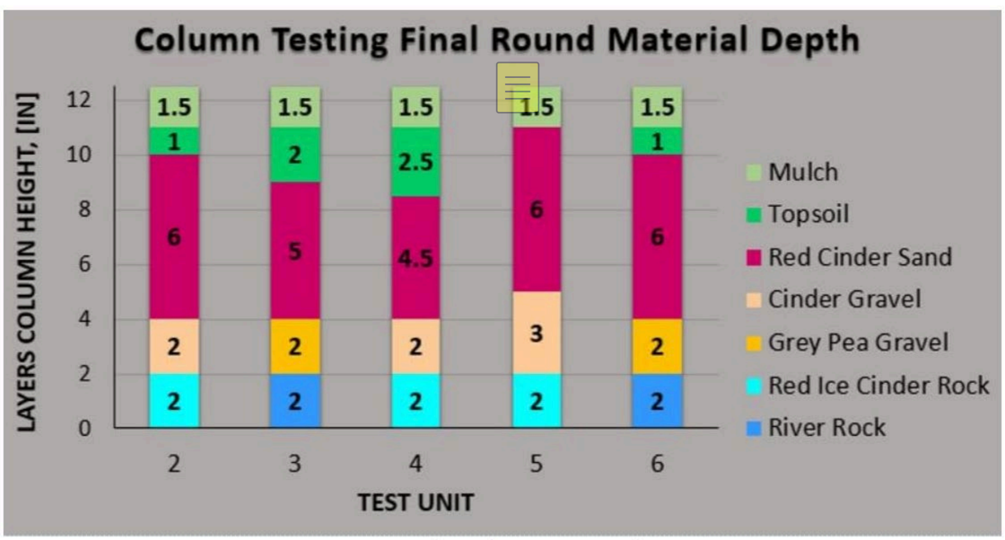

Figure 1. 2017 LID Capstone Final Round Column Designs [2]

Table 1. 2016 LID Capstone Final Design Infiltration Rates [2]

Final Design	Infiltration Rate (in/hr)	
	Unit 2	Unit 6
Saturated Test 1	2.49	1.95
Saturated Test 2	1.67	1.40
Saturated Test 3	1.39	
Void Space Storage (ml)	628	1372

2.2 Obtaining Local Soil

Locally sourced materials (top soil, red cinders, brown sand, and river rock) for the soil matrix design were acquired from the Landscape Connection TLC in Flagstaff, AZ. Different from the 2017 LID capstone group, the team decided to purchase all materials from a local landscaping materials provider instead of NAU Facility Services, as it was mentioned that NAU did not keep a constant range of materials compared to the Landscape Connection. The obtained selection included screened cinders with approximately 25% - 30% dirt, topsoil mix composed of approximately 80% City of Flagstaff sourced topsoil and 20% composted mule manure, 3/8" concrete sand from the Dyna Pit located in Winslow, Arizona, and ½" to ¼" river rocks from the Salt River located in Phoenix, Arizona.

3.0 Soil Testing

The team performed three trials to determine the hydraulic conductivity and specific gravity, and also performed a saturated surface dry test on the different obtained materials to further understand the material's ability to infiltrate stormwater.

3.1 Hydraulic Conductivity

The hydraulic conductivity testing was performed at Northern Arizona University in the soils lab. ASTM# D5084—16a "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter" was followed. The method was used to determine the properties of the soils to inform the design of the soil matrix per City of Flagstaff Low Impact Development (LID) requirements for infiltration. Along with obtaining hydraulic conductivity k, void ratio e, and porosity n were also calculated. Calculations were performed using Equations 1 through 5. The test results are provided in Table 2 found in Appendix A.

Equation 1. Hydraulic Gradient

$$i = \frac{h}{L}$$

Where *h* is the height from the surface of water to the bottom of the permeameter device and *L* is the height of soil in the permeameter.

Equation 2. Hydraulic Conductivity

$$k = \frac{Q}{A * i}$$

Where *Q* is the flow rate and *A* is the cross-sectional area.

Equation 3. Density of Soil Sample

$$\rho_d = \frac{M_2 - M_1}{A * L}$$

Where M_2 is the mass of the permeameter device with soil and M_1 is the mass of the permeameter device without soil.

Equation 4. Void Ratio

$$e = \frac{G_s * \rho_w}{\rho_d} - 1$$

Where G_s is the specific gravity of soil and ρ_w is the density of water.

Equation 5. Porosity

$$n = \frac{e}{1 + e} * 100\%$$

3.2 Specific Gravity and Saturated Surface Dry (SSD) Test

Specific gravity is the ratio of mass of an aggregate to the mass of a volume of water while the SSD is the relative density and absorption capacity determined after soaking the material in water. The specific gravity and SSD tests were performed at the Western Technologies Inc. geotechnical lab with the assistance of the geotechnical department. It was recommended that the team followed the ASTM C127-15 method for coarse aggregates such as the river rock and the red cinders, and to follow the ASTM C128-15 for fine aggregates such as the concrete sand [3] [4]. The results for specific gravity and SSD testing can be seen in Table 3 found in Appendix A. The geotechnical department at WTI recommended to not test the topsoil material as it could have harmed the testing equipment of their lab, therefore, the topsoil's specific gravity and SSD properties were not determined. Lastly, it is important to note that the red cinders were sieved through the #4 sieve (4.75 mm) to keep only the coarse aggregates per ASTM method. Equations 6 through 8 were used to determine the specific gravity G_s, SSD, and absorption.

Equation 6. Specific Gravity

$$G_s = \frac{W_d}{W_{SSD} - W_{sat}}$$

Where W_d is the mass of the dry soil, W_{SSD} is the mass of the saturated surface dry soil, and W_{sat} is the mass of the saturated soil.

Equation 7. Saturated Surface Dry (SSD) Specific Gravity

$$Specific\ Gravity\ (SSD) = \frac{W_{SSD}}{W_{SSD} - W_{sat}}$$

Equation 8. Absorption

$$Absorption = \frac{W_{SSD} - W_d}{W_d} * 100\%$$

4.0 Soil Matrix Design

Based on the infiltration properties tested through the hydraulic conductivity, specific gravity, and saturated surface dry tests, the team designed and tested different soil media combinations to pick the best soil matrix design based on infiltration timing. The soil media infiltration testing was performed by following the 2017 LID Capstone Soil Matrix Testing Method found in Appendix A and using the testing unit composed of six 6" diameter, 24-inch long PVC pipes as shown in Figures 2 and 3. The 2017 LID Capstone Soil Matrix Testing Method is based on the standard percolation test as it uses 6" diameter pipes, follows the maximum soil matrix depth of 12", and tests for dry, saturated, and void spaces. The team performed three rounds of infiltration testing with different soil material layer height variations.

Figure 2. Testing Unit Image (1)

Figure 3. Testing Unit Image (2)

4.1 Soil Media Design Testing Round #1

The first round of soil media testing consisted of two different soil matrix designs based on the column designs #2 and #6 from the 2016 LID capstone shown in Figure 1. The soil media testing designs for round #1 are demonstrated in Figure 4 below.

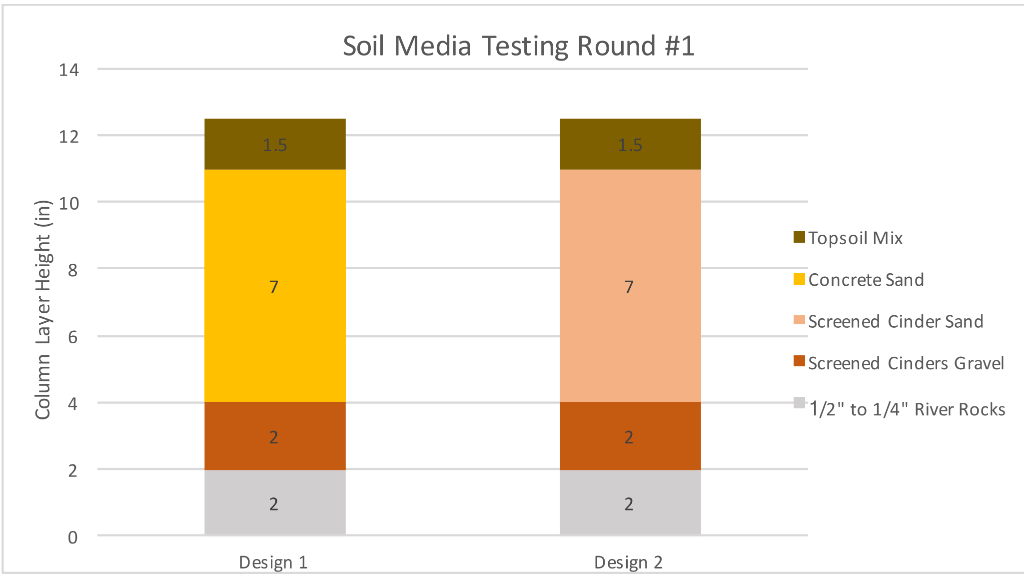

Figure 4. Soil Media Testing Designs Round #1

The first round consisted of the team selecting the best sand material for use in further infiltration testing. The screened cinders sand produced more consistent infiltration results and was selected for use in subsequent design alternatives. The dry and saturated infiltration testing results can be found in Table 5 found in Appendix B.

4.2 Soil Media Design Testing Round #2

The second round of infiltration testing consisted of three different designs that included varying top soil mix heights and one design which incorporated a grass layer, as demonstrated in Figure 5, below.

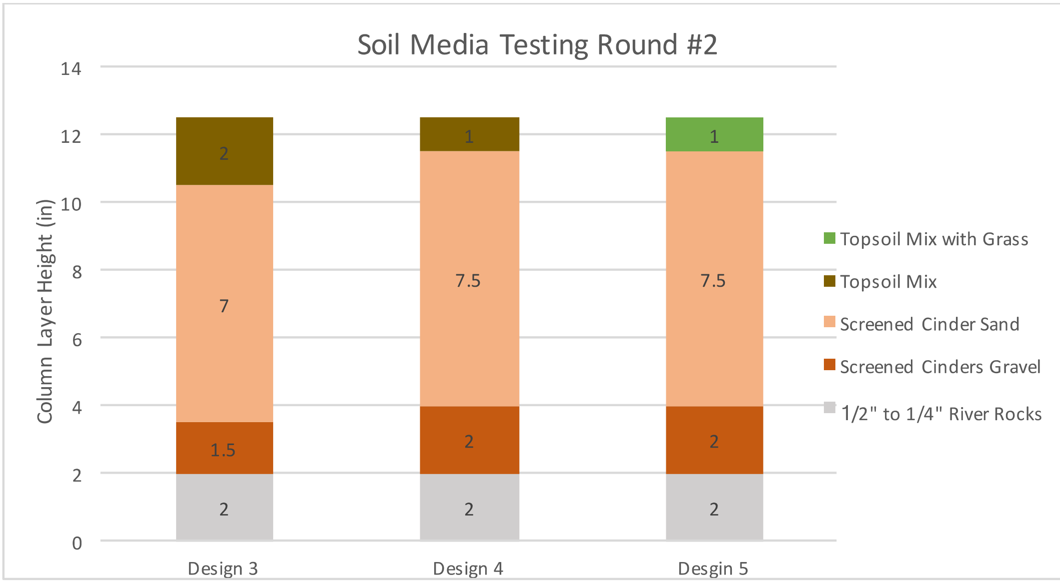

Figure 5. Soil Media Testing Designs Round #2

Results from round #2 can be found in Table 6 found in Appendix B. The results from round #2 demonstrated that small increases in topsoil depth significantly reduced infiltration rates. This confirmed the recommendation from the 2017 team to use less than 2 inches of topsoil. Additionally, for this test, the grass was grown in a separate container and was transported to the column. The transported layer was unstable, and broke apart when transplanted. The team decided to grow the grass directly in the columns for further testing so that it would not become destabilized. From the infiltration results, the team decided to pick design #4 as the final design and germinated grass on three columns to assess the impact of a grass layer included.

4.3 Soil Media Design Testing Round #3

For the final round the team decided to obtain more testing data on design #4 with and without grass to assess how the grass layer affected infiltration rates and void space. For round #3 the team tested the infiltration rates of the dry and saturated columns and the void space of three columns with a grass layer and three columns without a grass layer, results can be found in Tables 7 and 8 found in Appendix B.

5.0 Vegetative Coverage Testing

After the 2017 LID capstone team concluded their project, they determined that the topsoil layer of the soil matrix was the controlling factor for the infiltration rate and recommended adding grass or riprap on top of the soil media to improve water quality results and infiltration rates. To continue innovating the design of the soil matrix our team added a grass layer to the top layer of the soil media and tested the impact to both the quality of the stormwater and the infiltration rate. The grass layer was implemented to the soil columns by growing the grass in a container and then integrating the grass as a layer once the matrix was built in the 6” PVC pipe.

5.1 Identifying Native Species

For the purposes of this project, the LID basin must meet infiltration and retention requirements using only a matrix of soils. However, vegetative coverage can enhance the infiltration and remediating efficacy of the design. The impact of vegetative coverage on the soil matrix was included in the assessment. A native grass mix was obtained from Warner’s Nursery in Flagstaff, Arizona. The mixture included Sideoats Grama, Indian Ricegrass, sheep Fescue, Western Wheatgrass, Blue Grama, Little Bluestern, Alkali Sacaton, James Galleta, and Muttongrass. The grass seed mixture percentages and origins are showcased in Table 4.

Table 2. Native Grass Mix % and Origins [5]

Origin	Seed Common Name	Mix %
WA	Indian Ricegrass	19.93
CAN	Sideoats Grama	19.6
CAN	Fescue Sheep	11.72
WA	Western Wheat Grass	11.32
CAN	Blue Grama	10.75
MN	Bluestern Little	9.43
NM	Alkali Sacaton	4.99
TX	James' Galleta	3.43
CO	Muttongrass	1.93
-	Inert Matter	6.85
-	Weed Seed	0.05
TOTAL		100

5.2 Cultivating the Vegetative Coverage

The grass layer was harvested in a 15” x 21 ½” x 6” storage plastic container that had six ½” holes drilled at the bottom for drainage purposes. The container included about 2” of gravel at the bottom and about 2 to 3” of the topsoil mix obtained from the Landscape Connection, TLC, Inc. The team used the same topsoil mix from the infiltration testing to cultivate the grass to avoid discrepancies when testing the infiltration rates with the grass layer added. The mix of grass seeds was placed on the surface of the topsoil and covered by 1” of more topsoil. The grass took about 8 days to start germinating and took about two weeks to grow to 2” of height. Figure 5, below, showcases the full-grown grass after about three weeks of being germinated.

Figure 6. Full-Grown Grass Layer

5.3 Impacts of Vegetative Layer

One of the recommendations from the 2017 LID capstone team was to perform further infiltration and stormwater quality testing with a layer that included some type of vegetation. To perform this, the team performed testing on three soil media columns of the same design that included grass and three columns without grass. The results can be found in Tables 7 and 8 in Appendix B, and it can be concluded that the addition of a grass layer improved infiltration rates by increasing the rate to about 2.5 in/hr and increasing the void space volume by about 900 mL/ft^3. It was also concluded that the addition of the grass layer had positively impacts on the treatment of stormwater which is further explained in section 7 of this report.

6.0 Stormwater Runoff Sampling

6.1 Stormwater Runoff Sampling Alternative 1

Due to lack of precipitation during the testing timeframe, water was manually contaminated for quality testing purposes. Distilled water was poured over various features such as concrete steps, dumpster lids, and picnic tables as shown in Figure 7, below. The water was collected and taken to the lab immediately for testing.

Figure 7. Stormwater Runoff Sampling

7.0 Stormwater Testing

7.1 Fecal Coliform

Coliform bacteria are ubiquitous in the environment and are used as indicator organisms to indicate the likely presence of pathogens. A reduction in pathogenic organisms in water can be inferred from reduction in coliform bacteria. HACH Method 8074 was followed for fecal coliform analysis [6]. Plates were incubated in a selective nutrient broth which promotes the growth of coliform bacteria, which form metallic green colonies in the broth. As shown in Figure 8, below, sediment made plates challenging to read, therefore, the standard 20 mL of sample was reduced to 10 mL to reduce the amount of sediment. Colony forming units (CFU) per mL were consistent at both volumes. Full results are displayed in Tables 9 and 10 of Appendix D. The matrix did reduce coliform bacteria, and the addition of a grass layer improved the performance of coliform removal from the contaminated water. The design without grass decreased coliform contamination by 45%, and the deign with a grass layer decreased coliform contamination by 64%.

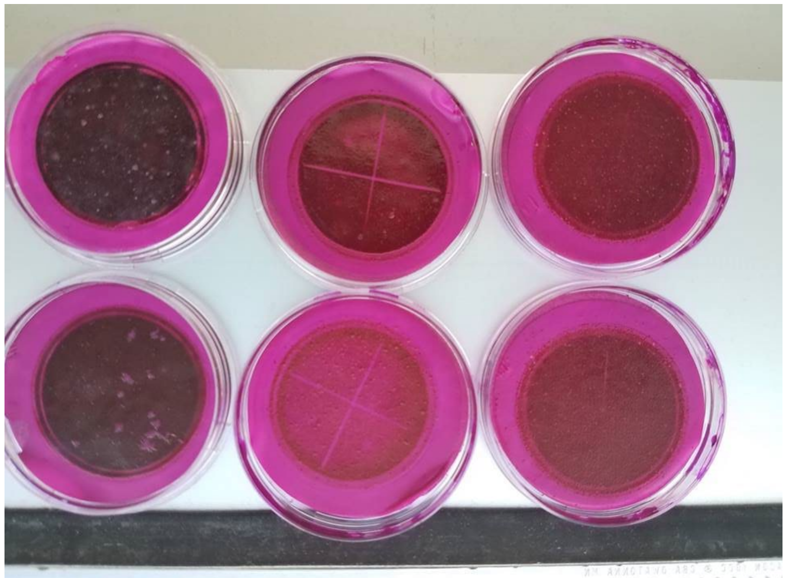

Figure 8: Petri Dishes After Incubation. From left to right: untreated stormwater, treated stormwater without grass, treated stormwater with grass

7.2 Nutrients

Nutrient pollution can cause negative impacts downstream, such as eutrophication, by promoting excessive growth of algae and plant life. Phosphorous is a limiting factor in plant growth and can be use used an indicator for nutrient pollution. HACH Method 10127 was followed to assess total phosphorous content of the water [7]. The matrix without grass decreased the total phosphorous by 90%, and the design with grass decreased total phosphorous by 96%. Full results can be found in Table 11 of Appendix D.

7.3 Turbidity

Turbidity is a measure of clarity of the water, which is negatively impacted by dissolved and suspended solids. To assess how well the design reduced turbidity, a HACH 2100Q portable turbidity meter was used according to the manufacturer's guidelines, which are in accordance with USEPA Method #: 180.1. Full results are displayed in Table 12 of Appendix D. Figure 9, below shows a visual comparison of the water clarity before and after being treated. The matrix without grass decreased turbidity by 69% and the layer with grass decreased turbidity by 90%.

Figure 9: From left to right: Stormwater before treatment, stormwater after being treated without grass, stormwater after being treated by column with grass

7.4 Summary of Water Quality Results

Table 13 found in Appendix D displays a summary of the results of the water quality analysis. The design reduced total phosphorous, turbidity and coliform bacteria contamination. The addition of a vegetative layer also improved remediation performance when compared to the results of the design without a vegetative layer.

8.0 Selection of Final Matrix Design

After performing the infiltration and stormwater quality testing the team decided to select design #4 with a grass layer as the final soil matrix design. The final soil matrix design was chosen because it showcased to perform at a higher infiltration rate with more void space volume for retention of stormwater and it also demonstrated to have higher percent removals for the tested stormwater quality parameters discussed in section 7. Figure 10 demonstrated the selected final design broken down in material type and corresponding height.

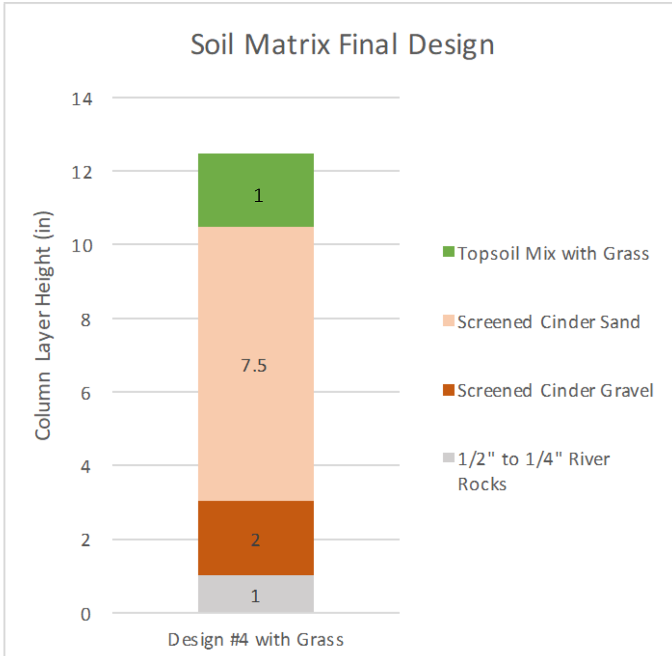

Figure 10. Soil Matrix Final Design

The final design can infiltrate water at a rate of 9.1 in/hr with a storage capacity 7.3 L/ft^2 and as demonstrated in Table 13 is can remove total dissolved solids by 90%, total phosphorus by 96%, and total coliform by 64%. Lastly, for a proposed area of 500 ft^2, the design can store a total of 128.5 ft^3 or 3,638 L of stormwater.

9.0 Implementation Costs

For the final design implementation costs the team considered the total excavation costs, and total materials cost including the soil and vegetative covering, based on a basin with an area of 500 ft^2. Tables 16, 17, and 18 found in Appendix F demonstrate the cost per unit for each considered section. Total implementation costs were to $478.08.

10.0 Project Impacts

10.1 Environmental Impacts

LID practices allow stormwater to infiltrate locally into the soil, reducing the overall volume of runoff that ultimately reaches receiving waters. This reduces the likelihood of flooding and erosion downstream and facilitates groundwater recharge.

The research and the testing that were performed indicates that the project can aid in reducing the negative environmental impact by remediating the stormwater runoff. Pollutants including sediments, nutrients, and coliform will be removed or reduced to improve the quality of the surface and groundwater of Flagstaff. This design would be well integrated in an existing natural landscape in Flagstaff, reducing disturbances or noticeable impacts to the environment.

10.2 Economic Impacts

The project can prevent negative economic impacts caused by stormwater runoff. Compared to conventional stormwater management systems, the overall volume that is conveyed away from an impervious site is greatly reduced. This reduces the likelihood of infrastructure damages caused by flooding and erosion downstream. Furthermore, by establishing a design that can be constructed from locally sourced materials, transportation costs are reduced.

10.3 Social Impacts

The project can aid in enhancing the Flagstaff community aesthetic by replacing the concrete stormwater management systems with a stormwater management system that incorporates natural materials and is integrated with the existing environment. Additionally, as pollutant transport is greatly reduced, receiving waters are less likely to be contaminated and closed off from recreational use due to health hazards.

11.0 Summary of Engineering Work

Tables 14 and 15 found in Appendix E showcase the estimated staffing hours from CENE 476 and the actual staffing hours table. As shown in the tables, the team estimated a total of 800 working hours to complete the project, however, it took a total of 500 hours to complete. The main differences in working time comes from being able to spend less time obtaining the soil materials from the selected provider, selecting a grass mix and growing the grass layer, performing the stormwater testing for the different parameters, project management, and project deliverables. Figure 11 found in Appendix E demonstrates the proposed and actual project schedules where blue items are the proposed timeline and the orange items are the actual. Discrepancies between the proposed and actual project timelines are due to taking more time during soil matrix infiltration testing but taking less time than proposed to complete the growing of the grass layer, performing the stormwater sampling, and the stormwater quality testing.

12.0 Summary of Engineering Costs

Table 18 found in Appendix F shows the staffing cost multipliers based on the Noble Midstream Services staffing multipliers for a senior engineer, lab manager, lab tech, and field tech positions based on the engineering work hours shown in Table 15 [6].

13. Conclusion

The primary conclusion of this analysis is that a bio-remediating stormwater retention basin can successfully be constructed according to City of Flagstaff LID guidelines using exclusively locally sourced materials. With an infiltration rate of 9.1 in/hr, the final matrix design meets and exceeds requirements for infiltration. The addition of a vegetative layer to the design significantly improved water quality remediation efficacy, and stabilized the topsoil layer. The storage capacity of the design is 7.3 L/ft^2, and can be scaled to meet the needs of a new development.

This design did not incorporate an underdrain, which is a common component of retention basins. However, according to City of Flagstaff LID guidelines, if the existing substrate 3 feet beneath the bottom of the basin has an infiltration rate greater than 1 in/hr, then an underdrain is not a necessary component. Therefore, this design could be used at any site in Flagstaff with appropriate substrate that does not necessitate an underdrain.

14.0 References

[1] "City of Flagstaff LID Requirement," *City of Flagstaff LID Requirement | City of Flagstaff Official Website.* [Online]. Available: http://www.flagstaff.az.gov/3736/City-of-Flagstaff-LID-Requirement. [Accessed: 04-Feb-2018].
[2] R. Pott; T. Alhamidi; F.DiFore; Z.Zhang. "CENE 486 Final Capstone Report: Low Impact Development Bio-Remediation Soil Design." 2017.
[3] ASTM Standard C128, 2015, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate"
[4] ASTM Standard C127, 2015, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of a Coarse Aggregate"
[5] Warner's Nursery. (2018). Grass Compositions and Prices.
[6]HACH Method 8074: Membrane Filtration; Total Coliform. DOC316.53.01224
[7]HACH Method 10127: Total Phosphorous; Molybdovanadate with Acid Persulfate Digestion Method. DOC316.53.01123
[8] "PROFESSIONAL CONSTRUCTION MATERIALS ENGINEERING & TESTING SERVICE FEE SCHEDULE FOR NOBLE MIDSTREAM SERVICES, LLC," p. 2016, 2016.

Appendix

A. Soil Testing Results

Table 3. Hydraulic Conductivity Results

Soil Material	Test #	k (ft/s)	e	n (%)
Screened Cinders	1	0.00149	0.25	20.009
	2	0.0012	0.148	12.873
	3	0.00127	0.218	17.902
AVERAGE		**0.00132 +/- 0.00015**	**0.205 +/- 0.052**	**16.928 +/- 3.67**
1/2" to 1/4" River Rocks	1	0.00151	0.255	20.314
	2	0.00136	0.231	18.772
	3	0.00136	0.255	20.314
AVERAGE		**0.00141 +/- 0.000087**	**0.247 +/- 0.014**	**19.8 +/- 0.89**
3/8" Concrete Sand	1	0.00102	0.183	15.448
	2	0.00108	0.204	16.919
	3	0.00105	0.182	15.383
AVERAGE		**0.00105 +/- 0.000030**	**0.189 +/- 0.012**	**15.916 +/- 0.87**
Topsoil Mix	1	0.00014	0.284	22.107
	2	0.00014	0.255	20.306
	3	0.00014	0.318	24.127
AVERAGE		**0.00014 +/- 0.00**	**0.286 +/- 0.032**	**22.18 +/- 1.91**

Table 4. Specific Gravity and SSD Results

Material	Test #	Specific Gravity	Specific Gravity (SSD)	Absorption (%)
Screened Cinders	1	2.031	2.300	8.808
	2	2.030	2.140	8.970
	3	2.032	2.190	8.990
AVERAGE		**2.031 +/- 0.001**	**2.21 +/- 0.082**	**8.923 +/- 0.099**
1/2" to 1/4" River Rocks	1	2.567	2.799	1.469
	2	2.667	2.676	1.325
	3	2.778	2.697	1.256
AVERAGE		**2.671 +/- 0.11**	**2.724 +/- 0.066**	**1.35 +/- 0.11**
3/8" Concrete Sand	1	2.487	2.643	2.045
	2	2.607	2.544	2.108
	3	2.578	2.654	2.044
AVERAGE		**2.557 +/- 0.063**	**2.614 +/- 0.061**	**2.066 +/- 0.037**

B. 2017 CENE 486 Capstone LID Soil Matrix Testing Method

Testing Unit – 6" diameter PVC filled with soil Sample bucket – orange 5-gallon bucket under testing unit Wvi – Volume of water poured into testing unit Wvf – Volume of water at end of test Wvr – Volume of water retained in testing unit Vv – Void space volume for each testing unit

1. Place material in sieve shaker to isolate desired material size. Sand is passing through the #4 sieve, but retained on the #40 sieve. Gravel is passing 3⁄4 sieve but retained on the #4 sieve. All material passing the #40 sieve is to be discarded as fines and not used. Material used in testing unit will be dried at room for 24+ hours.

2. Layer each material by desired height. Do not compact the rock or gravel, since the proctor hammer will only break or displace the material. For the sand, top soil, and mulch use the standard proctor hammer (5.5lbs) 5 times on each layer in a circular pattern. All layers together should be approximately 12" in depth, plus or minus 1⁄2 inch.

3. Dry Test

3.1 Weigh and recode the mass of sample bucket under testing unit.

3.2 Begin time at the beginning of pouring water into testing unit. Record how long it takes for water to beginning infiltrating through the bottom. Total infiltration time is recorded from beginning of pouring water to when water drips are greater than 20 seconds between drips.

3.3 Apply H2O at a rate of 1 L per 10 seconds until the max ponding depth of 10" is achieved. Record the volume of H2O used to achieve max ponding depth, Wvi.

3.4 Record infiltration time from application of H2O to H2O exiting testing unit, in seconds

3.5 Stop timing once water drips are greater than 3 seconds between drips.

3.6 Remove sample bucket immediately after timing has stopped. Weigh sample bucket on the same scale and record the mas of water.

3.7 Calculate volume of water from sample bucket from the after weight, Wvf.

3.8 Determine the volume of water retain in testing unit, Wvr, by calculating the difference between Wvi and Wvf.

4. Saturated test

This test is to be completed directly after Dry Test and to mimic worst case sernario of multiple storms within a short period of time.

4.1 Weigh and recode the mass of sample bucket under testing unit.

4.2 Begin time at the beginning of pouring water into testing unit. Record how long it takes for water to beginning infiltrating through the bottom. Total infiltration time is recorded from beginning of pouring water to when water drips are greater than 3 seconds between drips.

4.3 Apply H2O at a rate of 1 L per 10 seconds until the max ponding depth of 12" is achieved. Record the volume of H2O used to achieve max ponding depth, Wvi.

4.4 Record infiltration time from application of H2O to H2O exiting testing unit, in seconds

4.5 Stop timing once water drips are greater than 10 seconds between drips.

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4.6 Remove sample bucket immediately after timing has stopped. Weigh sample bucket on the same scale and record the mas of water. 4.7 Calculate volume of water from sample bucket from the after weight, Wvf. 4.8 Determine the volume of water retain in testing unit, Wvr, by calculating the difference between Wvi and Wvf.

5. Void Space Volume

5.1 Plug the bottom of testing unit with the 6.5" diameter rubber cap.

5.2 Ensure the seal is tight between rubber cap and bottom of testing unit.

5.3 Pour 2.5 L of H2O at a rate of 1 L per minute.

5.4 Let the testing unit sit for 12 hours plus or minus 1 hour.

5.5 After 12 hours inspect the testing unit.

5.6 Water will still be present on top of the mulch. Remove water until the water level is at the top layer of topsoil. Record the volume of water removed from the testing unit. 5.4 Subtract the water removed at the end of 12 hours from 2L. This volume of water is the storage capacity of the testing unit, Vv. 5.5 Calculate the void space volume per cubic foot of soil matrix by dividing Vv by the volume of soil within the testing unit.

6. Final Design Testing Contaminate Removal

This test will be ran through the final deigns soil matrix unit saturated. This test is used to determine the contaminate removal capability of the soil matrix final design. 6.1 Weigh and record mass of sample bucket, Wvi. 6.2 Pour 4 L of water into testing unit at a rate of 1 L per 10 seconds, to ensure all material is saturated. 6.3 Pour 3 L of contaminated water into testing unit at a rate of 1 L per 10 seconds. 6.4 Infiltration time will be ignored for this test. 6.5 Remove catch bucket once water drips are greater than 10 seconds between drips. 6.6 Weigh and record mass of catch bucket, Wvf. 6.7 Take "treated" contaminated water, the water from the sample bucket, and test water qualities. Compare water quality tests for before and after the contaminated water has run through soil matrix testing unit.

C. Soil Media Testing Results

Table 5. Soil Media Testing Round #1 Results

Round #1		
	Infiltration Rate (in/hr)	
Type of Test	**Unit 1 (screened cinders sand)**	**Unit 2 (concrete sand)**
Dry Test	8.95	8.55
Saturated Test	7.96	12.54

Table 6. Soil Media Testing Round #2 Results

Round #2			
	Infiltration Rate (in/hr)		
Type of Test	**Unit 3 (2in topsoil)**	**Unit 4 (1 in topsoil)**	**Unit 5 (topsoil mix with grass)**
Dry Test	2.98	8.30	8.82
Saturated	11.42	5.32	6.46

Table 7. Soil Media Testing Round #3 Results (Without Grass)

Round #3			
Test Type	**Design #4 Retest #1**	**Design #4 Retest #2**	**Design #4 Retest #3**
Dry Test (in/hr)	9.49	9.44	10.01
Saturated Test #1 (in/hr)	8.98	8.99	8.12
Saturated Test #2 (in/hr)	6.45	7.04	6.87
Void Space Volume (mL)	1646	1543	1536
Void Space Volume (mL/ft^3)	6330.77	5934.62	5907.69

Table 8. Soil Media Testing Round #3 Results (With Grass)

Round #3			
Test Type	**Design #4 with Grass #1**	**Design #4 with Grass #2**	**Design #4 with Grass #3**
Dry Test (in/hr)	11.24	11.49	11.04
Saturated Test #1 (in/hr)	10.92	9.13	10.3
Saturated Test #2 (in/hr)	9.86	8.66	8.78
Void Space Volume (mL)	1858	1755	1844
Void Space Volume (mL/ft^3)	7146.15	6750.00	7092.31

D. Stormwater Quality Testing Results

Table 9. Total Coliform Testing Results (20mL Sample)

Trial	Untreated Stormwater		Design #4 Without Grass		Design #4 With Grass	
	CFUs/20 mL	CFUs/ 100 mL	CFUs/20 mL	CFUs/100 mL	CFUs/20 mL	CFUs/ 100 mL
1	83	415	64	320	42	210
2	94	470	43	215	34	170
3	102	510	50	250	21	105
Average	93 +/- 9.539	465 +/- 47.696	52.33 +/- 10.693	261.66 +/- 53.463	32.33 +/- 10.599	161.66 +/- 52.993

Table 10. Total Coliform Testing Results (10mL Sample)

Trial	Untreated Stormwater		Design #4 Without Grass		Design #4 With Grass	
	CFUs/10 mL	CFUs/ 100 mL	CFUs/10 mL	CFUs/100 mL	CFUs/10 mL	CFUs/100 mL
1	35	350	19	190	16	160
2	39	390	21	210	13	130
3	29	290	14	140	11	110
Average	34.33 +/- 5.033	343.33 +/- 50.332	18 +/- 3.606	180 +/- 36.056	13.33 +/- 2.517	133.33 +/- 25.166

Table 11. Phosphorus Testing Results

Sample	Trial 1 (mg P/L)	Trial 2 (mg P/L)	Trial 3 (mg P/L)	Average (mg/L)
Untreated Stormwater	33.5	37.8	32.8	34.7 +/- 2.707
Design #4 Without Grass	4.2	3.8	3.7	3.9 +/-0.265
Design #4 Without Grass	2.9	2.7	2.6	2.73 +/- 0.152
Design #4 With Grass	1.2	1.4	1.1	1.23 +/- 0.153
Design #4 With Grass	1.4	1.9	1.8	1.70 +/- 0.265

Table 12. Turbidity Testing Results

Trial	Trial 1 (NTUs)	Trial 2 (NTUs)	Trial 3 (NTUs)	Average
Untreated Stormwater	916	836	840	864 +/- 45.078
Design #4 Without Grass	85	87	87	86.33 +/- 1.155
Design #4 Without Grass	86	88	87	87 +/- 1.000
Design #4 With Grass	281	286	283	283.33 +/- 2.517
Design #4 With Grass	251	251	250	250.66 +/- 0.577

Table 13. Stormwater Quality Testing Results Summary

	Turbidity		Total Phosphorus		Total Coliform	
	NTU		mg P/L		CFUs/ 100 mL	
Untreated Water						
Average	864 +/- 45.08		34.7 +/- 2.71		404.17 +/- 79.78	
After Treatment						
	Grass	**No Grass**	**Grass**	**No Grass**	**Grass**	**No Grass**
Average	86.5 +/- 1.03	267.25 +/- 17.97	1.47 +/- 0.67	3.32 +/- 0.32	147.50 +/- 60.53	220.83 +/- 40.21
Percent Removal	**90%**	**69%**	**96%**	**90%**	**64%**	**45%**

E. Summary of Engineering Work and Schedule

Table 14. Proposed Staffing Hours

Estimated Staffing Hours				
Task	**Senior Engineer (hr)**	**Lab Manager/P.E (hr)**	**Lab Tech (hr)**	**Field Tech (hr)**
1. Soil Identification	2	2	0	0
2. Soil Testing	3	3	20	0
3. Soil Matrix Design	5	10	10	0
4. Vegetative Coverage Testing	3	10	30	0
5. Soil Matrix Design Selection	2	5	48	0
6. Stormwater Run-off Sampling	2	10	0	40
7. Stormwater Testing	5	7	5	0
8. Design Economics	3	10	0	0
9. Selection of Final Soil Matrix Design	5	10	5	0
10. Project Impacts	3	6	0	0
11. Project Management	98	98	98	98
12. Project Deliverables	36	36	36	36
SUBTOTAL HOURS	**167**	**207**	**252**	**174**
			TOTAL HOURS	**800**

Table 15. Actual Staffing Hours

Actual Staffing Hours				
Task	**Senior Engineer (hr)**	**Lab Manager/P.E (hr)**	**Lab Tech (hr)**	**Field Tech (hr)**
1. Soil Identification	3	3	0	0
2. Soil Testing	9	9	9	0
3. Soil Matrix Design	28.5	33.5	28.5	0
4. Vegetative Coverage Testing	14	14	45	0
5. Soil Matrix Design Selection	5	5	25	0
6. Stormwater Runoff Sampling	0	0	0	4
7. Stormwater Testing	13.5	13.5	13.5	13.5
8. Design Economics	5	5	0	0
9. Selection of Final Soil Matrix Design	10	10	0	0
10. Project Impacts	3	3		0
11. Project Management	12.5	12.5	12.5	12.5
12. Project Deliverables	31	31	31	31
SUBTOTAL HOURS	**134.5**	**139.5**	**164.5**	**61**
			TOTAL HOURS	**499.5**

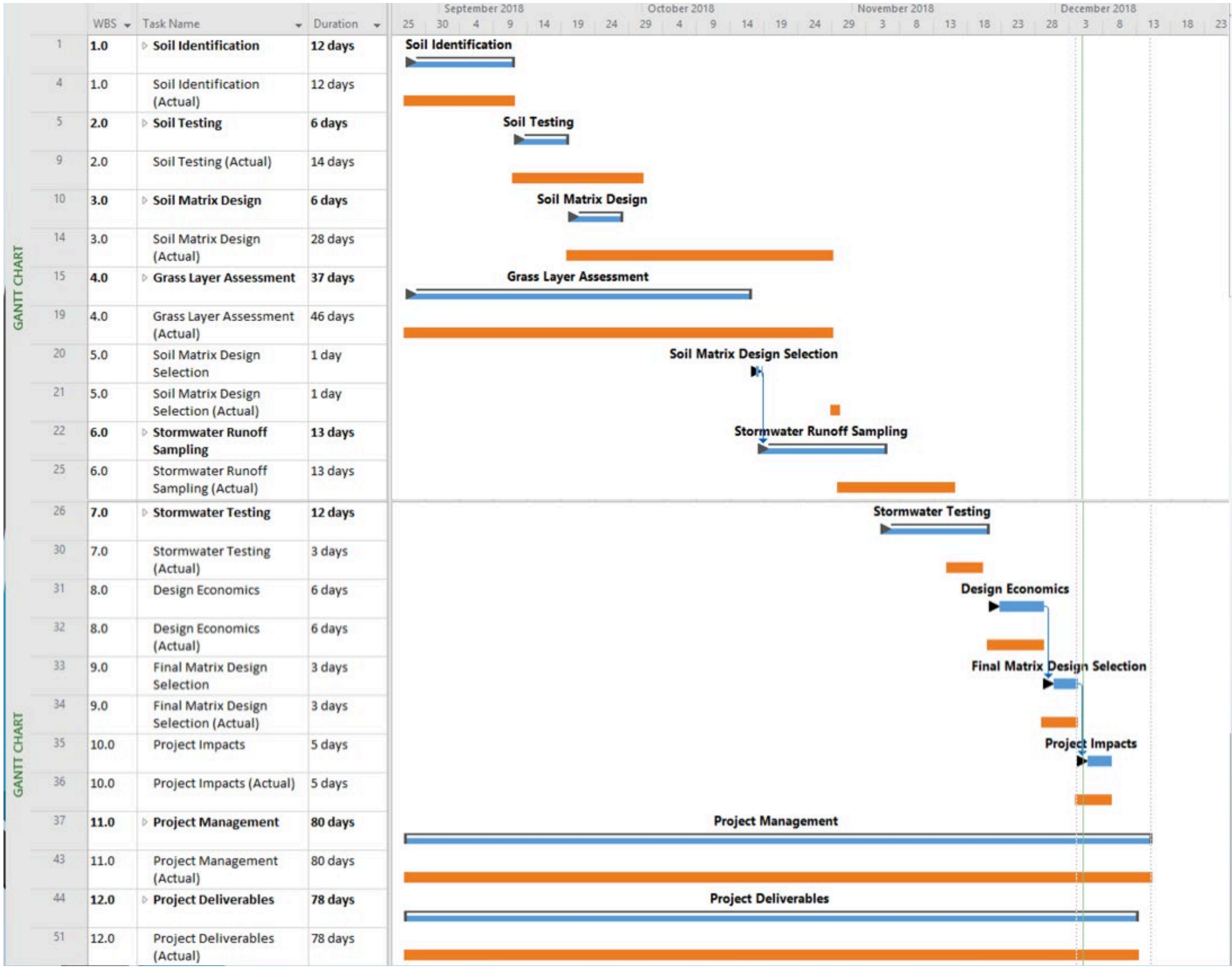

Figure 11. Project Schedule Comparison

F. Implementation Cost Summary Tables

Table 16. Total Excavation Costs

Excavation Cost	
Price Per Hour	9 $/cu. yd
Total Excavation Hours	19 cu. yd
Total Excavation Cost	$171.00

Table 17. Total Grass Costs

Grass Costs	
Grass Coverage	1000 ft^2/lb
Cost Per Pound	39.99 $/lb
Grass Coverage Area	500 ft^2
Grass Needed	0.5 lbs
Total Grass Cost	$20.00

Table 18. Total Soil Materials Costs

Soil Materials Cost					
Layer	**Area (ft^2)**	**Volume (ft^3)**	**Volume (cu. yd.)**	**Cost ($/cu. yd.)**	**Cost ($)**
Topsoil Mix with Grass	500	41.67	1.54	$14.00	$21.60
Screened Cinder Sand	500	312.50	11.57	$9.75	$112.85
Screened Cinder Gravel	500	83.33	3.09	$10.50	$32.41
1/2" to 1/4" River Rock	500	83.33	3.09	$38.95	$120.22
				Total Soils Cost	$287.08

Table 19. Engineering Costs

Item	Senior Engineer	Lab Manager/P.E.	Lab Tech	Field Tech
Pay ($/hr)	$92	$38	$18	$18
Multiplier	1.9	2.5	3.7	3.7
Cost ($/hr)	$175	$95	$65	$65
TOTAL HOURS	134.5	139.5	164.5	61
SUBTOTAL STAFF COST	**$23,511**	**$13,253**	**$10,651**	**$3,950**
			TOTAL STAFF COST	**$51,364**