NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

CENE 486C Capstone

Nitrification Column

50% Design Report

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Abbreviations

COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DI	Deionized Water

Acknowledgments

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1.0 Project Description

1.1 Project Understanding

Urine is an unsterile, nutrient-rich resource that can be used to fertilize plants. Human urine contains high quantities of nutrients such as nitrogen and phosphorous. Though urine is unsterile, it does not contain the same hazards, bacterial pathogens, which exist in the solid waste [1]. Separating urine from solid waste is an effective approach to recover nutrients. Exploiting the benefits of urine is a good way of 'closing the cycle' in agriculture nutrient flows. This system could also possibly reduce sewage costs and ecological consequences, as well as improve sanitation in developing areas. This project focuses on the nitrogen recovery from liquid waste as a laboratory model intended for future applications implemented on a household scale.

Liquid waste is mostly in the form of ammonia species and must be oxidized to nitrate before plants can take it up through their root systems. Nitrogen compounds are reduced and are sequentially oxidized to nitrite and nitrate by nitrifying bacteria through the nitrification process. The main purpose of the nitrification column is to convert nitrogen compounds in urine (Ammonia) to a form that can be used by plants directly. The nitrification column provides suitable growth and living conditions for the bacteria involved in the process of nitrification. The system will also have a nitrate solution dispersal system to provide the ability to utilize the solution on plants.

1.2 Project Information

Waste to Nutrients is the name of the nitrification column design project. The design and construction of a laboratory model, intended for future applications implemented on a household scale, will be completed in the CENE laboratory located in room 245 of the NAU Engineering Building.

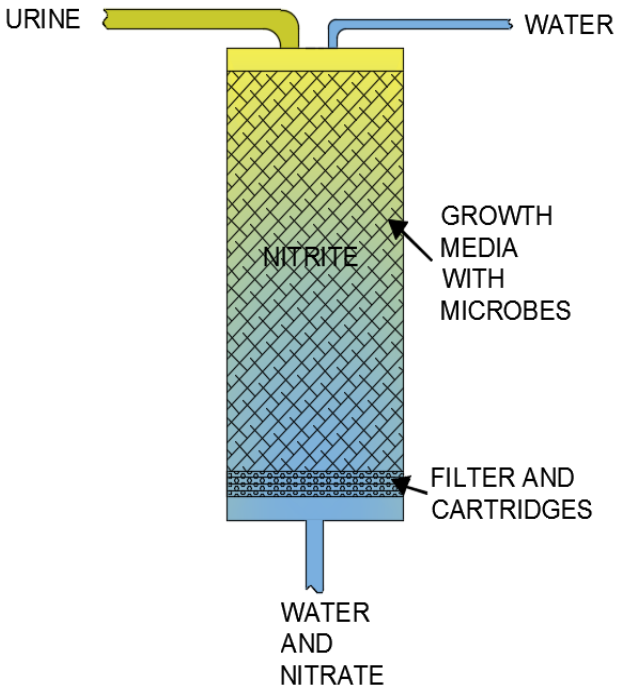

Figure 1: Nitrification Column Illustration

The figure to the left is an illustration of the nitrification column functions. In this system, urine is diluted with tap water and flows through the column packed with the nitrifying growth media. The natural ammonia from the urine oxidizes to the intermediate stage, nitrite. Continuing through the column, nitrite will oxidize again to nitrate. As can be seen from the illustration, a filter is required to prevent the growth media from traveling through the column. The cartridges are required to 'start' the system, allowing a colony of bacteria to form. The following equations describe the stoichiometry in the system.

Equation 1: First Step of Nitrification

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$$

Equation 2: Second Step of Nitrification

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + +2e^-$$

1.3Project Constraints & Challenges

The constrains of this project are limitations that the design work presents. This system only considers liquid waste inffluent. This system will not consider any solid waste inffluent, or the separation of the two types of waste. The only nutrient that this system is designed to collect and utilize is nitrate. The scale of this project is only four a household with home gardens. This excludes utility scale projects and mass agriculture. Though this project is a design for a household scale system, the design and construction of the laboratory model will be scaled.

The first and most difficult challenge experienced was the growth of a strong bacteria colony. Nitrifying bacteria are extremely fragile organisms, small changes in the surrounding conditions can have a huge impact on the health of the bacterial colony. These bacteria have a small range of acceptable conditions for growth. The entire colony could become inert or be exterminated if a change in conditions were to occur.

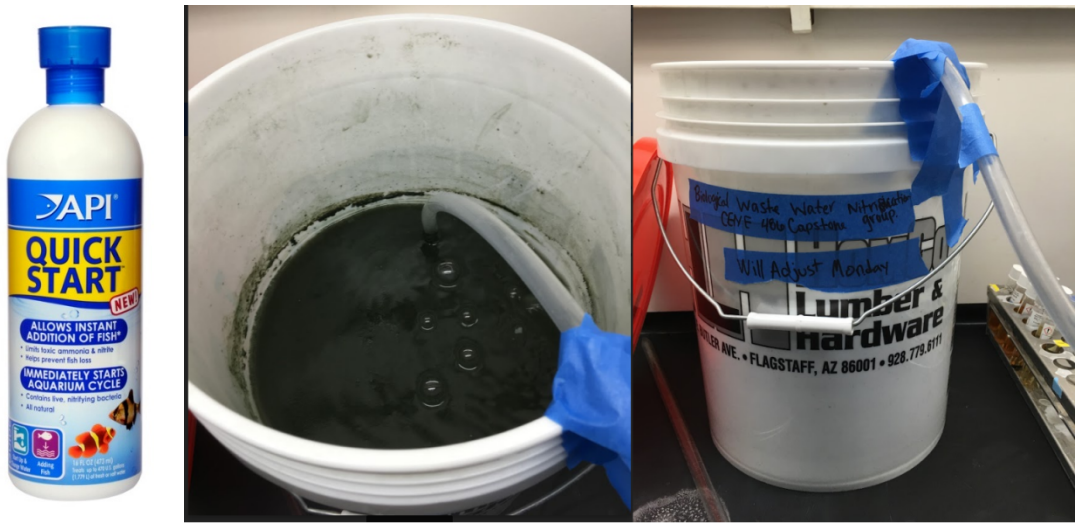

Figure 2: Nitrifying Bacteria

Bacteria species were collected through two means: Wildcat Hill Wastewater Treatment Facility and API Quick Start. Wastewater, pre-treatment, contains a plethora of microorganisms that need to be removed. Another challenge for our bacterial colony is inactivity. If the user chooses to leave town, causing the system to be inactive for long periods of time, there is a significant effect. Finding the maximum number of days with activity is a large consideration.

The only challenge faced in the material design of the system will be the proper construction of a system that creates the conditions that are necessary for growth. To allow for accelerated bacterial growth, the growth media is inoculated with nitrifying bacteria. The challenge in the inoculation is restarting the system. This is where the 'system-start' cartridge design takes effect.

The final challenge will be adding water flow to the system, this is an aspect of the design that has not yet been considered. The necessity of flowing water will be based on the dilution necessary to reach the selected concentration within the inflow for optimum growth. This water will not only be used to dilute the inflow but provide conveyance and distribution. The increased flow will allow for greater bacterial coverage and conveyance of waste products.

1.4 List of Tasks

This section identifies all activities required for the completion of this project. The following table describes the completed, in-progress, and future tasks for this design.

Table 1: List of Task Status

Behind Schedule	In progress	~~Completed~~	Next Two Weeks	Future Work

Task Name and Number	**End Date**	**Start Date**
~~Task 1: Determination of Legality and Sanitation~~	~~8/29~~	~~9/2~~
~~*Task 1.1 Determination of state, local, and federal regulations.*~~	~~8/29~~	~~8/31~~
~~*Task 1.2 Determination the regulations of effluent quality.*~~	~~8/29~~	~~8/31~~
~~*Task 1.3 Prediction of human health, sanitation, or negative impacts on the environment*~~	~~8/31~~	~~9/2~~
~~*Task 1.4 Determination of water usage restrictions*~~	~~8/31~~	~~9/2~~
~~Task 2: Determination of Urine Samples~~	~~8/31~~	~~9/2~~
~~*Task 2.1 Determination of surrogate or natural urine samples.*~~	~~8/31~~	~~9/2~~
~~*Task 2.2 Collection/Creation of urine samples*~~	~~8/31~~	~~9/2~~
~~*Task 2.3 Determination of antibiotic residuals in urine sample.*~~	~~8/31~~	~~9/2~~
~~Task 3: Determination of Lab Analysis Procedures~~	~~8/29~~	~~9/9~~
~~*Task 3.1 Determination of list of required standard methods.*~~	~~8/29~~	~~9/9~~
~~*Task 3.2 Acquire materials lab access.*~~	~~8/29~~	~~9/9~~
Task 4: Implementation of Lab Work	9/9	10/21
~~*Task 4.1: Determination of bacterial effectiveness.*~~	~~9/9~~	~~10/21~~
~~*Task 4.2: Determine bacteria growth parameters.*~~	~~9/9~~	~~10/21~~
~~*Task 4.3 Determination of urine dilution*~~	~~9/9~~	~~10/21~~
Task 4.4 Determination of growth media	9/9	10/21
Task 5: Preincubated Cartridge Analysis	10/21	11/4
Task 5.1: Determination of preincubated cartridge use.	10/21	11/4
Task 5.2: Preincubated cartridge design specifications.	10/21	11/4
Task 5.3: Construction of preincubated cartridge.	10/21	11/4
Task 5.4: Testing of preincubated cartridge.	10/21	11/4
Task 6: Design Concept Generation and Selection	11/4	11/18
Task 6.1: Design Concept Generation	11/4	11/18
~~Task 7: Conduction of Field Evaluation~~	~~11/4~~	~~11/18~~
Task 8: Conduction of Plant Evaluation	11/4	11/18
Task 9: Preformation of Design Calculations	11/18	12/2
Task 9.1: Determination of the physical dimensions of column	11/18	12/2
Task 9.2: Determine the overall efficiency of the system.	11/18	12/2
Task 10: Determination of Final Design	11/18	12/2
Task 10.1 Determination of materials needed for column.	11/18	12/2
Task 10.2 Determination of column size and dimensions.	11/18	12/2
Task 10.3 Final design will be submittal	11/18	12/2
Task 10.4 Feedback and Last Minute Adjustments	11/18	12/2
Task 11: Construction of Model Structure	11/18	12/2
Task 12: Conduction of Final Testing	12/2	12/16
Task 13: Project Management	8/29	12/16

2.0 Technical work

2.1 List of Required Standard Methods

The following list describes methods that are required for the success of this project. We have access to all of these standard methods in the HACH water analysis handbook in the environmental engineering lab. All interferences are listed in the associated standard method. The scope and application for all of the following methods is water and wastewater.

Temperature and pH

The data collection probe will analyze temperature and pH. These elements are necessary to determine the optimal temperature and pH ranges for the nitrifying bacteria. These ranges will aid in the survival of the bacteria as well as providing the highest nitrogen removal efficiency.

Alkalinity

Measuring alkalinity is important to determine the urine's ability to neutralize acid inputs. It is critical for the design of the nitrification column to operate in the optimal pH range. Therefore, it's necessary to determine the buffer range that all the nitrifying bacteria can keep alive. It is also necessary to determine any possible pH fluctuations that can occur in the system.

Oxygen Demand, Chemical

The chemical oxygen demand (COD) test is used to indirectly measure the amount of organic compounds in the urine sample. The mg/L of COD results are defined as mg of O2 consumed per liter of sample. COD commonly indicates the amount of oxygen required to oxidize soluble and particulate organic matter in the water. COD is an important water quality parameter because it provides an index to assess the effect discharged wastewater will have on the receiving environment. Higher COD levels mean a greater amount of organic material in the sample, which will reduce dissolved oxygen (DO) levels and could possibly have negative effects in our system and the environment. For nitrification column project, it is a necessary measurement to evaluate the quality of the urine sample.

Oxygen, Dissolved

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. For this project, it is an important parameter in assessing the urine quality because of its influence on the microorganisms in the system. The nitrification process is an aerobic process, both the ammonia oxidation and nitrite oxidation process are in need of oxygen. Therefore, it's necessary to find how much dissolved oxygen is available from the urine and is there any aeration needed to keep the nitrifying bacteria alive.

Nitrate

As we have discussed previously in this document, nitrate makes an excellent fertilizer for plants and agriculture. The purpose of this project is to exploit the benefits of this nutrient as a fertilizer, so the ability to collected nitrate data is critical for the success of this project.

Nitrite

Nitrite is an intermediate effluent that exists for this project. This effluent is oxidized in our sample to our final effluent, Nitrate. The ability to analyze this intermediate in the system is a critical aspect to the success of the column with regard to concentration and efficiency of our final design.

Nitrogen, Ammonia

The measurement of ammonia nitrogen is the system is important to determine the influent concentrations in the system. Ammonia is realized from the breakdown of urea. Ammonia is oxidized to nitrite, which is then oxidized to nitrate. The ability to analyze this influent in the system is a critical aspect to the success of the column with regard to concentration and efficiency of our final design.

Table 2: List of Required Standard Methods

Standard Method	Description
HACH 8221	Alkalinity (Buret Titration Method)
HACH TNT821	Oxygen Demand, Chemical (Dichromate Reactor Digestion Method)
HACH 8157	Oxygen, Dissolved (if 0.3 to 15.0 mg/L DO)
HACH TNT835	Nitrate (Cadmium Reduction Method)
HACH TNT839	Nitrite (Ferrous Sulfate Method)
HACH TNT830	Nitrogen, Ammonia (Salicylate Method)

2.1 List of Optional Standard Methods

Nitrogen, Total

There are three forms of nitrogen that are measured in this system: ammonia, nitrites, and nitrates. Total nitrogen is the sum of total nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. Because the design requires the application of nitrification, it is important to determine the sum of the nitrogen in the system.

Conductivity

Electrolytic conductivity is the capacity of ions in a solution to carry electrical current and is the reciprocal of the solution resistivity. In many cases, conductivity is linked directly to the total dissolved solids. The conductivity test is required for nitrification column to determine the urine quality before and after the nitrification process.

Phosphorus, Total

This standard method is not critical for our project. This would be an optional method that would provide insight into another nutrient, phosphorus that this system will produce.

Salinity

Urine has a lot of dissolved salts in its composition. The exact measure of the concentration of these salts will provide important information in regard to how this salt will build up in the system.

Conductivity

Electrolytic conductivity is the capacity of ions in a solution to carry electrical current and is the reciprocal of the solution resistivity. In many cases, conductivity is linked directly to the total dissolved solids. The conductivity test is required for nitrification column to determine the urine quality before and after the nitrification process.

Table 3: List of Optional Standard Methods

Standard Method	Description
HACH 8160	Conductivity (Direct Measure Method)
HACH 8190	Phosphorus, Total (Persulfate Digestion Method)
HACH 10071	Nitrogen, Total (Persulfate Digestion Method)
HACH 10073	Salinity (Mercuric Nitrate Method)

2.3 Determination of Nitrifying Bacteria Sample Characteristics

This area of analysis required the use of five test methods to monitor pH, alkalinity, temperature, ammonia concentration and chemical oxygen demand (COD). After the initial system parameters were found, urine was added to monitor the ability of our nitrifying bacteria to stabilize in the system. The pH data is displayed in the Figure 3 below.

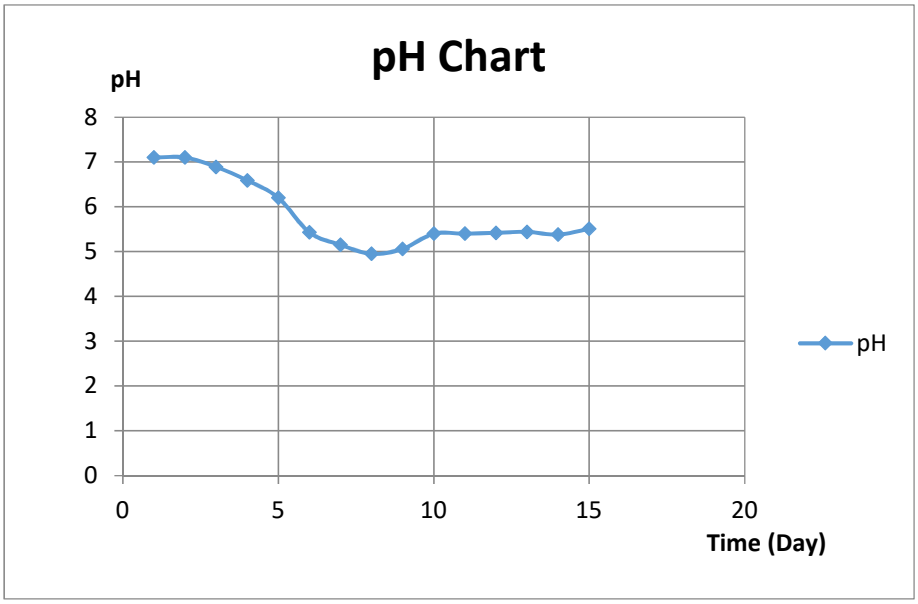

Figure 3: pH Chart

Our initial system has a pH of 7.1, however, the pH declined when the urine was added on day 4. This was expected due to the increase of free hydrogen-ions caused by the urea dissolving in the sample. As the system oxidized, converting the ammonia, the pH of our system began to increase steadily.

Testing alkalinity is critical in understanding the properties of our project. The following equation was used to determine the alkalinity of our sample. Where N=0.017.

Equation 3: Alkalinity

$$Alkalinity\ \left(mg\frac{CaCO3}{L}\right) = \frac{A * N * 50{,}000}{50\ (mL)}$$

In addition to establishing the system pH, the base sample alkalinity was determined. This is illustrated in the following graph.

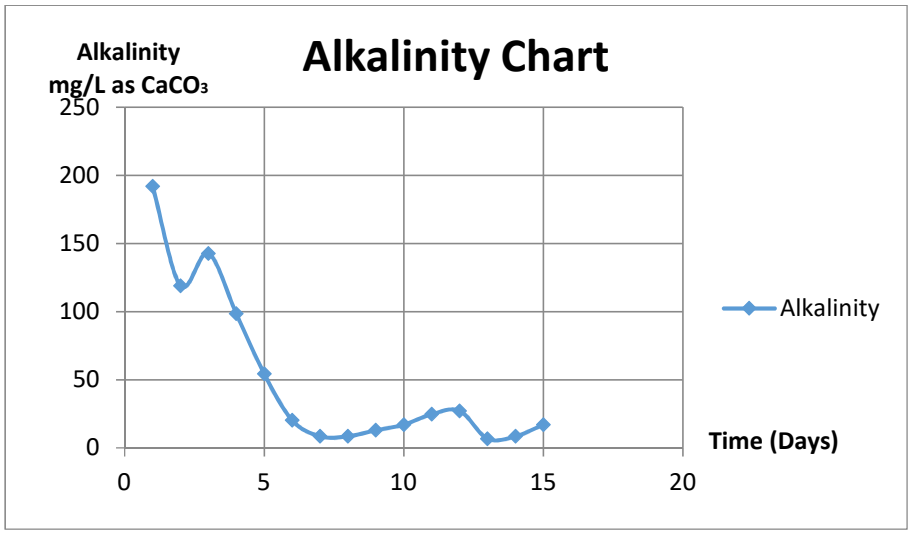

Figure 4: Alkalinity Chart

The initial Alkalinity of our system is high but with the addition of urine the alkalinity declined as the ions present reacted with the added hydrogen ions. Like the pH, the alkalinity recovered as the system approached equilibrium. However, the rate in which alkalinity increases in the system is dependent on the content of the water added to the system. The addition of tap water provided the necessary ions when added on a consistent basis. This dependency is the key reason that water must be added to the system.

The most important set of data was the ammonia concentration values that were collected. This value critical in the process of nitrification, and in the development of a mass balance.

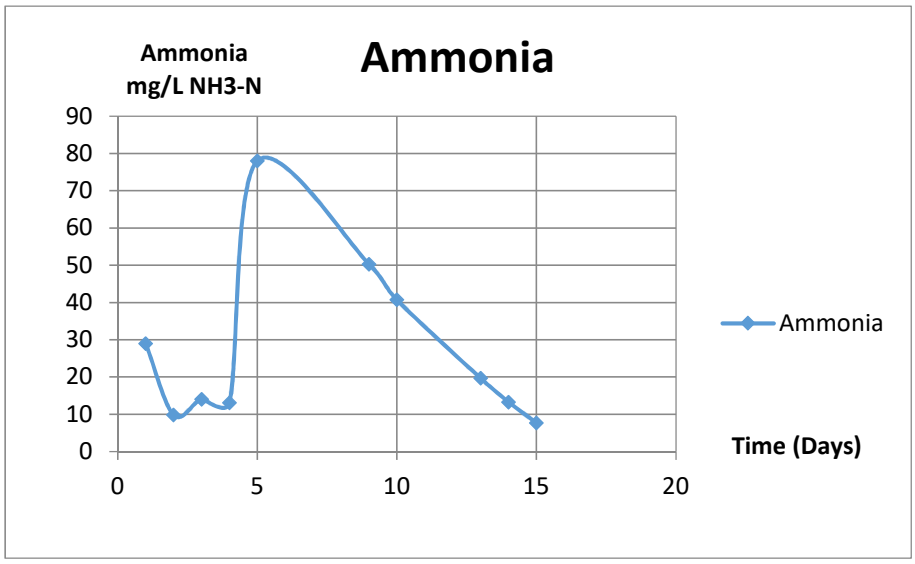

Figure 5: Ammonia Concentration Chart

The system ammonia change is significant sue to the urine additive. The maximum concentration in the system is 78 mg/L. After 10 days the ammonia concentration decreased back down to 7.7 mg/L. The rate of conversion for ammonia for our nitrifying bacteria is approximately 7mg/L/Day, which shows the

nitrification process is functional. Over the course of these experiments, the system was kept consistently at 25C. The Chemical Oxygen Demand of the system was consistently above 2000mg/L. This means that consistent reactions were occurring in the system, proving consistent biological activity.

2.4 Determination of Urine Dilution

Given that the average ammonia concentration for a household is 7 mg/L, the urine influent does not require dilution. Nitrifying bacteria work optimally when the concentration of Ammonia is below 15-20 mg/L, therefore the average household concentration is acceptable.

The concentration of ammonia in the natural samples of urine we collected was 7.5 mg/L. This value corresponds with the average household value and confirms that no dilution is necessary for concentration.

However, as previously mentioned in the Bacteria Characteristics section, the alkalinity of the system requires the addition of two ions which are found in tap water. The addition of urine to the system, at a high concentration, will decrease the pH to a level below optimal efficiency levels. This requires tap water to be added to dilute the urine in the final design.

2.4 Determination of Growth Media Characteristics and Selection of Bacterial Source

Three growth medias were tested under the same conditions. The medias tested were Pine Shaving, Cedar Shaving and Dry Straw. These medias were selected for their apparent Absorbability, Decomposability and Compressibility. Each of these medias were also tested with one of each type containing the natural sample and one of each with the “pure” sample (Quickstart TM). This can be seen in the following figure.

Figure 6: Second Growth Media Test

The samples were tested two days after urine addition. This was done to gauge the change in the system for each of the bacteria types. This data collected from these samples are found in the following table.

Table 4: Growth Media Test Data

Growth Media Test #	Bacteria Sample	Growth Media Mass (g)	Tap Water Volume	Test Time	COD (mg/L)	NH_3 (mg/L NH_3-N)	NO_2^- (mg/L NO_2^--N)	NO_3^- (mg/L NO_3^--N)
Pine #1	Wildcat	15.02	240 mL	Oct 10	2145	5.9	0.15	9.22
				Oct 12	5320	12.3	0.63	16.5
Pine #2	Pure	15.02	240 mL	Oct 10	2144	6.1	0.10	9.79
				Oct 12	5400	10.6	0.54	15.3
Cedar #1	Wildcat	15.02	240 mL	Oct 10	2169	6.1	0.13	11.2
				Oct 12	2640	13.9	0.29	14.6
Cedar #2	Pure	15.04	240 mL	Oct 10	2131	6.3	0.12	10.0
				Oct 12	3170	17.2		20.5
~~Straw #1~~	~~Wildcat~~	~~15.03~~	~~240mL~~	~~Oct 10~~	~~3402~~	~~20.9~~	~~0.98~~	~~20.7~~
~~Straw #2~~	~~Pure~~	~~15.02~~	~~240mL~~	~~Oct 10~~	~~4459~~	~~18.7~~	~~1.19~~	~~24.2~~

The table above shows alternatives for growth medias and bacterial source. The test data in yellow, pine #2 and cedar #2, show the greatest increase in present Nitrate. The “pure” source of nitrifying bacteria seems to come with less interference from other bacterial activity. The crossed out data is the growth media we have chosen to remove from the testing regime. This is due to an incredibly high presence of alternate biological activity and the presence of other solid waste material. Thus, we have selected the “pure” bacteria as our source.

The concentration for ammonia in each of the systems was found to be higher than the previous test, even though there was an increase in the nitrate concentration. This discrepancy is due to the presence of ammonia Chloride in the system breaking down into ammonia due to the increased presence of hydrogen ions. Any loss of nitrate is due to the formation of nitrogen based gases. These gases form naturally in water based systems due to mixing and the air-surface interface of water. In the next stage of testing, these values will potentially become negligible over time as the system stabilizes.

3.0 Summary of Project Costs

4.0 Appendix

4.1 Staffing Time Table

The table below represents the hour load for each completed task and sub task for each team member.

Table 5: Detailed Estimation Classification Required Work Time

Task	Planned Hours	Actual Hours	Emily	Adrian	Siwen
1.0 Determination of Legality and Sanitation	**10**	**10**	**2**	**1**	**7**
1.1 Determination and list creation of state, local, and federal regulations.	2.5	5	-	-	5
1.2 Determination the regulations in regard to effluent quality.	2.5	1	-	1	-
1.3 Prediction of human health, sanitation, or negative impacts on the environment.	2.5	2	2	-	-
1.4 Determination of water usage restrictions.	2.5	2	-	-	2
2.0 Determination of Urine Samples	**32.5**	**24.5**	**8.5**	**16**	**0**
2.1 Determination of surrogate or natural urine samples.	7.5	7.5	7.5	-	-
2.2 Collection/Creation of urine samples.	15	15	-	15	-
2.3 Determination of antibiotic residuals in urine sample.	10	2	1	1	-
3.0 Determination of Lab Analysis Procedures	**15**	**43**	**18**	**18**	**7**
3.1 Determination of complete list of required standard methods.	7.5	34	15	15	4
3.2 Acquire materials and summer lab access.	7.5	9	3	3	3
4.0 Implementation of Lab Work	**75**	**147**	**49**	**50**	**48**
4.1 Determination of bacterial effectiveness and parameters	25	90	30	30	30
4.2 Determine Growth Media	25	27	9	10	8
4.3 Urine Dilution	25	30	10	10	10
5.0 Preincubated Cartridge Analysis	**175**				
5.1 Determination of preincubated cartridge use.	12.5				
5.2 Creation of preincubated cartridge design specifics.	50				
5.3 Construction of preincubated cartridge.	57.5				
5.4 Testing of preincubated cartridge.	55				

Task	Planned Hours	Actual Hours	Emily	Adrian	Siwen
6.0 Design Concept Generation and Selection	**30**				
6.1 Design concept generation	12.5				
6.2 Design selection.	12.5				
6.3 Submit preliminary design.	5				
7.0 Conduction of Field Evaluation	**7.5**	**6**	**2**	**2**	**2**
8.0 Conduction of Plant Evaluation	**10**				
8.1 Determination of the feasibility of edible plants.	5				
8.2 Determination of the urine dilution required in system.	5				
9.0 Preformation of Design Calculations	**10**				
9.1 Determination of the physical dimensions of column design model.	5				
9.2 Determine the overall efficiency of the system.	5				
10.0 Determination of Final Design	**20**				
10.1 Determination of materials needed for column.	5				
10.2 Determination of column size and dimensions.	5				
10.3 Final design will be submittal to technical advisor and client.	5				
10.4 Feedback Consideration and Last Minute Adjustments	5				
11.0 Construction of Model Structure	**22.5**				
12.0 Conduction of Final Testing	**17.5**				
13.0 Project Management	**25**	**55**	**20**	**15**	**20**
Total Hours	**450**	**285.5**	**99.5**	**102**	**84**

4.2 Raw Data Collected

The following table depicts the raw data collected from the wildcat hill wastewater treatment facility.

Table 6: Raw Data Collected for Wildcat Bacteria Sample Test

Date	Day	pH	Alkalinity (mg/L as $CaCO_3$)	Temperature (°C)	Ammonia (mg/L as NH_3-N)	COD (mg/L)	Nitrite (mg/L as NO_2^--N)	Nitrate (mg/L as NO_3^--N)	Notes
26-Sep	1	7.1	192.1	25	29	＞2000	-		-
27-Sep	2	7.1	119	25	9.8	＞2000	-		-
28-Sep	3	6.89	142.8	25	14	＞2000	-		Added 1mL of "pure" nitrifying bacteria
29-Sep	4	6.59	98.6	25	13.1	＞2000	-		Added 1000 mL of pure urine
30-Sep	5	6.2	54.4	25	78.2	＞2000	-		-
1-Oct	6	5.43	20.4	25	-	＞2000	-		-
2-Oct	7	5.15	8.5	25	-	＞2000	-		-
3-Oct	8	4.95	8.5	25	-	＞2000	-		Added 3000 mL of tap water
4-Oct	9	5.06	12.3	25	50.2	＞2000	0.44	148	Added 500 mL of tap water
5-Oct	10	5.4	17	25	40.8	＞2000	0.53	32.2	Added 500 mL of tap water
6-Oct	11	5.41	22.8	25	-	-	-		Added 500 mL of tap water
7-Oct	12	5.42	27.2	25	-	-	-		Added 500 mL of tap water
8-Oct	13	5.44	6.8	25	19.7	-	-		Added 500 mL of tap water
9-Oct	14	5.38	8.5	25	13.3	-	-		Added 500 mL of tap water
10-Oct	15	5.51	17	25	7.7	＞2000	0.13	106	Added 500 mL of tap water

4.3 Initial Growth Media Tests

Our main sources of growth media were the pine and cedar shavings. The first tests conducted on these two media was water absorbency. 200 mL of DI water and 5g of growth media were applied in a sealed flask. The water absorbency has been witnessed over the past 10 days. The following image illustrates the results of this test, showing that pine is more adsorbent.

Figure 7: Growth Media Absorbency Test

The first growth media that was analyzed was the pine, 25g and 400mL of DI water as added to each beaker. Four mL of nitrifying bacteria was added to each beaker, in addition to 50 mL of urine diluted by a factor of 10 with tap water. It was clear that using DI water was a mistake in saturating the system. We needed the dissolved minerals in the tap water to have an effective system. This correction was made in the later growth media tests. The raw data collected for this test are listed in the table as below.

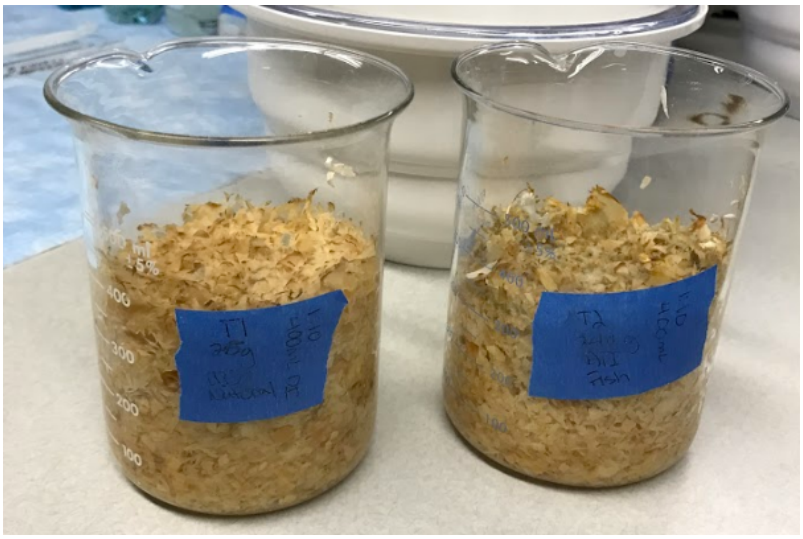

Figure 8: Initial Growth Media Test

Table 7: Raw Data Collected for Initial Growth Media Test

Growth Media	Bacteria Sample	Growth Media Mass	Tap Water Volume	COD (mg/L)	NH_3 (mg/L NH_3-N)	NO_2^- (mg/L NO_2^--N)	NO_3^- (mg/L NO_3^--N)
Pine	Wildcat	25.3 g	400 mL	1430	0.93	0.11	6.52
Pine	Pure	24.0 g	400 mL	1476	1.04	0.103	5.01

5.0 References

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