May 10, 2017

Mark Lamer, PE
Northern Arizona University
Flagstaff AZ, 86011

Dear Mark Lamer:

Attached is the ASCE Environmental Design team's final design report.

The proposed design consists of a gravity-fed, tiered water treatment system constructed of 2 in. by 4 in. wooden studs, ¾ in. thick plywood, and 5 gallon buckets. The water treatment process begins with sedimentation, filters through sand, resin, then granular activated carbon. Finally, the remaining water is disinfected with chlorine.

The total cost to implement this design equals approximately $58,200 which includes testing, system, staffing, and travel costs.

If you have any questions please do not hesitate to email us.

Thank you for working with us.

Sincerely,

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American Society of Civil Engineers Environmental Design Competition Design Report

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May 10, 2018

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Table of Abbreviations

ASCE	American Society of Civil Engineers
ASU	Arizona State University
Cl^-	Chlorine ion
CTU	Colony-Forming Unit
EIT	Engineer in Training
g	Gram
GAC	Granular Activated Carbon
In.	Inches
L	Liter
mg/L	Milligrams per Liter
mL	Milliliter
$N\text{-}NO^{3-}$	Total Nitrogen as Nitrate
NAU	Northern Arizona University
NTU	Nephelometric Units
$P\text{-}PO_4^{3-}$	Total Phosphorus as Phosphate
PE	Professional Engineer
PM	Project Manager
ppm	Parts per Million
PSWC	Pacific Southwest Conference
PVC	Polyvinyl Chloride
Tech	Lab Technician
UGRADS	Undergraduate Research and Development Symposium
WHO	World Health Organization

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Acknowledgements

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Adam Bringhurst should also be recognized for his assistance in the environmental laboratory and for supplying the team with the required testing methods and materials.

The Rio de Flag Wastewater Treatment Plant is appreciated for providing the team with effluent from the secondary clarifier.

Lastly, the team owes their gratitude to the American Society of Civil Engineers (ASCE) student chapters at Northern Arizona University (NAU) and Arizona State University (ASU) for hosting the 2018 Pacific Southwest Conference (PSWC).

1.0 Project Introduction

1.1 Objectives

The purpose of the ASCE Environmental Design Competition is to design and construct a low technology, low cost water treatment device that may be utilized within the households of developing nations. The 2018 Pacific Southwest Conference will be hosted by ASU and NAU and held at ASU's campus located in Tempe, Arizona on April 12, 2018.

844 million people currently do not have access to safe water [1, 2]. Of these individuals, 842,000 die each year from diarrheal diseases related to contaminated drinking water [2]. The United Nations have set sustainable development goals; one of which is to achieve universal and equitable access to safe and affordable drinking water for all by 2030 [3]. Household water treatment technologies are being considered to help reach this goal. However, the cost of these devices are not feasible for production in developing areas, such as Ethiopia and Bangladesh [4]. Low-cost, low-technology treatment systems are needed in order to quickly improve the health and well-being of populations within developing countries.

1.2 Competition Constraints and Limitations

The PSWC Environmental Design rules have outlined simulated wastewater with the following contaminants [5]:

- 1000g Miracle Gro All Purpose Plant Food
- 1000g Bulk Apothecary Kaolin Clay
- 30mL Star Kay White Pure Lavender Extract
- 20 mL Wastewater Treatment Plant effluent

The simulated wastewater must be treated to the following the standards [5]:

- 1 mg/L Total P-PO_4^{-3}
- 10 mg/L Total N-NO_3^-
- 1 NTU
- 4 ppm residual chlorine
- No presence of coliforms
- No presence of odor

The competition requires teams to construct their wastewater treatment device within a 3.05m x 3.05m area. Thirty minutes are allotted for the construction of the device. After construction, teams will be allowed ten minutes to pour the 34L sample into the treatment system. Another twenty minutes is then permitted for the system to treat the contaminated water. A treated water sample will be collected and a series of tests will be conducted to measure the contaminants within the treated water. Budgets must not exceed $500. This includes all materials and equipment found inside the 3.05m x 3.05m space during the construction portion of the competition [5].

1.3 Competition Deliverables

In addition to the design and construction of the wastewater treatment device, teams are required to prepare a technical presentation, technical report, and process flow diagram detailing the overall project. These items must address the team's design process, final design, treatment principles utilized, environmental impacts, cost analysis, and tables of material and operational costs [5].

1.4 Project Scope

In order to design a wastewater treatment device that successfully provides potable water in accordance with World Health Organization (WHO) standards [5], a thorough literature review was conducted regarding water treatment methods and developing country resources. Then, treatment components were prototyped for the individual testing parameters. These components were combined into the final design and tested for effectiveness. Finally, the water treatment design was presented at the PSWC and ranked against 18 other universities on its proficiency.

1.4.1 Tasks

The proposed and actual schedule can be viewed in A-2. The tasks that determined the critical path for this project were defined by design tasks and deliverable deadlines. Below in Table 1, the 13 tasks are outlined and described in the order they are scheduled to begin.

Table 1: Tasks and Subtasks Descriptions

Task	Description
1.0 Literature Review	Treatment methods and developing country resources were researched through the conduction of a literature review to better understand the effective mechanisms for removing contaminants.
2.0 Unit Design	Components that remove turbidity, total nitrogen, total phosphorus, total coliforms, odor, and chlorine will be prototyped individually. Software modeling may then be used in order to visualize the design.
3.0 Acquisition of Materials	In order to have an effective design, various materials and parts will need to be purchased. These materials and parts may be purchased from vendors such as Home Depot, Walmart, and Amazon.
4.0 30% Report	A 30% design report was produced to fill the requirement for the CENE 486C course.
5.0 Fabrication	The fabrication of each unit or combined units will be constructed during the initial stages of the design. This may be extended into the construction period of the final design.

6.0 Prototype Analysis	Data collection will be used to verify the treatment results for each component of the filtration system. These components include: turbidity, total nitrogen, total phosphorus, total coliforms, odor, and chlorine.
7.0 Finalize Design	The results from the prototype analysis will be compiled into the final design. This will determine which units require a certain order of progression and which units can be combined.
8.0 60% Report	A 60% design report was produced to fill the requirement for the CENE 486C course.
9.0 PSWC Requirements	As required by the 2018 Pacific Southwest Conference Environmental Competition rules, the device must be constructed on site, a process flow diagram must be displayed, and a technical presentation must be given.
10.0 Website	The website was produced to provide project information to professionals attending the UGRADS presentation and the general public.
11.0 Final UGRADS Presentation	After completing the design and construction of the water treatment device, a final presentation was produced for the client which outlines the selected design and estimated costs of implementation.
12. Final Proposal	After completing the design and construction of the water treatment device, a final proposal was produced for the client which outlines the selected design and estimated costs of implementation.
13. Project Coordination	To keep the project progressing, time was allocated to assign tasks, hold meetings, and attend consultation appointments throughout the entirety of the project.

2.0 Considered Design Alternatives

The parameters tested for in the competition correspond directly with the WHO standards. The alternatives considered are the specific units for each of the water quality parameters: turbidity, $P\text{-}PO_4^{3-}$, NO_3^-, odor, coliforms, and chlorine. After testing each unit prototype, the most effective treatment units are to be integrated within the final design. As a result, this will produce a well scored and high functioning system which may be used for real life application.

2.1 Turbidity Removal

Based on the literature review, the alternative unit designs for turbidity primarily consist of filtration and sedimentation [6]. The filter prototypes that have been tested for performance vary in regard to filter media. Those media include gravel, sand, zeolite, cotton, silk, and polyester fabrics.

The other method for turbidity removal is sedimentation. As clay is the primary contributor to the turbidity, a sedimentation system has been prototyped for the initial removal of clay. Another method that may utilized to decrease the amount of turbidity found within the contaminated water is through the use of the Moringa seed. Research suggests that the Moringa seed may act as a substitute where resources are limited [7].

2.2 Nitrate and Phosphate Removal

Nitrate and phosphate are parameters which require chemical or biological systems for effective removal [7, 8]. In a biological system, nitrogen is removed from water through the processes of nitrification and denitrification [8]. Both of these biological methods are carried out by microorganisms. Ion exchange can also be used to exchange undesired nitrate ions for other ions of a similar charge by passing the water over resin beads.

Phosphorus is mainly treated through chemical or biological methods. Flocculants, such as aluminum or iron cations, are added to a water sample in order to chemically react with phosphorus; this causes phosphorus to precipitate and allows the precipitate to be removed through physical processes. Biological phosphorus removal is based on microorganisms that store phosphorous which can also be used within the waste activated sludge process. Waste activated sludge containing phosphorus can then be removed by physical processes [7].

Due to the 30 minute treatment time constraint associated with the competition, biological methods are not realistic for this project. Chemical removal of the nutrients was the main alternative being explored. Flocculants, cation resins, and nitrate reduction using inorganic materials were all researched. Resin was decidedly the best alternative for nutrient removal.

2.3 Odor Control

Odor can be treated by using granular activated carbon (GAC). The large surface area provided by the material removes the source of odors. GAC has proven to be effective for sulfur-based odors [9]; however, the source of odor in the simulated sample is lavender extract oil. Other methods, such as biological membranes, are not being considered due to the 30 minute time constraint.

2.4 Disinfection

Total coliforms are treated through the use of disinfection which may include UV disinfection, distillation, or chlorine addition. Filtration may remove the majority of the bacteria, however additional treatment is necessary [10].

Chlorine will be used as a disinfectant and will require a residual level of 4 ppm. This unit will take place towards the end of the treatment system to ensure bacteria and pathogens are properly inactivated, and residual levels are maintained. In order to avoid the formation of trihalomethanes, GAC will succeed the chlorine disinfection process [5, 10].

3.0 Testing and Analysis

3.1 Testing Methods

The testing methods outlined in Table 2 were used for initial and final design testing.

Table 2: Water Quality Parameter Testing Methods

Parameters	*Methods*
$P\text{-}PO_4^{3-}$	HACH Method 8048: Phosphorus, Reactive (Orthophosphate) [11]
$N\text{-}NO_3^{-}$	HACH Method 8039: Nitrate [12]
Turbidity	HACH Method 8237: Turbidity [13]
Total Coliforms	HACH Method 8074: Coliforms, Total, Fecal and E. Coli [14]
Odor	Blind Odor Test [15]
Chlorine	HACH Method 8021: Chlorine, Free [9]

3.2 Raw Water Testing

The wastewater sample was reproduced using the contaminants specified in the 2018 PSWC Environmental Competition Rules. The sample was tested for the following parameters outlined in Table 1: phosphorous as orthophosphate, nitrogen as nitrate, turbidity, total coliforms, and odor.

The following table gives the testing results of the initial raw water sample.

Table 3: Initial Raw Sample Results

Parameter	*Value*	*Units*
$P\text{-}PO_4^{3-}$	3,990	mg/L
$N\text{-}NO_3^{-}$	50	mg/L
Turbidity	2,590	NTU
Total Coliforms	Present	CFU
Odor	Present	Unitless

3.3 Component Testing

Table 4 below outlines the results from the component testing.

Table 4: Unit Prototyping Results

Parameter	*Unit*	*Trial 1*		*Trial 2*	
		Value	*Description*	*Value*	*Description*
$P\text{-}PO_4^{3-}$	mg/L	210	Media Filtration Pads	180	Ion-Exchange Resin
$N\text{-}NO_3^-$	mg/L	5		49.1	
Turbidity	NTU	> 1000	Cloth Filtration	192	Sedimentation with cloth filtration
Total Coliforms	CFU	Present	Liquid Chlorine (Cl_2)	Not Present	Bleach (NaClO)
Odor	Unitless	Present	No method applied	Reduced	GAC

Unit prototype testing was conducted in relation to each water quality parameter. Table 4 highlights the various data obtained from each water quality parameter test. A total of two trials were conducted for each parameter.

In order to successfully reduce the phosphorus and nitrogen content within the sample, the water percolated through a series of filtration pads. Within the first trial, the water was treated using three different media filtration pads: Acurel LLC Phosphate Reducing Media Pad, Acurel LLC Nitrate Reducing Media Pad, and an Acurel LLC Ammonia Reducing Media Pad. This filtration method had no impact on the initial water sample quality. As a result, an ion-exchange resin was utilized throughout the second trial. The amount of nitrogen and phosphorus within the water significantly decreased, thus proving the ion-exchange resin to be an effective method.

For the first turbidity trial, the raw water sample was filtered through various forms of cloth. The turbidity reading remained too high to be read by the turbidimeter. The second trial incorporated a sedimentation period to allow the clay to settle at the bottom of the container. The clearer water was then slowly transferred to a sand filtration container. This trial resulted in a turbidity reading of 193 NTU and was adopted into the final design.

The first trial to reduce total coliforms utilized liquid chlorine. It eliminated the coliforms present. Bleach was used in the second trial due to its cost effectiveness. It again removed the coliforms and was therefore integrated into the final design. The quantity of clorox needed to disinfect the system was determined using the following equation.

Equation 1: Volume of Clorox Needed

$$Clorox\ (L) = 0.01\ L\ Cl^{-} \times \frac{100L\ Clorox}{\%\ Available\ Cl^{-}} \times \frac{Dose}{10\ L\ Water} \times \frac{L\ Water}{1{,}000}$$

Where Cl^{-} is chlorine, Dose is the volume (mL) of 1% stock solution needed to raise 10 L of treated water the desired residual chlorine level, and the volume of water is divided by 1,000 to convert Dose into liters. Dose is determined by a series of tests using 1 percent solution in 10 L samples. 0.4 mL was calculated to reach a residual chlorine level of 4 ppm, and the value was rounded to 1 mL for a factor of safety.

In order to remove odor from the system, it was first assumed that the simulated water would contain no odor if the other parameters were effectively treated. This was proven as false when odor resulted in trial 1. The simulated wastewater was filtered through GAC, and although still present, the odor is reduced.

3.4 Final Design Results

Table 5 below gives the final design treatment results integrating the components described in the above subsection so the water will be treated by each treatment unit described in the second trial.

Table 5: Final Design Treatment Results

Parameter	*Units*	*Competition Goal*	*WHO Standard*	*Raw Water Result*	*Final Water Result*	*Percent Eliminated*
$P\text{-}PO_4^{3-}$	mg/L	≤ 1	1	3,390	200	94%
$N\text{-}NO_3^{-}$	mg/L	≤ 10	10	50	2.1	96%
Turbidity	NTU	≤ 1	1	2,590	275	89%
Chlorine	ppm	4 ± 1	4 ppm	0 ppm	4 ppm	N/A
Total Coliforms	Unitless	No Coliforms	≤ 5%	Present	Not Present	100%
Odor	Unitless	No Odor	N/A	Present	Present	N/A

4.0 Final Design Recommendations

In order to effectively design and construct the water treatment device, a series of filtration processes are needed to improve the water quality of the sample. The final design is a gravity fed system and contains a series of five filtration steps. Table 6 on the following page describes the various steps throughout the filtration process.

Table 6: Final Design Filtration Steps

Step	*Process*	*Description*
1	Sedimentation	For a duration of eight minutes, the clay particles will undergo the process of sedimentation within a large storage bin. After the clay settles, the clearer water on top will be poured into a five-gallon bucket for easy transfer to the next step.
2	Sand filter	The water will percolate through the sand filter in order to decrease turbidity.
3	Ion-exchange resin	The phosphorus and nitrogen content within the water will be decreased through the process of ion-exchange. Approximately 4.5 kilograms of resin are utilized in the design.
4	GAC	About 4.5 kilograms of GAC will be in the third bucket of the tiered system. Its purpose is to reduce the odor from the lavender extract contaminant.
5	Collection bucket	Treated water will be collected in this step. Already in the container will be 1 mL of bleach. This will disinfect the water of coliforms.

A system diagram of the final design can be viewed in A-1.

Due to time constraints, biological methods could not be used to treat the wastewater. These methods however would have been the most effective way of removing nutrients from the wastewater. The timing issue also caused chemical coagulation and flocculation to be unreasonable. These chemical methods would have been more successful at removing the turbidity of the water. Moringa seeds were a cost-effective alternative for treating turbidity, but this natural coagulant requires at least two hours for treatment. It is recommended for future projects that more time be allowed for the treatment process, so that more effective units can be integrated into the design.

5.0 Summary of Engineering Work

5.1 Lab Testing

The list of materials below were used when testing the described treatment parameters. Each specific material and their respective quantity are listed below.

Table 7: Lab Materials Used for Parameter Testing

Lab Material	*Quantity*
Blue Absorbent Pad	16
Tot. Phosph. Hi Range Test 'N Tube Set	13
Tot. Nitrogen Hi Range Test 'N Tube Set	4
NitraVer 5 Powder Pillows	16
PhosVer 3 Powder Pillows	4
Petri Dishes	16
Glass Microfiber Filters, 691	17
m-Endo Total Coliform Broth Ampules	16

Following the methods provided using the above materials yields results that are accurate within five percent of the true value.

5.2 Software

Autodesk AutoCAD 2018 was used in the design process. The program was able to accurately provide a scaled model of the design. Numerous layers were utilized to properly identify the various design components and materials. Throughout the construction and water quality testing processes, the design was able to be modified and adjusted accordingly. This design can be viewed in A-1.

Microsoft Excel 2013 was utilized in order to conduct data analysis. The results from the water quality testing were analyzed within this software.

5.3 Field Work

To gain adequate results the team assembled a prototype of the final treatment unit. The team pre-drilled the 2 in. by 4 in. wooden studs, pre-cut the plywood, and pre-cut the five gallon buckets. The team also simulated final design construction in a thirty minute time frame by tightening the screws and fabricating the entire system. The buckets were filled with their respective filter media and the simulated wastewater was ran through the treatment device. This treated water was then tested for the specified parameters.

5.4 Staffing Hours

Table 8 below gives the amount of work the professional engineer, project manager, engineer in training, and lab technician put forth towards the completion of the project for each of the specified tasks.

Table 8: Staffing Hours

Task	*Staff (hrs)*				*Proposed Total (hrs)*	*Actual Total (hrs)*	*Difference (hrs)*
	PE	*PM*	*EIT*	*Tech*			
1. Literature Review	0	0	40	0	40	40	0
2. Unit Design	5	10	20	20	55	65	+10
3. Acquisition of Materials	0	0	3	3	6	6	0
4. 30% Report	6	6	6	0	18	21	+3
5. Fabrication	4	25	50	60	139	152	+13
6. Prototype Analysis	5	5	25	40	75	80	+5
7. Finalize Design	30	25	25	35	115	120	+5
8. 60% Report	10	10	15	0	35	35	0
9. PSWC Requirements	14	24	35	10	83	85	+2
10. Website	0	5	10	0	15	15	0
11. Final Presentation	5	5	7	0	17	21	+4
12. Final Proposal	10	10	10	0	30	35	+5
13. Project Coordination	10	10	10	10	40	40	0
Staff Total	*99*	*135*	*256*	*178*	*668*	*715*	*+47*

Table 9 justifies the staffing hours for each of the four engineering positions on this project.

Table 9: Proposed Staffing Hours Justification

Positions	*Total Hours*	*Justification*
Professional Engineer (PE)	99	The PE worked the least amount of hours as they are the most experienced. It was their job to aide in component prototyping, fabrication, and the final design. The professional engineer was required to attend the PSWC competition and help compose the final proposal.
Project Manager (PM)	135	The project manager was in charge of foreseeing the project and ensuring it was completed on time within the specified budget.
Engineer in training (EIT)	256	The engineer in training was allocated the most amount of work as they were under the direct supervision of the professional engineer and project manager.
Lab technician (Tech)	178	The lab technician position was primarily involved in prototyping and fabrication tasks, both of which require the most amount of hours.

As indicated in Table 9, the EIT position will require the most amount of work hours, followed by the lab technician, and the project manager. The professional engineer will work the least amount of hours for the completion of this project.

6.0 Summary of Engineering Costs

6.1 Testing Costs

Table 10 below displays the cost of the materials used to simulate the contaminants found in the local water sources of developing countries.

Table 10: Total Cost of Contaminants For a Single Batch

Item	*Unit Cost*	*Quantity*	*Total Cost*
Kaolin Clay 1 Pound	$8.99	2	$17.98
Miracle-Gro	$10.87	1	$10.87
Lavender Extract	$13.32	1	$13.32
Total Cost of Contaminant Materials			$42.17

The sample was predicted to be replicated 10 times causing the estimated cost to be about $420. The batch was actually recreated 6 times, bringing the total testing cost to about $255.

6.2 System Costs

Table 11 below list the various materials and the respective prices of the materials used in the final design.

Table 11: Total Cost of System

Item	*Vendor*	*Unit*	*Cost Per Unit*	*Quantity*	*Total cost*
2 in. by 4 in. Prime Stud	Home Depot	104.625 in. Stud	$3.77	4	$15.08
Plywood		48 in. x 96 in. Sheet	$9.98	1	$9.98
5 Gallon Bucket		1 Bucket	$3.25	5	$16.25
Screws		90 nails	$8.38	1	$8.38
30 Gallon Storage Tote		1 Tote	$9.97	1	$9.97
Screwdriver		1 Screwdriver	$0.87	4	$3.48
Men's Crew T-Shirts	Walmart	10 T-Shirt Pack	$19.93	1	$19.93
Rubber Bands		64 Bands	$1.27	1	$1.27
Deionization Resin	Amazon	5 Pounds	$45.00	4	$180.00
Bleach		30 Ounces	$8.14	1	$8.14
Activated Carbon		39 Ounces	$16.99	8	$135.92
Sand		50 Pounds	$28.41	1	$28.41
Total Cost					*$436.81*

As indicated in Table 11, the final cost of the system is approximately $440. The items were obtained through vendors such as: Home Depot, Walmart, and Amazon. The proposed budget of the system was $500, as specified in the PSWC rules.

6.3 Staffing Costs

Table 12 outlines the cost of engineering work as referenced in Table 7.

Table 12: Total Staffing Costs

Position Title	*Base Pay Rate/Hour*	*Benefits % of Base Pay*	*Actual Pay/Hour*	*Proposed Hours*	*Proposed Total Cost*	*Actual Hours*	*Actual Total Cost*
PE	$90.00	40.00%	$126.00	99	$12,474	110	$13,860
PM	$70.00	40.00%	$98.00	135	$13,230	150	$14,700
EIT	$50.00	30.00%	$65.00	256	$16,640	265	17,225
Tech	$40.00	30.00%	$52.00	178	$9,256	190	$9,880
Total				*668*	*$51,600*	*715*	*$55,665*

The total staffing costs equates to approximately $56,000. This includes the total hours and pay per hour as determined for each of the four positions: Project Engineer, Project Manager, Engineer in Training, and Lab Technician.

6.4 Travel Costs

Table 13 displays travel costs for the team to attend the 2018 PSWC located at Arizona State University in Tempe, Arizona. The table outlines the costs of gas, hotel rooms, meals, and the vehicle rentals for five days and four nights.

Table 13: Total Travel Costs

Expense	*Units*	*Quantity*	*Average Cost Per Unit*	*Proposed Total Cost*	*Actual Total Cost*
Rental Car	Days	4	$55.00	$220	$208
Gasoline	Gallons	40	$3.00	$120	$110
Hotel Rooms	2 Rooms	4	$400.00	$1,600	$1,240
Meals	3 Meals	16	$30.00	$480	$320
Total Travel Costs				*$2,420*	*$1,878*

The total travel cost equates just under $1,900.

6.5 Total Cost of Project

Table 14 summarizes the total costs of the system.

Table 14: Total Costs Summary

Average Cost Per Unit	*Proposed Total Cost*	*Actual Total Cost*
Testing Costs	$421.70	$253.02
System Costs	$500.00	$436.81
Staffing Costs	$51,600.00	$55,665.00
Travel Costs	$2,424.00	$1,878.00
Total Costs	*$54,945.70*	*$58,232.83*

Adding the testing, system, staffing, and travel costs brings the total cost of the project to approximately $58,200.

7.0 Conclusion

7.1 Final Results

The water treatment device can be implemented for approximately $440. The effluent does not comply with World Health Organization standards, but it performs successfully given the oversaturation of contaminants. This design came in fourth overall in the competition out of nineteen universities and placed first in Arizona.

7.2 Final Considerations

A number of final design recommendations could be considered to improve the quality of the treated water. A chemical coagulant, such as aluminum sulfate, may have been utilized to reduce the turbidity in the untreated water. Due to the various competition rules, chlorine was the only chemical that may be used to improve the treated water. With additional treatment time, biological methods may be applied to reduce the amount of nutrients in the effluent water. Furthermore, moringa seeds were a cost effective method for removing turbidity if more time was allocated to the treatment phase. Thus, if the project was not constrained to the rules of the Pacific Southwest Conference Environmental Competition, the design would have been approached differently.

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9.0 Appendices

A-1: AutoCAD Final Design Rendition

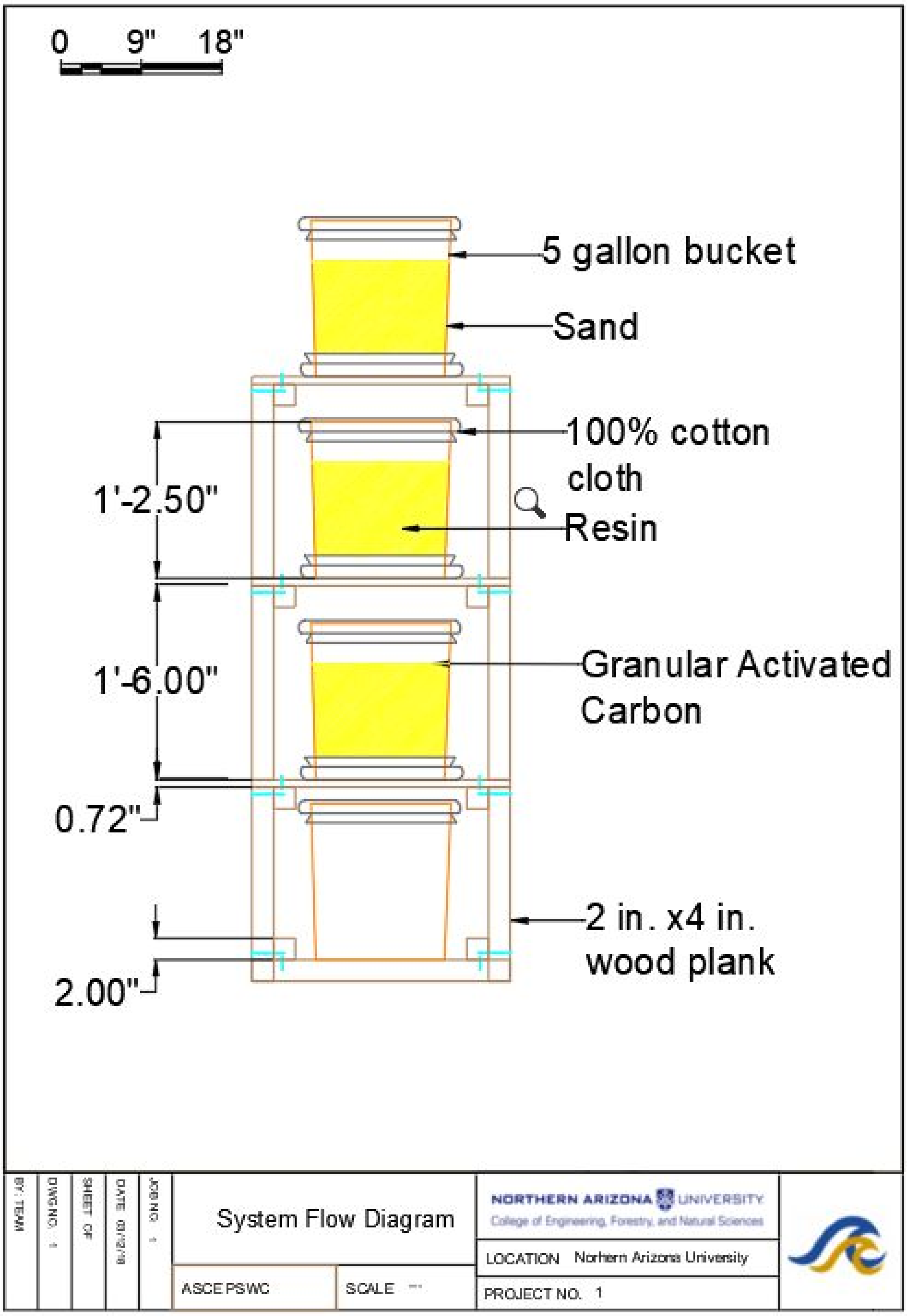
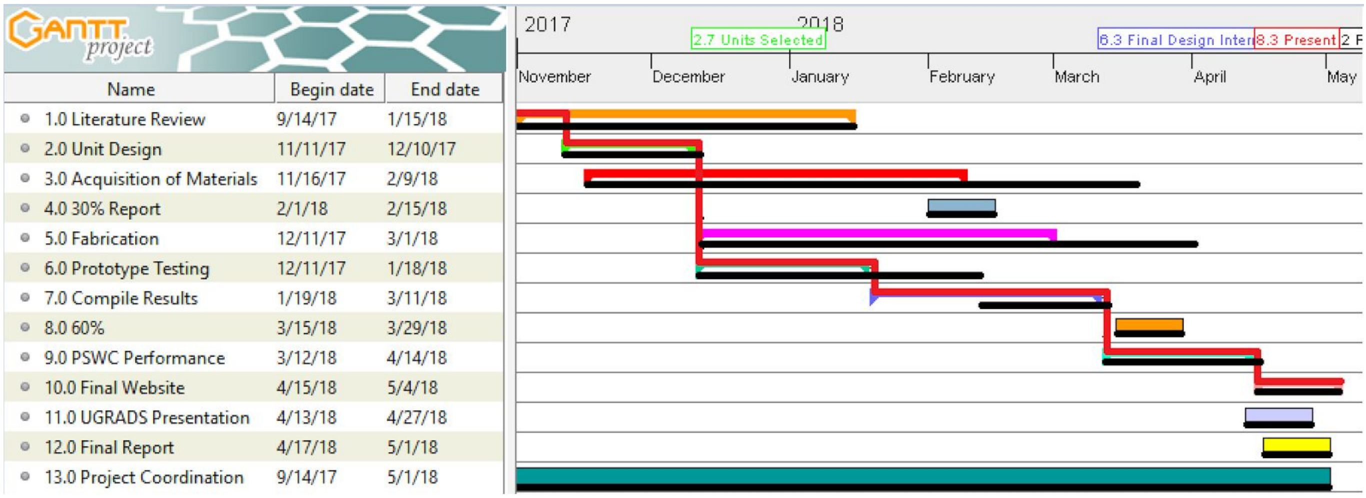


Figure 1: Final System Design

A-2: Project Schedule



Name	Begin date	End date
1.0 Literature Review	9/14/17	1/15/18
2.0 Unit Design	11/11/17	12/10/17
3.0 Acquisition of Materials	11/16/17	2/9/18
4.0 30% Report	2/1/18	2/15/18
5.0 Fabrication	12/11/17	3/1/18
6.0 Prototype Testing	12/11/17	1/18/18
7.0 Compile Results	1/19/18	3/11/18
8.0 60%	3/15/18	3/29/18
9.0 PSWC Performance	3/12/18	4/14/18
10.0 Final Website	4/15/18	5/4/18
11.0 UGRADS Presentation	4/13/18	4/27/18
12.0 Final Report	4/17/18	5/1/18
13.0 Project Coordination	9/14/17	5/1/18

Figure 2: Project Schedule (Red line is critical path, Black line is actual schedule)