Stormwater Utilization on NAU Campus

Final Report

Prepared for: Bridget Bero, CENE 486C Grading Instructor

Prepared by: Dorshanna Coolie, Madalyn Marcolina, and Jiayu Zhang, CENE 486C Students

Company Name: DMJ Engineering

CENE 486C-EGR Design Capstone

December 12th 2018

Table of Contents

List of Figures

List of Tables

List of Abbreviations:

EIT: Engineer in Training
NAU: Northern Arizona University
SHB: Science and Health Building
TDS: Total Dissolved Solids
TSS: Total Suspended Solids

Acknowledgements

DMJ Engineering would like to recognize our client, Jon Heitzinger for giving the team the opportunity to complete our project, Stormwater Utilization on Northern Arizona University Campus. The team would like to thank our technical advisor, Jeffery Heiderscheidt for providing guidance in completing the project.

We appreciate our client and technical advisor for helping us through the challenges of the project. Our team would also like to acknowledge the grading instructor, Bridget Bero, for giving the team constructive feedback on the work completed. Without the help of all three individuals, DMJ Engineering would not have completed this project to our full potential.

Sincerely,

DMJ Engineering

1.0: Project Description

The project description is an overview of the project, Stormwater Utilization on NAU campus. The following sections include the purpose, location and background information about the project.

1.1: Introduction

The purpose of this project is to develop a stormwater utilization plan using existing and future stormwater being collected in three underground detention tanks on Northern Arizona University's (NAU) campus. The project focuses on conveying, treating, and reusing the detained stormwater. The project requires the following; hydrologic analysis, stormwater testing, water treatment system design, hydraulic system design, and a cost analysis. The project is coordinated with NAU facilities; the information provided by NAU facilities has provided a better understanding of the system for design aspects. The project is an innovative green infrastructure project to help NAU's campus through managing stormwater pollution while benefiting the campus community and the environment [1].

The treated stormwater will be stored in two domestic water storage tanks, which currently reside inside the NAU Heating and Cooling Plant. The stormwater will be used to replace domestic fresh water in the cooling process of the plant. The benefits of reusing the stormwater are cost savings from reducing serviced water and decreasing the overflow into the nearby washes.

The location of the project is on Northern Arizona University's campus located in the northern region of Arizona in Flagstaff. Figure 1-1 below demonstrates NAU's location in relation to Flagstaff, Arizona.

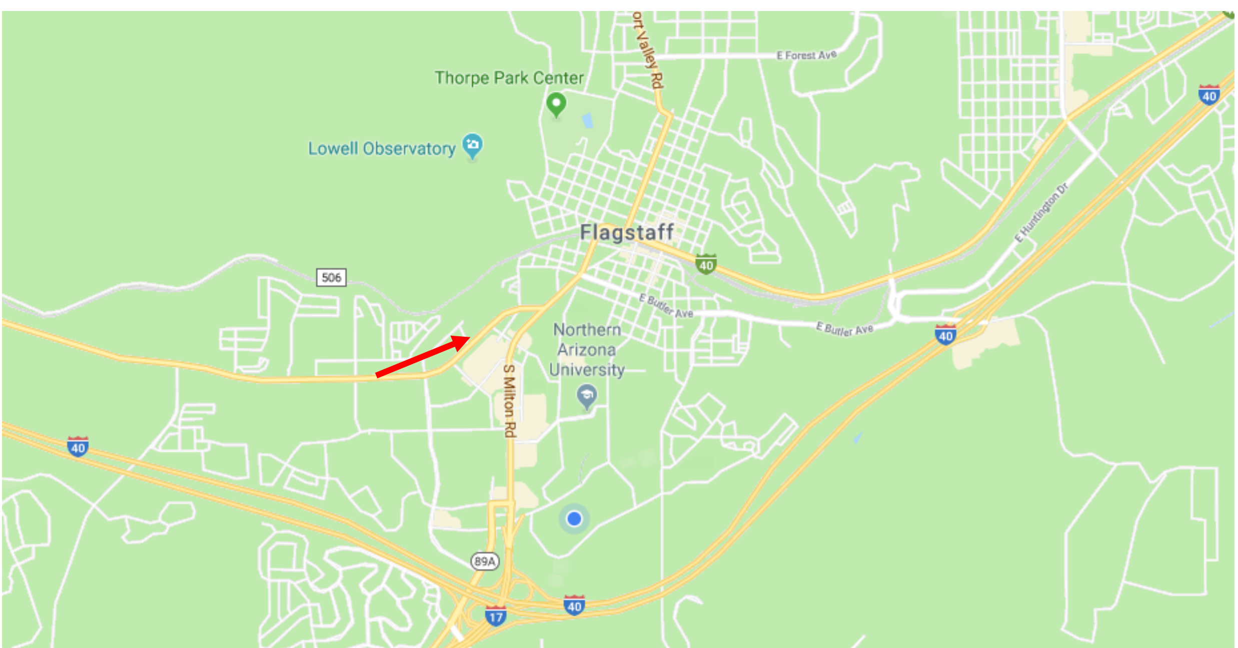


Figure 1-1: Northern Arizona University Location in Northern Arizona [2]

More specifically the project focuses on the detention tanks located near the Science and Health Building (SHB) and the Heating and Cooling Plant located on North Campus of NAU. The three underground detention tanks are shown in Figure 1-2 below in yellow, next to the Science and Health Building. The figure also shows the orientation of the project with nearby streets and surrounding buildings identified.

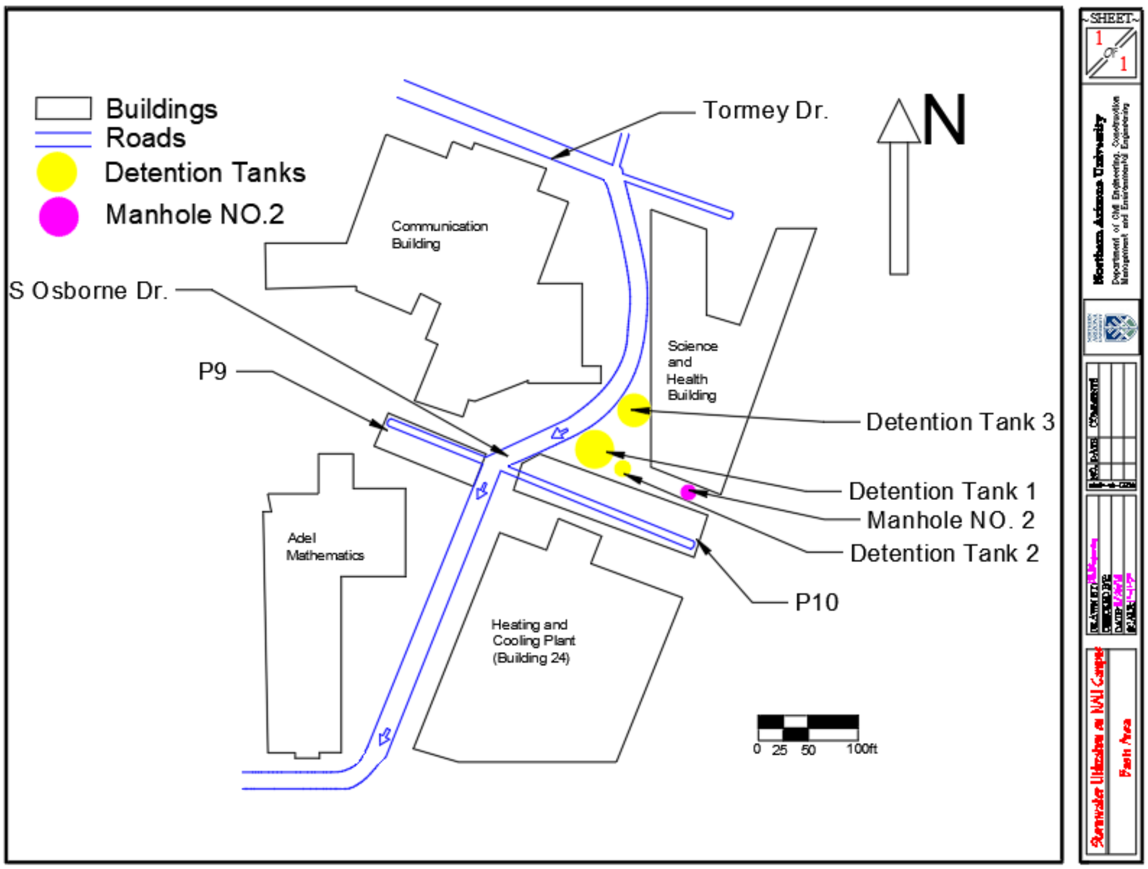


Figure 1-2: Location of the underground Detention Tanks near the Science and Health Building [3]

1.2: Background

The overall goal of the cooling process is to provide cooling to buildings on the north side of NAU campus. Figure 1-3 displays a block diagram, which demonstrates the process where water is being conveyed from the detention tanks, to the treatment system, to where the treated stormwater will be used in the cooling process of the Heating and Cooling Plant. The process schematic is described in detail in the following paragraphs.

First, the stormwater flows into detention tanks one and three, then both tanks flow into tank two. Then the stormwater flows into a storm drainage pipe network. This pipe network uses a gravity system, where the water flows with no pumps. The project starts from intercepting the water as it is coming out of tank two before it is conveyed out the storm drain. The stormwater is then conveyed to the water treatment system where it will be treated to water quality required to be used in the Heating and Cooling Plant. The last part of the project includes delivering the treated water to the remote sump, where the water will be used in the cooling process.

The treated stormwater will be conveyed into the remote sump tanks, where it is then conveyed to the chillers. Inside the chillers the water is pumped through cooper tubes submerged in refrigerant. Then, the chilled water is sent throughout campus, demonstrated with the arrow going to the buildings in Figure 1-3. The heat being collected from the buildings comes back to the cooling towers, located on top of the Heating and Cooling Plant. These are the open-air structures with suction air fans located on the top of the towers. Then, the hot water travels to the top of the cooling tower where it is sprayed downwards. The suction fans are then used to cool the water where the heat is expelled as latent heat of evaporation. Once the water has been cooled down it goes back into the remote sump where the process is repeated at maximum four times until the water is no longer reusable in the cooling cycle [4] This process requires 30,000 gallon per day to make up for the evaporated water.

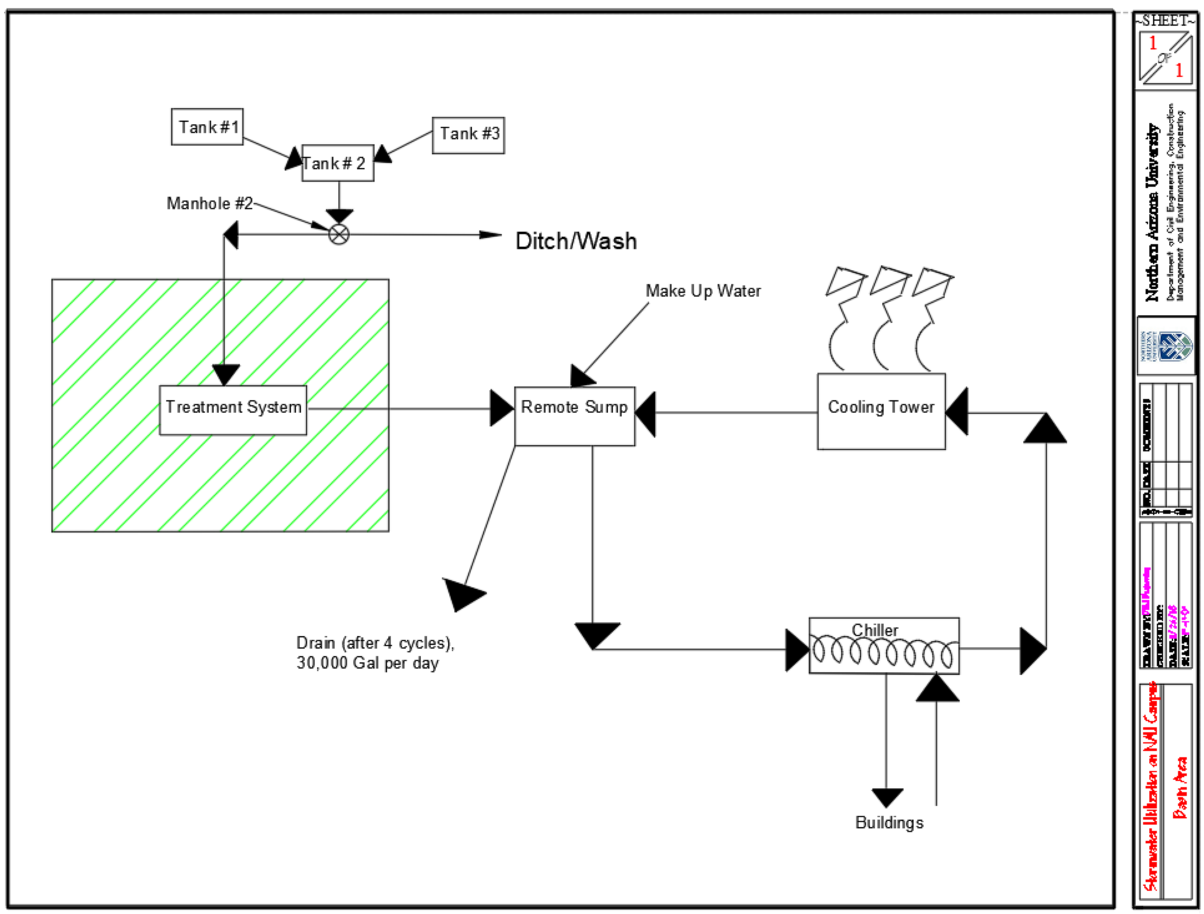


Figure 1-3: Process Schematic of the Project and Cooling Cycle of the Plant

2.0: Site Visit

The site investigation/visit was to the Heating and Cooling Plant on November 12, 2018. The site visit allowed the team to see which area in the Heating and Cooling Plant the stormwater will be conveyed to and treated in. The site visit indicated that a storage tank after treatment is not necessary, since the stormwater can be stored in the current domestic water tanks.

3.0: Hydrologic Analysis

The hydrologic analysis was conducted to determine the average precipitation and snowmelt that flows into the detention tanks. The client provided a NAU Stormwater Drainage Report, which specifies the drainage basins shown in Appendix A, Figure A-1. Figure A-1 demonstrates the location of each drainage basin in relation to the project location. The basins represent drainage areas for stormwater runoff that is collected in the detention tanks. The area for each basin is shown below in Table 3-1.

Table 3-1: Drainage Area and Flowrate per Basin [3]

Basin Number	Drainage Area (acres)
1	2.15
2	0.64
3A	0.20
3B	0.18
4A	1.22
4B	2.40
5	1.40
Total	**8.19**

3.1: Average Precipitation and Snowmelt Analysis

The hydrologic analysis also includes finding the average precipitation and snowmelt over a period of two years as suggested by the client. The average precipitation and snowmelt data were analyzed for year 2016-2017 in Flagstaff, Arizona from US Climate Data [5]. The snowmelt was converted to liquid water, since every ten inches of snow is roughly one inch of rain*. The precipitation and snowmelt were added together to make the water equivalent. Then the data recorded were converted to feet. The precipitation/snowmelt was then multiplied by the total drainage area of the basins, above, to determine the volume of rain for each month of 2016 and 2017.

Appendix B, Table B-1 showcases the water equivalent, and the average daily volume for each month of 2016-2017. Table B-1 helped the team to better understand the average volume that the detention tanks could generate after storm events. Though the table demonstrates that the system could provide up to 58,411gpd, the client requested that the team only needs to provide 30,000gpd for the cooling process.

Here is an example for how the average daily volume of January 2016 was calculated:

$$8.16acres * 43{,}560sf = 356{,}756sf$$

$$356{,}756sf * 0.47ft = 167{,}676cf$$

$$167{,}676cf * \frac{7.48gal}{cf} = 1{,}254{,}211gal/month$$

$$\frac{1{,}254{,}211gal}{month} * \frac{1month}{30days} = 41{,}807gal/day$$

3.2: Design Flowrate

The design flow for the system was provided in the NAU Stormwater Drainage Report. The minimum storm event provided in the report was a two-year storm event. Therefore, the pipe network and pump will be designed for the flow of a two-year storm event since that is most relatable to an average rainfall event than a 10, and 100 storm events. The design flow for the system was determined to be 17.47 cubic feet per second (cfs).

Table 3-2: Developed Hydrology [3]

Basin Number	Q (2 yr) cfs
1	5.16
2	1.45
3A	0.45
3B	0.40
4A	3.14
4B	3.51
5	3.36
Total Flow	**17.47**

4.0: Stormwater Testing Analysis

Stormwater testing focused on the nine different water quality parameters shown below in Table 4-4. The stormwater collected from the detention tank and surface stormwater collected from a parking lot were tested. A total of three trials per stormwater were tested. The stormwater testing results were compared to drinking water quality standards, for a better understanding of treatment to be required in the final design. The testing parameters included pH value, nitrate, ammonia, nitrogen, total coliform, total hardness, turbidity, total suspended solids (TSS), and total dissolved solids (TDS). Each test was conducted following the HACH or Standard Methods shown in the table below. The following paragraphs explain the reasoning of why each test parameter was selected.

Table 4-1: Test Parameters and Test Methods [6], [7]

Test Parameter	Test Method
pH	HACH Method #8156: pH
Nitrate	HACH Method #8171: Nitrate
Ammonia	HACH Method #10031: Ammonia
Total Nitrogen	HACH Method #10071: Total Nitrogen
Total Coliform	HACH Method #8074: Total Coliform
Total Hardness	HACH Method #8266: Total Hardness
Turbidity	Standard Method #2130B: Nephelometric Method
Total Suspended Solids	Standard Method #2540 C: Suspended Solids
Total Dissolved Solids	Standard Method #2540: Total Solids

The pH value is used to indicate the content of hydrogen ions in water, which are the acidity and alkalinity of water. If the pH is high or low it can affect the processing procedures such as the following: chemical coagulation, disinfection, redox, and water softening. If the pH is low this may corrode the piping and the equipment used to covey the water. Testing the pH of level of the stormwater will determine if the pH needs to be adjusted to be adequate for the designed system.

Due to stormwater being used in the cooling process, the hardness of the water needs to be tested. If the hardness of the water is too high, the piping will start to scale, which will negatively impact the system. When the ammonia in the water is too high, drinking this water will combine with protein to form nitrosamines, which is a strong carcinogen. Long-term drinking is extremely detrimental to the body. In addition, it also causes the proliferation of microorganisms.

Total nitrogen is the total amount of various forms of inorganic and organic nitrogen in the water. This test parameter was chosen to help assess the contamination of water bodies. If the nitrogen in the surface water exceeds the drinking water standard, the microorganisms multiply and plankton grows vigorously. The presence of large amounts of nitrate in the water can produce algae. The nitrite in water may combine with protein to form nitrosamine, which is a strong carcinogen and is extremely detrimental to human health.

Turbidity was tested due to the possibility of it increasing the load on the filtration process to achieve efficiency and increase the maintenance cost. In addition, when disinfecting in public water, some bacteria or other vitamins may be adsorbed on the particles causing turbidity and resist the disinfectant such as chlorine or ozone.

TDS refers to the total amount of solid matter dissolved in water such as the salt content or the total amount of ions. TSS refers to the total amount of solid materials suspended in water, including inorganic substances, organic matter, soil particles, and microorganisms. Suspended matter is the main factor for affecting the turbidity, color, and odor of water. TSS and TDS need to be tested since they directly affect the conductivity and hardness of the water.

4.1: pH Test Results

The pH in surface water is from 6.5-8.5. According to the test results shown in Table 4-2, the pH of detention tank stormwater and surface stormwater are both low. Therefore, pH needs to be adjusted in the design project.

Table 4-2: pH Test Results

Sample No.	Tank Water	Surface Water	Standard (EPA)	Standard (ADEQ)
1	5.16	5.58		
2	4.96	5.65		
3	4.98	5.65		
Average	**5.03**	**5.63**	**6.5-8.5**	**6.5-8.5**
Standard Deviation	0.11	0.04		

4.2: Nitrate Test Results

The nitrate test results are shown below in Table 4-3. Through comparison of the EPA and ADEQ Standard and the stormwater samples, it is evident that the nitrate levels are within the Standards for the tank water. The surface water did have higher levels, but the treatment design for the project is reflected solely on the tank stormwater results.

Table 4-3: Nitrate Test Results

Sample No.	Tank Water (mg/L)	Surface Water (mg/L)	Standard (EPA)	Standard (ADEQ)
1	0.8	1.4		
2	0.7	1.3		
3	1	1.4		
Average	**0.83**	**1.37**	**<1mg/L**	**N/A**
Standard Deviation	0.15	0.06		

4.3: Ammonia Test Results

After testing for ammonia concentration both the tank and surface stormwater were lower than the water quality standards. The ammonia test results are shown in Table 4-4 below along with the average and standard deviation for each stormwater sample. As demonstrated in the results below, the ammonia levels in the samples for both the tank and surface water were below EPA and ADEQ Standards for treatment; therefore, ammonia does not need to be treated.

Table 4-4: Ammonia Test Results

Sample No.	Tank Water (mg/L)	Surface Water (mg/L)	Standard (EPA)	Standard (ADEQ)
1	0.5	0.2		
2	0.2	0		
3	0.1	0		
Average	**0.27**	**0.07**	**N/A**	**<1.5 mg/L as N**
Standard Deviation	0.21	0.12		

4.4: Total Nitrogen Test Results

The total nitrogen test results are summarized in Table 4-5 below. Based on the results given there is very little total nitrogen in the water. The total nitrogen results are within the drinking water quality standards.

Table 4-5: Total Nitrogen Test Results

Sample No.	Tank Water (mg/L)	Surface Water (mg/L)	Standard (EPA)	Standard (ADEQ)
1	0.3	0.7		
2	0.8	1		
3	0.4	0.4		
Average	**0.50**	**0.70**	**N/A**	**<10 mg/L**
Standard Deviation	0.26	0.30		

4.5: Total Coliform Test Results

For total coliform test results are shown below in Table 4-6. The total coliform stormwater testing results indicated that levels are below the standards for EPA and ADEQ.

Table 4-6: Total Coliform Test Results

Sample No.	Tank Water (CFU/100mL)	Surface Water (CFU/100mL)	Standard (EPA)	Standard (ADEQ)
1	3	3		
2	3	6		
3	5	5		
Average	**3.67**	**4.67**	**< 5%**	**< 23 CFU/100mL**
Standard Deviation	1.15	1.53		

4.6: Total Hardness Test Results

Table 4-7 below demonstrates the results of the total hardness of the stormwater from the detention tank and surface runoff. Based on the results the water is soft. Due to the standard deviation being small the results are accurate results. Total hardness will not be treated for in the water treatment process since the water is already soft.

Table 4-7: Total Hardness Test Results

Sample No.	Tank Water (mg/L) as CaCO3	Surface Water (mg/L) as CaCO3	Standard (EPA)	Standard (ADEQ)
1	20.00	7.14		
2	19.60	6.71		
3	16.00	6.72		
Average	**18.53**	**6.86**	**< 200 mg/L**	**< 200 mg/L**
Standard Deviation	2.20	0.25		

4.7: Turbidity Test Results

According to the turbidity test results, the levels indicate that filtration will be included in the water treatment design. Due to the standard deviation being low the results are accurate. The turbidity test results are shown below in Table 4-8. The results indicate that the surface stormwater turbidity does not fit water quality standards due to being too high. However, through the ASHRAE water chemistry requirement taken from 'Liquid Cooling Guidelines for Datacom Equipment Centers', the turbidity requirements for the cooling process is less than 20 NTU. Therefore, the turbidity levels are fit for the cooling process and do not require treatment.

Table 4-8: Turbidity Test Results

Sample No.	Tank Water (NTU)	Surface Water (NTU)	Standard (EPA)	Standard (ADEQ)
1	3.03	29.10		
2	3.54	29.60		
3	2.85	29.10		
Average	**3.14**	**29.27**	**< 5 NTU**	**< 5 NTU**
Standard Deviation	0.36	0.29		

4.8: TSS Test Result

The stormwater results for TSS are shown below in Table 4-9. The concentration of TSS in the samples are higher than the EPA and ADEQ standard requirements. Therefore, TSS will need to be treated for the design system to prevent long term clogging and pipe damage.

Table 2-9: TSS Test Results

Sample No.	Tank Water (mg/L)	Surface Water (mg/L)	Standard (EPA)	Standard (ADEQ)
1	90	176		
2	110	228		
3	64	230		
Average	**88**	**211.33**	**N/A**	**< 25 mg/L**
Standard Deviation	23.07	30.62		

4.9: TDS Test Results
The results of Total Dissolved Solid in the stormwater are shown in Table 4-10. The concentration of detention tank water is lower than the EPA and ADEQ standards, but the concentration of surface water is higher than the EPA and ADEQ standards. This error may be due to faulty lab equipment.

Table 4-10. TDS Test Results

Sample No.	Tank Water (mg/L)	Surface Water (mg/L)	Standard (EPA)	Standard (ADEQ)
1	306	2042		
2	222	2150		
3	1,938	2076		
Average	**264**	**2089.33**	**< 500 mg/L**	**< 500 mg/L**
Standard Deviation	59.40	55.22		

5.0: Stormwater Treatment Alternatives
Since the stormwater testing indicated that TSS and pH do not meet EPA and ADEQ Standards, the team had to determine appropriate treatment solutions. The stormwater treatment includes the possible technologies outlined below.

The option evaluated to remove TSS from the stromwater include the following technologies: reverse osmosis, activated carbon filter, and pressurized sand filtration. The reverse osmosis is highly effective for removal of TSS and easy to maintain, although it is expensive to construct. Reverse osmosis filters water with high precision, as well as removes heavy metals and scales. Activated carbon filters are small in size and can even be used in line. Activated carbon removes TSS, as well as VOC and odors. For the pressurized sand filter has minimal cost and is easy to maintain.

The TSS treatment decision matrix in Table 5-1 was used to depict which TSS treatment best suites the overall design. The scales parameters used for treatment evaluation include effectiveness, capital cost, the size dimensions, and maintenance duration. The scale parameter scoring ranges from one to three, where three is the best case scenario and one is the worst case scenario. The points for each of the scale paraments are outlined in Table 5-2.

Table 5-1: TSS Decision Matrix

Scale Parameter	Weight (%)	Reverse Osmosis		Activated Carbon Filter		Pressurized Sand Filtration	
		Point	Total	Point	Total	Point	Total
Effectiveness	40	3	1.2	3	1.2	3	1.2
Cost	20	1	0.2	2	0.4	3	0.6
Size	20	1	0.2	1	0.2	2	0.4
Maintenance Occurrence	20	3	0.6	1	0.2	3	0.6
Total	100		2.2		2		2.8

Table 5-2: TSS Treatment Scale Factors

Scales				
Points	**Effectiveness**	**Cost**	**Size**	**Maintenance**
1=	reduce TSS < 30 mg/L	More than $3000	More than 30000 in3	less than 6 months
2=	reduce TSS < 25 mg/L	$2000-$3000	20000-30000 in3	6-8 months
3=	reduce TSS < 20 mg/L	Less than $2000	less than 20000 in3	more than 8 months

The decision matrix aided in determining that the TSS treatment that best fits our design is a pressurized sand filter. Based on the flowrate which is 200 gpm, the filtration number for treatment was calculated using the following equation:

$$N = 0.0195 * Q^{0.5}$$

The filter number was determined to be 1. By using the flowrate and filter number, the filter rate was calculated to be 6.048m^2 with a dimeter of 1.378m. Next, the media was chosen to find the height of the tank. Figure 5-1 shown below demonstrates the layout and dimensions of the pressurized sand filter that will be used for the TSS treatment.

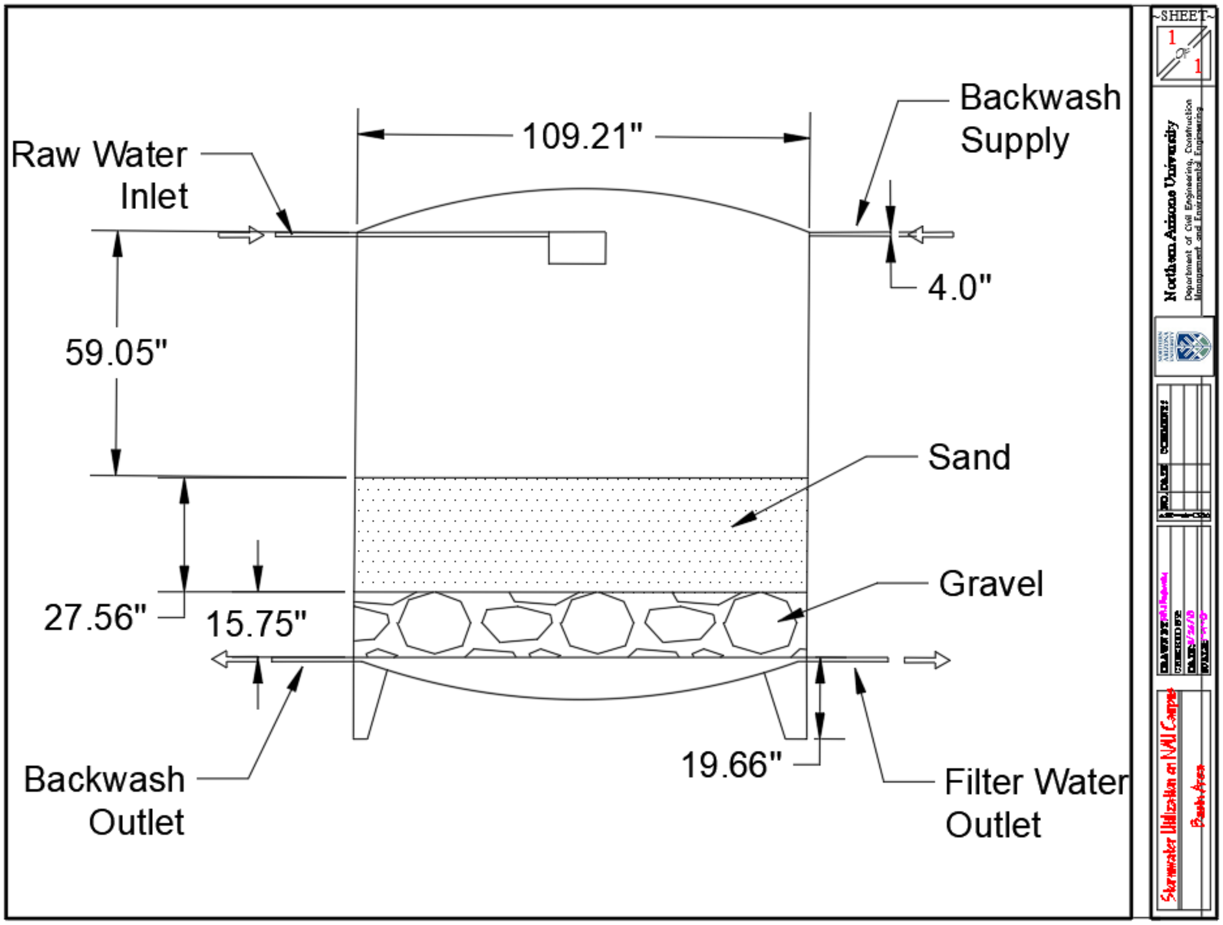


Figure 5-1. TSS Pressurized Sand Filter

For pH treatment, two chemical treatments were evaluated. The two pH solutions evaluated for the system were sodium hydroxide and calcite and calcite-corosex blend neutralizers. The benefit of sodium hydroxide is that it will not influence the hardness of water. Sodium hydroxide may easily increase the pH, but it is costly to use. The calcite-corosex blend neutralizers can be used as an inline pH adjustor. Calcite and calcite-corosex blend neutralizers can be easily accessed and have a low cost. The maintenance duration is more than 6 months for calcite and calcite-corosex blend neutralizers. However, calcite and calcite-corosex blend neutralizers do influence the hardness of water.

The pH treatment decision matrix in Table 5-3 was used to depict which pH treatment best suites the overall design. The scale parameters used for pH treatment include effectiveness, chemical cost, and maintenance cost. The scale parameter scoring ranges from one to three, where three is the best case scenario and one is the worst case scenario. The given points for each of the scale paraments are outlined in Table 5-4.

Table 5-3: pH Decision Matrix

Scale Parameter	Weight (%)	Add Sodium Hydroxide		Calcite &Calcite-Corosex Blend Neutralizers	
		Point	Total	Point	Total
Effectiveness	40	3	1.2	3	1.2
Chemical Cost	30	1	0.3	3	0.9
Maintenance Cost	30	3	0.9	3	0.9
Total	100		2.4		3

Table 5-4. pH Treatment Scale Factors

Scales			
Points	**Effectiveness**	**Cost**	**Maintenance**
1=	Raise range low	more than $0.08/kg	Hard
2=	Raise range medium	$0.05-0.08 /kg	Medium
3=	Raise range High	less than $0.05/kg	Easy

The pH decision matrix aided in determining that the TSS treatment that best fits our design is an in-line Calcite and Calcite-Corosex Blend Neutralizer injector. Through research for treatment ability, 1 cubic feet calcite-corosex can treat 1,278,730 gallons low pH water. The pipe network for the design system was diameter of four inches. Based on the pH treatment velocity, the injector diameter is required to be six inches. Figure 5-2 shown below demonstrates the layout and dimensions of the in-line Calcite and Calcite-Corosex Blend Neutralizer injector that will be used for the pH treatment.

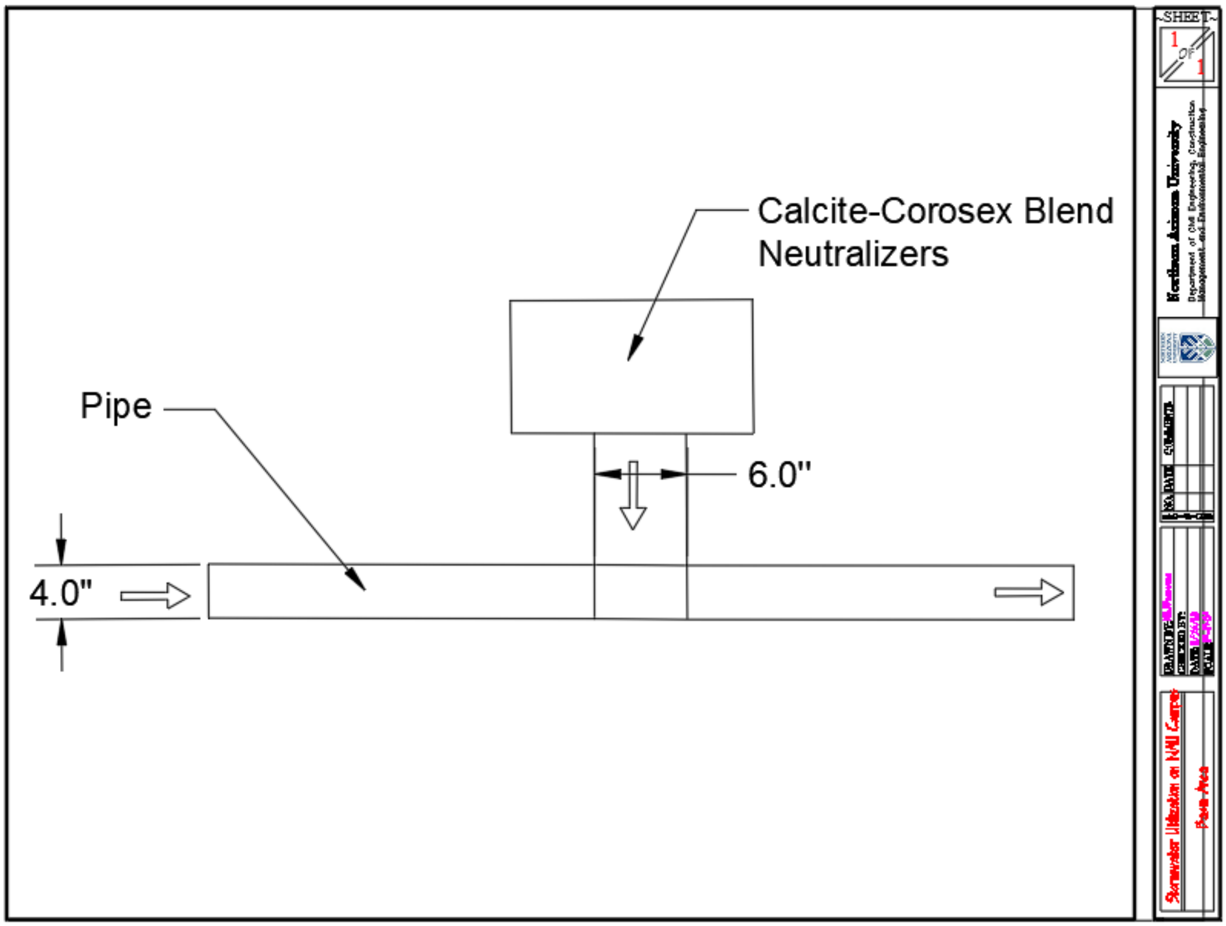


Figure 5-2: In-line pH Injector

6.0: Hydraulic Design Alternatives

The hydraulic design alternative includes designing a pipe network and determining an appropriate pump for the overall system. The design will start from the bottom of manhole 2 and terminate the remote sump, located in the Heating and Cooling Plant. The following sections outline the process for determining the pipe network and pump selection.

6.1: Pipe Network Design

Currently stormwater from tank 1 and tank 3 are flowing into tank 2, which the pumps the stromwater into a storm drain. Our pipe network will tie in at manhole 2 and continue to the Heating and Cooling Plant, were the stormwater will be treated and discharged into the remote sump. The pipe will be buried three feet below the ground surface after tying off of manhole, until the piping reaches the Heating and Cooling Plant where it will be brought above the ground surface for treatment and reuse. The piping material requested to be used by our client is C-900 PVC, which is a pressure pipe material. The overall system design will be pressurized, therefore the stormwater will be conveyed and treated without opening to the atmosphere until being discharged into the remote sump. Figure 6-1 shown below indicated the direction of flow and the tie in point for the pipe network.

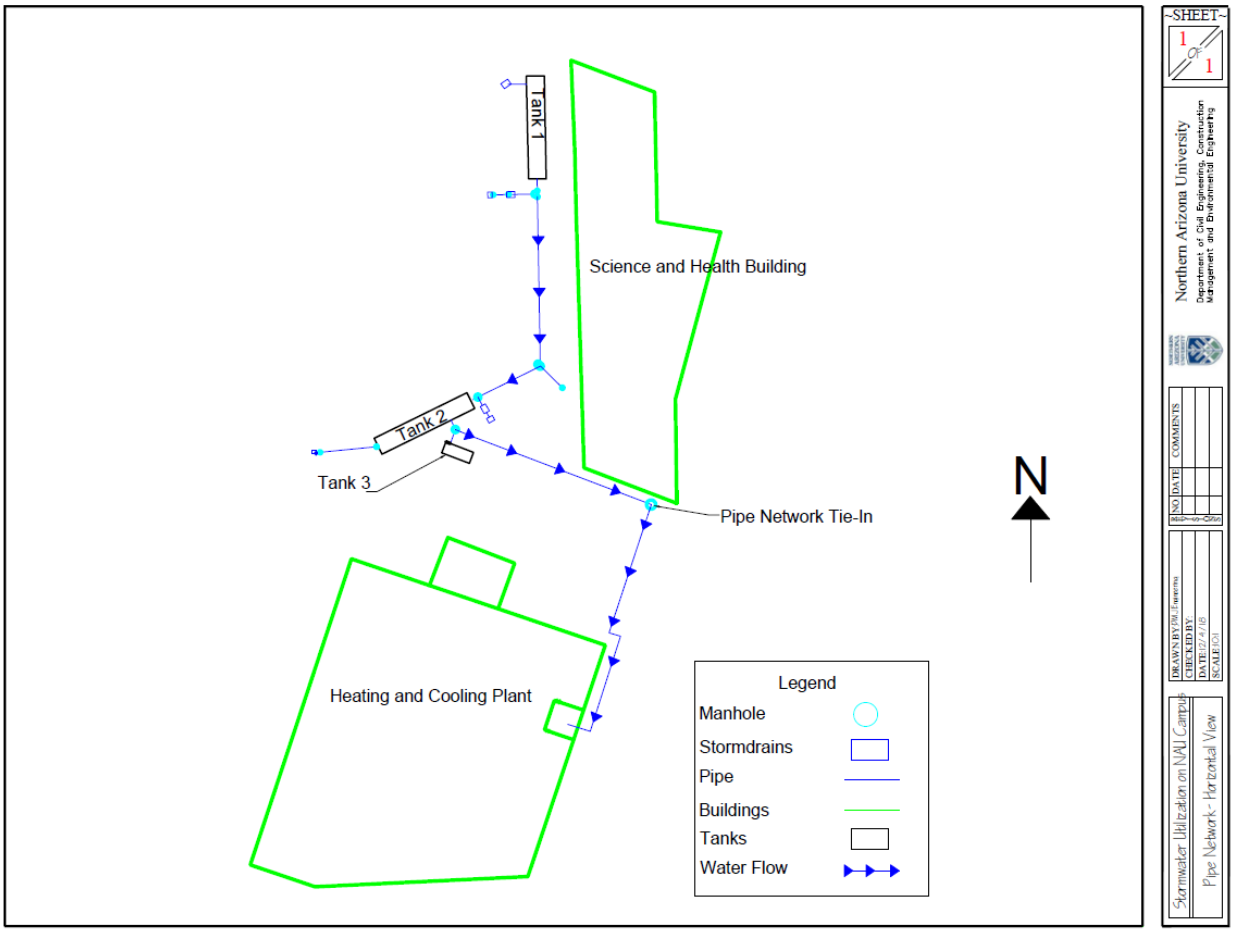


Figure 6-1: Pipe Alignment

A profile view of the pipe network is shown below in Figure 6-2, where the treatment and discharge location are demonstrated. The pump for the system will be place at the tie off point, at the bottom of manhole 2. The pipe then has a vertical increase till, three feet below the ground surface and continues till reach the Heating and Cooling Plant. The stormwater then enters the TSS and pH treatment. Next, the piping continues to the remote sump. There is a door located between the treatment and discharge point, therefore there is an increase of eight feet after treatment to go around the door outcropping. Then an additional seven feet increase is made to reach to top of the remote sump for the water to be discharged in for further use in the cooling process. Overall, the total length on the pipe network, including the horizontal and vertical change, was 288 feet.

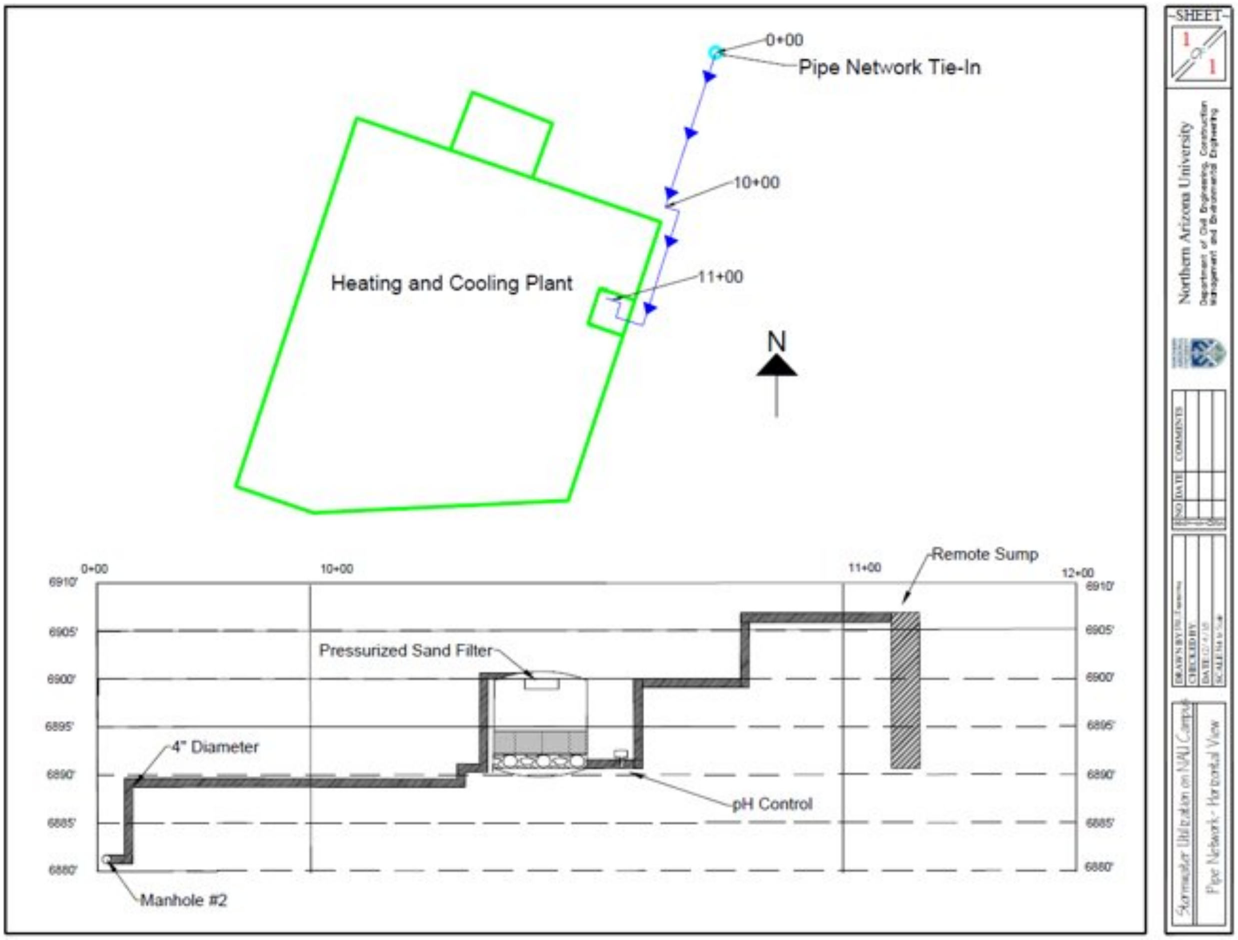


Figure 6-2: Profile Pipe Network

6.2: Pump Selection

The flowrate for the system must be less than or equal to the flowrate generated from the two pumps in parallel location at the bottom of tank two. Our system must be able to pump stormwater out of manhole two just as fast as it is being pumped in. The pump model for the pumps located at the bottom of tank 2 was provided in the Northern Arizona University Stormwater Drainage Report [3]. The pump model found for tank two is the EBARA Pump Model 50DSH61.5 (2HP) submersible sump pump [3]. The team found further information in regard to the provided pump model through an online manufacture's manual. The manual gave the performance curve for a single pump shown below in Figure 6-3.

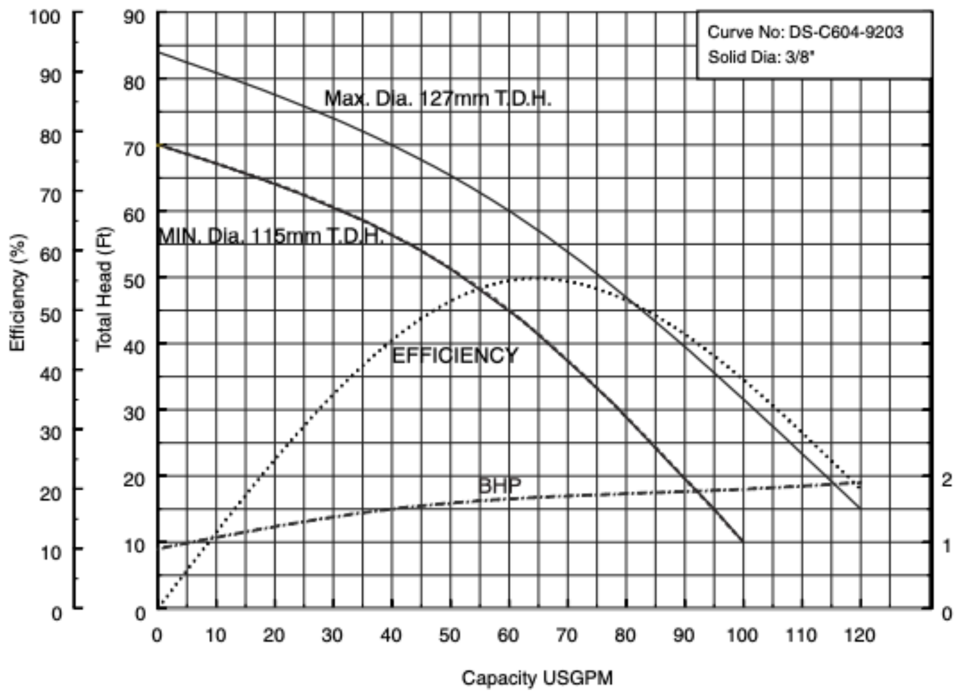


Figure 6-3: Tank Two Pump Performance Curve

Since tank two had two pumps in parallel, the capacity (flow) for the maximum diameter performance curve had to be doubled. The system curve for tank two was determine through an Excel system curve generator. The system curve generator is shown in Appendix C Figure C-1, where the length, diameter, minor loss coefficients, etc. are inputted. Excel then takes to known parameters and varies the flowrate to generate a system curve. The following figure shows the pump curve for a single pump (blue line), the pump curve for two pumps in parallel (orange line), and the system curve for tank two (gray line).

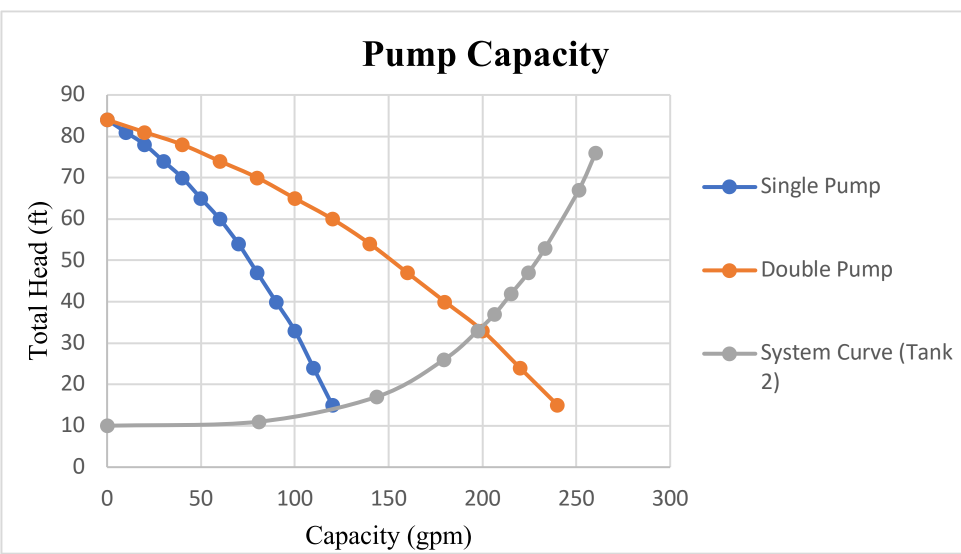


Figure 6-4: Tank 2 System Curve

The intersection point of the double pump and the system curve for tank two indicated the max capacity (flow) generated by the two pumps in parallel, which was 200gpm. Since the team had to design our system to be within the capacity of tank two, an additional system curve had to be generated for our design with the appropriate parameters. The total pipe length of the design pipe network and total dynamic head were calculated, then the diameter was varied until the system had a max capacity less than or equal to 200gpm. The system curve generator is shown in Appendix C Figure C-2, where the length, diameter, minor loss coefficients, etc. are inputted. Figure 6-5 shows the system curve for the design pipe network with a diameter of four inches.

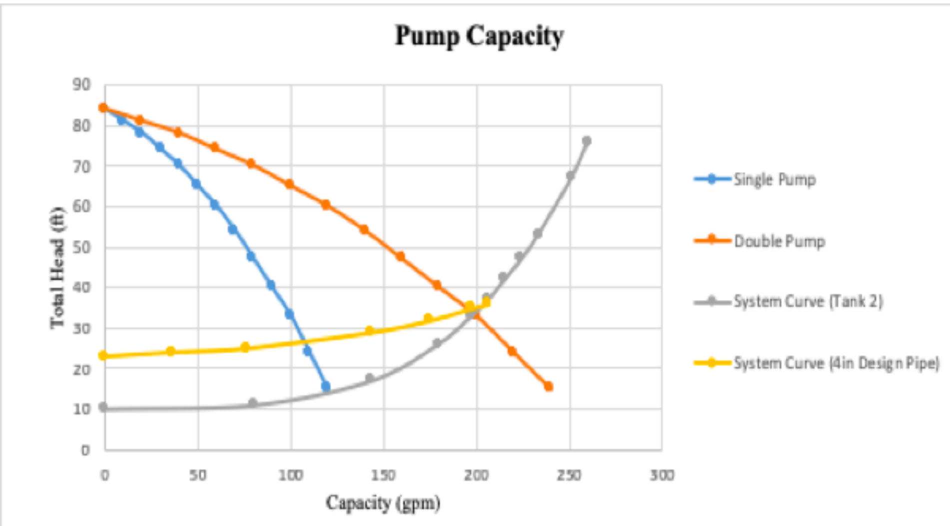


Figure 6-5: Design Pipe System Curve

The system curve for the design pipe with a diameter of four inches crossed the doubled pump curve at 193gpm, therefore the design system is within capacity of tank two's system. The team used the same pump model as tank two, the EBARA Pump Model 50DSH61.5 (2HP). Two pumps will be used in parallel to maximize the capacity of the design system.

7.0: Final Design

Overall, the final design started from the bottom of manhole number two to conveying the water to the Heating and Cooling Plant through a water treatment system inside Room 144, then to the remote sump. The design included two pumps in parallel to convey the water through a pressurized pipe all the way to the remote sump. The design included nine fittings, two valves, one pressurized sand filter, one calcite-corosex blend neutralizer, and about 300 feet of C900 PVC piping.

7.1: Design Conclusion

The overall design meets the client's requirements of using a pressurized pipe of C-900 PVC and designing the pipe network to the destination of the remote sump in the Heating and Cooling Plant. The design of the project met the requirement of treating the water in the Room 144 to domestic water standards to be used in the cooling cycle. The water was treated to domestic water standards by following the EPA and ADEQ standards. The piping met the requirements of following City of

Flagstaff regulations of having the piping three feet underground for the design. The project portrayed three impacts of following under a social, environmental, and economic. Using a natural resource in the overall project creates and environmentally friendly design. The use of reusing the stormwater also prevents from possible flooding within the area of the project site. The project helps the Heating and Cooling Plant economically by reducing the amount of serviced water paid for, since the stormwater will offset the need and cost of serviced water.

7.2: Cost of Implementation

The cost of implementation for the overall project is summarized in the Table 7-1 below. This includes the piping material per foot, the total cost for the two water treatment systems, and the two pumps within the design system. Each system within the design is provided with the cost per unit, which is multiplied by the quantity to get the total cost. The cost of the construction and labor for installing the C900 PVC pipe segments were provided through the book referenced by Agnes Drogi [10]. The fittings and valves were calculated through the pricing provided from The Home Depot [11,12]. The total capital cost came out to be about $8,608.

Table 3-1: Cost of Implimentation

Water Treatment	Quantity	Cost Per Unit	Unit	Total Cost ($)
Pressurized Sand Filtration	1	1500	LS	1500
Calcite-Corosex Blend Neutralizer	1	600	LS	600
Pipe Network				
4" PVC C-900 [10]	288	2.67	LF	768.96
Fittings [11]	9	2.42	LS	21.78
Valve [12]	2	46	LS	92
Pump				
EBARA Pump Model- 50DSH61.5 (2HP)	2	2000	LS	4000
Construction/Labor				
Pipe Segment [10]	288	5.642	LF	1624.896
			Total Cost	8607.636

8.0: Summary of Engineering Costs

The following tables showcase the engineering costs towards the completion of this project which includes the staffing, materials, and implementation costs.

8.1: Staffing Cost

Staff members for the project included a Senior Engineer, Engineer in Training (EIT), and a Lab Technician. Table 8-1 shows the anticipated hours of work for each staff member.

Table 8-1: Projected Staffing Hours

Task	Staff			Task Total
	Senior Engineer	EIT	Lab Technician	
1.0 Hydrologic Analysis	15	45	0	60
2.0 Water Testing	10	10	40	60
2.1 Stormwater Quality/ Initial Water Quality	5	5	20	0
2.2 Post Treatment Water Quality	5	5	20	0
3.0 Water Treatment Process Design	10	40	0	50
4.0 System Design	45	90	0	135
4.1 Pipe Network	15	30	0	0
4.2 Pump Network	15	30	0	0
4.3 Treatment Water Quality	15	30	0	0
5.0 Cost Analysis	15	50	0	65
6.0 Project Management	40	130	0	170
6.1 Meetings	0	0	0	0
6.1.1 Team Meetings	5	20	0	0
6.1.2 TA Meetings	5	20	0	0
6.1.3 Client Meetings	5	20	0	0
6.1.4 GI Meetings	5	20	0	0
6.2 Deliverables	0	0	0	0
6.2.1 30% Report	4	10	0	0
6.2.2 60% Report	4	10	0	0
6.2.3 Final Report	4	10	0	0
6.2.4 Website	4	10	0	0
6.2.5 Final Presentation	4	10	0	0
Staff Total (hr)	**135**	**365**	**40**	**540**

However, the actual hours of work for each staff member were less than the anticipated hours from CENE 476C. The variance in hours is due to Task 2.2 and 4.3 being removed from the scope, as well as over estimating the anticipated hours for each of the staff members. The actual hours of work for each staff member is shown below in Table 8-2.

Table 4-2. Actual Staffing Hours

Task	Staff			Task Total
	Senior Engineer	EIT	Lab Technician	
1.0 Hydrologic Analysis	5	13	0	18
2.0 Water Testing	7	15	68.25	90.25
2.1 Stormwater Quality/ Initial Water Quality	7	15	68.25	0
3.0 Water Treatment Process Design	6	30	0	36
4.0 System Design	11	24	0	35
4.1 Pipe Network	5	12	0	0
4.2 Pump Network	5	12	0	0
5.0 Cost Analysis	4	12	0	16
6.0 Project Management	48	162	0	210
6.1 Meetings	0	0	0	0
6.1.1 Team Meetings	11	44	0	0
6.1.2 TA Meetings	5	18	0	0
6.1.3 Client Meetings	3	9	0	0
6.1.4 GI Meetings	7	24	0	0
6.2 Deliverables	0	0	0	0
6.2.1 30% Report	6	8	0	0
6.2.2 60% Report	5	21	0	0
6.2.3 Final Report	6	13	0	0
6.2.4 Website	2	13	0	0
6.2.5 Final Presentation	3	12	0	0
Staff Total (hr)	**81**	**256**	**68.25**	**405.25**

8.2 Materials Cost

The materials cost is a summary of the lab material needed to complete the stormwater testing for the surface and detention tank water. The item number, item quantity, and the total cost were found from the HACH website for each of the water testing methods. The total cost for the stormwater testing is shown in Table 8-3.

Table 8-3: Materials Cost

Material Needed	Quantity	Item No.	Item Quantity	Total Cost ($)	Unit Cost ($)
Broth ampule, m-Endo	6	2373550	50/pkg	83.69	10.04
Membrane filter, 0.45 micron	6	1353001	200/pkg	161	4.83
Petri dish with absorbent pad, 47-mm	6	1471799	100/pkg	62.7	9.57
ManVer 2 Hardness Indicator Powder Pillow	6	85199	100/pkg	18.69	1.12
Hardness 1 Buffer Solution (1 mL per test)	6mL	42432	100ml	17.65	1.06
TitraVer Hardness Titrant (1mL per test)	6mL	102149	500mL	33.6	0.40
Test 'N Tube LR Total Nigtrogen Reagent Set	6	2672245	50 vials	159	19.88
NitraVer® Nitrate 5 Reagent powder pillow (10mL per test) <Powder pillows>	60mL	2106169	100/pkg	54.5	3.27
Nitrogen Ammonia, Reagent Set, High Range Test 'N Tube™ AmVer	12	2606945	100/pkg	109	15.26
filter and filter tray	6	2546100	100/pkg	172	10.32
Total					**75.75**

10.0: References

[1] US EPA. (2018). What is Green Infrastructure? | US EPA.
[2] Google Maps. (2018). *Flagstaff, Arizona*.
[3] Northern Arizona University Stormwater Drainage Report. (2013). Flagstaff: GLHN Architects & Engineers Inc.
[4] U. Network, "Heating and Cooling Process | Utility Services", *Fmo.unl.edu*, 2018.
[5] US Climate Data. (2018). Climate Flagstaff- Arizona and Weather Averages in Flagstaff.
[6]"Water Quality Testing and Analytical Instruments | Hach", *Hach.com*, 2018.
[7] Terry Baxter, Standard Method (2018). NAU Professor
[8]"PSEP: Fact sheets: Nitrate: Health Effects in Drinking Water", *Psep.cce.cornell.edu*, 2018.
[9]"Health Effects Information: Ammonia", *Oregon.gov*, 2018.
[10] RS Means - Reed Construction Data, Inc. - 2009
[11]"4 in. PVC 90-Degree Hub x Hub Elbow", *The Home Depot*, 2018.
[12]"4 in. PVC Solvent Socket Ball Valve", *The Home Depot*, 2018.

Appendices

Appendix A- Drainage Basin Locations

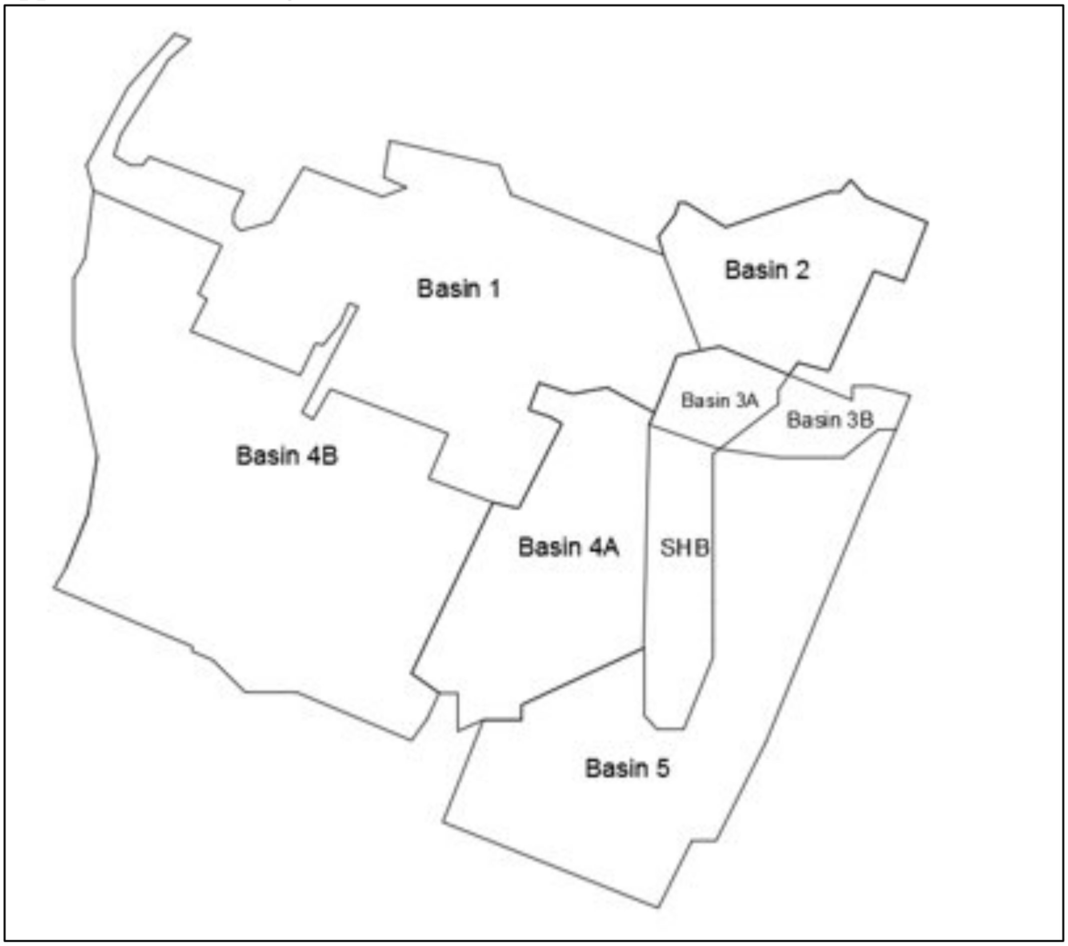


Figure A-1: Drainage Basin of the Water Being Collected in the Detention Tanks [3]

Appendix B- Average Precipitation and Snowmelt Data

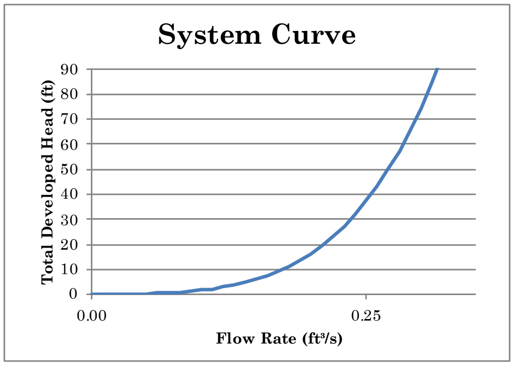
Table B-1: Average Precipitation and Snowmelt Data

Month/Year	*Water Equivalent (ft)	Average Daily Volume (gal)
Jan-16	0.47	41,436
Feb-16	0.11	9,859
Mar-16	0.04	3,262
Apr-16	0.11	10,007
May-16	0.18	16,159
Jun-16	0.08	7,264
Jul-16	0.43	38,027
Aug-16	0.25	22,608
Sep-16	0.18	16,382
Oct-16	0.07	6,597
Nov-16	0.31	27,204
Dec-16	0.40	35,951
Jan-17	0.39	34,320
Feb-17	0.00	-
Mar-17	0.31	27,204
Apr-17	0.02	1,483
May-17	0.02	2,076
Jun-17	0.00	-
Jul-17	0.66	58,411
Aug-17	0.36	31,652
Sep-17	0.07	6,078
Oct-17	0.00	-
Nov-17	0.00	371
Dec-17	0.00	-

Appendix C- System Curve Analysis

Tank 2 Pumps (2 in parallel)

T	60	°F
g	32.2	ft/s²
ν	1.21E-05	ft²/s
z_1	0	ft
z_2	10	ft
TSH		ft
D_1	0.166667	ft
$k_{s\,1}$	4.90E-06	ft
$k_{s\,1}/D_1$	2.94E-05	
A_1	0.022	ft²
L_1	20.0	ft
$K_{entrance}$	1	
K_{bend}	2	
K_{valve}	0	
K_{exit}	1	



Color Key
Givens
Calc'd for You
Your Calcs.

$$R_e = \frac{\bar{V}D}{\nu}$$

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

$$h_{Lf} = f\frac{L}{D}\frac{\bar{V}^2}{2g}$$

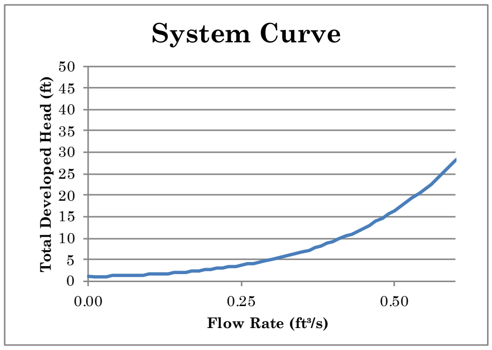
$$h_{Lm} = K\frac{V^2}{2g} =$$

Q (ft³/s)	V (ft/s)	R_e	f	$V^2/2g$ (ft)	h_{Lf} (ft)	Minor Losses (ft) Entrance	3 Bends	Valve	Exit	Total h_{Lm} (ft)	TDH (ft)
0.00	0.000	0.00E+00	0.0E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
0.01	0.4584	6.31E+03	3.5E-02	0.0032624	0.01	0.0032624	0.019574	0.000000	0.0032624	0.00	0
0.02	0.917	1.26E+04	2.9E-02	0.013050	0.05	0.0130497	0.07830	0.000000	0.013050	0.00	0
0.03	1.375	1.89E+04	2.6E-02	0.029362	0.09	0.029362	0.17617	0.00000	0.029362	0.01	0
0.04	1.833	2.53E+04	2.4E-02	0.052199	0.15	0.052199	0.31319	0.00000	0.052199	0.02	0
0.05	2.292	3.16E+04	2.3E-02	0.08156	0.23	0.081560	0.48936	0.00000	0.08156	0.05	0
0.06	2.750	3.79E+04	2.2E-02	0.11745	0.31	0.117447	0.7047	0.00000	0.11745	0.11	0
0.07	3.209	4.42E+04	2.1E-02	0.15986	0.41	0.159858	0.9592	0.00000	0.15986	0.20	1
0.08	3.667	5.05E+04	2.1E-02	0.20879	0.52	0.20879	1.2528	0.0000	0.20879	0.35	1
0.09	4.125	5.68E+04	2.0E-02	0.26426	0.64	0.26426	1.5855	0.0000	0.26426	0.56	1
0.10	4.584	6.31E+04	2.0E-02	0.32624	0.78	0.32624	1.9574	0.0000	0.32624	0.85	2
0.11	5.042	6.94E+04	1.9E-02	0.39475	0.92	0.39475	2.3685	0.0000	0.39475	1.25	2
0.12	5.500	7.58E+04	1.9E-02	0.46979	1.08	0.46979	2.8187	0.0000	0.46979	1.77	3
0.13	5.959	8.21E+04	1.9E-02	0.55135	1.24	0.55135	3.3081	0.0000	0.55135	2.43	4
0.14	6.417	8.84E+04	1.8E-02	0.63943	1.42	0.63943	3.8366	0.0000	0.63943	3.27	5
0.15	6.875	9.47E+04	1.8E-02	0.73404	1.61	0.73404	4.4043	0.0000	0.73404	4.31	6
0.16	7.334	1.01E+05	1.8E-02	0.8352	1.80	0.83518	5.0111	0.0000	0.8352	5.58	7
0.17	7.792	1.07E+05	1.8E-02	0.9428	2.01	0.94284	5.657	0.0000	0.9428	7.11	9
0.18	8.251	1.14E+05	1.8E-02	1.0570	2.23	1.05702	6.342	0.0000	1.0570	8.94	11
0.19	8.709	1.20E+05	1.7E-02	1.1777	2.46	1.17773	7.066	0.0000	1.1777	11.10	14
0.20	9.17	1.26E+05	1.7E-02	1.3050	2.70	1.30497	7.830	0.0000	1.3050	13.62	16
0.21	9.63	1.33E+05	1.7E-02	1.4387	2.95	1.43873	8.632	0.0000	1.4387	16.56	20
0.22	10.08	1.39E+05	1.7E-02	1.5790	3.20	1.57901	9.474	0.0000	1.5790	19.95	23
0.23	10.54	1.45E+05	1.7E-02	1.7258	3.47	1.7258	10.355	0.0000	1.7258	23.83	27
0.24	11.00	1.52E+05	1.7E-02	1.8792	3.75	1.8792	11.275	0.000	1.8792	28.25	32
0.25	11.46	1.58E+05	1.7E-02	2.0390	4.04	2.0390	12.234	0.000	2.0390	33.26	37
0.26	11.92	1.64E+05	1.6E-02	2.2054	4.34	2.2054	13.232	0.000	2.2054	38.91	43
0.27	12.38	1.70E+05	1.6E-02	2.3783	4.64	2.3783	14.270	0.000	2.3783	45.25	50
0.28	12.83	1.77E+05	1.6E-02	2.5577	4.96	2.5577	15.346	0.000	2.5577	52.34	57
0.29	13.29	1.83E+05	1.6E-02	2.7437	5.29	2.7437	16.462	0.000	2.7437	60.22	66
0.30	13.75	1.89E+05	1.6E-02	2.9362	5.62	2.9362	17.617	0.000	2.9362	68.97	75
0.31	14.21	1.96E+05	1.6E-02	3.1352	5.97	3.1352	18.811	0.000	3.1352	78.63	85
0.32	14.67	2.02E+05	1.6E-02	3.3407	6.32	3.3407	20.044	0.000	3.3407	89.28	96
0.33	15.13	2.08E+05	1.6E-02	3.5528	6.69	3.5528	21.317	0.000	3.5528	100.98	108
0.34	15.58	2.15E+05	1.6E-02	3.7714	7.06	3.7714	22.628	0.000	3.7714	113.78	121
0.35	16.04	2.21E+05	1.6E-02	3.9965	7.44	3.9965	23.979	0.000	3.9965	127.77	135
0.36	16.50	2.27E+05	1.5E-02	4.2281	7.83	4.2281	25.369	0.000	4.2281	143.01	151
0.37	16.96	2.34E+05	1.5E-02	4.4662	8.23	4.4662	26.797	0.000	4.4662	159.58	168
0.38	17.42	2.40E+05	1.5E-02	4.7109	8.65	4.7109	28.266	0.000	4.7109	177.54	186
0.39	17.88	2.46E+05	1.5E-02	4.9621	9.06	4.9621	29.773	0.000	4.9621	196.98	206
0.40	18.33	2.53E+05	1.5E-02	5.2199	9.49	5.2199	31.319	0.000	5.2199	217.98	227

Figure C-1: Tank 2 System Curve Analysis

Designed System

T	60	°F
g	32.2	ft/s²
ν	1.21E-05	ft²/s
z_1	0	ft
z_2	23	ft
TSH		ft
D_1	0.333333	ft
$k_{s\,1}$	4.90E-06	ft
$k_{s\,1}/D_1$	1.47E-05	
A_1	0.087	ft²
L_1	288.0	ft
$K_{entrance}$	1	
K_{bend}	9	
K_{valve}	2	
K_{exit}	1	



Color Key
Givens
Calc'd for You
Your Calcs.

$$R_e = \frac{\bar{V}D}{\nu}$$

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

$$h_{Lf} = f\frac{L}{D}\frac{\bar{V}^2}{2g}$$

$$h_{Lm} = K\frac{\bar{V}^2}{2g}$$

Q (ft³/s)	V (ft/s)	R_e	f	$V^2/2g$ (ft)	h_{Lf} (ft)	Minor Losses (ft) Entrance	3 Bends	Valve	Exit	Total h_{Lm} (ft)	TDH (ft)
0.00	0.000	0.00E+00	0.0E+00	0.00	1.17	0.00	0.00	0.00	0.00	0.00	1
0.01	0.1146	3.16E+03	4.4E-02	0.0002039	1.18	0.0002039	0.005505	0.000408	0.0002039	0.00	1
0.02	0.229	6.31E+03	3.5E-02	0.000816	1.19	0.0008156	0.02202	0.001631	0.000816	0.00	1
0.03	0.344	9.47E+03	3.1E-02	0.001835	1.22	0.001835	0.04955	0.00367	0.001835	0.00	1
0.04	0.458	1.26E+04	2.9E-02	0.003262	1.25	0.003262	0.08809	0.00652	0.003262	0.00	1
0.05	0.573	1.58E+04	2.7E-02	0.00510	1.29	0.005098	0.13763	0.01020	0.00510	0.00	1
0.06	0.688	1.89E+04	2.6E-02	0.00734	1.34	0.007340	0.1982	0.01468	0.00734	0.00	1
0.07	0.802	2.21E+04	2.5E-02	0.00999	1.39	0.009991	0.2698	0.01998	0.00999	0.00	1
0.08	0.917	2.53E+04	2.4E-02	0.01305	1.45	0.01305	0.3523	0.0261	0.01305	0.01	1
0.09	1.031	2.84E+04	2.4E-02	0.01652	1.51	0.01652	0.4459	0.0330	0.01652	0.01	2
0.10	1.146	3.16E+04	2.3E-02	0.02039	1.58	0.02039	0.5505	0.0408	0.02039	0.01	2
0.11	1.261	3.47E+04	2.3E-02	0.02467	1.65	0.02467	0.6661	0.0493	0.02467	0.02	2
0.12	1.375	3.79E+04	2.2E-02	0.02936	1.73	0.02936	0.7928	0.0587	0.02936	0.03	2
0.13	1.490	4.10E+04	2.2E-02	0.03446	1.82	0.03446	0.9304	0.0689	0.03446	0.04	2
0.14	1.604	4.42E+04	2.1E-02	0.03996	1.91	0.03996	1.0790	0.0799	0.03996	0.05	2
0.15	1.719	4.74E+04	2.1E-02	0.04588	2.01	0.04588	1.2387	0.0918	0.04588	0.07	2
0.16	1.833	5.05E+04	2.1E-02	0.0522	2.11	0.05220	1.4094	0.1044	0.0522	0.08	2
0.17	1.948	5.37E+04	2.0E-02	0.0589	2.21	0.05893	1.591	0.1179	0.0589	0.11	2
0.18	2.063	5.68E+04	2.0E-02	0.0661	2.33	0.06606	1.784	0.1321	0.0661	0.14	2
0.19	2.177	6.00E+04	2.0E-02	0.0736	2.44	0.07361	1.987	0.1472	0.0736	0.17	3
0.20	2.29	6.31E+04	2.0E-02	0.0816	2.56	0.08156	2.202	0.1631	0.0816	0.21	3
0.21	2.41	6.63E+04	2.0E-02	0.0899	2.69	0.08992	2.428	0.1798	0.0899	0.25	3
0.22	2.52	6.94E+04	1.9E-02	0.0987	2.82	0.09869	2.665	0.1974	0.0987	0.30	3
0.23	2.64	7.26E+04	1.9E-02	0.1079	2.96	0.1079	2.912	0.2157	0.1079	0.36	3
0.24	2.75	7.58E+04	1.9E-02	0.1174	3.10	0.1174	3.171	0.235	0.1174	0.43	4
0.25	2.86	7.89E+04	1.9E-02	0.1274	3.25	0.1274	3.441	0.255	0.1274	0.50	4
0.26	2.98	8.21E+04	1.9E-02	0.1378	3.40	0.1378	3.722	0.276	0.1378	0.59	4
0.27	3.09	8.52E+04	1.9E-02	0.1486	3.55	0.1486	4.013	0.297	0.1486	0.68	4
0.28	3.21	8.84E+04	1.8E-02	0.1599	3.71	0.1599	4.316	0.320	0.1599	0.79	5
0.29	3.32	9.15E+04	1.8E-02	0.1715	3.88	0.1715	4.630	0.343	0.1715	0.91	5
0.30	3.44	9.47E+04	1.8E-02	0.1835	4.05	0.1835	4.955	0.367	0.1835	1.04	5
0.31	3.55	9.79E+04	1.8E-02	0.1959	4.22	0.1959	5.291	0.392	0.1959	1.19	5
0.32	3.67	1.01E+05	1.8E-02	0.2088	4.40	0.2088	5.637	0.418	0.2088	1.35	6
0.33	3.78	1.04E+05	1.8E-02	0.2220	4.59	0.2220	5.995	0.444	0.2220	1.53	6
0.34	3.90	1.07E+05	1.8E-02	0.2357	4.77	0.2357	6.364	0.471	0.2357	1.72	6
0.35	4.01	1.10E+05	1.8E-02	0.2498	4.97	0.2498	6.744	0.500	0.2498	1.93	7
0.36	4.13	1.14E+05	1.7E-02	0.2643	5.16	0.2643	7.135	0.529	0.2643	2.16	7
0.37	4.24	1.17E+05	1.7E-02	0.2791	5.37	0.2791	7.537	0.558	0.2791	2.42	8
0.38	4.35	1.20E+05	1.7E-02	0.2944	5.57	0.2944	7.950	0.589	0.2944	2.69	8
0.39	4.47	1.23E+05	1.7E-02	0.3101	5.78	0.3101	8.374	0.620	0.3101	2.98	9
0.40	4.58	1.26E+05	1.7E-02	0.3262	6.00	0.3262	8.809	0.652	0.3262	3.30	9
0.41	4.70	1.29E+05	1.7E-02	0.3428	6.22	0.3428	9.254	0.686	0.3428	3.64	10
0.42	4.81	1.33E+05	1.7E-02	0.3597	6.44	0.3597	9.711	0.719	0.3597	4.01	10
0.43	4.93	1.36E+05	1.7E-02	0.3770	6.67	0.3770	10.179	0.754	0.3770	4.41	11
0.44	5.04	1.39E+05	1.7E-02	0.3948	6.90	0.3948	10.658	0.790	0.3948	4.83	12
0.45	5.16	1.42E+05	1.7E-02	0.4129	7.14	0.4129	11.148	0.826	0.4129	5.29	12

Figure C-2: Design System Curve Analysis