

Final Report

NET ZERO HOME: WATER SYSTEM

Margot Shore

Brittany Meraw

Opé Onipe

James Croth

Rudy Udovc

Rayan Haque

Ramsey Dupuis Gauthier



uOttawa

Dr. Muslim Majeed

GNG1103: Engineering Design

University of Ottawa

Abstract

This objective of this project was to provide sustainable and self-sufficient housing alternative to the Algonquin reservation at Barriere Lake. The net-zero house has to provide shelter, heat, water, and electricity to the residents, while also being modular and easy to transport. To accomplish this task, a group was created for each subsystem: water, construction, automation, and solar. As the water group, our task was to collect, filter, heat, and distribute the water to the residents. We ultimately achieved this goal by using a rainwater collection system that included gutters, collection tanks, and automated faucets. This report documents the steps, challenges, and solutions that we encountered throughout the design process.

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1 - Introduction

Millions of people around the world do not have access to sufficient housing, water, or electricity. While these issues are present and well known in third world countries, there is also a housing crisis much closer to home. The Algonquin reservation at Barrière Lake is facing an ongoing struggle to find suitable housing for its residents. Many houses are in disrepair, or do not have access to potable water due to contaminated lake water and an overloaded water treatment center.

In order to provide solutions for residents of Barriere Lake, the GNG1103 Design Class has been tasked with providing three net-zero homes. These homes must be entirely self sufficient; they have to provide electricity, heat, water, and shelter. All of the energy for the home is provided off-grid using solar panels, and the primary source of water will be rain. Once constructed, the home can effectively provide the basic necessities of life anywhere in the world, in particular in remote locations (such as Barriere Lake).

In addition to affordable housing, net-zero homes could help reduce carbon emissions. As the electricity and heating for the home is provided by completely renewable energy sources, the resulting carbon footprint is negligible (“net-zero”). On a larger scale, net-zero homes could drastically reduce carbon emissions and the world’s overall fossil fuel consumption. Net-zero homes could not only resolve housing crises in remote or impoverished areas, but also have enormous potential as more global initiatives are undertaken against climate change.

In our particular case, the students were divided into four specific groups to design each subsystem of the home. These groups were construction, automation, solar, and water. As the water system group, our task was to collect, filter, heat (in conjunction with the solar group), and distribute the water to the residents of the shed.

In order to accomplish this task, we employed the design-thinking model that was presented during the course. This model includes five steps; empathize, define, ideate, prototype, test. We began by meeting with the client to identify the needs and situation in Barrière Lake. After getting a better idea of the resources available to the residents and their needs, we did considerable research and benchmarking of available products. Finally, we began proposing designs for the water system.

At the ideate stage we began brainstorming (both individually and as a group) ideas for a design. Several themes recurred throughout the brainstorming process: due to the weather conditions, cost, and possibility of failure, we opted to not include a pump in the design. We also determined that several smaller tanks would be more effective than a single, large tank, and would allow the residents constant access to both hot and cold water. Both of these traits distinguished our water system from the other groups. Many of our design choices were dictated by the cost of materials, as we were given a \$100 budget for the entire system.

The final prototype of the shed was completed for Design Day (March 28, 2018). Our system was the only design that did not have a single outdoor collection tank or a pump, however we were the only group to provide running water to our

shed without excessive flooding. Overall, we are satisfied with the final design and believe that it will serve the future residents of the home well.

2 – Design Process

2.1 - The Client and the User

The client, Monique, is a representative of the Algonquins of Barriere Lake, a small community of 792 members located in Quebec, Canada. In the community the housing is no longer adequate for proper living. Much of the community's housing is in poor condition and requires significant improvement. Renovation would be ideal but is limited due to many external issues. These issues that run through the community can be aided through our shed. To provide a proper temporary residence for members of the community, we must be able to provide them usable water. To provide them with an adequate amount of water we must have an effective collection method, which will be done through the use of gutters and a water tank. The water should also be clean enough for proper use. Having unpotable water is not an option as our residents would not be able to use it, therefore a proper filter system is required for our water system.

After the collection and filtration of water, it must be distributed to the user; to resolve we will need something simple and effective, such as a tap. A preference for the distribution of the water would also be to provide an option for hot and cold water. Lastly, the water system has to be transportable, as the sheds will likely be moved to several different locations. This was not a problem because the water collection system took place in the shed and not the area surrounding the shed.

Finally, due to the remote location of the reservation, it is important that the system be intuitive and straightforward. We wanted the users to be able to make repairs (in the worst case scenario that the system fails in the long term) using the materials that were available to them; in other words, we did not want to rely on specialized materials such as pumps or replaceable filters as the system would be unusable in the case of failure.

The client gave us an overview of the situation in Barriere Lake during her first visit. Using both the information from Monique and our previous knowledge, we were able to identify a list of user needs and their relative importance. These needs are compiled in Table 1.

Table 1: Customer needs identification

Number	Need	Importance (1-5)
1	Access to a constant source of water (year round)	5
2	Running water in the shed	4
3	Drinkable/potable water	5
4	Availability of materials	3
5	Self-sufficiency	4
6	Aesthetic	1
7	Durability (to cold weather, wind)	4
8	Drainage system to remove used water	3

2.2 - Problem Statement

The main goal of this project was to build a shed that has the capabilities to provide water, electricity, and above all, to be portable while also covering the other

needs that were discussed with the client, Monique. Being the Water Team, our goal is to establish a year-round source of water for the shed. Therefore, we had to define our specifications further by having the requirements to collect, filter, and distribute the water throughout the shed.

Having a set budget, we needed to prioritize the collection and distribution of the water the most. The client prioritized that the Alonquins of Barriere Lake need a collection system so that the residents no longer need to transport water themselves from streams in the area. Moreover, the distribution of water is also a main concern as it will simplify their access to water and satisfy their need for running water in the home. We can condense our task as the water group into a single problem statement, which is:

The Alonquins of Barriere Lake require a reliable system to collect, filter, and distribute water that is suited to the environment and to the resources that are available to the community.

2.3 – Benchmarking

The design process is an intricate process that must be carried out to provide the best results for the client. A crucial aspect of the design process stems from the work of others and the hurdles they have encountered during similar projects. Our group was able to converse with past students of this design class. This was extremely helpful, giving us ideas as to where the tanks should be stored, size of pipes etc. Despite how helpful the information from past students was, we found that our project possessed a unique characteristic that other projects in the past

have lacked, notable the issue of the water pressure produced by the force of gravity and atmospheric pressure. This led our team to use the Internet as a major aid in the planning of our project. Through our research we were able to determine that a gutter/roof water shed collection method was optimal. With this method we could have the water flow from the gutters into our raised tanks allowing us to utilise our “pumpless” system. Preventing mistakes that have been made in the past can save an abundance of money and time when the proper research is done.

Many criteria needed to be met for the client and the users to be satisfied with our work. The client involved with our project had explained to us that currently the residents boil their water, and supplement their supply using nearby uncontaminated streams. This left one viable option for our team, the collection of water from precipitation.

The materials that were required for this project had to be extremely durable due to the harsh nature of northern Canadian winters. The materials also needed to withstand routine abuse from transportation, falling branches etc. The budget was 100\$, meaning our materials needed to be well made/efficient, yet inexpensive. The client preferred a minimal amount of routine maintenance to the water system.

Due to the nature of the water system, the benchmarking was performed for each individual component, rather than for the system as a whole. Typical rainwater harvesting systems are applied to much larger structures, and information regarding costs and materials varied significantly for each project and was not readily available online. The water barrel, tubing, filter, and gutters were all benchmarked independently to achieve the best overall benchmarking.

Table 2: Benchmarking water filtration alternatives

Specifications	Sediment	Solar	Slow Sand	Bamboo
Filter	Sediment Filtration	Solar Sterilization	Slow Sand Filter	Bamboo Charcoal Filter
Cost	\$8/6 months	None	\$15-\$60	\$4/month
Size	10 inches tall, 2.5 inches in diameter	Custom size	1 meter tall, 0.3 square meters	Custom size
Effectiveness	Removes 99.9% of bacteria	Removes between 9-86% of bacteria	Removes between 90%-99% of bacteria	Removes all organic impurities
Lifetime	Each filter lasts 6 months	Unknown	10 years	Each bamboo stick lasts 1-2 months
Maintenance	None	None	Little to none	Bamboo must be boiled once a week. Replace every 1-2 months
Flow Rate	3 gallon per minute	6 hours of sunlight to sterilize a volume of water	Up to 0.6 litres per minute, 36 litres an hour.	8 hours to sterilize a volume of water.

Table 3: Ranking water filtration alternatives

Specifications	Importance (weight)	Sediment	Solar	Slow Sand	Bamboo
Filter		Sediment Filtration	Solar Sterilization	Slow Sand Filter	Bamboo Charcoal Filter
Cost	2	2	3	1	2
Size	3	2	3	1	3
Effectiveness	5	3	1	3	3
Lifetime	3	2	1	3	1

Maintenance	3	3	3	2	1
Flow Rate	5	3	1	2	1
Total		55	37	45	39

Table 4: Benchmarking of gutter alternatives

Specifications	Vinyl	Aluminum	Steel	Copper
Cost	4\$-8\$ per 10 ft	6\$-12\$ per 10 ft	11\$-33\$ per 10 ft	40\$-100\$ per 10 ft.
Lifetime	Mediocre (Approximately 10 years)	Good (Approximately 20 years)	Good (Approximately 20 years)	Very Good (Approximately 50 years)
Health Concerns	None	Yes	None	None
Durability	-Easily warped/damaged -Susceptible to damage of extreme temperatures -Possible leaking issues	-Damage is possible but unlikely, can be easily dented, - Susceptible to damage of extreme temperatures	-No Concerns	-No Concerns

Table 5: Ranking of gutter alternatives

Specifications	Importance (weight)	Vinyl	Aluminum	Steel	Copper
Cost	3	3	2	2	1
Lifetime	3	1	2	2	3
Health Concerns	2	3	1	3	3
Durability	2	1	2	3	3
Total		20	18	24	24

Table 6: Benchmarking tubing/pipe alternatives

Specifications	PVC Pipe	Distribution Tubing	Eco-Lock Pipe	Copper Pipe
Cost	\$10.37/10 ft (\$1.04/ft)	\$16.28/100 ft (\$0.16/ft)	\$29.50/100 ft (\$0.30/ft)	\$19.29/6 ft (\$3.22/ft)
Material	PVC	PE Blend	Recycled Material	Copper
Size	¾ in x 10 ft	¼ in x 100 ft	½ in x 100 ft	¾ in x 6 ft
Weight	2.13 lb	1.8 lb	5.4 lb	2.51 lb
Temperature Range	Cold water use	Outdoor use	Cold water use	Cold/Hot water use

Table 7: Ranking of tubing/pipe alternatives

Specifications	Importance (weight)	PVC Pipe	Distribution Tubing	Eco-Lock Pipe	Copper Pipe
Cost	3	2	3	2	1
Material	3	2	2	3	2
Size	5	3	2	1	3
Weight	2	2	3	1	2
Temperature Range	3	3	2	3	3
Total		34	37	31	37

Table 8: Benchmarking collection barrels

Specifications	Plastic Rain Barrel + added spigot	Plastic Dock Rain Barrel	Rain Barrel Kit + Spigot
Water Capacity	55 gallons	45 gallons	55 gallons
Cost	\$48	\$20	\$90
Ease of Use	Self-installed Spigot	No Spigot	Installed Spigot

Table 9: Ranking of collection barrels

Specifications	Importance (weight)	Plastic Rain Barrel + added spigot	Plastic Dock Rain Barrel	Rain Barrel Kit + Spigot
Cost	3	3	2	3
Material	2	2	3	1
Size	2	2	1	3
Total		17	14	17

The benchmarking was extremely helpful when budgeting and determining the overall quality of the materials at our disposal. The key components of our system consisted of: water filtration, water barrel, tubing, and gutters.

For the water filtration system, it was determined that the sediment filtration system would be most effective for the criteria researched. The system had one of the best bacterial removals from all the four options and also has some of the better features such as its size, lifetime and maintenance. It was later found that the flow rate of such filter was poor, and adjustments were made to increase the water pressure in our tubing.

When deciding on rain barrels, the most efficient barrel was selected in terms of water capacity, cost, and ease of work. Initially the plastic dock rain barrel was chosen. This decision was made because it was one of the most cost-efficient barrels as we only have a \$100 budget in total and the barrel could hold 45 gallons of water. This choice was later changed to a much smaller 3-liter bucket. Two of these were used to store the water within the shed and reduce the amount of space taken up.

Furthermore, for the tubing used inside of the shed, the best option was found to be the distribution tubing. This was chosen due to its cost efficiency at only 0.16\$ per foot and it still stays within good range of its other criteria.

Finally, the vinyl gutters were determined to be the best fit for our budget and shed requirements. This material had no health concerns and it was the most cost-efficient option. Despite it having one of the lowest lifetimes from the others, it was still the best choice as it is easily replaced at a low cost and still lasts approximately 10 years

2.4 -Design Criteria

After identifying the user’s needs, our team developed design criteria that satisfy those needs, as portrayed in Table 10. The design criteria were moulded by the requirements and characteristics of the water system. The needs were separated into functional and non-functional requirements. The functional requirements affect the function of the project while the non-functional requirements do not. This identifies the importance of the needs to achieve the goal of having a functional water system.

Table 10: Design criteria translated from customer needs

Number	Need	Importance (1-5)	Functionality	Design Criteria
1	Access to a constant source of water (year round)	5	Functional	Maximum/minimum storage amount Cleanliness of water
2	Running water in the shed	4	Functional	Collection system Distribution system

3	Drinkable/potable water	5	Functional	Purity of water: <ul style="list-style-type: none"> • No visible debris • Water testing (pH, bacteria, etc.)
4	Availability of materials	3	Non-functional	Replacements to the Barriere Lake residents
5	Self-sufficiency	4	Functional	Simple design that can be easily repaired if necessary
6	Aesthetic	1	Non-functional	Neat construction/hidden tank and pipes through making a vanity
7	Durability (to cold weather, wind)	4	Functional	Minimum / maximum operable temperatures Max wind speed it can withstand
8	Drainage system to remove used water	3	Functional	Distribution system with clear flow pattern
9	Low cost	4	Functional	Stays within budget

Due to the unreliability of the water from near by water sources, the most viable option was the collection of water from precipitation. The materials required for the water system had to be extremely durable to withstand the harsh winds, cold temperature and snowfall in Quebec as well as the wear and tear from everyday use. This wear and tear includes transporting the system to remote location for hunting and falling branches etc. Minimal routine maintenance was admirable due to a lack of resources, skills and, tools in Barriere Lake to fix any problems that arise.

The design criteria were analyzed to produce a metric shown in Table 11. A metric, a list of measurable attributes for the system, was created to measure the performance of the water system where applicable using units of measure. The

metric is a combination of all the functional requirements derived from the customer needs.

Table 11: Functional requirements

Design Specification	Relation	Value	Units	Verification
Functional Requirements				
Running Water	=	Yes	N/A	Analysis/Test
Stored Water	>	45	Gallons	Analysis
Clean Water	=	Yes	N/A	Test
Self Sufficient	=	Yes	N/A	Test

Designing the water system in such a remote location as Barriere Lake, comes with several constraints. The most evident constraints are shown in Table 12 and correlate to the harsh weather conditions in this region as well as our miniscule budget.

Table 12: Constraints

Design Specification	Relation	Value	Units	Verification
Constraints				
Cost	=	100	\$	Estimate, Final check
Operating Conditions (Temperature)	=	-40 to 30	°C	Test
Operating Conditions (Wind)	=	0 to 25	mi/h	Test

Non-functional requirements for the water system are aspects of the design criteria that do not affect the functionality of the water system although they do improve the customer’s satisfaction of the final product. The non-functional requirements are analyzed in Table 13.

Table 13: Non-functional requirements

Design Specification	Relation	Value	Units	Verification
Non-Functional				
Product life	>	2	Years	Test
Aesthetic	=	Yes	N/A	Test
Reliability	=	Yes	N/A	Test
Availability of materials	=	Yes	N/A	Test

2.5 – Conceptual Designs

Each shed has a different water system, and the design of the water system is based off of each team’s solutions to the proposed problems. We found a couple of designs that would satisfy all the criteria given by the client, made several key decisions, and overcame a couple of major problems on our way to our final design.

There were three designs that our team made, based on the different designs proposed by our group members. Each design features the same gutter system, on one side of the shed.

One of the proposed designs included two tanks, one for hot water collection and one for cold water collection. There would be a filter featured after the tank before the water reaches the sink. Since there will be two tanks instead of one big tank, the tanks will be able to be positioned to economise space. This design’s purpose is to economise space without affecting the cost.

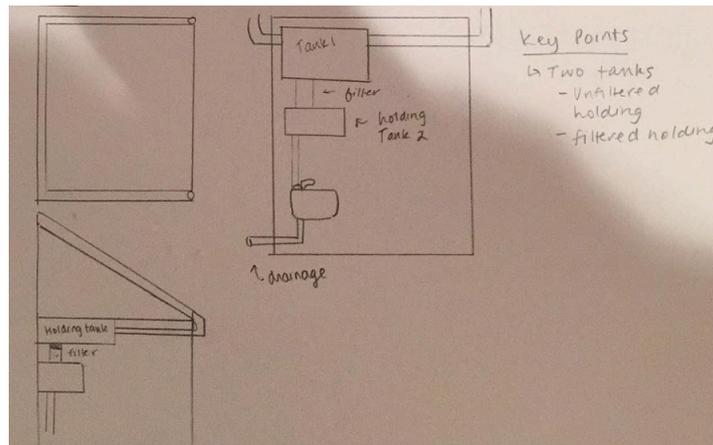


Figure 1: Conceptual Design 1 (Holding Tank)

The second proposed design included a foot pump and features the tank on the outside of the shed. This design would create a lot of space inside the shed and create water pressure. However, this design is not ideal, as the water may freeze in the winter, and the foot pump would overcomplicate the design.

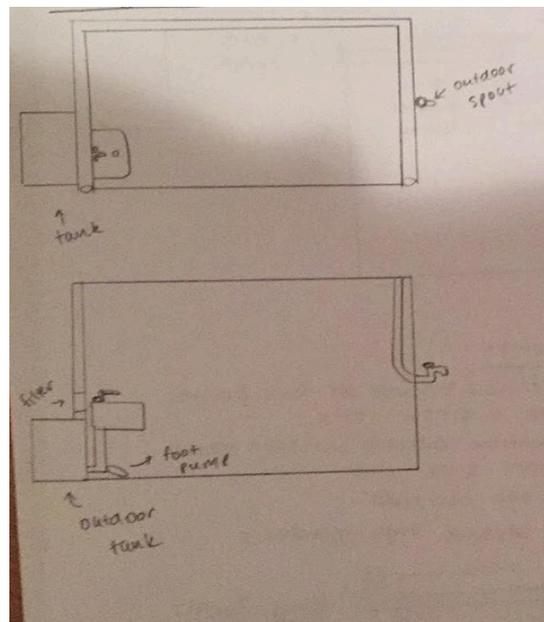


Figure 2: Conceptual Design 2 (foot pump)

The final design was a combination of the other designs, however, we eliminated the flaws. Our final design will have two tanks, and the filter inside the tanks. There will be a separation for the hot and cold water and the drain will be situated behind the sink.

Every design will be under the \$100 budget constraint.

2.6 – Final Design

Once we completed our conceptual designs and compared the results, we were able to confirm our final design. Our final design used gutters to collect the water. The water from these gutters was funnelled into a “colander,” which concentrated the flowing water into a much smaller stream. The outflow of the colander led into the tank through a network of vinyl tubes; the water was then split evenly between two tanks, via an inlet at the top of the tank. Although we had initially planned to incorporate three tanks (one being an overflow tank to store more cold water), we decided late in the construction process to eliminate the third tank, as it was unnecessary and overcomplicated the design.

Each tank had several outlets; the hot and the cold tanks had an overflow outlet at the top of the tank, and the main outlet that led to the faucet at the bottom of the tank. The hot water tank had an additional subsystem to heat the water. The construction and solar teams had built a wood stove as part of their design. Copper tubing was heated in the hot water tank, and carried hot air into the tank. This tube was coiled through the hot water tank, before exiting the tank and releasing hot air into the home. To ensure that the connections were watertight, specific barbs and hose adaptors were chosen whose threads effectively screwed

into the tank wall. All of the connections were reinforced with a waterproof sealant to further protect against leaks.

The outlet of the tanks led directly to two solenoid valves, which acted as faucets. The automation team was able to fully automate the faucets, and they are operated using switches on either side of the “vanity.” We also installed a metal sink, which disposes of wastewater using a network of PVC pipes out of the shed. The overflow tubing leads out of the tank and around the outside of the sink, before joining the disposal pipes outside the shed.

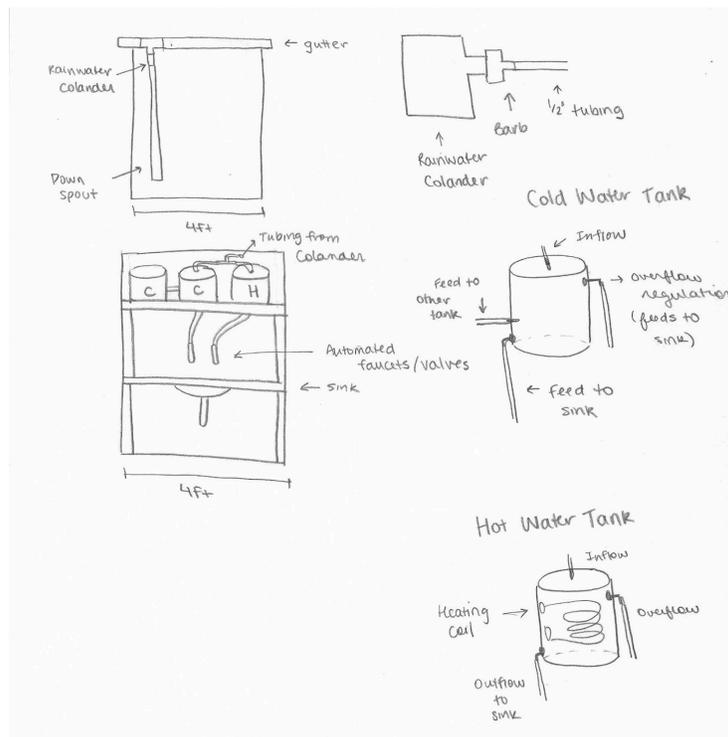


Figure 3: Sketch of Final Design

2.7 – Prototyping and Testing

2.7.1 Testing Criteria

As the final steps, prototyping and testing are one of the most crucial parts of the design thinking process. A prototype is a visual representation of the idea. It is

an model of the final project, and an illustration that allows for the various changes that we went through upon seeing what our ideas would look like when completed. The task at hand required that clean water was collected and distributed to the users, and three prototypes were made before deciding on the best final design.

Our testing protocol focused primarily on water quality and water retention. Although we would ideally want to test the pH level and purity of the water, we were limited to using the visual appearance and odour of the water as our main testing criteria. We also tested water retention; if the prototype retained 90% of the water that was used during a test, this was considered acceptable.

2.8.2 Initial Prototypes

The first prototype was created using simple items that can be located around the household, such as; an empty boxes, make-shift gutters (straws), one bottle that contained sand and rocks to act as a filter, and tape to put it all together. This was just a basic prototype, which did not show all of the features of the design. After the first round of prototyping, we were uncertain if we had the right sand to use as a filter and decided to perform testing using charcoal rather than sand.



Figure 4: Prototvne 1

The second prototype was more focused on the essential parts of the water system. It was a visual representation of all the internal components such as the downspouts flowing to the two buckets, then two filters and their flow to the tap and the sink, as well as the drainage from the sink. We used most of the same items as earlier, with the main change being the replacement of the sand with activated charcoal. We preferred the results of the activated charcoal, as we were unsure of the origin of the sand and would prefer to not add contaminants to the water.



Figure 5: Prototype 2

2.7.3 Final Prototype

The final prototype that we tested was our final design, however we specifically focused on the rainwater colander, which connected the external and internal systems of the shed. We had used a commercial product, which transported the water from the gutters and condensed it into a single stream, which led into the shed. The collar of the colander was extended using vinyl pieces in order to connect it to the gutters, and it was sealed with silicone. However, when tested, the colander underwent catastrophic failure. Little to no water was retained, and the silicone

proved to be a very weak sealant. To solve this issue, we constructed a homemade colander (with the exact dimensions of the gutter downspout) out of Plexiglas, which we installed and tested. This new colander/condenser proved to be much more reliable and watertight, as is consequently included in the final design.



Figure 6: Interior of final design



Figure 7: Water tanks of final design



Figure 8: Exterior of final design

3 - Conclusions and Recommendations

In conclusion, we were tasked with providing a solution for the shortage of housing the Algonquins of Barriere Lake face, more specifically the water system for the housing. This would act as a net zero home which is a viable residence for the residents of Barriere Lake as it is a self-sufficient form of housing. We had our first meeting with our client, Monique, and developed a list of needs and requirements to be included in our design. The client's needs and requirements were referenced to produce a set of achievable design criteria. After developing several designs, we

learned that there are several designs that satisfy the client's needs but due to the budget restrictions of \$100 most of these designs were not feasible. From the designs, we examined the functional requirements, customer's needs, and our design criteria, to select the design that was the most effective considering our timeline, budget and resources available. We then developed three prototypes each with a specific component that we wanted to test. Since our client was unable to attend our meeting, we took the feedback given from Dr. Majeed and the PM's on our design and altered our final design and future prototypes to incorporate their suggestions. Obtaining feedback on our design is not only an essential part of the design process but it enhances the quality of the final product. Finally, we constructed the water system insuring that we integrated the client's needs and feedback we were given throughout the design process.

We learned many valuable lessons while designing and implementing our ideas in the net zero home such as the importance of communication, time management and planning. As a team we had difficulty communicating which in the end resulted in us having to spend extra hours trying to complete the water system before Design day. Once our groups were made in the lab session, we developed a Facebook group to share essential information on the progress of the system as well as submission dates for deliverables. A Google drive folder was also created to organize and complete our deliverables. This Facebook group chat allowed for all the group members to discuss future meetings and plans for all lab sessions. This allowed for us to be more productive when we had our lab sessions. We needed to have better communication with the other groups. There was a miscommunication

with the construction team on which wall our sink and water tank were going on. This miscommunication delayed not only the construction team but also the solar and automation teams (who were also unsure of the layout of the home).

We learned the importance of time management and versatility. Despite having a plan with a specific timeline, we had to alter our plan to improve the overall design. For example, we planned to have gutters on all four walls, but we had to adapt our design to account for the connection of the net zero homes constructed by the students in the other lab sessions as well as the substantial expense of having gutters on all four walls. Throughout the design process, we had to alter our design to account for the lack of resources and time to complete the water system desired. We designed a sand filter but since we were not using a pump we did not think there was sufficient water pressure to filter the water effectively. We also did not want to further contaminate the water by using inadequate materials to construct the filter. We needed to manage our time better so that we did not set back the automation and solar team as they needed us to complete our part to implement some of their key components including the hot water tank and the faucet. It would have been beneficial to account for failure when we were planning and setting timelines for each task.

If we were to move forward with this project, there are a few aspects of our design we would like to adapt and add to our system. If we had more time and funds, we would first improve our sink drainage, tank and gutter connection so that they are leak proof. We would do this by adding a weatherproof sealant to all the drainage pipes as it is currently held together with electrical tape and silicone,

which is not weatherproof. We would also improve the aesthetics of our water system by adding a vanity, which includes a counter top that covers the plywood, cabinets with easy access to the plumbing and water tanks if anything were to malfunction. We would also find a way to incorporate a filter; although it may not be essential as we are collecting rainwater, it would put the clients at ease and provide additional filtration. Overall, we are very pleased with the water system for our net zero home design especially since our water system was the only functional water system at Design day. We look forward to seeing our design implemented in the future homes for the Algonquin's of Barriere Lake.