University of Michigan
ME 450 Capstone Project

Water Resiliency on North Campus:

Large Scale Water Storage and Treatment

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Professor Skerlos

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Executive Summary

Currently, in the United States, there are water shortages around the country, and the situation around water resources does not look to get any better. With climate change progressing, the future will bring more water shortages, with droughts and heat waves becoming more frequent. Rainfall patterns will shift, in many places trending to lower overall rainfall but increasingly severe individual rain events. Even beyond the borders of the United States, such shifts in water resources are occurring around the world.

This has led to our project: to collect, store and treat rainwater in order to provide water for North Campus' water needs, in an attempt to decrease our water dependency on the Huron River, which is currently the main source of water for North Campus, and Ann Arbor in general. While the Huron River looks to be a steady supply of water right now, and the University of Michigan likely having enough influence to secure enough water from the Huron River to meet North Campus needs for the foreseeable future, there are sustainability concerns with the status quo.

Our project is an exploratory project, which aims to provide the basis of a design that could be implemented in the future. Currently, the primary stakeholders are our team and Professor Skerlos. More distant stakeholders as of this stage include local utilities companies, UM administration, UM Office of Campus Sustainability, North Campus students, faculty, and staff, UM Custodial & Grounds Services, UM Facilities and Operations. the City of Ann Arbor, and Ann Arbor residents

Through research and benchmarking, we have been able to identify some key factors that we will look to address in our specifications which include, but are not limited to, treatment level, collection and distribution of rainwater, system materials/elements used, system insulation, rainwater capture volume calculations. We have also analyzed data on rainfall and water usage to provide initial estimates on the capacity needed for our storage units. From this, we have defined our stakeholder requirements and engineering specifications; our team generated 11 specifications based on 6 requirements, as presented in Table 1. The specifications with significant uncertainty are highlighted in red; these uncertain specifications will continue to be refined as we collect more data and work out the details of our concept.

The main engineering fundamentals relevant to our project are fluid dynamics, thermodynamics, statics, and material science. Storage volume and catchment area are the main design drivers, as they have a cascading impact on our decisions regarding water treatment, system design, and considerations of environmental and social sustainability.

We currently have a final design solution that has been partially verified/validated, with outlined plans for further verification and validation methods beyond our manpower and capability. Some current challenges that our team faces are uncertainties around the costs and construction disruptions that the university is willing to bear, issues around the judging and minimization of negative aesthetic impacts, and how best to incorporate modularity and the capability for expansion. We hope that our analysis and design will provide a solid foundation for future teams also working upon this problem of rainfall collection, storage, and treatment on the University of Michigan North Campus.

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Project Description

As we move forward in time, it is becoming abundantly clear that the world does not have an infinite amount of water suitable for human needs, one of our most important resources. This is plainly seen in the fact that in August 2021 the United States called a water shortage on the Colorado River [2]. With human-induced climate change being ever present, the situation around water resources only looks to get worse, both in the United States and around the globe. Heat waves are projected to increase, along with the length of dry seasons; while total precipitation is projected to fall, extreme precipitation events are projected to increase, especially in the Midwest [3][4]. Thus, issues surrounding water resources will be of prime importance in the future. Ann Arbor, Michigan, where the University of Michigan, Ann Arbor campus is located, currently pulls the majority of its water from the Huron River, which is then filtered through the City of Ann Arbor water system. UM, including North Campus, currently relies on the city to provide its water [5]. However, as seen with the Colorado River, we cannot say with certainty that this will continue to be an option ten, twenty, fifty years from now. In the future, the Huron River may become unable or unavailable to satisfy our water needs. Even if the Huron River remains an option, there will be sustainability concerns, both environmental (ecosystem damage to the Huron River and surrounding environs) and social (social equity issues around the fair distribution of water), should UM continue to draw an increasing large percentage of decreasing river water.

With this background, our project looks to explore options to capture, store and treat rainwater for North Campus' water needs. In an ideal scenario, all of the water needs on North Campus would be provided for via the capture of rainwater. However, due to many factors, such as rainfall amount, time constraints, scope of project, etc, we are looking at creating a system that will subsidize the current water use of North Campus to alleviate the dependency on the Huron River, with a focus on irrigation of vegetated areas of North Campus. In addition, this project looks to create a basis for further exploration of rainwater collection, storage, and treatment for the future, and lay out what we believe to be a viable pathway.

Intellectual Property

For this project, as of our current stage, there is no intellectual property at stake and thus we have not concerned ourselves with such.

Social Context Assessment

With creating a water storage system, there are certainly aspects that could affect the public's health and safety. For starters, we should address that the rainwater being captured for the project will be filtered to greywater standards for irrigation and thus will not be considered for potable use. This is important to note as if it was for potable use, we would have to be very articulate about how we filtered the water and about testing the water's quality every so many days. However, because it is for irrigation purposes, we are more than satisfied with the first flush system for greywater quality. The storage tanks themselves will be underground, which minimizes, but does not completely eliminate the chances of flooding and overpressurization leading to failure. Both these problems are addressed in our design. We will first have a control valve that will be communicating with the storage and tank and should close when the tank is full. There is also a drainage system which will go to the sewer system if there is too much water in the system which should minimize the chances of flooding. Lastly, there is a pressure relief design that will have a relief pressure of 10% higher than the maximum operating pressure that will be given in the tank specifications that we elected. One more thing that could lead to failure and be a cause of concern for public health is to make sure that water cannot flow backward in piping going out of the storage tank (outlet and drainage) which will build up pressure and may cause failure. This has been addressed by adding check valves in the outgoing pipes which will only allow flow in one direction.

In a global context, we hope that our project will demonstrate the theoretical viability of large-scale rainwater collection and storage systems, especially for large institutions like universities. Though every system must be tailored to its specific location due to differences in rainfall, appropriate methods of rainwater collection, and water needs, however, the adoption of rainwater collection and storage systems would help alleviate pressure on local water resources no matter the context.

We do not expect there to be many significant social impacts associated with the manufacture, use, and disposal of our design. We plan to use commercially-available parts; in that area, the only concern our team has is the recyclability of the four 25,000 gallon water tanks. These tanks are made of fiberglass which is a versatile material to use, and fiberglass can be made from recycled glass. However, fiberglass is known to be hard to recycle. We expect the environmental impacts that our solution will bring to outweigh the negative impacts of recyclability of the tanks. Taking North Campus irrigation off of the City of Ann Arbor water system will likely lead to a decrease in city revenue, which would have a social impact on city residents, but would also lower the costs borne by the city by reducing the overall amount of water they need to provide.

In terms of economic concerns, our team expects our solution to pay for itself. Our system will alleviate the costs of paying the City of Ann Arbor for capturing and filtering the water from the Huron river. Besides the upfront costs of installation and materials, the only other costs would be power to the pumps and occasional maintenance. All our parts and tanks are expected to be purchased from the manufacturer. General studies of these kinds of rainwater capture and storage systems point towards short payback times, which will likely also be true in this case.

In our social context assessment, we only used the stakeholder/ecosystem map to analyze those affected by our design. However, because of the exploratory nature of our project, we focus primarily on the needs of our primary stakeholders. We did not use any other tools such as the life cycle assessment of our materials because we felt that the items we included in our design was ultimately a recommendation to future teams and could be changed/swapped out if necessary.

Stakeholder Analysis

Because this project is still in an early stage, it is primarily exploratory. Because of this nature, the primary stakeholders of this project are limited to our team members and Professor Skerlos. We are the only ones who are currently working on the project and hence the only one affected by it at its current stage. We also additionally constitute as the only resource providers of this project. Once the project reaches its build stage (which is not in our project's scope) in the future, other resource providers will be introduced. As the project develops in the future, there will be some other distant stakeholders that will become more relevant as the project progresses. The UM Custodial and Grounds Services and UM Facilities and Operations are both considered as secondary stakeholders as beneficiaries and customers. Because of our shared goal, the UM Office of Campus Sustainability are also secondary stakeholders and considered as a part of complementary organizations/allies group on our ecosystem map. The last group we placed as a secondary stakeholder are local utilities companies who are considered supporters and beneficiaries of the status quo. Finally, we have the UM administration and City of Ann Arbor as additional beneficiaries and customers, BLUElab as complementary organizations/allies, and North Campus students, faculty and staff as well as Ann Arbor residents as affected/influential bystanders who are all considered our tertiary stakeholders. A diagram of our ecosystem and stakeholder map can be found below in Figure 1.

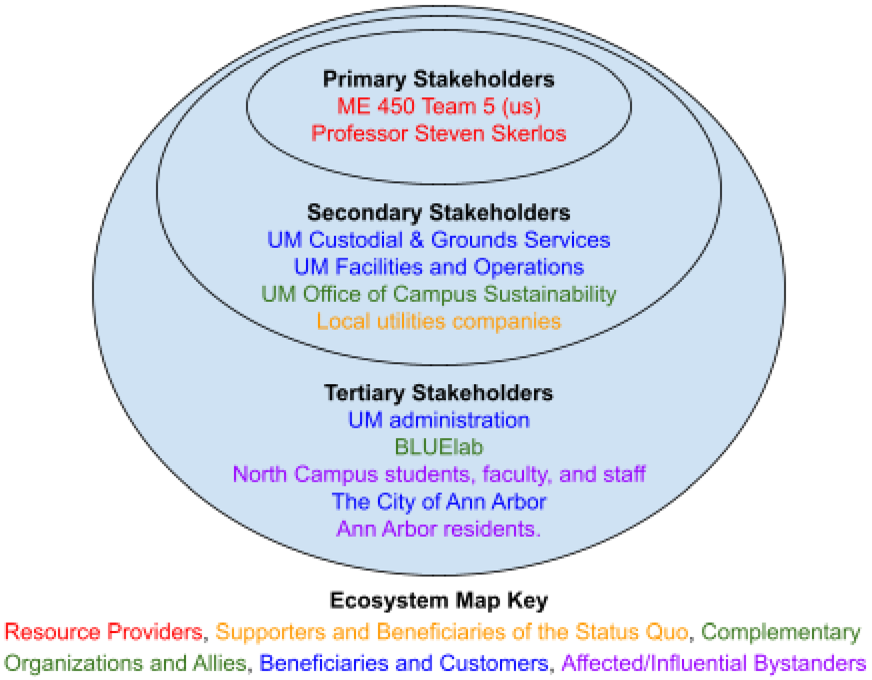


Figure 1. A combined stakeholder and ecosystem map of our project

Library

As a team, we have not engaged with the librarian, or other library staff, to any significant degree, but the resources of the University of Michigan Library have greatly benefited our project. In particular, the library was helpful in providing access to a variety of online scientific journals and databases, which we used to find articles and studies describing existing systems useful for benchmarking. We also relied on the library for databases about relevant standards, and to explore previous work done in a variety of relevant realms, like the sizing of gutters or material properties required for water storage tanks.

In terms of information gathering challenges experienced, the main issue was the lack of easy availability of information such as building plans for various North Campus buildings (in particularly building heights and roof layouts), and overall elevation maps of North Campus; this greatly hindered aspects of our analysis and validation/verification, particularly in the calculation of header pressure needed to transport water across North Campus from various points, and specification of piping layout. There was also not much information available on existing underground structures, which also complicated our attempts at tank placement and pipe routing.

Inclusion and Equity

Overall, due to our decision to not bring in external stakeholders beyond Professor Skerlos simplified the power dynamics and interactions over the course of the project. However, it still took some time to come to a balance regarding input from Professor Skerlos; especially in early weeks, we as a team overly focused on the BLUELab Living Building Challenge report that he initially provided and suggested we focus on, to the detriment of finding other benchmarks and obtaining a more balanced knowledge of how rainwater collection systems could be implemented.

We tried to balance the ideas selected to inform the project through group discussions of ideas, where everyone had the opportunity to bring up and comment on ideas. Input from Professor Skerlos was usually prioritized, especially when said input was around concerns about the feasibility of aspects of our design.

With regards to the impacts our individual identities, cultural perspectives, and experiences had on the project, these factors expressed themselves in different ways for different team members. Some team members had prior experience with certain aspects of the project, and thus were able to apply their expertise.

The members of this group come from very different cultural backgrounds, as we were raised and came up with different standards and cultural contexts. This allowed us to each have a very unique way of seeing the problem, and coming up with solutions. This was especially helpful in the concept generation stage where we were able to come up with many different solutions to the problem. Cultural diversity is very important in engineering groups as it allows a plethora of different minds to attack a problem head on with many different experiences in their background. Different cultures experience very different things, and thus having a group of very like minded people will result in a very narrow-headed approach to the problem, and eliminate other compelling solutions.

Ethics and Sustainability

As mentioned briefly further above, there are both social and environmental concerns regarding the current pattern of consumption of large amounts of water from the Huron River by the University of Michigan. These concerns, though they may not be severe currently, have the potential to be exacerbated by climate change in the coming years. In a future with less water, overdrawing on the Huron River will lead to disaster for the river’s aquatic and riparian ecosystem. In turn, this will also lead to the loss of an important recreational area for the local population. On a social front, should availability of water via the Huron River decrease, the issue of socially equitable distribution of water emerges; though the University of Michigan certainly has the political clout to guarantee water supplies, whether or not that would be in the best interests of Ann Arbor as a whole would be extremely questionable. These concerns are part of what drives our project.

In addition, related ethical and environmental considerations are a key portion of any design aimed at addressing this problem of water resources. Ethically, we have a responsibility to human safety and health; reflecting this commitment, we must make sure that the materials we select for our system, for both transportation and storage, will not result in contamination of the water. We cannot allow for any reasons, such as cheaper pricing, for a hazardous material to be used for this system. Likewise, we must also assure that the water quality is what we expect it to be, and that there are no shortcuts taken in making sure that this is achieved. This means testing many samples to make sure the selected treatment methods are providing water of the desired quality. A more far-sighted safety responsibility is to ensure that the system is adaptable to changing climate conditions, even those beyond our current predictions, by building in modularity and flexibility. It is imperative that the system does not transition from being a benefit to a liability due to unforeseen changes in the environment in which it is to operate. Environmental concerns include flooding, and water seepage/leakage. We recognize these issues, and have tasked ourselves to design a system that meets these requirements, both in terms of the system itself not releasing water in destructive ways, and in terms of the collection methods not causing flooding during rainfall events. In addition, we are aware of preexisting watersheds on North Campus, and have/will endeavor to not harm these ecosystems.

Design Process

Throughout the project, our team primarily used the ME 450 Design Process Framework. Once we started working on our project, one of our first steps was to determine the scope of our project and define the specific problem that we were trying to solve. During this step in the process, we reviewed different literature of similar problems and solutions that had been previously done as a way to set various benchmarks in our project. As a part of this step in our problem definition, we additionally met with Professor Skerlos, our primary stakeholder, twice a week to get his input as well as provide him a consistent update on the trajectory of our project. This allowed us to define our requirements and specifications of our design. The next step of the Design Process Framework was concept exploration. During this phase of our project, we used a variety of tools such as functional decomposition, design heuristics, TRIZ, morphological charts, and a pugh chart in order to come up with different ideas and choose a final design. Once we chose a final design, we began the solution development and verification phase of our design process. We conducted additional research and performed engineering analysis to help finalize the details of our design. Because our project had an exploratory nature, we were unable to completely verify all aspects of our design. While some specifications were verified through a quick calculation, we were unable to verify certain specifications in a practical manner. Instead, we came up with plans on how to verify our design once it was physically formed by future project teams. The design process of our project is currently left off with the culmination of our research and final design. We leave behind in this report our final recommendations for the future project teams after us to build upon.

The use of such a design process in every step of our project allowed us to keep a focus on our goal both in the long run and short term. As a team, we were constantly aware of what we were trying to reach as a final goal as well as what we were trying to accomplish on a weekly basis. The design process worked well into the natural flow of our project where aside from trying to meet a few deadlines, we were always on track and following the design process without trying to.

Scope and North Campus Statistics

After discussions with Professor Skerlos, we have decided to mainly consider the area of North Campus bounded by the four streets of Bonisteel, Beal, Hayward, Murfin, which emcompasses the area that is colloquially known as “The Grove”. To a large degree, this is an arbitrary limitation that we have placed upon ourselves in order to render the project something that is able to be contained within a single semester; the geographic scope will likely need to be expanded as this idea of rainwater capture, storage, and treatment for North Campus is iterated upon in future semesters of ME450.

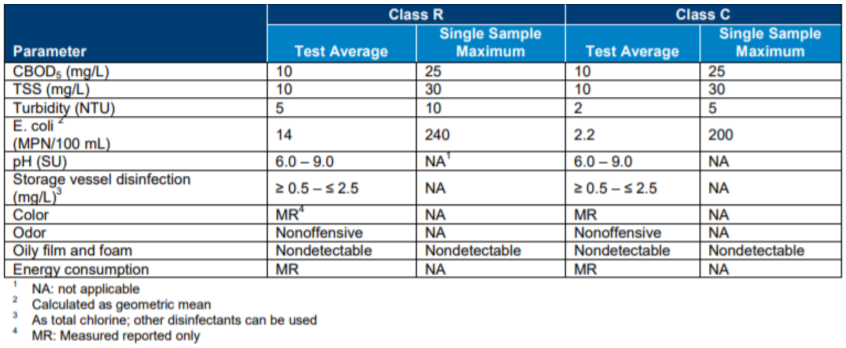
Initial rainfall data was obtained from Ann Arbor's Department of System Planning's rain gauge located on North Campus [6]. The data extends back up to 2013; across the past 9 years the average total amount of rainfall per year is 31.76 inches. We first looked at how much water this is for the grove as a preliminary estimate and given the area for the grove, the maximum amount of water that we can collect is about 3.5 million gallons. After this, we then extended our estimate to the main area of North Campus and received a maximum water estimate of about 53 million gallons. Aside from initial water estimates, because our project is working in the long term as a future goal, we plan to also use this data to extrapolate into 10-20 years into the future to help predict any changes in rainfall due to climate change.

Water use data for North Campus buildings was obtained from the Office of Campus Sustainability's Building Energy Data website; the total gallonage used by buildings within the area of consideration during the 2020 financial year was 62,278,480 gallons [7]. Water usage during the 2020 financial year was comparable to those of past financial years. Unfortunately, this data was not broken down by water treatment quality; as expressed through email correspondance, the Office of Campus Sustainability only had data from the city water meters [8]. For landscaping and irrigation, total yearly water use was estimated to be roughly 650,000 gallons per year, based on planted area, past water use figures [9], and irrigation system efficiency numbers [10]. Moving forward, the assumption is that these consumption levels will stay constant through the future.

From these numbers, it can be seen that while satisfying North Campus' overall water needs with rainfall alone is not possible, the available rainfall is more than able to fulfill all of its irrigation needs. Combined with the far more complicated concerns and regulations around treatment for the collected water to reach potable levels (equivalent to the majority of in-building water usage), we have decided to focus on irrigation as the end use of collected water in our design. This decision primarily impacts the treatment of collected water, with fewer effects on collection and storage. As with the limitation that we have placed upon ourselves in regard to the geographic area considered, this limitation to irrigation is something that we believe will be revised as future semesters of ME450 students continue to build upon our work.

Relevant Standards

In Chapter 3.1.1 of the 2012 EPA Guidelines for Water Reuse [11], it states that landscaping and recreational field irrigation is an acceptable use of reclaimed water. In our case, the water is not reclaimed, but from these guidelines we can derive relevant standards for the water quality required for such applications. Chapter 2.4.2 brings up the NSF/ANSI Standard 350 *Onsite Residential and Commercial Water Reuse Treatment Systems*, the details of which are presented below in Figure 2, which establishes water quality criteria for on-site systems (including for outdoor irrigation); we judge this standard as an acceptable target for our water quality treatment.



Parameter	Class R		Class C	
	Test Average	Single Sample Maximum	Test Average	Single Sample Maximum
$CBOD_5$ (mg/L)	10	25	10	25
TSS (mg/L)	10	30	10	30
Turbidity (NTU)	5	10	2	5
E. coli [2] (MPN/100 mL)	14	240	2.2	200
pH (SU)	6.0 – 9.0	NA[1]	6.0 – 9.0	NA
Storage vessel disinfection (mg/L)[3]	≥ 0.5 – ≤ 2.5	NA	≥ 0.5 – ≤ 2.5	NA
Color	MR[4]	NA	MR	NA
Odor	Nonoffensive	NA	Nonoffensive	NA
Oily film and foam	Nondetectable	Nondetectable	Nondetectable	Nondetectable
Energy consumption	MR	NA	MR	NA

[1] NA: not applicable

[2] Calculated as geometric mean

[3] As total chlorine; other disinfectants can be used

[4] MR: Measured reported only

Figure 2. NSF/ANSI Standard 350 *Onsite Residential and Commercial Water Reuse Treatment Systems* specifications for water quality, with Class R signifying residential systems, and Class C signifying commercial systems.

Benchmarks

As part of gathering information on our problem, we looked at several studies and projects on the same topic of rainwater harvesting. These were used to give us an idea of various routes that have already been explored, expand the solution space, and serve as benchmarks for our own ideas.

BLUELab Living Building Challenge [12]

One of the more interesting ones was the Living Building Challenge (LBC) done by a BLUElab team. In essence, their project was trying to take a historic house in Ann Arbor, and be able to capture, store and filter enough water to be able to provide all the water needs of this household from their shower to their sink. While this is on a much smaller scale than the project we are addressing (all of North Campus vs. one household), it did a very good job of explaining some of the engineering standards that we have to address.

The first important concept they covered was the filtration needed for the house. Given that the LBC project was covering all the water needs of a house, the water needs to be filtered to drinking levels, going into depth of different filtration methods, along with having a prefilter to get rid of bigger debris as shown in Figure 3 below. For our scope, we will only be using the water captured in North Campus for irrigation purposes, and thus do not need to reach such a high level of filtration.

Another standard discussed was source of supply and distribution. This encompassed calculating the catchment (collection) area necessary to get all the rainwater for the household's needs and also taking into account the material that is used in the catchment area. The Bluelab team was able to program a spreadsheet to calculate an estimated rainwater collection volume for specified collection areas and then use that to find the necessary size of the collection area. This was a very thorough way of finding the collection area, and something we will look to model after. They also talked about the considerations taken for transferring the rainwater from the collection area to the storage tank. They used the gutters there which they found out was leaking lead into the water, which they had to take care of. This is very important as any type of dangerous metals or chemicals must be addressed and removed from any water supplies going to the school.

Another engineering consideration was insulation on the piping and storage tanks to prevent any water from freezing. With Michigan winters, this is a very important consideration. Lastly, they had a water level sensor to be able to calculate the water level to be able to give useful information to the household along with knowing how much water is in the storage tank.

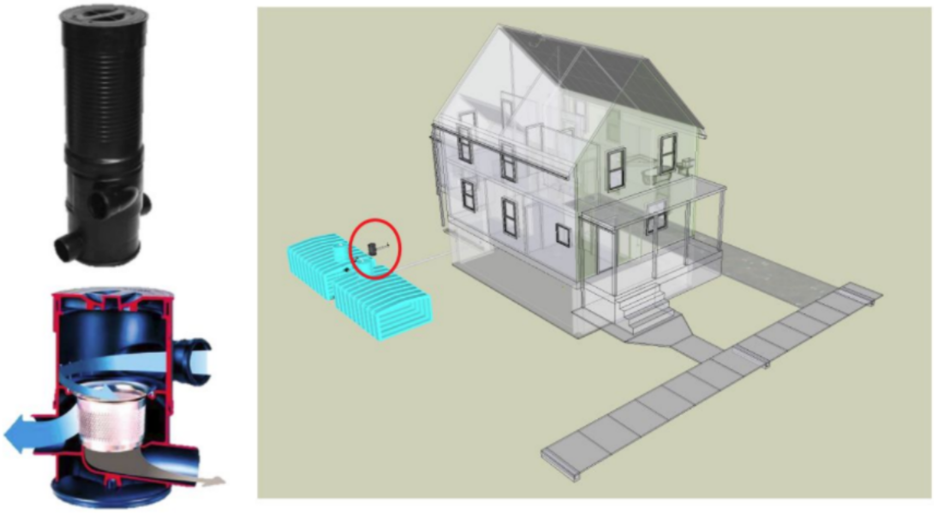


Figure 3. On the left, we can see the prefilter used by the BLUElab team in the LBC project. On the right we can see storage tank location in relation to the household, along with the prefilter location on the storage tank.

Kerbside Rainwater Collection in India [13]

There was an investigation and experimental approach done by S Mythili, M Kalamani, R Krishnaraj and B Soundarya, of the Bannari Amman Institute of Technology and Velalar College of Engineering and Technology, Erode, Tamil Nadu, India on kerbside rainwater collection . This team was influenced by climate change which has caused backlogs of rainwater in their drainage system. The team's design solution is to save some of this rainwater through fitted piping along the street and store the water. This is accomplished by using rain sensors to detect when it rains and trigger a motor that will open a valve. With this valve opened, the rainwater can run along the new piping and into storage. Our team used some of their subfunction ideas to inspire more ideas in the concept generation process. The subfunctions ideas include piping, rainwater sensors, motors, and sidewalks.

Vanishing Ponds and Regional Water Resources in Taoyuan, Taiwan [14]

Yuei-An Liou, Hsiao-Lan Liu, Tai-Sheng Wang, and Chin-Hung Chou, of the National Central University, Zhongli, Taiwan, R.O.C., the Taiwan Group on Earth Observations, Hsinchu, Taiwan, R.O.C., and the Taiwan Geographic Information System Center, Taipei, Taiwan, R.O.C. studied traditional Hakka artificial ponds, and their relations to water resource availability, in Taoyuan, Taiwan. These 2 to 3 meter deep ponds are dug in the impermeable soil with the dual purpose of collecting rainwater and containing floodwater during Taiwan's intense rainy season. The collected water was and is used for a variety of purposes, including crop irrigation and aquaculture. Aerial surveys estimate 37.6 to 56.4 million cubic meters of water storage capacity are available in the form of these ponds. However, processes like water treatment, and construction concerns like site placement and sizing were not mentioned. In addition, the climate, and specifically rainfall patterns, of Taiwan is vastly disparate from those of Ann Arbor.

A Review of Roof and Pond Rainwater Harvesting Systems for Water Security: The Design, Performance and Way Forward [15]

Husnna Aishah Zabidi, Hui Weng Goh, Chun Kiat Chang, Ngai Weng Chan and Nor Azazi Zakaria of the Universiti Sains Malaysia, Penang, Malaysia, carried out a review of roof and pond rainwater harvesting systems, with an emphasis on developing tropical regions (like Malaysia). They looked at design drivers for both styles of systems, and case studies of runoff reduction, water supply capacity, and water quality of already-installed systems in various countries, and concluded that roof harvesting systems are more commonly applied, but limited by small scale, while pond harvesting systems have greater potential for large-scale systems, especially once problems of evaporation and seepage are tackled. Both generally have high benefit returns and short payback periods. As a broad overview, the system performance of the covered case studies were analyzed, however, specifics regarding their design and implementation, and, more importantly, the basis behind the included specifics, were not discussed.

Rainwater Harvesting System at Texas A&M Campus [16]

Another very useful benchmark we have found is a rainwater harvesting system at the Texas A&M Campus for irrigation purposes. This is almost an identical project to what we are doing, with very similar decisions to make. One interesting talking point of the paper is the discussion of using an underground versus above ground storage system. It describes the advantages of the underground system being that the tank's visual absence, safety, and value of land are all kept, while the advantages of an above ground system is that it is a more cost effective installation and easy access for maintenance. Another interesting talking point was the effect of runoff on this project. They talked about a runoff coefficient used to calculate the supply of rainfall, which is based on the runoff coefficient used for the Rational Method, which lists off different characteristic coefficients depending on the ground cover used. It also talked about the beneficial aspects of general runoff that a rainwater harvest system would have, limiting the amount of runoff in the area. One more interesting talking point of this paper is the cost analysis of the system they bought. They had two different scenarios, with the two initial costs being $8,530,000 and $5,800,000, respectively. They include a table of the water conservation savings, and estimate that the first more expensive scenario will have a break even point, or time it takes to recover initial investment of 20 years, and the second scenario in 14 years. This table includes many helpful statistics that can help us later on.

Kajiado Sponge City, Kenya: Enhancing water infiltration through urban infrastructure [17]

In Kenya, Kajiado Town faces a number of serious water challenges. Thus, to alleviate the water scarcity, the creation of a sponge city is used. As an urban construction model proposed by Chinese researchers in 2014, the sponge city in Kajiado is designed to hold, clean and drain water in a natural way. It also adjusts the environmental flows to increase investment in sustainable water and decrease pollution of the town's resources. A sponge city is designed to have many permeable surfaces to allow water to seep through and get absorbed into the ground. Additionally, it requires a large amount of green space in order to be able to catch more water. This fits well with our project on North Campus as we already have a large amount of greenery on the grove that can be reformed to catch water if we choose to use some of the ideas found in this literature review. It may not be entirely plausible to convert the entire North Campus into a sponge city, but it may be advantageous to have certain parts of the campus such as the grove be able to catch water in a more environmentally natural manner.

Requirements and Engineering Specifications

Requirements are an important part of the design process because they allow the clear identification of the needs of the problem. Requirements are then assigned testable parameters, called specifications, that allow us to test our concepts and final design. Since the team and Professor Skerlos are currently the main stakeholders of the project, we have developed our own requirements and specifications, and refined them with the professor, which are presented in Table 1 on the following page. We used Donald FireSmith's article, "Specifying Good Requirements" [18], to guide our requirements; more specifically, we used characteristics such as Lack of Ambiguity, Correctness, and Customer/User Orientation. Moreover, both the requirements and specifications needed to stay solution neutral, yet capture the needs of the problem.

Table 1. This table ties the requirements that our team developed and their respective specifications. Uncertain specifications are labeled in red and the darker the color the more uncertain our team is on that specification.

Requirements	**Specifications**
Capture at least 650,000 gallons per year (North Campus' yearly water need for irrigation)	Be able to hold 100,000 gallons of water at any given time Be able to have a catchment area of at least 3,423 square meters
Achieve sufficient water quality for irrigation purposes	Achieve grey water quality equivalent to the specifications of NSF/ANSI Standard 350 *Onsite Residential and Commercial Water Reuse Treatment Systems*
Achieve a system that does not require constant human interaction to run	Water will come into and out of the system with a 0 touch system
Store water without losing the quality or quantity of water	Water quality will be maintained at desired quality for at least 14 days There will be a maximum of 0.5 gallons lost due to leakage or evaporation of system over a 14 day period
Ability for design to be modified to meet future changes in rainfall and/or water usage due to climate change and other factors	System capacity should be able to be doubled whenever necessary
Make sure system is simple to maintain and does not	System must prevent water from freezing at least

cause adverse impacts on surrounding environment	temperatures above -20 degrees Fahrenheit (-29 C) System will not require maintenance more than once a month System will have a life expectancy of 50 years System will not cause flooding. 0 leaks, 0 overflows

The requirement to capture at least 650,000 gallons of water per year comes from our estimates of North Campus irrigation water usage, as laid out under the "Scope and North Campus Statistics" section. From that requirement, required storage volume and capture area specifications were derived, with the calculation methods presented below in the "Storage Tank Sizing" section.

From the requirement of reaching sufficient water quality for irrigation purposes, we looked to the 2012 EPA Guidelines for Water Reuse [11], which specified irrigation as an acceptable use of reclaimed water; The BLUELab Living Building Challenge report also brought up the use of greywater for irrigation. Thus, we thought it appropriate to specify that the collected water be brought to a similar level of quality, as outlined in the NSF/ANSI Standard 350 *Onsite Residential and Commercial Water Reuse Treatment Systems*, because it would be going towards the same use.

In order to ensure that the resulting design was easy to operate, and could function in everyday situations without constant human oversight (practical from a facilities and grounds standpoint), we devised a requirement for a system that does not require human interaction to run. The specification for a zero touch system is a natural outgrowth of this.

The specification to store water without a decrease in quality for a period of 14 days was based on our preliminary generalization of rainfall data for the past year. It does not yet take into account seasonal variation and forecasted climate changes, which are a source of significant uncertainty in the specification; the 14 day period will definitely be revised once we complete more through rainfall modelling. The maximum of 0.5 gallons lost to evaporation or leakage during the said 14 day period was also an estimate, and we will look further into data for systems of this size.

In discussion with Professor Skerlos, and in our general observations on the weather over the course of our residing in Ann Arbor, we agreed that climate change is driving changes in weather and rainfall that will differ from current and past conditions, and perhaps also from models of the future. In any case, it is beneficial to build flexibility into whatever solution we may come up with to anticipate unforeseen future challenges. Thus we developed the requirement that the system be able to be modified to fit future needs, with an arbitrary specification that system capacity must be able to be doubled when necessary.

We broke the requirement that the system should be simple to maintain and does not cause adverse impacts on the surrounding environment into several parts from which to derive relevant specifications. Keeping Michigan's winter weather in mind, especially the recent polar vortex winter storm of 2019, we specified that the system must prevent water from freezing at temperatures above -20 degrees Fahrenheit;

this corresponds to Ann Arbor's record cold temperatures [19]. The specification that the system will not need maintenance more than once a month is from an initial rough estimate of what seemed appropriate. It will likely change as we continue to conduct research and explore ideas, like other specifications that bear uncertainty. Similar estimates went into our specifications for lifespan and avoidance of floods, leaks, and overflows. In addition, the specification for zero floods, leaks, and overflows is based on potential problems that could occur with water collection, storage, and treatment systems.

Comparisons to the BLUElab Living Building Challenge

Looking at the BLUElab's project, their design solution would fall short based on the water needing to be stored. Our requirement calls for larger amounts of water to be collected and stored. Their solution was based on a triangular roof shape, whereas the spaces we will be working on have flat roofs. However, their filtration system which filters water to a potable level does exceed our current water filtration specification. Thus, parts of their filtration system can be considered in concept generation.

Comparisons to Kerbside Rainwater Collection in India

Revisiting the kerbside rainwater collection solution in India, they plan to capture 19% more rainwater than what India is currently saving. This design solution does not consider how to filter the water for the needs of India. One of our requirements is to have the water filtered for irrigation purposes, so their design solution could not be applied to our design problem. They are also limiting their catchment area to the streets of India. With respect to our problem, our main catchment area is over grass, sidewalks, and roofs. Overall, this design solution would fall short based on our requirements.

Comparison to Ponds in Taoyuan, Taiwan

While ponds are a viable solution in areas of the world with an intense rainy season, and in agricultural applications where large expanses of land are available for pond creation, that does not completely overlap with our situation on North Campus. However, the idea of using environmental/landscape features for water capture and storage has featured in our concept generation

Concept Generation

An outline can be seen below, in Figure 4, of how the team went through the process of generating, developing, and selecting a design.

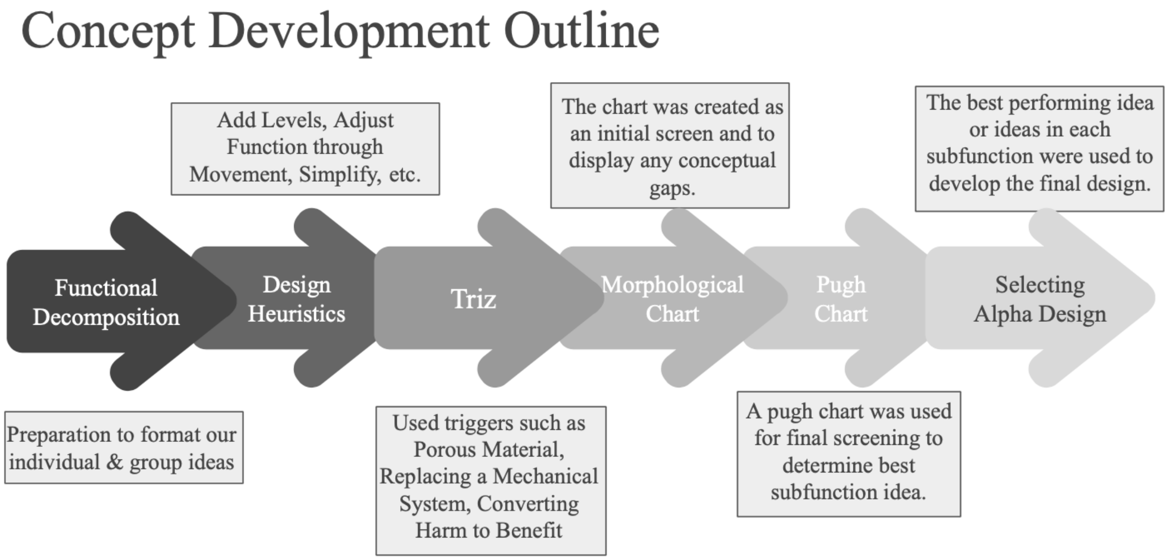


Figure 4. Outline of the concept development process as followed during the course of this project.

Functional Decomposition

Our team began by utilizing the ME 450 Functional Decomposition process to organize our ideas [20]. First, we defined the overall function that needs to be accomplished, as seen in the list below. Next we decomposed the problem into four subfunctions, those being water capture, water storage, water treatment, and water transport. Within each subfunction, we labeled what that subfunction must accomplish, which directly reflects our requirements:

Design Problem: To develop a sustainable rainwater system.

- Water Capture
    - Capture at least at least 650,000 gallons per year (North Campus' yearly water need for irrigation)
- Water Storage
    - Achieve a system that does not require human interaction
    - Makes sure system is simple to maintain and not cause adverse effects on the environment
    - Store water without losing quality of water
- Water Treatment
    - Achieve sufficient water quality for irrigation
- Water Transport
    - Be able to transport high volumes of water.

We began our concept generation by using the functional decomposition to organize our ideas. We individually came up with ideas for each subfunction. By doing so, we were able to come up with 12,096 unique ideas by combining all combinations of ideas. Table 2 displays an example of how our ideas were ordered; see Appendix B for the full list.

Table 2: Sample of initial idea generation using functional decomposition. Full table in Appendix B

		Individual Concepts			
		Arthur	Carlos	Emilio	Lambert
Levels	Water Collection	Channels under porous pavement	Big Bowl	North Campus Roof collection Area	Use Grove as a porous area
	Water Transport	Artificial streams	Open gutters	Automated control valves connected to water level sensor	Use of capillary action into water storage
	Water Storage	Large Basin underneath the ground	Any sorts of tanks	Sponge City capturing water	Open Ponds
	Water Treatment	Reverse Osmosis	UV Disinfection	Sandstone	Constructed Wetlands

Our team initially used divergent concept generation in the form of individually coming up with ideas for each subfunction. After individual divergent thinking, we then converged our thoughts into one table while eliminating unfeasible ideas. Then as a team, we developed new ideas and added them to the chart, again divergent thinking, as outlined in the sections on Idea Development, Design Heuristics, and TRIZ below. Once we were done coming up with a single table, our group moved on to the concept selection process, converging on the best subfunction ideas.

Idea Development

After we individually generated ideas, our team came together and used different techniques to further develop our ideas. We used design heuristics and TRIZ to help generate more ideas together and then used a morphological chart to start combining the different design concepts and act as an initial screen for ideas that weren't compatible with the other functionalities of our system.

Design Heuristics

As a team we were able to use different design heuristics to help us come up with more concepts for each level of our system. We used the heuristic of adding levels and discussed the possibilities of having underground, aboveground, rooftop storage tanks and collection systems. We also considered the idea of having a water tower. This heuristic also prompted us to think more about the material that we planned on using but without any engineering analysis done, we cannot finalize on any decisions regarding the material. Another heuristic that we used was to adjust the function through movement. We entertained the idea of having the storage location of our tanks be at a higher elevation and simply using gravity to pull the water to the final destination. Lastly, we attempted to simplify our design by seeing if it was possible to work our design into the existing system that North Campus has instead of creating a whole new filtration and transport system.

TRIZ

In addition to design heuristics, we used different TRIZ principles to help inspire new ideas. In relation to our literature on sponge cities, we considered the principle of using porous materials and formed the idea of using sandstones to allow for water to seep through the sidewalks as a part of our water collection system. We also discussed transforming the water into steam to make it easier to transport and remove the need for insulation as part of the phase change principle. A final principle that we used was converting harm to benefit by trying to make use of the extra runoff from sidewalks and the ground and thinking of a way to collect the water to help mitigate flooding.

Morphological Chart

We generated a morphological chart, as can be seen on the following page in Figure 5, as part of our idea development step to help us begin connecting ideas and forming systems that work well together. We were also able to use our chart as an initial screening of ideas to eliminate ideas that were not compatible with the other functionalities of the system.

In the water collection subfunction of our system, we decided that a rain and gutter system as well as an inverted roof and gutters would fit well with a water transportation system of piping. The two ideas that we screened out were shoveling snow over a water drain and having a big bowl over North Campus. For the water transportation system subfunction, we decided the use of capillary action was too complicated and slow. The four ideas that we thought were easiest to incorporate with ideas in other subfunctions in the water treatment sub-function were the first flush system and prefilter, a sand filter, UV disinfection, and a mesh/cartridge filter. This system would lead into the water storage subfunction, where we figured that storage tanks would be the most compatible with generalized ideas for other subfunctions. while open ponds and underground aquifers would be hampered by seepage, and in the case of open ponds, evaporation as well.

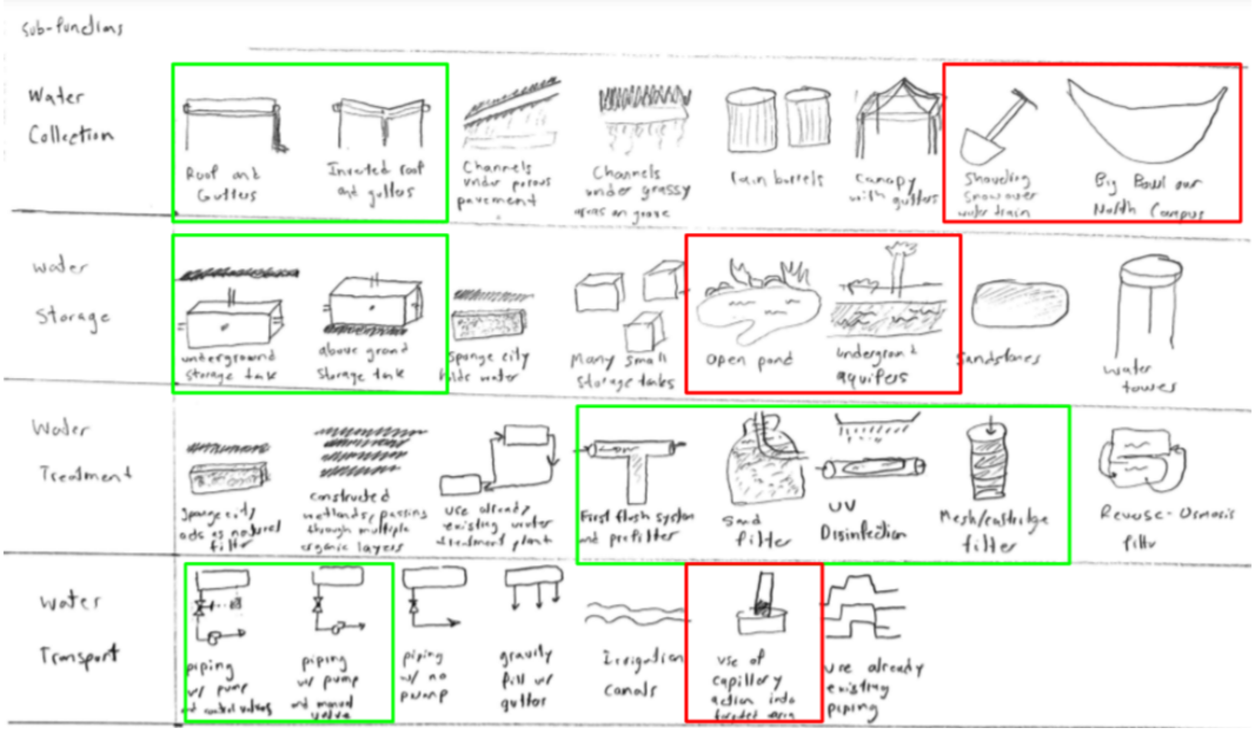
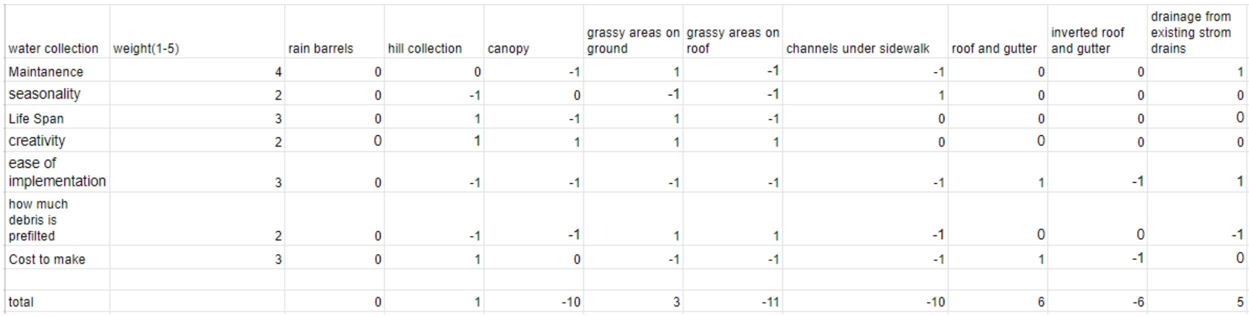


Figure 5. Our morphological chart; the green boxes indicating ideas that would work best in conjunction with our design and the red boxes indicating designs that would not be as feasible.

Concept Selection Process

As was outlined above, after coming up with our full list of ideas and creating a morphological chart, there were some ideas that we discarded based on simple judgement calls on feasibility and appropriateness. For example, the big bowl design for water collection was discarded because the challenge and cost of engineering such a large structure to place above North Campus made it unrealistic.

Once such outlier ideas in terms of practicality were removed, we then evaluated the remaining ideas using Pugh Charts, one for each subfunction. A sample Pugh Chart, the one for water collection, is shown on the following page in Figure 6, while the complete charts for each subfunction can be found in Appendix C.



water collection	weight(1-5)	rain barrels	hill collection	canopy	grassy areas on ground	grassy areas on roof	channels under sidewalk	roof and gutter	inverted roof and gutter	drainage from existing strom drains
Maintanence	4	0	0	-1	1	-1	-1	0	0	1
seasonality	2	0	-1	0	-1	-1	1	0	0	0
Life Span	3	0	1	-1	1	-1	0	0	0	0
creativity	2	0	1	1	1	1	0	0	0	0
ease of implementation	3	0	-1	-1	-1	-1	-1	1	-1	1
how much debris is prefilted	2	0	-1	-1	1	1	-1	0	0	-1
Cost to make	3	0	1	0	-1	-1	-1	1	-1	0
total		0	1	-10	3	-11	-10	6	-6	5

Figure 6. Sample Pugh Chart for the water collection subfunction.

Each subfunction's Pugh Chart had certain shared criteria with the same weighting that we thought important across all subfunctions: maintenance, seasonality (impacts of the seasons on the idea), life span, creativity, and ease of implementation; each also contained some criteria that were unique to that subfunction, such as loss (via seepage or evaporation) for water transport and water storage, and flow rate for water transport. Weightings represented the importance that was attached to each criteria, with five being the most important, and one being the least.

The emphasis on maintenance, lifespan, and ease of implementation across all subfunctions reflects our desire for a design that is simple to maintain, lasts a long time, and is easy to implement across North Campus, all essential characteristics necessary for adoption of infrastructure systems. Creativity was included as we believed that, as a research university rather than a public utility, the University of Michigan would place a certain value in more out-of-the-box solutions, something that represented a more experimental approach.

From these Pugh Charts, we arrived at a roof and gutter system for water capture, piping with pumps and automated control valves for water transport, a first flush system combined with a prefilter for water treatment, and above ground storage tanks for water storage.

Beyond the results of the Pugh Charts, more research is needed to determine finer details, such as storage tank and piping material, piping sizes, specific system architecture, etc. In addition, just because our analysis settled on these ideas for each subfunction, does not mean that the other ideas are completely worthless. Many have their own benefits, and may be applicable in more niche situations currently beyond the scope and consideration of this project as it is right now. For example, ponds by the Earl V. Moore Building of the School of Music, Theatre & Dance and Engineering Research Building 1, while outside of our narrow geographic scope, do hold potential for water storage. Likewise, porous sidewalks and green roofs could prove to be interesting and productive avenues of investigation. We encourage future ME450 groups to do more research into these ideas as auxiliary systems that can increase the capabilities of a more conventional main system.

Initial Engineering Analysis

The initial engineering analysis of this project began by calculating the storage volume and collection area that will result in capturing the full 650,000 gallons of irrigation water needed by North Campus in a year (based on last year's irrigation needs). To do this, we started by collecting 5 years of rainwater data in Ann Arbor and finding the monthly rainfall in inches every month. We then averaged the inches in each of the months getting an average rainfall for every month from the last 5 years. There were significant differences from year to year, and thus had a significant standard deviation for every month. This part of the analysis will be iterated for more than 5 years in the future to get more accurate figures for monthly rainfall. We then were able to see how much area would be needed to fully capture this 650,000 gallons of rainfall, which gave us a collection area of roughly 36,850 square feet or 3,423.5 square meters. This was all done on a spreadsheet.

Next, we moved on to calculating the storage volume we would need to be able to capture all the rainwater. We did this very similar to the LBC project basing our sizing on a 5 year-design storm and a more conservative 10 year-design storm. With a 5 year, 24 hour design storm, the precipitation produced would be 4.51 inches, and with a collection area of 36,850 square feet (3423.477 m^2), this would need a roughly 104,000 gallon tank. Being more conservative, we would base our design on a 10 year, 24 hour design storm, which would have a precipitation of 5.21 inches, producing a tank of roughly a 120,000 gallon tank. We will most likely be starting off with the tank sized for a 5 year, 24 hour design storm, but it is good to have a more conservative sizing in case we realize that we need to use that instead. The 5 year and 10 year design storms were obtained from the LBC challenge report. This is a good estimate since that project was done for Ann Arbor as well, so we thought that would be the most accurate.

This is our initial analysis, and our iterations and expansions on it can be found further down in this report.

Screenshots of the spreadsheets used for calculation in Appendix D.

Alpha Design Concept

From the Pugh Charts, we were able to come up with four final decisions from the four sub functions, which we were then able to put together to make our alpha design, shown on the following page in Figure 7.

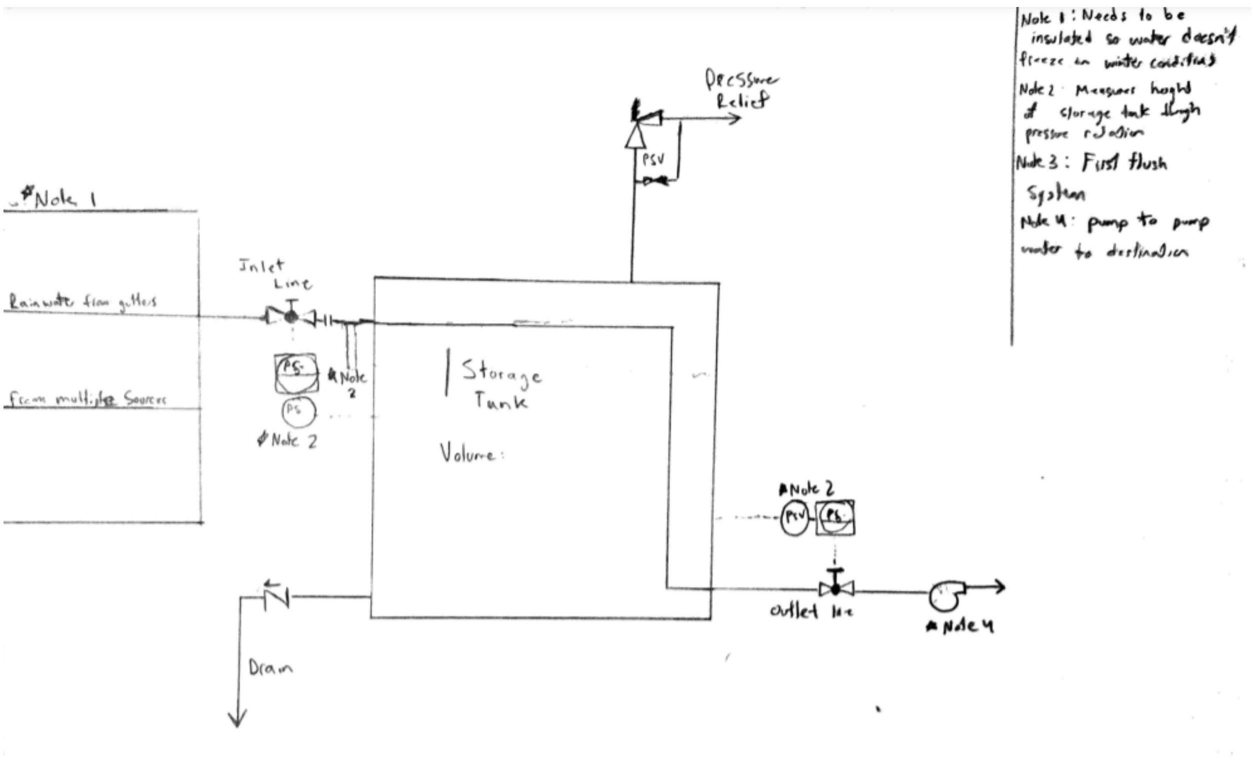


Figure 7. This is the initial PFD (process flow diagram) of the Alpha design which includes inlet pipes coming from roof captures, which will then go into an above ground storage tank, and go to the final destination through outlet piping. Inlet and outlet piping are both automated with control valves talking to pressure transducers. There is a design pressure relief and drain system to make sure there is no overpressurization or flooding, respectively. Some other features include the first flush system and the pump in the outlet.

Selected Concept Description

To sum it up, our final design will consist of the following elements,

- Roof and gutter system
- Underground tank system
- Piping with pump
- Water treatment through first flush system, sand filter, UV disinfection, and mesh filter if needed

We plan to develop a final solution with each of these elements in mind. However, currently, we do not plan on using treatment due to rainwater being sufficient for irrigation. If we plan to capture more water than is needed for irrigation, then we would consider water treatment to bring the collected water up to a level of quality where it can be used for other, perhaps in-building, applications.

In addition, we have changed our storage tanks from above ground to underground since the Pugh chart analysis, to better reflect our concerns about aesthetic impacts on North Campus and protection from the elements.

Engineering Analysis

Our team performed further calculations, research, and modeling to develop each element of the concept description. This allowed us to determine key specifications and characteristics of our collection systems, water tanks, piping, and placements.

Roof Area Evaluation and Rooftop Collection System

Based on the roof and gutter system selected via Pugh chart, our team took a look at the area and types of roof available within our geographic scope, highlighted in red in the following figure:

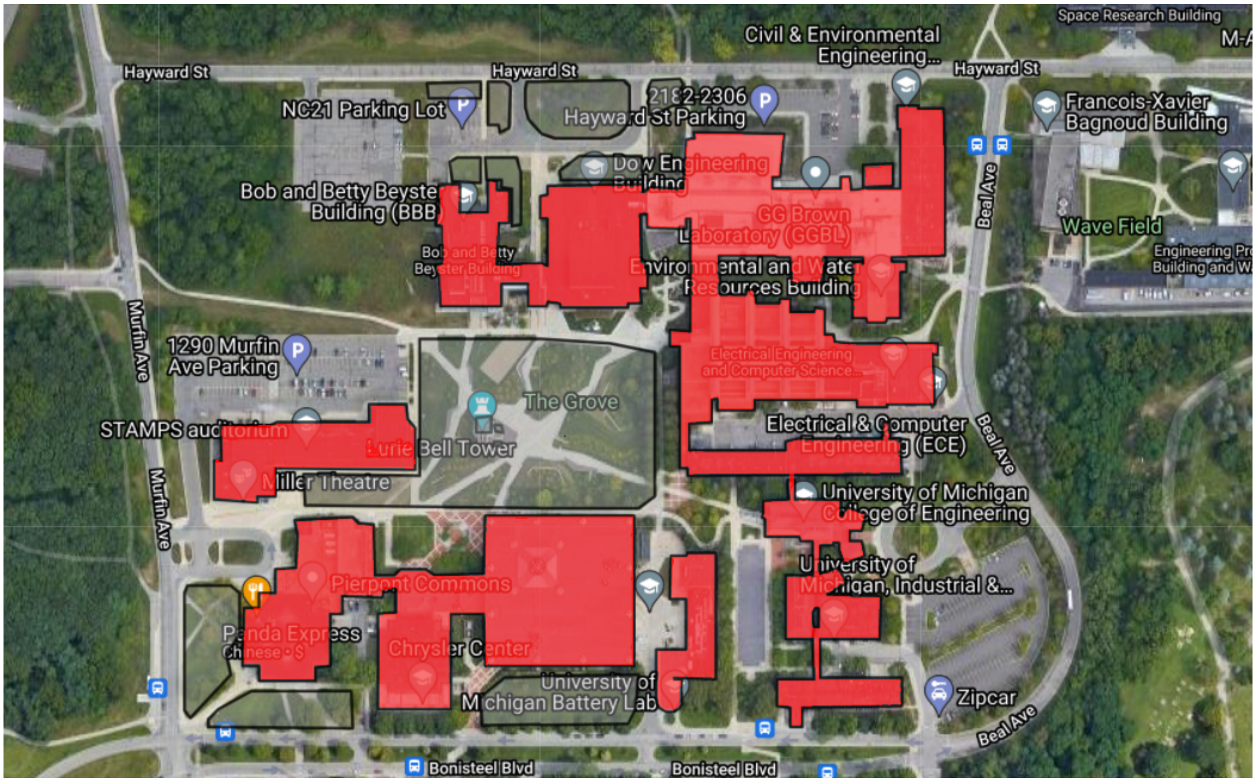


Figure 8. Google Maps screen capture of North Campus, with available roof area highlighted in red.

Through measurements with an online map area calculator [21], total available roof area was estimated at 56800 m^2; this area can be divided into two sections based on the current roof design, with approximately 2300 m^2 of sloped roof (with existing drainage gutters) mostly concentrated around the Robert H. Lurie Engineering Center and the Industrial and Operations Engineering Building. The remaining majority of available roof area, 54500 m^2, consists of flat roofs with internal drainage systems, an example of which can be seen in Figure 9 below. Overall, the available roof area far surpasses the specification for 3423 m^2 of collection area.

Figure 9. Sample photographs of flat roofs and internal drainage system above the Herbert H. Dow Building (Photos by Arthur Yang). Water can be seen pooling in the background of the right picture, behind the internal drain opening.

As can be noticed in the above pictures, the internal drainage system is not optimal for water collection purposes because water pools in areas due to obstructions by roof installations, and where the roof is not sloped correctly. This poor efficiency led us to come up with a simple system that can be placed on any flat rooftop with small modifications, in order to improve the efficiency of water collection, see Figure 10. We did an initial analysis of the sizing of the gutter system, and we came up with the gutters' volume must hold 1.08 gallons of water per second. This came from figuring out how much water falls on our largest roof area, Duderstadt library, per second on heavy rainfall of 1.74 inches in a day. Thus, the gutter system must be able to hold about 1.08 gallons of water per second.

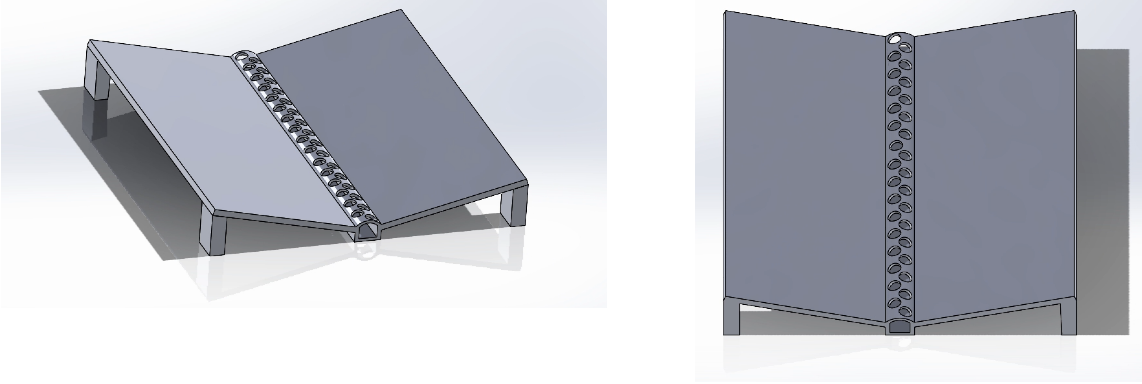


Figure 10. Computer Aided Design models of the collection system placed on any rooftops. The Design consists of an inverted roof with a mesh in the middle to stop large debri from falling in. For future considerations, attaching a heating element can make these operational year round.

We do not yet have concrete specifications for this rooftop collection system; it is currently something that we imagine could be placed in rows atop flat roofs, with the dimensions being adjustable to suit the various roof dimensions on North Campus. Further research would need to be done to determine various aspects of the rooftop collection system, like material, angle of the slope, mesh sizing, etc., and we figure that it will be a productive area of interest for future teams.

Supplemental Analysis: Available Water for Collection

Our team came up with a model that can predict on average how much water will be in the tanks after a given amount of days, see Equation 1**.** This is a linear equation that takes into account the influx of water, usage, and loss of water. The loss of water comes from leakages, evaporation, and other losses. It uses the ratio of rainless days in a season to approximate the amount of water that will be in the tanks. This equation only applies seasonally which does not include November 1st through March 1st. This is because it snows which our team is not considering.

$$SW(t) = IN(1-R)(t) - OUT(R)(t) - loss(t) \tag{1}$$

Where, SW: Amount of rainwater in gallons in the tanks after "t" days.

R : Ratio of rainless days over total total days, not including winter. [R = 0.7336]

t : The amount of days

IN : Average intake of rainwater on a rainy day. [IN = 51216 gal/day]

OUT : Average usage of greywater on a dry day. [OUT = 2663 gal/day]

Some key takeaways from Equation 1 is that the influx is greater than usage and loss terms combined. This means that our tanks will be gaining water throughout the season. At the end of the season, we expect 2.9 million gallons left over, accounting for usage.

Storage Tank Sizing

Initial Approach

Our initial attempt at finding dimensions for our tank is by looking at the largest storage of rainwater. The highest surge of rainwater in the past 5 years in Ann Arbor happened on March 26, 2020. It rained for 3 consecutive days at 1.74 inches per day. Multiplying by our collection area gives us a volume of water. The total amount of water it rained was approximately 2 million gallons of water. To put this number in perspective, 56% of the total rainwater for the season in 2020 fell just within the 3 days in March. In order to collect 2 million gallons of rainwater, one would need a water tank as seen in Figure 11.

Figure 11. Prescott Valley water tank that can hold 2 million gallons of water [22]

After looking at similar tank sizes at 2 million gallon tanks, we decided that it would be unfeasible to construct a tank of this size on North Campus. Consequently, we developed a second approach to characterize our tank.

Second Approach

Our second approach was to look at the longest drought in the past 10 years. In 2018, there were 18 consecutive days where it did not rain, not considering winter. We then assumed a consumption rate of 2,663 gal/day and a safety factor of 2. With this data, we will pick a tank that can hold 100,000 gallons which is the amount of water needed to sustain 18 consecutive days of water irrigation with a safety factor of 2.

A single tank of 100,000 gallons is large and does not have a back up plan if it fails. Thus, our team decided on four smaller tanks that hold 25,000 gallons of water. That way if one tank fails, there are 3 other tanks that can be used instead during maintenance. This also helps in terms of directing water flow from rooftops. Further details on material and tank specifications can be found below.

Materials Discussion

For this project, our team looked at three main materials: steel, fiberglass, and plastic. The first material we looked into was steel. There are many types of steel that could be used for this project such as galvanized, corrugated, and stainless steel, so we first looked at the bigger picture of the general pros and cons of steel as a material, before doing further research if need be. Steel is the toughest of the three materials, and will be able to hold the most volume as it can handle the most water pressure from the storage tank. It also offers the most resilience, and has the longest lifespan along with being good in harsh environments, and resistant to harmful ultraviolet rays. A big disadvantage of steel however, is that it is by far the most expensive material, and thus makes it an unlikely choice. Another disadvantage is that, while not likely, any damage done cannot be easily repaired and usually needs a specialist to come fix it.

The second material we considered is fiberglass. Fiberglass is also a very strong material, which can withstand well in adverse climates and impacts. It is also very sturdy and non-porous which will keep out any intruding chemicals that might leak into the system. Some other advantages are that it is resistant to corrosion and that fiberglass storage units have an average lifespan of 30-40 years, which is relatively high. The cons of Fiberglass is that it is not an easy material to recycle at the end of its lifespan because of all the elements that go into making it, which is a negative environmental effect. It also cannot handle as big capacities as steel does due to not being able to handle the internal water pressure at higher volumes.

The last material we considered was plastic. Plastic is the most cost-effective material that we are considering due to being very cheap in regards to the other materials and still a very good material. It is non-corrosive and non-porous, which is very nice for a storage tank. Plastics are also very light in comparison with the other materials, and thus are the easiest to handle and move around. It is also very environmentally friendly, and can be recycled at the end of its lifetime very easily. The disadvantages of plastic are that it is the most susceptible of the materials in consideration to damage. It also cannot handle bigger capacities because they are not able to handle the internal water pressure of higher volumes [23].

From this research, we were able to find the ideal material for different volumes of storage. Plastic is the best material for volumes less than 20,000 gallons, fiberglass is the best material for volumes between 20,000 to 50,000 gallons, and steel is the best material for volumes higher than 50,000 gallons. Due to these material considerations, along with viable storage tank locations and locations of the collection areas, we have decided to take the 100,000 gallons of water that we need to store and break it into four 25,000 gallon fiberglass tanks.

Final Design Description

A bill of materials for the final design is presented in Appendix E.

Map Overview

A map overview of the final design can be seen below, in Figure 12:

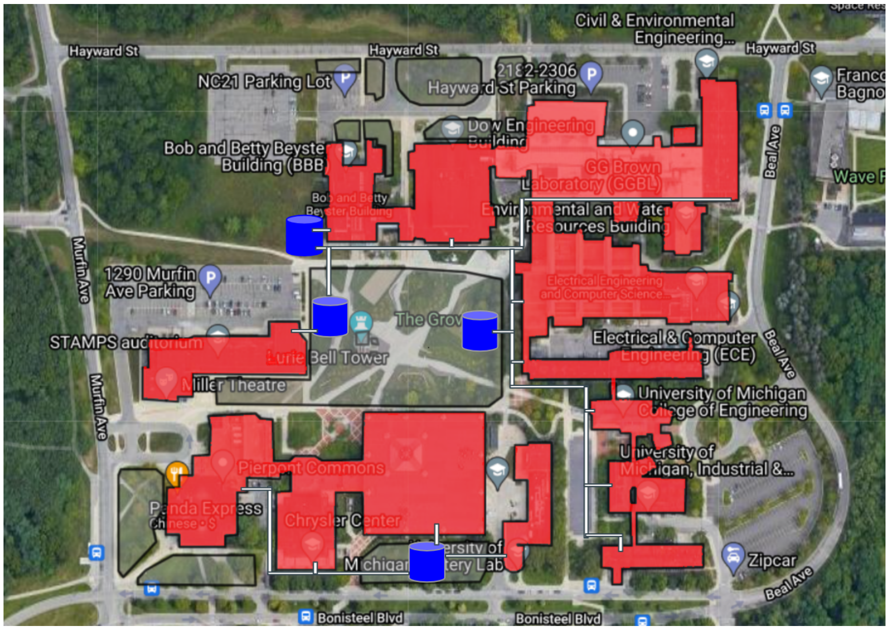


Figure 12. Map overview of the final system design, Collection areas are highlighted in red, tank locations are represented with blue cylinders, and piping is represented with white lines outlined in black.

The collection area, highlighted in red, has remained unchanged from our prior analysis. Blue cylinders mark the preliminary planned locations for storage tanks; these areas were picked because of their openness and lack of preexisting sidewalks, to reduce the disruption associated with the construction necessary to place the tanks. They were also placed to be relatively close to areas with need of irrigation; however, their placement may change as we proceed with head calculations and piping layout. With regard to the geologic profile of North Campus, there is ample space to place tanks underground, as the top ~90 feet are composed of cross-bedded coarse sand and till, with another ~145 feet of blue clay and till, before hitting shale rock [24]. This leaves ample space for tanks, even with a frost line of 42 inches [25].

On the subject of piping layout, the layout as shown here is simply a rough estimate; much more work needs to be done in deciding on optimal pipe placement, taking into account the elevations of various building roofs, changes in elevation on the grounds, etc. Consideration will also be made of how best to connect all of the tanks, to ensure that vacant space in any tank can be taken advantage of, and to build in a measure of redundancy should a tank fail. We currently plan to run the pipes underground, below the frost line of 42 inches, if possible, both to protect them from possible tampering, and to insulate them from the elements.

Tank and Piping Details

Given our analysis on the material and sizing of the tanks, we have found what we believe to be a suitable tank for our design [26]. Our fiberglass tank has a diameter of 120 inches (10 feet) and a length of 540 inches (45 feet) and will be placed horizontally in the ground (see Figure 12). The tank includes a 24 ISO inch Manway and can hold up to 25,000 gallons. We also are able to add a wide variety of flanges and couplings that range between 2-16 inches. For our piping, we have decided to go with an 8 inch diameter pipe made out of insulated PVC. Based on the piping schematic shown in Figure 13, we estimate a need of about 4000ft of pipes.

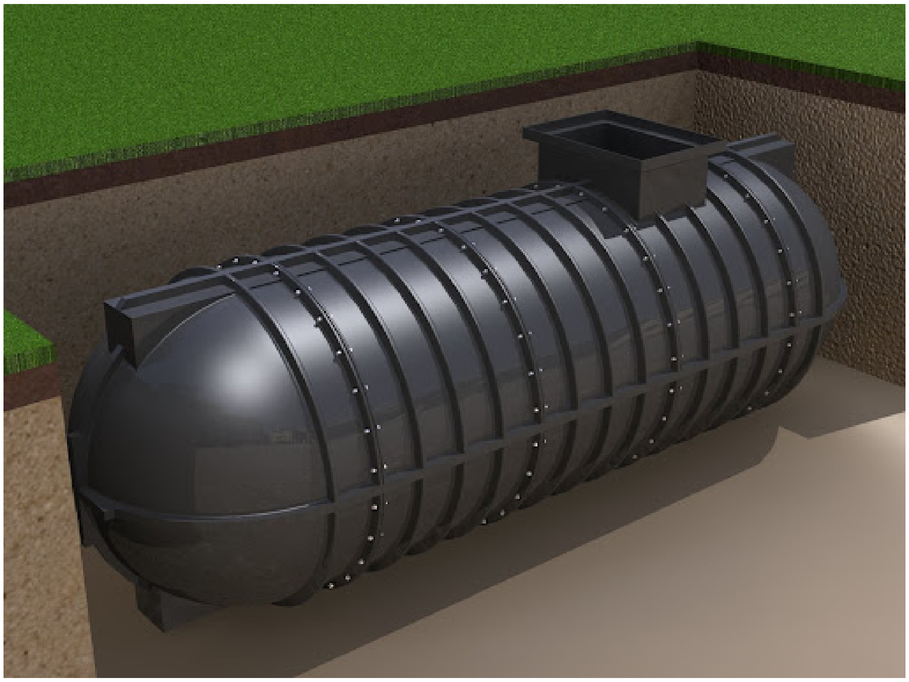


Figure 13. A model of what our tank would look like placed in the ground. Note that this is not the exact tank we are specifying, but meant to be a visual aid of the tank.

P&ID

Lastly, we will present a P&ID (piping and instrumentation diagram) of what we envision the storage tank, valves and piping associated with it to be, as shown in Figure 14. It will be described in detail below.

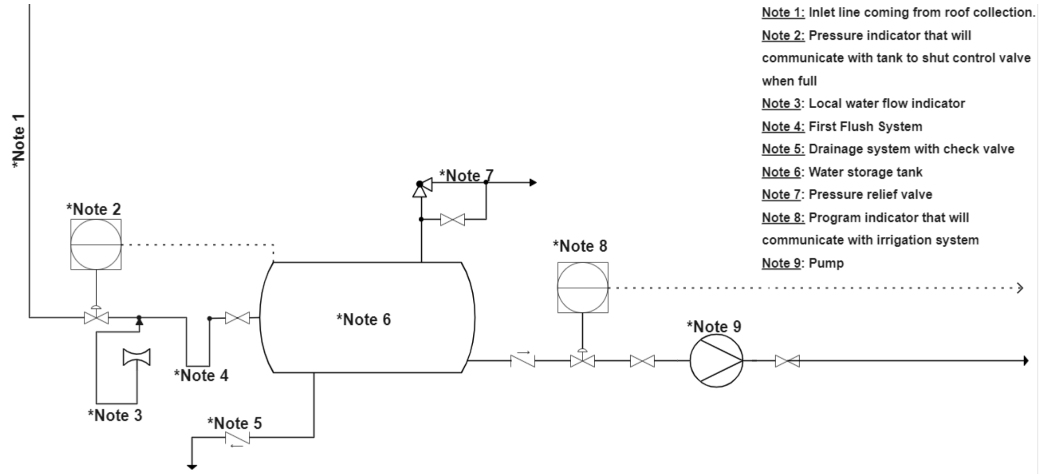


Figure 14. This is the P&ID of one of the four 25,000 gallon tanks. Each will have its own unique geometry and orientation in accordance to spacing and piping position, but all will include similar things. The important details to note are the inlet pipes coming from roof

collection areas, the inlet control valve which is talking with the storage tank through a pressure transducer, a first flush filtration system, the design pressure relief and drain system to make sure there is no overpressurization or flooding, respectively, and the outlet piping with a control valve talking to some mechanism that will trigger when irrigation needs are there, along with a pump to allow the water to get there. Another detail that is added is a local flow meter on the inlet line (Note 3) to allow reading of the flow if need be. It should also be noted that there will be valves on each side of any equipment such as the tanks and the pumps to facilitate cleaning and maintenance.

Environmental Considerations and Sabotage

Other than our system being a sustainable system, there are a few worst case scenarios that can occur with our final design. An environmental concern that our team discussed is leakage of harmful chemicals from the catchment system or tanks. Our team took careful consideration on the material choice so that our tank will not corrode or release harmful chemicals. Another environmental concern is tank failure causing large flooding. We did try to minimize these effects by having multiple tanks. With respect to sabotage, any outside piping is prone to people tampering with it, such as using it as a skateboard ramp. Another concern is people can launch harmful contaminants into the catchment systems on the roofs. Although highly unlikely, a solution can be to create a fence that blocks any large debri from entering the catchment area, endeavor to place as much piping as possible underground, and to fence off all aboveground piping.

Verification and Validation Plan

In our design, we had certain specifications that were used quantitatively when we first generated our design. Many of these specifications, such as the water collection area and amount of water stored at a time can be (and has been) verified through a simple calculation since the specifications were incorporated into the design when created. Our design has four tanks that can hold 25,000 gallons. This satisfies our specifications of being able to hold 100,000 gallons of water at any given time. Additionally, we have determined that the roof areas that we used collectively have a sufficient water catchment area that meets our catchment specifications of 56,800 m^2. Additionally, the locations of each of our tanks have been carefully chosen so that there is additional space to add more tanks when needed in order to verify our specifications of being able to double in storage capacity.

However, we have other specifications that while we have not completed verifying, we have developed plans that will allow us to do so. These specifications include limiting water loss, being able to transport the water to its needed location, and preventing system failure due to floods or leaks. We believe that all of these specifications can be initially verified through technical analysis. Once this initial verification is complete, with enough time and resources, we may be able to build a small model to test our design experimentally. To verify our specification regarding water loss, we would calculate how much water is likely to evaporate from our tanks. Model testing further on would make sure that our tanks and pipes don’t leak any water in storage and in transport. To verify that we are able to transport our water, we plan on calculating the header pressure needed for water from each tank to travel to the farthest location from it. This will ensure that the water from any tank will be able to reach any desired destination. Header pressure can be calculated by rearranging the definition of pressure into the form presented in Equation 2.

$$(p2 - p1) = \Delta h * \gamma \tag{2}$$

The difference between $p2$ and $p1$ is the pressure difference the pump needs to produce to raise a liquid of specific weight γ a height of Δh. With the assumption that piping will be underground, the greatest upward difference in ground elevation over which we plan to run pipes within our geographic scope is roughly 10 feet [27]. Lastly, another pressure calculation around the tank is necessary to determine if our design can actually hold and transport the amount of water it was designed to without failure. Our pressure analysis would make sure that our tank and pipes are strong enough to function without bursting or flooding.

Since this is an exploratory project by nature, and we will not end up building any of our final design, we will give in detail how we would empirically test our design to let us meet our requirements. The first empirical test we would do is to test our inverted roof design. We would create a miniature version of the inverted roof design with the slope that we have selected, and test it out in the rain to see what the actual yield of the design is. There will be losses that we cannot account for in calculations, such as losses due to wind, to droplets bouncing off, etc, so this will allow us to compare what we should have gotten by doing the inches of rain times the area of the miniature inverted roof to the actual yield that we will collect in a buckets of sort. This will result in a percentage of yield that we will be more confident on. The second empirical test would be to test the gravity fill of the tanks. This would be done by getting a sample of the piping, and setting up a model to test out the highest angles and minimum slopes that we plan to use to see if the water will be able to fully get delivered with just a gravity fill. We would do this in many different temperatures and conditions such as windy to make sure that it is not affected by any exterior factors. If it is able to successfully pass through all the angles and slopes, we will know with good certainty that the gravity fill will work. Lastly, we will need to verify that the minimum slope that will meet the gravity fill can be achieved in relation from any of the collection areas to the given tank that it needs to transport it to.

To validate that our design is actually meeting the requirements and fulfilling the goal of our project, we can also perform technical analysis to determine this. It is almost impossible to predict with certainty that our design will actually fulfill our goal of reducing dependence on the Huron River without actually implementing our design and gathering empirical data from it simply due to the large dependence on the changing climate and weather conditions. However, we believe with high confidence that if our design is implemented, we are able to reach our project goal. Our plan to validate our design is simply determining the total amount of water that our system can collect and use. This will be equal to the amount of water that we subsidize from the river. Depending on the efficiency of our system, we will be able to determine exactly how much impact our design will have.

Discussion

Due to the exploratory nature of our project, our team had a lot of control of what to include and what not to include in our overall design. As such, our team took certain liberties in choosing what to and what not to focus on when designing our system. For example, while we chose to use the rainwater that we collect for the purpose of irrigation on North Campus, we could also have decided to collect snow as well as other precipitation and use the water for purposes other than irrigation. Given more time and resources, we would have definitely taken these ideas into consideration. We would have explored more possibilities of capturing snow as well as improving our collection system to account for both rain and snow. This would have required more research and data modeling as well as a better understanding of how snow can be moved around and melted into water. Additionally, our team would have looked into the additional uses of the water collected. This would have involved a lot more data collection from the University and further research on water treatment procedures to make sure that the water quality is sufficient for such purposes.

Given our final design, our team was satisfied with what our design was able to achieve. Our design was able to meet our most important specifications and requirements. We achieved our target storage volume, collection area, and water quality which were what we considered to be the most crucial aspects of our design. We also felt that our design sufficiently encompassed our defined scope. We did our best to use all our available opportunities provided in our scope. Lastly, the best thing that our design was able to achieve was to simply demonstrate the viability and potential of large-scale rainwater harvesting for the University. The culmination of our research and final design can help open the door to new possibilities and efforts in water collection opportunities around the rest of the University. We hope that our project can be used as a baseline for future groups.

However, our team remains unsatisfied with a few aspects of our design. While we were able to reach our scope as much as we could given our constraints, we also felt that it limited our potential to collect even more water. We estimate that our system could be slightly altered to collect an additional 2.9 million gallons of water based on the amount of surface area available. Additionally as mentioned earlier, we neglected to consider the winter season as we were ultimately unable to incorporate certain intricacies such as the heating and cooling of snow into our design. Furthermore, because of the limitations of our problem definition, we cannot use any of our extra water beyond our level of greywater treatment. Finally, our greatest disappointment regarding our design is simply the inability to verify/validate certain specifications/requirements. Due to the theoretical nature of our project, we were unable to conduct any experiments or build any models that would be enough to simulate the conditions that our system would go through. Hence, this resulted in certain specifications going unverified. While we were able to include plans on how to verify such specifications, we were still nonetheless disappointed that we were unable to verify it ourselves.

Recommendations

Based on our experience throughout this project, we have several recommendations, primarily aimed at future groups seeking to reference or expand upon our work. These recommendations can be roughly divided into two groups, those concerning the design itself, and those concerning interactions and stakeholder engagement.

First, regarding the design, our most major recommendation is to expand the scope of this project. In our view, it would be better for any rainwater collection and storage system to encompass the whole of North Campus. The decision to focus on the area bounded by the four streets of Bonisteel, Beal, Hayward, and Murfin was an arbitrary decision, made to simplify the project and make it easier to get off the ground. However, this arbitrary scope ignores the wealth of opportunities available beyond its boundaries, and also ignores the fact that similar water needs are also present across all of North Campus. There are various ponds across North Campus that could be used for water storage, and storage tank farms could be sited on vacant land on the periphery of North Campus. In addition, considering the campus as a whole would allow the construction of a much more unified end system.

In addition, the focus on irrigation as the primary end-point of collected water can easily be expanded. Non-irrigation water use makes up the majority of North Campus water needs, and being able to address them would be a major step towards self-sufficiency. As shown in our analysis, even just relying upon roof area, there is the potential to collect enough water to make a significant dent in non-irrigation water needs, and there are definitely viable ways to expand water collection area beyond roofs. Though they come with their own challenges of implementation, methods like porous pavements (combined with large parking lots around the edges of campus) and rain garden landscaping can dramatically expand the collection area.

The presence of a significant winter season in Michigan also presents its own opportunities, particularly those around the heating of snow for water, and the storage of water in the form of snow or ice for extended periods of time.

Also, while wastewater treatment was not tackled within the present project scope, it remains a fruitful avenue of progress, with the potential for both increasing water supply, and alleviating concerns of collecting so much water from the environment. Combined with existing wetlands and ponds on North Campus, engineered wetlands could be constructed to treat wastewater and return it to the environment, and would also contribute to a healthier and more diverse campus ecosystem. In general, investigating such alternatives to conventional systems as sponge cities, ecosystem benefits of wetlands, etc. will likely be informative.

On the side of stakeholder engagement, we strongly encourage future teams to reach out to stakeholders like UM Facilities and Operations, and UM Custodial & Grounds Services, preferably early on in the design process. We expect their input to dramatically shape implementation plans, and they are better placed to provide information on the details of various buildings and grounds that are difficult to find via the library or scout out in-person. In addition, university administration should be probed as to the costs they are willing to bear for such a project; oftentimes the majority of cost in rainwater collection and storage systems is from the storage tanks [28], and storage capacity will determine how much capture area is actually needed, among other design details.

Overall, there is potential, with the idea of rainwater collection and storage, for the project to evolve beyond just the question of water, into a more comprehensive reappraisal of the current North Campus. It would not be an unreachable dream to work towards the design of a North Campus that is more sustainable, more ecologically-friendly, more integrated into the surrounding nature, and more welcoming for the entire community.

Conclusions

The U.S. declared its first-ever water shortage on the Colorado River in August. Will this ever happen with the Huron River? Our team was tasked to develop a solution to mitigate the dependence on the

Huron River. Specifically, we looked into supplying the irrigation needs around The Grove on North Campus, as defined by the area bounded by the four streets of Bonisteel, Beal, Hayward, and Murfin. Our solution consisted of four fiberglass, 25,000 gallon tanks, roof collection system, piping and tank locations, and a P&ID. Our team hopes that future teams build off our initial research and conclusions.

Acknowledgements

We would like to acknowledge the invaluable assistance and advice provided by Professor Steven Skerlos, who first introduced us to this problem of rainwater capture and storage, and throughout the gestation of the project offered invaluable insight, guidance on directions to explore, and experienced critiques of our various ideas. We would also like to thank our peers in Section 3 of ME450, who brought up many wonderful and focused critiques over the course of our three design review presentations, often bringing to light issues that we had overlooked, or that were more apparent from an outside perspective. The audience of our peers from the design expo presentation also contributed many important and insightful points. Lastly, the resources of the University of Michigan Library system have been invaluable, especially in the gathering of research and studies on rainwater collection, systems to benchmark from, material properties, sizing equations, and much more.

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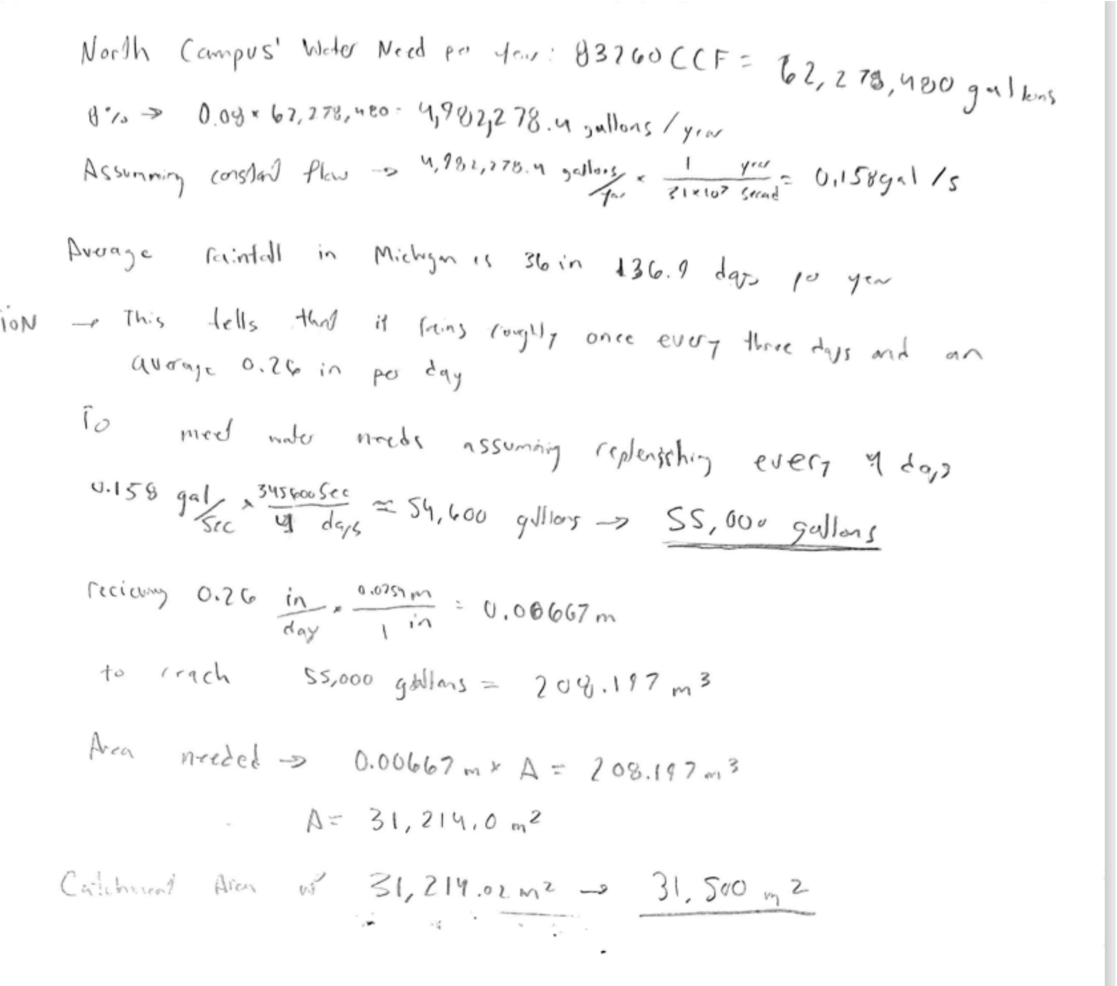
Appendix A: Original Storage Volume and Collection Area Calculations



North Campus' Water Need per Year: 83260 CCF = 62,278,480 gallons

8% → $0.08 \times 62{,}278{,}480 = 4{,}982{,}278.4$ gallons / year

Assumming constant flow → $\frac{4{,}982{,}278.4 \text{ gallons}}{\text{year}} \times \frac{1 \text{ year}}{3.1\times10^{7} \text{ second}} = 0.158 \text{ gal/s}$

Average rainfall in Michigan is 36 in 136.9 days per year

ASSUMPTION → This tells that it rains roughly once every three days and an average 0.26 in per day

To meet water needs assuming replenishing every 4 days

$0.158 \frac{\text{gal}}{\text{sec}} \times \frac{345600 \text{ sec}}{4 \text{ days}} \approx 54{,}600$ gallons → $\underline{\underline{55{,}000 \text{ gallons}}}$

recieving $0.26 \frac{\text{in}}{\text{day}} \times \frac{0.0254 \text{ m}}{1 \text{ in}} = 0.00667 \text{ m}$

to reach 55,000 gallons = 208.197 m^3

Area needed → $0.00667 \text{ m} \times A = 208.197 \text{ m}^3$

$A = 31{,}214.0 \text{ m}^2$

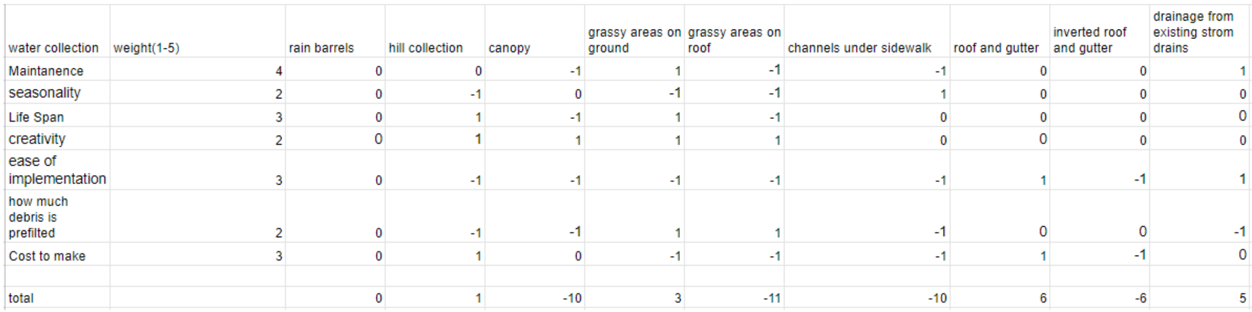
Catchment Area of $31{,}214.02 \text{ m}^2$ → $\underline{31{,}500 \text{ m}^2}$

Appendix B: Full Concept Generation Table

	Carlos	Lambert	Arthur	Emilio			water collection	water transport	water treatment	water storage
Water Collection	Big Bowl	Use of the grove as a porous area to absorb rainwater	Channels under porous pavement	Use the roofs on North Campus as collection areas			Big Bowl	gravity fill gutters	Sponge city acts as natural filter	Underground Storage tanks
	Capture rainwater at the bottom of hill	Green roofs to catch rainwater	Landscaped drainage areas with retaining ponds	Implement collection area under grassy area on North Campus			Capture rainwater at the bottom of hill	piping with pump	constructed wetlands: passing water through multiple layers of organic plants	Aboveground storage tanks
	A canopy over crosswalks that turns on when it rains and allows sunlight through when it is off	When shoveling snow, move over a drain that collects the water when the snow melts	Diversion from existing storm drains	Create inverted roof			A canopy over crosswalks that turns on when it rains and allows sunlight through when it is off	piping without pump/ gravity fill	sand filter	fiberglass tank
	Rain Barrels		Channels along exterior walls to guide rainwater to collection points				Rainbarrel	Automated control valves connected to water level sensor w/ a pump	UV disinfection	plastic (polyethylene) tank
	Gutters						Use of the grove grassy areas as a porous area to absorb rainwater	Automated control valves connected with some sort of application so human can control outgoing flow remotely	Take rainwater to treatment plant and then back to storage	carbon welded steel tank
	Heating sidewalks to melt snow then collect snow water for usage						Green roofs to catch rainwater	irrigation canal	A First Flush System and prefilter before entering Storage	big bowl open to atmosphere
Water Transport	Gutters	Use of capillary action into water storage area	Artificial/landscaped streams	Automated control valves connected to water level sensor w/ a pump			When shoveling snow, move over a drain that collects the water when the snow melts	Use of capillary action into water storage area	Cartridge filter	sponge city holds water
	Pipes,pumps			Automated control valves w/ remote control interface			Channels under porous pavement	Artificial/landscaped streams	Reverse-osmosis filter	already existing water tank in north campus
	Trenches			regular piping with manual valves and use a gravity fill through pipes to reach destination on north campus			Landscaped drainage areas with retaining ponds	use already existing piping to tranport water		water tower
Water Treatment		Sponge city acts as natural filter	Constructed wetlands	Take rainwater to treatment plant and then back to storage			Diversion from existing storm drains			sandstones
			Sand filter	A First Flush System and prefilter before entering Storage			roof and gutter			multiple small tanks
			UV disinfection	Cartridge filter			Inverted roof and gutter			open pond (pre-existing)
Water Storage	Tanks	Sponge city holds all the water in its natural basin	Open ponds (pre-existing or constructed)	Many small tanks around North Campus						Construct and dam an artificial creek
	Rain Barrels	Large basin beneath the grove to gather the water	Underground aquifers	Concrete/cinder block cistern/tank						Underground aquifers
	Large tank in the bell tower		Store water in the open as snow/ice in the winter							
			Water towers							
			Construct and dam an artificial creek							

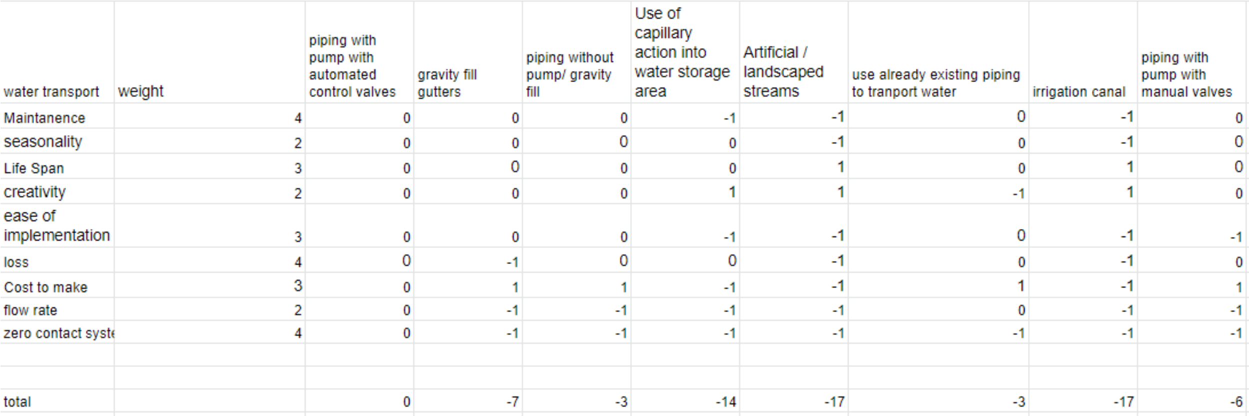
Appendix C: Pugh Charts

C.1 Water Collection



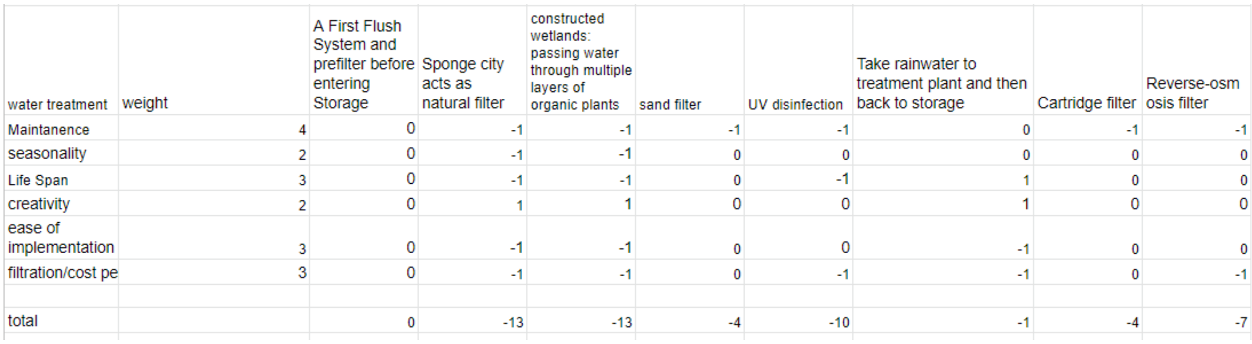
water collection	weight(1-5)	rain barrels	hill collection	canopy	grassy areas on ground	grassy areas on roof	channels under sidewalk	roof and gutter	inverted roof and gutter	drainage from existing strom drains
Maintanence	4	0	0	-1	1	-1	-1	0	0	1
seasonality	2	0	-1	0	-1	-1	1	0	0	0
Life Span	3	0	1	-1	1	-1	0	0	0	0
creativity	2	0	1	1	1	1	0	0	0	0
ease of implementation	3	0	-1	-1	-1	-1	-1	1	-1	1
how much debris is prefilted	2	0	-1	-1	1	1	-1	0	0	-1
Cost to make	3	0	1	0	-1	-1	-1	1	-1	0
total		0	1	-10	3	-11	-10	6	-6	5

C.2 Water Transport



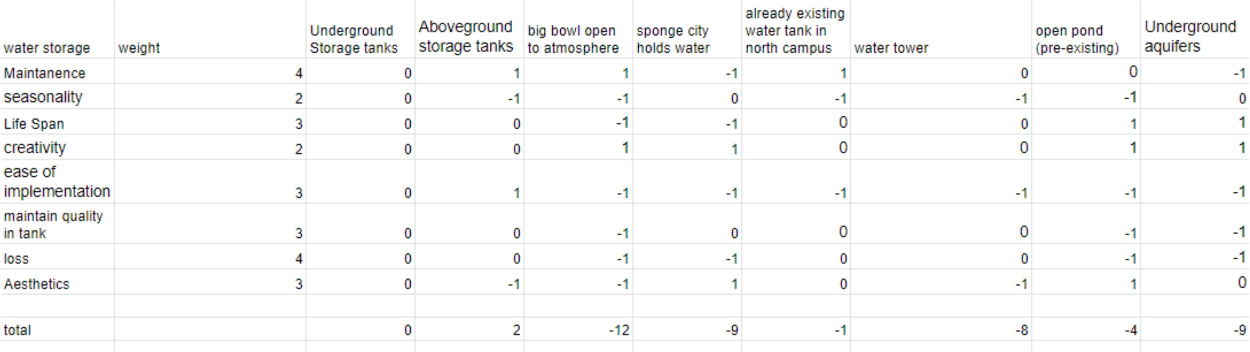
water transport	weight	piping with pump with automated control valves	gravity fill gutters	piping without pump/ gravity fill	Use of capillary action into water storage area	Artificial / landscaped streams	use already existing piping to tranport water	irrigation canal	piping with pump with manual valves
Maintanence	4	0	0	0	-1	-1	0	-1	0
seasonality	2	0	0	0	0	-1	0	-1	0
Life Span	3	0	0	0	0	1	0	1	0
creativity	2	0	0	0	1	1	-1	1	0
ease of implementation	3	0	0	0	-1	-1	0	-1	-1
loss	4	0	-1	0	0	-1	0	-1	0
Cost to make	3	0	1	1	-1	-1	1	-1	1
flow rate	2	0	-1	-1	-1	-1	0	-1	-1
zero contact syste	4	0	-1	-1	-1	-1	-1	-1	-1
total		0	-7	-3	-14	-17	-3	-17	-6

C. 3 Water Treatment



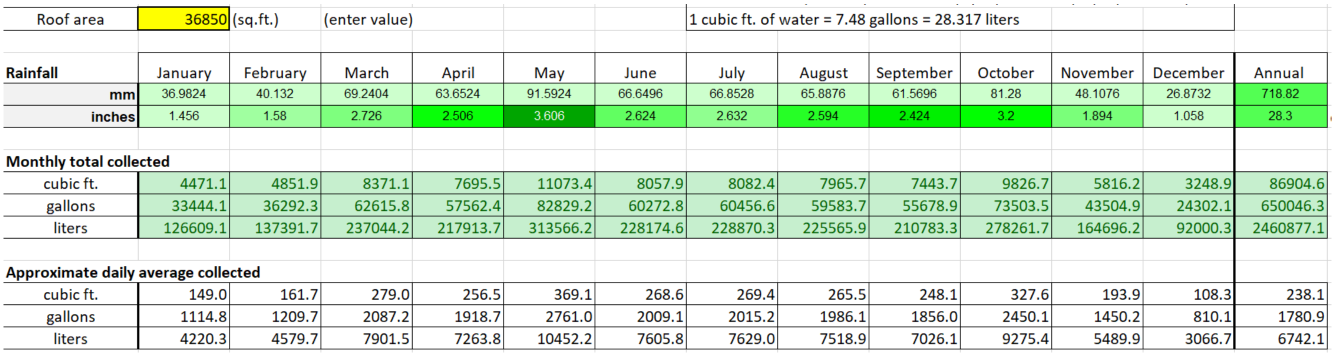
water treatment	weight	A First Flush System and prefilter before entering Storage	Sponge city acts as natural filter	constructed wetlands: passing water through multiple layers of organic plants	sand filter	UV disinfection	Take rainwater to treatment plant and then back to storage	Cartridge filter	Reverse-osmosis filter
Maintanence	4	0	-1	-1	-1	-1	0	-1	-1
seasonality	2	0	-1	-1	0	0	0	0	0
Life Span	3	0	-1	-1	0	-1	1	0	0
creativity	2	0	1	1	0	0	1	0	0
ease of implementation	3	0	-1	-1	0	0	-1	0	0
filtration/cost pe	3	0	-1	-1	0	-1	-1	0	-1
total		0	-13	-13	-4	-10	-1	-4	-7

C.4 Water Storage



water storage	weight	Underground Storage tanks	Aboveground storage tanks	big bowl open to atmosphere	sponge city holds water	already existing water tank in north campus	water tower	open pond (pre-existing)	Underground aquifers
Maintanence	4	0	1	1	-1	1	0	0	-1
seasonality	2	0	-1	-1	0	-1	-1	-1	0
Life Span	3	0	0	-1	-1	0	0	1	1
creativity	2	0	0	1	1	0	0	1	1
ease of implementation	3	0	1	-1	-1	-1	-1	-1	-1
maintain quality in tank	3	0	0	-1	0	0	0	-1	-1
loss	4	0	0	-1	-1	0	0	-1	-1
Aesthetics	3	0	-1	-1	1	0	-1	1	0
total		0	2	-12	-9	-1	-8	-4	-9

Appendix D: Excel Rainfall Data Calculation



Roof area	36850	(sq.ft.)	(enter value)				1 cubic ft. of water = 7.48 gallons = 28.317 liters						
Rainfall	January	February	March	April	May	June	July	August	September	October	November	December	Annual
mm	36.9824	40.132	69.2404	63.6524	91.5924	66.6496	66.8528	65.8876	61.5696	81.28	48.1076	26.8732	718.82
inches	1.456	1.58	2.726	2.506	3.606	2.624	2.632	2.594	2.424	3.2	1.894	1.058	28.3
Monthly total collected													
cubic ft.	4471.1	4851.9	8371.1	7695.5	11073.4	8057.9	8082.4	7965.7	7443.7	9826.7	5816.2	3248.9	86904.6
gallons	33444.1	36292.3	62615.8	57562.4	82829.2	60272.8	60456.6	59583.7	55678.9	73503.5	43504.9	24302.1	650046.3
liters	126609.1	137391.7	237044.2	217913.7	313566.2	228174.6	228870.3	225565.9	210783.3	278261.7	164696.2	92000.3	2460877.1
Approximate daily average collected													
cubic ft.	149.0	161.7	279.0	256.5	369.1	268.6	269.4	265.5	248.1	327.6	193.9	108.3	238.1
gallons	1114.8	1209.7	2087.2	1918.7	2761.0	2009.1	2015.2	1986.1	1856.0	2450.1	1450.2	810.1	1780.9
liters	4220.3	4579.7	7901.5	7263.8	10452.2	7605.8	7629.0	7518.9	7026.1	9275.4	5489.9	3066.7	6742.1

Appendix E: Bill of Materials

Item	Quantity	Catalog #	Cost per unit	Contact	Notes
25000 Gallon Fiberglass Non Potable Underground Water Tank	4	NTP-10-45NP	$20,000 - $30,000	Nationwide Tank and Pipe	Price will vary depending on flanges, manway, etc. for each tank
8” x 10’ PVC Pipe	400	48925K46	$293.80	https://www.mcmaster.com/	Quantity would vary based on need
240V AC Open Drip Proof Centrifugal Pump, 1-Phase, 4 in Flange Inlet Size	1	6BF1K1E0	$4,138.26	Goulds Water Technology (Grainger)	Might need more than one pump
Flanged Full Port Pressure Reducing Control Valve, 8 in Pipe Size	8	M115-8 FL	$6,566.04	WATTS (Grainger)	2 for each tank, one in the inlet, and one in the outlet
Gate Valve, Valve Class Class 125, PVC, Slip Connection Type, Pipe Size - Valves 8 in	20	6801	$550.10	VALTERRA (Grainger)	Need gate valve on each side of machinery (tanks, pumps)
Check Valve, 8 in, Single, Inline Wafer, Cast Iron, Flanged Wafer x Flanged Wafer	8	DD1F-CI-34136-800	$579.64	KECKLEY (Grainger)	

Authors

Arthur Yang
Arthur is from the city of Palo Alto, CA, and is currently a senior aiming to graduate in Winter 2022 with a Bachelor's Degree in Mechanical Engineering. His interests within mechanical engineering include fluid dynamics, control theory, and the interaction between engineering and ecosystems. He does not yet have any concrete future plans, but is considering the option of going to graduate school. In his free time, he has a hobby of observing and photographing birds, insects, and other organisms; he has first records for Ann Arbor for several species of robber flies, weevils, and jumping spiders on the biodiversity-cataloguing citizen science platform iNaturalist.

Carlos Ceballos
Carlos was born and raised in Chicago, IL. He is looking to graduate in Fall 2021 with a Bachelor's Degree in Mechanical Engineering and Minor in Mathematics. His interest in mechanical engineering rose from being able to have the opportunity to work with space organizations with that degree. His plans after graduation are still unknown, but he would like to get a Phd or Masters in Physics so that it is easier to achieve his dream job. A fun fact about Carlos is that he devotes his hard work and resilience to his parents who are immigrants from Mexico. Through his parents' hardships and no experience with college , Carlos will be able to achieve a Bachelor's degree in Engineering this Fall 2021.

Emilio Chufan Bordon
Emilio grew up in a small suburb outside Baltimore, MD, called Howard County, and is originally from Argentina. He is currently a senior working towards a Bachelor's Degree in Mechanical Engineering and Minor in Computer Science. His interest in mechanical engineering derives from his pleasure in problem solving and physics. He had an internship over the summer at Air Products, where he has accepted a full time job to go back there when he finishes college. In his free time, he enjoys playing sports, traveling, and hanging out with friends.

Lambert Huang
Lambert was born and raised in New York City. He is currently a senior looking to graduate in Winter 2022 with a Bachelor's degree in Mechanical Engineering and a Minor in Computer Science and Physics. He is planning on pursuing a graduate degree after he graduates but is unsure whether he wants to pursue it immediately. His interests in mechanical engineering stems from his love for physics and its applications in real world solutions. Lambert works as an Resident Assistant at the University of Michigan and is actively involved in various campus groups. Apart from school, Lambert spends a majority of his time serving at his church where he currently leads a small group every week. Some of his other hobbies are running and other sports, hanging out with friends, and more recently, playing chess.