



SCHOOL *of* ENGINEERING
& APPLIED SCIENCE

Final Report

DESIGNING A DEVICE TO CLEAN DRINKING WATER

May 5, 2025

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Final Report Project:

Clean My Water

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List of Acronyms

CFU	Colony forming units
TNTC	Too numerous to count

Executive Summary

The Clean My Water project was initiated to address the lack of accessible, affordable, and eco-friendly methods for purifying water during extended outdoor activities. Emphasis was put on the need for a solution that could eliminate harmful microorganisms like *E. coli* without relying on heat, chemicals, or expensive components. Commercial filters such as LifeStraw offer a strong level of protection but are expensive and depend on synthetic materials with a limited lifespan, requiring frequent replacements. In response, the team was tasked with designing a biodegradable, portable water filtration system using natural materials that could safely improve water quality.

Following a literature review and client consultations, the team identified plant xylem as a promising filter medium due to its unique ability to block bacteria through its vascular microchannels. The initial concept involved a 3D-printed container connected to a water bladder, with a segment of pine wood serving as the xylem filter. This early prototype encountered issues such as water leakage and an unstable filter attachment, which compromised usability. After evaluating multiple design options and conducting low-fidelity prototyping, the team shifted to a single-piece 3D-printed housing with the xylem filter tightly secured at the base, allowing water to pass through the wood and collect safely below. This design resolved earlier sealing issues and streamlined the overall structure for durability and ease of use.

Once the new design was finalized, the team conducted a series of tests to evaluate its effectiveness. Bacteria analysis using microfilters and lactose agar plates confirmed a significant reduction in *E. coli* presence, although trace amounts remained. Turbidity tests revealed noticeable improvement in water clarity, while mechanical tests demonstrated the physical robustness of the filter under typical outdoor conditions. While the project was successful in developing a viable, low-cost, and lightweight filter, time constraints prevented the team from exploring other xylem types or dimensions that could improve filtration speed.

The final prototype consisted of a compact PLA-printed unit housing a pine xylem segment, with all components selected for simplicity and cost efficiency. It proved capable of reducing bacterial loads and improving clarity, while withstanding handling and simulated environmental stress. However, slower filtration speed and the occasional presence of bacteria indicated areas for continued refinement. Future iterations may experiment with other types of wood, layer thicknesses, and pressurization methods to enhance both filtration rate and microbial removal.

The Xylem Filtration project successfully created an environmentally friendly water purification system that meets the client's specifications. The design offers a sustainable, affordable, and effective solution, with room for future improvements in filtration speed and overall reliability.

1. Introduction

1.1 Client Problem

Prolonged outdoor activities such as hiking call for the need for increased efficiency in obtaining filtered water. Microbes present can present severe health risks, from stomach cramps, nausea, fevers, etc., which are a result in serious complications. Over a million people in the U.S. get sick from drinking water every year, and the goal is to create a possible solution to exacerbate this pressing issue that is both environmentally sustainable and affordable. An existing product is LifeStraw, which utilizes a hollow fiber membrane to filter water through tiny pores catching bacteria and microplastics, as they are too large to pass through. However, once the membrane filter is used up sufficiently, it no longer operates to the same initial capacity and must be replaced by a new unit.

1.2 Objective and Approach

The goal of the Clean My Water project is to design and create an eco-friendly and low-cost alternative to expensive portable water filters currently available on the market. A well-executed product for this filtration system is constrained by not having to rely on a direct heat source or chemical processes (such as boiling, acid-base neutralization, etc.). Despite these obstacles, the resulting filtered water should still be safe for human consumption and completely free of protozoa, harmful bacteria, and sediments. To accomplish this, the first objective was to research the most effective natural water filters and their limitations and then use that data to find the most optimal filter combination for the given objective. After research the idea was to iterate multiple designs to test how the proposed filter performed under multiple conditions and compare the test data to decide how the filter was best used. The client assisted in the designing process, giving suggestions that were tested in later iterations in addition to setting the testing criteria. These included speed of filtration, effectiveness, ease of use, and the level of importance for each of the criteria. This allowed the team to create 3 designs that were centered around one specific level of test criteria, then select the one with greatest overall standards. This filter was then optimized to create the best possible filter in the time allotted.

1.3 Report Organization

Chapter 1 – Introduction

The first chapter gives a general overview of project and its inception. This section includes the original client problem of high accessibility, low-cost filtration as well as the generalized solution approach to creating the final product, the xylem filter.

Chapter 2 - Literature Review, Problem Definition, and Final Product Considerations

This chapter involves the literature review, or a discussion of preexisting filtration designs and their relevance to the search for a cheaper, higher-accessibility filtration device. It also includes project considerations such as the problem definition and model, sociotechnical considerations, and client notes.

Chapter 3 - Selection of Initial Design and Plan for Remainder of Project

This chapter discusses the process of picking the most effective design and details the initial chosen solution. It begins with the development of multiple possible solutions inspired by the research compiled in the previous chapter, followed by an analysis of the proposed solutions and how the team ultimately chose the xylem filter as the final design. The chapter concludes with detailed information regarding an actionable plan for the remainder of the project, including product maintenance, a work plan (Gantt chart), and a list of materials to be ordered.

Chapter 4 - Testing Strategy, Results, and Resulting Revisions

This chapter details the testing, manufacturing, and iteration process for the initial xylem filter. It goes through the series of tests done on the filter and shows how the results of those tests are interpreted to turn them into actionable data.

Chapter 5 - Summary of Final Solution

Final product details and review.

Chapter 6 - Recommendations and Future Work

Discussion of future work and further development of project. Review of problems and iterations along the last stage.

References and Appendices

This section includes all citations to studies referenced throughout the report and is in APA format, ensuring proper credit to original authors and allows readers to locate the referenced studies. The appendices contain client meeting notes as well as full procedures for the tests performed on the filter and the filtered water.

2. Problem Definition

2.1 Client Discovery

2.1.1 Client Interview Summary

The clients for this project are a group of professors in the chemical engineering department at UVA who have challenged several engineering teams to create a new type of water filter that has not already been produced and advanced on the market. In the interview, the clients presented a slide show with some background information regarding the nature of the problem, creating a fictional scenario in which a hiker in Shenandoah Valley goes on a weeklong camping trip lacking the necessary storage to carry enough water.

The clients told the team's representatives that to fix this problem, they were looking for a low-cost solution filtration system that can effectively filter out pathogens, microbes, sediments, and anything else that can make a person sick. According to the client, the resources used in the filter must be cheap or present in the local ecosystem. The team is also not allowed to use any chemical processes to kill bacteria or microbes nor is the team allowed to apply heat to the water. Some other aspects of filtration the client wants teams to consider are filtration time, the process of obtaining and storing the water, and general accessibility needs. Other than those constraints, the project is up for interpretation. It also does not have to be an item that someone would purchase and can instead be a process such as creating a homemade filter from available materials.

The project, Clean My Water, is the biggest project across this year's Engineering Foundations course. With 14 teams, there will be many different interpretations and solutions to the client's problem. To encourage creativity and product efficiency, the client has proposed a competition in which teams will be competing for the best designs in the categories of accessibility, cleanliness (effectiveness of removing contaminants), and volume of water filtered. More detailed information about the client interview can be found in Appendix A.

2.1.2 Model of problem

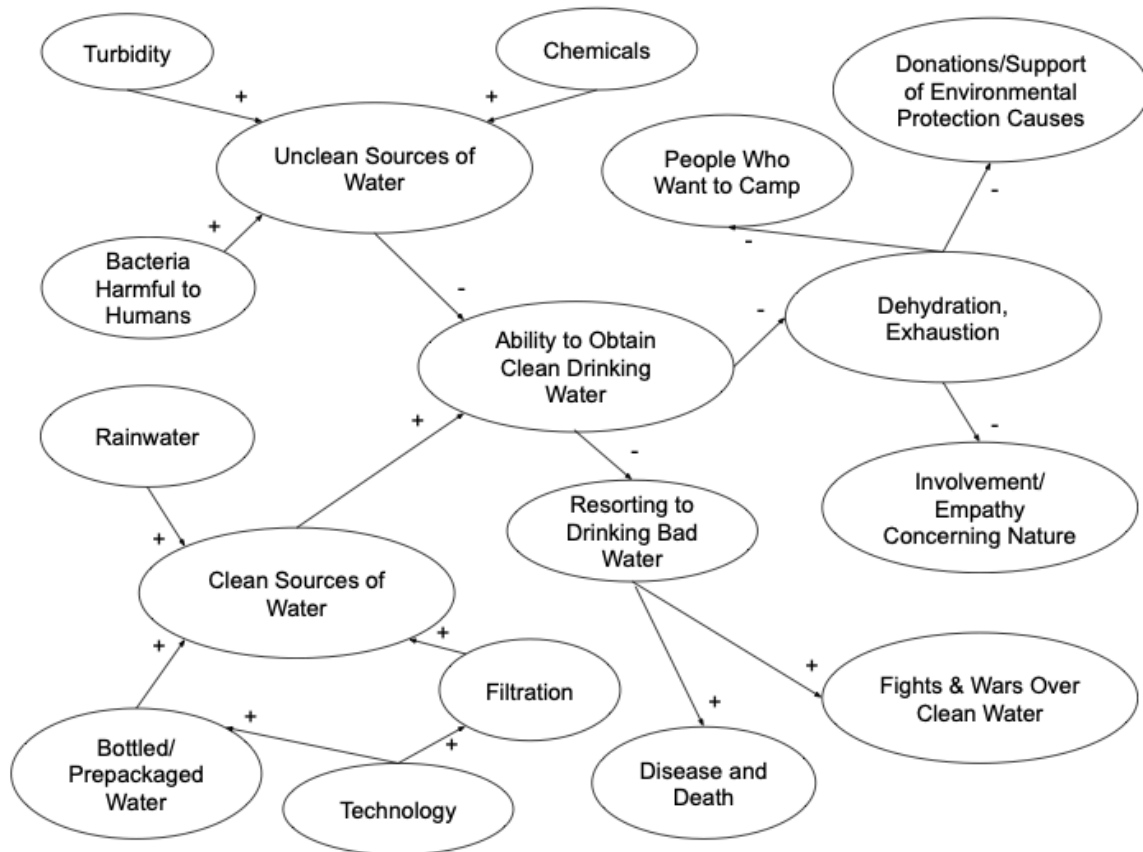


Figure 1: Model of Problem System
 ("+" means supports, "-" means detracts)

2.2 Literature Review

2.2.1 Introduction

Equitable access to clean water is a prevalent issue that affects millions worldwide, driven by a combination of economic, geographical, and environmental constraints. Contaminated water poses serious health risks due to harmful bacteria, viruses, and parasites, which can lead to various waterborne diseases. Common symptoms of these diseases include stomach pain, vomiting, and in some cases, even kidney failure. Hepatitis A, for example, is one disease that can be transmitted from contaminated water and can cause severe health complications, particularly for individuals with weakened immune systems (World Health Organization, 2023). While such diseases are rare in developed countries like the United States, underdeveloped states still suffer under a lack of affordable and effective access to clean water. Current water purification methods, such as chemical treatments and filtration systems, often fail to meet these needs due to cost and accessibility issues. Additionally, widespread pollution released by industry, agriculture, and residency continues to compromise water sources, further

contributing to a lack of fresh drinking water (Babuji et al., 2023). As a result, people in underdeveloped countries without access to modern filtration technology remain at high risk of exposure to harmful pathogens in contaminated water that can lead to serious health issues.

The team's research comes from a variety of sources, including scientific journals, international reports, and studies on water purification methods. These sources focus on three primary areas: the health risks of contaminated water, the effectiveness of current purification solutions, and the physical methods available for purifying water. The aim of this review is to identify key gaps in existing technologies and propose a solution that improves both accessibility and effectiveness. By reviewing these resources, the team gains a deeper understanding of the challenges and can build upon existing knowledge to create a more effective solution. This approach ensures that the development of new water purification technologies will be based on well-established research, addressing both the immediate and long-term needs of global water security.

2.2.2 Themes

Water is a vital resource for any civilization, developing or not. According to the United Nations, the use of fresh water worldwide has increased sixfold in the past century and has grown at an average rate of about 1% each year since the 1980's (United Nations, 2021). This growing demand underscores the critical role water plays in sustaining human life and supporting economic development. Despite this increased demand for water use, only 2.5% of the Earth's water is fresh, and only 0.77% is accessible for human use, the rest is trapped in glaciers and ice caps. Even more alarming, only a fraction—about 10%—of this accessible fresh water is deemed “suitable for human consumption” (Steven et al., 2022). This disparity between water demand and availability paints a concerning picture. As the global population continues to rise, already limited water resources will be further strained. Safe access to clean water free from chemical and biological contamination remains an ongoing challenge, with hundreds of thousands of people, particularly in developing countries, dying each year due to waterborne diseases. It is estimated that 80% of diseases worldwide and 50% of child deaths are directly caused by poor water quality and unsafe sanitation practices (Lin et al., 2022). These figures highlight the urgent need for comprehensive solutions to improve water quality and accessibility across the globe, especially in regions that are most vulnerable to contamination and water scarcity. There are a wide range of microbial, chemical, and physical contaminants that must be carefully considered when assessing the safety of water sources. Microbial contaminants include harmful bacteria, viruses, and parasites; common diseases produced by these organisms are cholera, dysentery, and typhoid fever. Chemical contaminants, such as heavy metals (e.g., lead, mercury, and arsenic), pesticides, and industrial pollutants, pose serious health risks when consumed over long periods, leading to conditions such as poisoning, developmental issues, and cancers (Babuji et al., 2023).

Another common theme prevalent in various research journals revolves around methods to physically purify water, each looking to filter out specific impurities. One paper describes a method of filtration using layers of powdered charcoal (making its structure more porous and absorbent). This charcoal is somewhat effective in eradicating bacteria in the water and has “[shown] very high turbidity removal efficiency (i.e. up to 98%) after a seven-number repeated filtration runs” (Musa et al, 2020, para. 1). The same paper explains how activated carbon has been found to be effective in causing contaminants to adhere to the surface of the carbon granules or be trapped in the pores of said carbon, a process called adsorption. Another paper states that activated carbon improves the taste of water, and is commonly used in portable water filters, since it can be easily washed and reused (M. A et al, 2018). Furthermore, activated carbon filters can produce water resulting in the complete removal of chlorine, fluorine, and certain organic materials such as bacteria and viruses. This makes them a popular choice in both household and industrial applications where water quality is a priority. The chemical characteristics of the contaminants and the filter material are crucial in determining the efficiency of any purification method. For instance, the charge of the contaminants plays a pivotal role in the electrostatic attraction between the particles and the surface of the charcoal. This interaction affects how well the contaminants are adsorbed, with negatively charged contaminants often being more readily attracted to positively charged carbon surfaces, and vice versa. Understanding the specific chemical properties of impurities in any sample of unfiltered water is essential to optimizing processes like adsorption and maximizing the effectiveness of physical filtration materials such as activated carbon. A third paper discusses the use of plant xylem as a method of water filtration (Boutilier et al., 2014). The paper discusses how plant xylem from coniferous trees can remove bacteria from water by simple pressure-driven filtration and can easily meet the water needs of a single person in a day. This style of filtration could become an inexpensive and easy method of filtration in third world countries, as trees are found almost everywhere on Earth. Xylem pores are about 500 nanometers wide, making them small enough to trap *E. coli* bacteria, but large enough to easily allow flow of water through them. This makes them an effective yet inexpensive form of filtration, which is an important need for the project.

Current solutions fall into several categories, including natural materials, advanced membranes, and hybrid systems. An example of prior art consistent throughout the research is the presence of current products in the market already designed to combat the need for filtration in various areas. One such product is *Swach*, a water filter developed by the Indian company Tata Group. This filter uses natural materials like sand, sugar cane, and coconut coir to remove impurities from water. These materials work together to effectively reduce contaminants, and the filter has been shown to lower the concentration of heavy metals in a particular sample from 6-5 ppm to 0.3-0.1 ppm (Anvekar et al., 2022). This example highlights how high-performing, low-cost water filters can be developed using sustainable, environmentally friendly ingredients. *Swach* represents an innovative step toward providing clean water in regions where access to safe drinking water is limited. Another notable product on the market is *LifeStraw*, a portable

water filtration device designed to provide safe drinking water in emergency situations or outdoor settings. *LifeStraw* uses a hollow fiber membrane that can remove exceedingly small microorganisms from water, such as *Cryptosporidium*, a parasite with a diameter of only 3-5 micrometers (Naranjo & Gerba, 2010). This advanced filtration technology can purify water down to the microscopic level, making it effective in removing pathogens that are often missed by traditional water filtration methods. While the membrane used in *LifeStraw* cannot be sourced from natural materials, it still exemplifies a significant leap in filtration technology that ensures even the smallest bacteria and parasites are removed from the water, making it an invaluable tool for outdoor enthusiasts, travelers, and those living in areas with unreliable water quality. These products, *Swach* and *LifeStraw*, serve as important examples of how diverse the solutions for water filtration can be, from natural materials to cutting-edge technology. They both demonstrate the potential for creating filtration systems that are not only effective but also scalable and affordable for populations in need. By leveraging innovative methods such as natural material filters or advanced membrane technologies, these products showcase different approaches to solving water contamination challenges.

2.2.3 Gaps

In the ever-increasing progression of technology and advancements, there are many gaps in the research for simple water filters. Many research papers regarding water filtration investigate technical and industrial solutions, and although these are of course extremely important areas of research, there is a lack of research around simple techniques to aid in cases of emergency. For example, in a situation where a hiker accidentally deviates from the trail for an extended period and exhausts their water supply. How they might be able to use the resources around them (depending on the climate they were situated in) is an area that does not have many scientific studies to back up solutions. While advanced filtration technologies such as membrane filters and chemical treatments are well-documented, there is minimal research on how individuals in survival scenarios can create effective, makeshift water filtration systems using naturally available materials. Another area with limited research is the long-term effectiveness and sustainability of low-cost, natural material filters in comparison to commercial products. While studies have investigated filtration materials like activated carbon, coconut coir, and sand, few have assessed how these materials degrade over time or maintenance requirements. More research is needed to determine how natural filtration methods perform in more widespread environmental conditions and whether certain types of filters respond best to certain ecological conditions.

In conclusion, while there is significant progress towards advanced water filters, there remains gaps toward simple, accessible, and low-cost solutions in the context of emergency and survival situations. Addressing these gaps is important in ensuring that individuals without access to expensive commercial products can still obtain clean water safe to drink by using their surrounding resources.

2.3 Problem Definition

Camping is a beloved pastime of people across the globe, but sometimes one can run into the common problem of a lack of clean water. The scope of the project specifically includes hikers on a long trip in the Shenandoah Valley region. Campers can choose to either bring along a large supply of clean water which takes up precious space, or they can consider bringing a water filter. However, finding the right one can be difficult and expensive. It's important to find an effective filter because contaminants can be found in almost any water source on Earth from pollution, algae, organisms, and more. Studies found that over 80% of sewage created by humans is discharged into rivers and oceans without any sort of purification process. Drinking unsafe water can cause cholera, trachoma helminthiasis, and schistosomiasis (Lan et al, 2022). Ultimately, a lightweight, low-cost, and effective filter would be ideal.

Guidelines require water purifiers to be able to kill or remove protozoan parasites and should be capable of reducing challenge levels of microbial contaminants as just a few examples (Naranjo et al, 2010). The U.S. Environmental Protection Agency has created a standard procedure to classify water safety. As the team creates an effective solution, these are all the requirements that need to be put in place to create an effective filter. When it comes to constraints, the clients were very lenient. All resources used must be easily accessible for the average consumer, whether it is a low-cost purchasable product or a process that requires the use of locally foraged resources. The team also must rely on the use of physical reactions only. The water passed through the filter should be at a standard fit for human consumption. Clients stated that the results of an E. coli test alone can be indicator of other harmful bacteria present and will generally serve as a good test of clean water. Hence, the filtered water will be tested for E. coli and the number of CFUs will be counted. Other than these constraints, the final product is up for interpretation. The clients mentioned that the final product could either be something that consumers would purchase, or it could be a process that a user would implement. They did mention that it would be preferable to efficiently be able to filter out larger quantities of water, but this is more of a preference rather than a requirement. When it comes to the final look and process of use, there aren't really any requirements, so the team has more freedom when it comes to creating a final design.

2.4 Summary of Sociotechnical Considerations

Any problem or project involving clean water is going to have many applications to societal issues. Although this project's focus is on creating a filter for specific use and for a specific population, the general concept of creating an easy-to-use, cheap, and effective water cleaning method will be at the forefront of societal issues until clean water access becomes universal. As much as one quarter of the world's population does not have adequate access to clean water and sanitation, and half of all child deaths are related to a lack of clean drinking water (Lin et al., 2022). Although this project alone will not solve global water scarcity, it's

important to recognize how this type of work—especially when designed with sustainability and accessibility in mind—can have a larger impact than originally intended.

Around the world, millions of people lack access to clean drinking water. Not only are microbes a major cause of sickness, but harmful chemicals and heavy metals from industrial runoff or spills also pose major health threats. Even in areas like the Blue Ridge Mountains, where this product is intended for recreational use, water safety cannot be guaranteed. These habitats have a specific ecology, so the filter can be tailored to target local microbial species and sediment types that are more likely to occur in Appalachian water sources. Although the clients will not be the primary users of the filter, they will act as a key part of the distribution network—helping to share the product with members of their community who are in need. This adds a unique social dimension to the project, emphasizing the importance of community trust and local knowledge in the success of any technology.

To create a sustainable and eco-friendly product, it's important to ensure that the filter is both easy to use and made from biodegradable or natural materials. If someone were to accidentally leave the product behind, it should not cause harm to the environment it was meant to serve. Sustainability also includes considering the full lifecycle of the product: from material source and manufacturing to disposal. On a broader level, water filtration on a large scale is notoriously expensive and energy intensive. While this project works at a much smaller scale, it aims to offer a model for how decentralized and low-cost water filtration could supplement existing infrastructure or provide emergency support in underserved regions.

Another major sociotechnical goal is accessibility—not just in terms of physical design or affordability, but also in terms of usability, cultural fit, and equitable distribution. The product needs to be intuitive to use, especially for individuals without prior experience with filtration systems. This includes designing with low literacy levels in mind and avoiding any reliance on external power sources or complicated instructions. Keeping the product inexpensive was a high priority for the client, as current market options like LifeStraw are often too costly for low-income users. But affordability is only one part of equity. Making the product lightweight, portable, and usable by a wide age range, including children or older adults, adds another layer of accessibility. Equity in design also means considering who might be excluded by default and actively building features that make the product usable and beneficial to a broader range of people.

2.5 Closing

Many studies the team came across utilized carbon as a filtration technique. Whether carbon is activated or layered carbon powder, carbon is found to be a common and effective method. Carbon has also been proven to be an efficient eradicator of bacteria and turbidity. Therefore, it will likely be a good approach to develop the team's product with the use of carbon in some form. With the combination of other filtering materials such as porous rock, sand, and

5. SUMMARY OF FINAL DESIGN

gravel, an effective, natural, and cheap filter can be produced for the client. While there are many more technical ways to go about the solution, such as the use of high-quality materials and manufacturing seen in products on the market, it is important to keep in mind that the client is hoping for a product that can be produced in nature and at a low cost. The use of these low-cost, easily accessible materials also results in a sustainable product that protects the environment.

3. Initial Solution Ideation

3.1 Development of Alternate Designs

Originally, the problem definition led the team to conceptualize possible physical filtration systems in water bottles, plastic bags, and other containers for the solution. These ideas were primarily built upon existing designs such as Swach and LifeStraw. Existing solutions utilize the physical properties of certain materials such as activated charcoal to attract and separate impurities from contaminated water. During the client meeting, the team determined that a key part of creating a successful design was volume. Although there are many products on the market and in nature that can remove the smallest contaminants, these products often lack the necessary speed required for a parched camper to obtain sufficient water. Therefore, the decision was made to incorporate a method of accelerating the process of filtration into the design.

The research conducted by the team resulted in multiple designs (attached below), but some of these designs lacked the ability to filter out the smallest of viruses and bacteria. The only solution that fits the constraints described in the problem definition well, which required that the product be made only with natural materials and avoid chemical processes involves a tree xylem. Following the requirement of volume discussed in the client meeting, another decision was made to try to add a pressurizing component to the xylem attachment, to accelerate the filtration process further. Once this design was formulated, it far surpassed all other options and became the primary design.

Xylem Filtration

The preliminary idea was to utilize a xylem filter that utilized the properties of certain tree woods to clean water. What made this idea so appealing was the abundance of suitable trees in nature, such as pine, spruce, and cedar, in addition to being naturally occurring, biodegradable, and free of chemicals. The main drawback of this design idea is the slow rate of filtration, as the water would have to be processed through a dense piece of wood with some thickness. Compared to other methods, including those in Figures 2 and 3, the xylem has the benefit of being capable of trapping particles that may be several micrometers in diameter, a feature that is not present in faster processes. In Figure 2, the plant xylem filter is held by a detachable 3D printed PLA tube that has threading for sealing onto the bottle holding the unfiltered water. The detachable characteristic of the attachment allows for easy refilling of unfiltered water. The other two solution ideas are the typical filters one can imagine when it comes to filters. The idea of a xylem filter is not something that is not researched or experimented with as much, presenting an opportunity for the team to further innovation and discovery in this area.

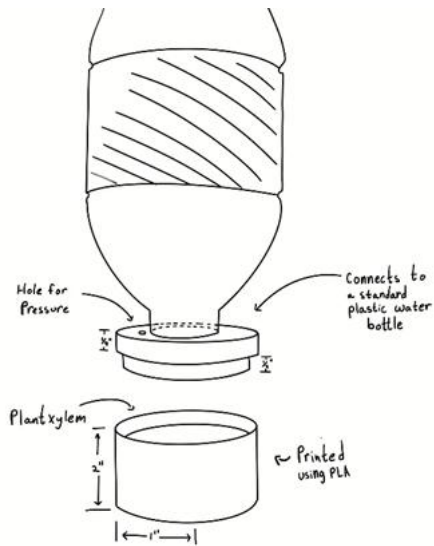


Figure 2: Plan-Xylem post-coagulation filtration system

Multi-layer Filtration (Bottle)

The second preliminary solution idea involved layers of gravel, sand, activated carbon, and some sort of mesh. These materials each serve a specific purpose. For example, activated carbon utilizes adsorption to trap impurities in the pores of the carbon, while gravel and sand both reduce turbidity. These different filtration layers would be arranged in a water bottle, and pressure from squeezing the empty part of the container would force water through the layers of filtration into a separate, clean container under the water bottle. Some benefits of this idea were that all materials were cheap and easy to find and could be sourced from recycled materials. Using gravity to drive the filtration process, this filter is also a relatively fast worker. However, a major drawback from this design was that the filtration materials could be contaminated, defeating the purpose of filtration. To expand on that, the natural filter components such as the sand and gravel could potentially have contaminants themselves adding another factor to the process. Additionally, the filtration materials are not able to filter the smallest of microbes, so a critical part of the problem definition – that the filter must filter out bacteria and protozoa– was not satisfied by this prototype.



Figure 3: Multi-Layer Bottle Filtration System

Multi-layer Filtration (Bag)

The third preliminary solution idea involved layers of filtration (like Figure 2), each serving a similar purpose. However, instead of a water bottle, layers of each filtrate would be placed in an empty bag, allowing gravity to force water through the filter. This design differed from Figure 2 as the bag could be passively attached to a tree, eliminating the need for an exhaust camper to push the water through the bag. A benefit of this characteristic is that it removes the need for filtration speed, as the camper can use the device passively while they tend to other necessities like building a shelter. Additionally, this design also implemented the layers in different orders, as it doubled both the layers of sand and gravel compared to Figure 2. These additional layers can provide further filtering, improving the efficacy of the filter. The main drawbacks of this prototype were the same as those in Figure 2.

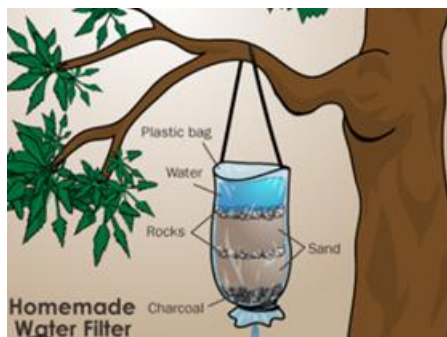


Figure 4: Multi-Layered Bag Filtration System

3.2 Selection of Initial Design

Originally, all three solutions seemed viable relative to the design criteria consisting of the actual filtration process, usability, and cost efficiency. During the roundtables, there was no apparent gravitation towards any single design. Participants from the various groups listed pros and cons for each idea, placing priority on total filtration time for each process and the need to replace filter parts throughout their lifespan. After receiving initial feedback on the three designs, the team began considering aspects addressing the concern of necessary volume for prolonged use such as a weeklong hike in the woods. Both the multi-layer filtration designs were already relatively fast, so no adjustments were required to improve the filtration rate. However, the team did make a change to the xylem design, where the original rigid plastic container containing the unfiltered water was replaced with a malleable bag, allowing the user to apply pressure to the container and thus speed up the filtration process. The team also decided to add a coagulator to the updated design for the xylem filtration system as the client, Professor George Prpich, had recommended flocculation as a method to better rid of the larger particles that would cluster due to physical properties such as Van der Waals and other charge negating effects. The team did not incorporate the coagulation system into the other two multi-layered models, as the process of filtering finer and finer particles exists inherently in the utilization of multiple layers and would not likely affect the process in general.

The xylem filtration concept as a decision matrix considering filtration performance, ease of use, portability, health benefits, etc., found that the xylem filtration technique was the most effective method of removing as many contaminants as possible (factors that were consistent throughout all 3 iterations were ignored, such as water capacity). Also, although Figure 2 and Figure 3 both outpace Figure 1, they are inadequate in filtering out many bacteria and viruses. Unlike xylem, none of the materials in either filter can separate contaminants such as *Cryptosporidium* (3-5 micrometers in diameter) from the water, as these contaminants are too small. Additionally, materials such as gravel and sand may be difficult to find in general parts of nature. Activated carbon is almost impossible to find in the environment and would have to be prepared beforehand. For the sociotechnical considerations that are incorporated into the design, the three main considerations are affordability, availability, and usability. The materials that are in the filter are both easy to find and affordable, as the goal of this filtration system is to be highly accessible. The most pressing consideration from the client and throughout the entire design process was affordability, as the motivation for the project was that the current products are too expensive. The current design utilizes both materials that are either easily found in nature (and are essentially free) or were the lowest cost product that fit the plan, meaning it is both affordable and available. In addition, because the materials are so easy to come by, using the filter becomes a much simpler process. The current design uses gravity to pull the water through the system, so the user does not have to worry about having to pump the water through the filter. This makes the filter very intuitive, not requiring any sort of technical expertise to use or fix.

Scores range from 1 (worst) to 5 (best)

Table 1: Design Matrix and Reasoning

DECISION MATRIX	Multiple Layers in Bottle	Multiple Layers in Bag	Xylem
Ease of Use	3	3	4
Portability	5	5	5
Affordability (2x)	10	10	8
Speed of Filtration (2x)	8	8	2
Maintenance/Cleaning	2	2	3
Durability/Build Quality	2	2	4
Availability in nature	5	5	5
Effectiveness of filtration (2x)	6	6	10
SUM	41	41	41

Description of Score System:

1 – Poor:

- Ease of Use: Requires complicated setup or extensive effort to operate, may require background knowledge of system.
- Portability: Heavy, bulky, or not practical to carry.
- Affordability: Expensive relative to alternatives on the market.
- Speed of Filtration: Very slow; takes minutes to filter a small amount.
- Maintenance/Cleaning: Requires frequent or difficult cleaning, special tools, or replacement parts.
- Durability/Build Quality: Fragile, prone to breaking, or poorly built.
- Availability in Nature: Requires specialized components or is not practical for a typical user.

5. SUMMARY OF FINAL DESIGN

- Effectiveness of filtration: Does not filter out larger sediment, bacteria, or protozoa.
- Creativity:

2 – Fair:

- Ease of Use: Tricky to operate, requiring effort or multiple steps.
- Portability: Large or heavy but still manageable.
- Affordability: Moderately expensive but justified.
- Speed of Filtration: Slow but functional, taking noticeable time.
- Maintenance/Cleaning: Requires regular maintenance, but not overly complex.
- Durability/Build Quality: Materials are of a decent quality but wear down quickly.
- Availability in Nature: Some natural materials may be used but most materials need to be brought beforehand.
- Effectiveness of filtration: Filters out larger sediment but leaves some smaller sediment. Does not filter out bacteria or protozoa.

3 – Good:

- Ease of Use: Simple to operate but may have a minor learning curve.
- Portability: Compact and lightweight.
- Affordability: Reasonably priced with excellent value for cost.
- Speed of Filtration: Moderate; provides a steady flow without being too slow.
- Maintenance/Cleaning: Occasional cleaning needed, but easy to do.
- Durability/Build Quality: Solid construction with decent lifespan.
- Availability in Nature: Possible to build in nature with effort but requires skill.
- Effectiveness of filtration: Filters out most sediments but leaves in bacteria and protozoa.

4 - Very Good:

- Ease of Use: Intuitive and user-friendly with minimal effort.
- Portability: Lightweight and designed for easy transport.
- Affordability: Affordable for most users while maintaining quality.
- Speed of Filtration: Fast, providing clean water in short time.
- Maintenance/Cleaning: Minimal maintenance with simple cleaning.
- Durability/Build Quality: Well-built with long-lasting materials.
- Availability in Nature: Can be made with accessible natural materials with relative ease.
- Effectiveness of filtration: Filters out all sediments and protozoa, but no bacteria.

5 - Excellent

- Ease of Use: Effortless operation with no learning curve.

- Portability: Ultra-lightweight and compact.
- Affordability: Extremely budget-friendly with no compromise on performance.
- Speed of Filtration: Very fast, delivering clean water instantly.
- Maintenance/Cleaning: Rarely needs cleaning and is easy when required.
- Durability/Build Quality: Highly durable, resistant to damage, and built to last.
- Availability in Nature: Easily built from natural materials with minimal effort.
- Effectiveness of filtration: Filters out all sediments, protozoa, and bacteria.

Interpretation of Results:

All three prospective designs scored the exact same in the decision matrix. Although all categories are important, the categories that mattered the most in the decision-making process were affordability, speed, and filtration efficiency. To note this distinction, the weight of those three categories was multiplied by two to give them a higher influence on the overall score. Without further development of the final solution, as of right now, the only categories the other solution ideas beat the xylem filter in are speed and affordability. Because the xylem pieces have such small pores, which are essentially the main filtration system, it will take a considerable amount of time for the water to filter through. With the assistance of pressure, however, the speed of xylem filtration will almost certainly increase. The final solution idea will likely also be more expensive to build than the initial design, to increase both durability and quality. Another factor that was important in the selection but was not included in the design matrix itself was creativity. The multi-layered solutions are both generally standard examples of water filters, and the team wanted to try something a bit different that stood out for the project. The idea of a plant xylem water filter is a topic that not many people are familiar with, and the team agreed that it was the more niche and therefore interesting topic to pursue for the rest of the project.

3.3 Detailed Description of Design

The original idea involved pouring dirty water into a water bottle, attaching a 3D printed chamber with the xylem inside (made using PLA) to the bottle cap, and squeezing the bottle to pour out the filtered water. The plant xylem would act as a membrane to filter out debris, bacteria, and protozoa.

After meeting with the client a second time, they recommended using some sort of coagulant to prevent larger particles from blocking the filter. In the second iteration, coagulants would be added to the previous design to filter out more large particles. The team also replaced the water bottle in the first design with a bag/bladder which could be used to allow more pressure. The team also considered including a spout with two openings: one to dispel the sludge created by the coagulant and the other to allow the water void of large particles through to the xylem. To control flow, a removable pin would be added to each spout. However, the team chose to not include the spout.

5. SUMMARY OF FINAL DESIGN

Although the spout could have been successful, the team decided to adjust the final solution to make the 3D printing process simpler. Instead of creating two separate tubes for the water to flow out, the water will exit the container in the same way as the original design. Additionally, the final design includes the user still adding coagulant and dirty water to the top of the bag. When the coagulant settles to the bottom, the user will pull out a pin to release coagulant sludge. Afterwards, the user may screw on the chamber with plant xylem, pull out the pin once again, and apply pressure to filter the remaining water.

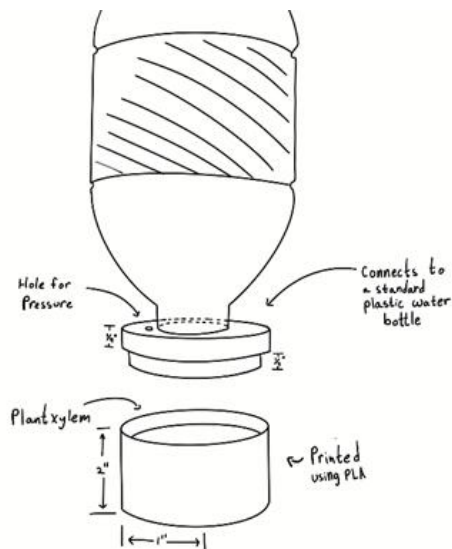


Figure 5: Plastic bottle design

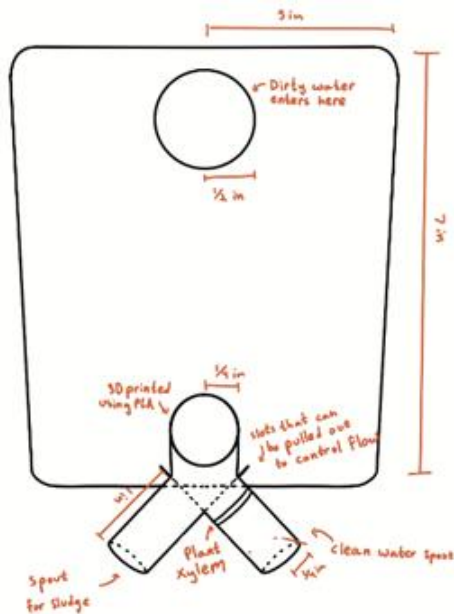


Figure 6: Multi-spout design

3.3.1 Detailed Product Description

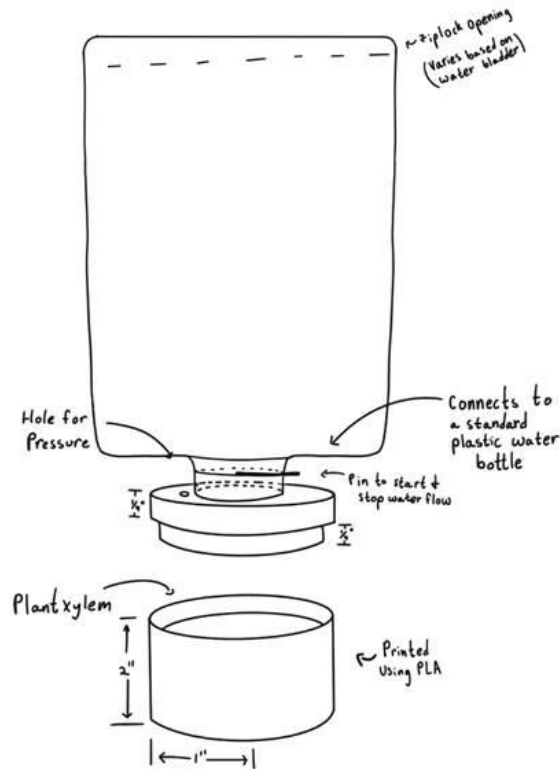


Figure 7: Water bladder design

The final design is comprised of three permanent parts: the water bladder, waterspout, and a chamber. The team is sourcing the water bladder from an online source while the waterspout and chamber will both be 3D printed using PLA. The coagulant, bentonite clay, and plant xylem will have to be replaced after every use (for the coagulant) or after a week (for the clay and xylem). The bentonite clay can be purchased online while the plant xylem can either be purchased ahead of time or be harvested from a non-flowering tree such as pine or ginkgo. If harvested, the tree branch will need to be carved to fit within the chamber. When in use, the user will pour dirty water and coagulant into the top opening of the bladder. Once larger sediments have settled to the bottom, the user may pull out the pin located at the spout and close once only clear water is left. Afterwards, the user will place plant xylem into the chamber and screw it onto the spout. Finally, the user may squeeze out the remaining water to be filtered.

3.3.2 Product Maintenance and Lifespan

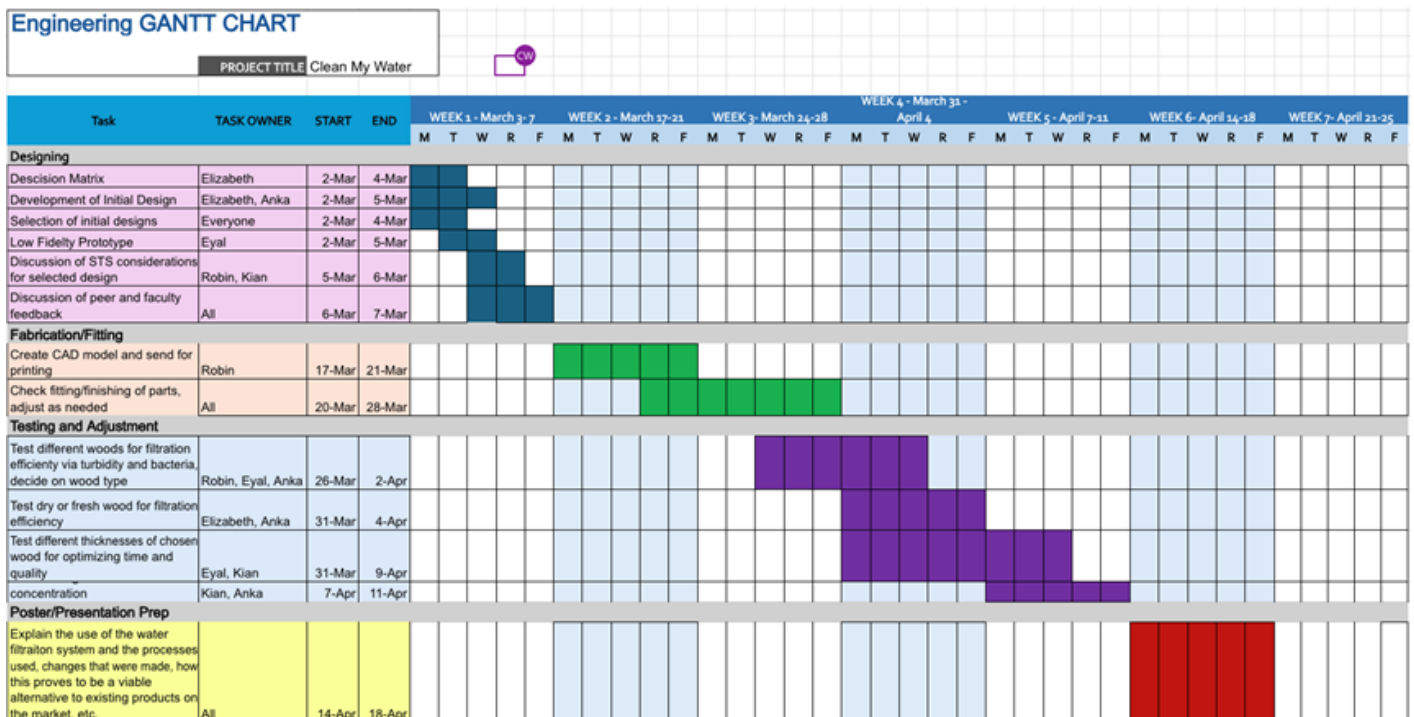
Ideally, all components of the system—except for the xylem filter—are designed to last indefinitely, requiring replacement only in the event of physical damage. However, given the rough conditions this product may be subjected to (e.g., outdoor use, frequent handling, exposure to sharp objects), the water bag itself poses a significant risk of wear and tear over time. To mitigate this, the bag should be made from a puncture-resistant, flexible material such as TPU (thermoplastic polyurethane), which offers durability without compromising portability.

5. SUMMARY OF FINAL DESIGN

Additionally, providing users with a lightweight patch kit or encouraging them to carry a backup bag could help ensure the system remains functional in the event of a leak or tear in the bag. The xylem filter, in contrast, has a naturally limited lifespan. Bacteria will gradually accumulate in the pores of the xylem, slowing filtration over time, and the organic material is prone to mold growth and microbial degradation. This does not significantly hinder usability, as the filter can be easily replaced by cutting a new segment from a tree branch—ideally oak, due to its dense and robust xylem structure—and inserting it into the PLA housing. Keeping the xylem damp helps preserve its filtration function between uses. The most vulnerable component of the entire system is the seal between the water bag and the 3D printed xylem housing. This joint bears the full weight of the system and is subject to mechanical stress, making it prone to cracks, leaks, or complete failure over time. If this failure occurs, the entire filtration function could be compromised. To address this, the design should emphasize quick detachability and field-replaceability. Since this component is small, lightweight, and inexpensive to print, users could easily carry one or more spares and swap them out as needed without tools. This approach enhances the system's resilience and makes it more dependable for long-term or remote use.

3.4 Work Plan

Table 2: Gantt Chart



The final week (Week 7, April 21-25) has been left blank to accommodate buffer space in case fabrication and/or testing and iterating takes longer than expected, that way the team has time to finish up whatever is needed.

Preliminary Testing Plan:

One of the most important criteria the project entails is clean water. Therefore, testing for parasite and microbe concentration is a key part of this criteria. The team will be using the laboratory in Wilsdorf hall (provided by the client) to assess E. coli concentrations and turbidity. The client provided lactose agar with a dye component to test the bacteria. The bacteria consume lactose, and the dye will be absorbed into the bacteria, which will turn them pink. The filtered water is fed through a vacuum pump through a microfilter, which has pores larger than the size of E. coli microbes. After about a day, the bacteria become visible on the filter plate. Other microbes will not be tested as the client proposed that testing E. coli alone will serve as a good indicator for other microbes present. E. coli concentration will also be evaluated by the client on presentation day, so it is important to be prepared for this factor during the final test. The team has not decided whether they will be utilizing fresh newly torn wood or old wood for the xylem filter. There are findings that fresh wood would save time but is less efficient, while old wood would take longer but would result in a cleaner product. The team will be testing the different types of wood for its speed and its effectiveness in filtration to ultimately optimize the xylem filter. Moving on, the team has also not chosen a tree species from which to obtain the wood. Research from MIT utilized wood from coniferous trees for their xylem filter. However, considering the environmental habitat of the east coast, Shenandoah Valley might be more straightforward to use wood from oak, hickory, or ash trees as they are more available in the context of the project location. It is important for the filter to be accessible. Therefore, if the team determines that coniferous trees are a better option, they will also consider their obtainability before coming to a final decision.

Material Considerations

List of materials needed:

1. Coagulant- Bentonite clay powder

Bentonite clay is an excellent coagulant known for its ability to remove suspended particles, impurities, and contaminants. Ultimately since it is an affordable and easy to access product, it was chosen as the coagulant.

2. Water bag 1

The reason this bag was chosen was because it is simple and durable. It has an opening compatible with sawyer filter, a filter company, which on the website states its thread is universal. This will make the process of producing the CAD for the solution much smoother while also giving the benefit of making the product accessible. This bag can also sustain 2 Liters of water which is almost ample enough to last an entire day out.

5. SUMMARY OF FINAL DESIGN

3. Wood

The team has not definitively decided whether fresh or dry would be used. Hence, the team will be testing out natural pine wood slices to evaluate this factor.

4. Water bag 2

In case water bag 1 is not ideal for the filter, a secondary water bag filter is ordered for extra safety.

5. CAD Model

A CAD model printed with a mostly watertight and nontoxic material will be needed. (PLA)

6. Screw/pin

The pin will be taken out and used to let out coagulated sediments and put back in shortly after to let filtered water stay in place.

Table 3: Bill of Materials

Item Number	Item Name	Description	Quantity	Source	Cost	Notes
-	Turbidity tester		1	Client	-	Provided by client, have not seen the kits yet
-	Bacteria tester		1	Client	-	Provided by client, have not seen the kits yet
UPC: 85003 78791 51	Coagulant	Bentonite clay powder that will function as the natural	1	Amazon : <u>Bentonite Clay</u>	\$11.99	This clay will function as the coagulant that comes before the xylem filter

5. SUMMARY OF FINAL DESIGN

		coagulant .				
Model Name: LC-Z799-US-XD	Collapsible Water Container for Camping Hiking Fishing or Traveling (Water bag)	2L water bag, TPU material, Compatible with multiple different installable water filters	1	Amazon <u>Water Container</u>	\$15.99	This is the bag that will be using to hold the water as it is being filtered (will use gravity to pull the water through the filter)
-	4.3-4.7 inch Unfinished Natural with Tree Bark Wood Slices	Little pieces of oak branches that the team will be testing as the xylem filter.	1	Amazon <u>Pine Slices</u>	\$11.99	The team will be testing both fresh pine and the dry pine.
	Water Storage Bag, BPA Free Food Grade Clear Water Storage Cube Premium Collapsible Water Bottles Container Bag Gallon Water Jug Portable Water Bladder Tank	8 Liter bag with two nozzles, PVC material	1	Amazon : <u>Water Container</u>	\$6.99	This is the bag that the team will be using to hold the water as it is being filtered (will use gravity to pull the water through the filter)

4. Testing Strategy, Results and Design Revision

4.1 Initial Fabrication and Testing Plan

During the first week of fabrication, a low fidelity prototype was constructed to better visualize what the ideal system would look like. Figure 8 displays how the water is planned to flow, with an attachable vessel containing the unfiltered water, and the lower portion with the xylem puck holder and a valve to control the flow rate.

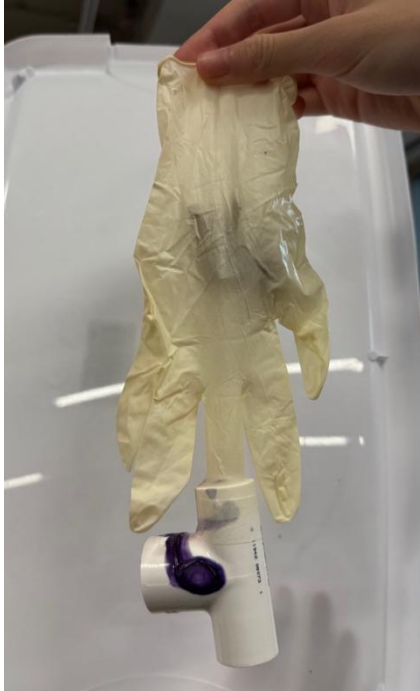


Figure 8: Low Fidelity Prototype

The low fidelity prototype is nonfunctional due to its materials, as the latex glove would not be able to hold the pressure/weight of the water. The team's end goal was to create a 3D printed chamber holding a piece of plant xylem and attach it to a bag filled with water. The xylem filter was decided to be pine, and was cut using a hole saw drill bit to create a snug circular fit in the chamber. The team had purchased two water bladder options to test out which would be the easiest to attach the xylem chamber to.

Inspired by the designs of the purchased water bladders, the first 2 CAD designs for the xylem holder utilized standard water bottle threading scaled accordingly to fit the water bladders. A potential issue with the 2-piece filtration device is leakage at the joining section. Unless the addition of rubber or other viable gasket replacements does not work, an alternative design would have to be explored to prevent this should the issue occur.

Testing Plan

Four tests were conducted: leakage, E. coli and turbidity, weight, and static stress, with the caveat that further testing would not happen without passing the first test.

The leakage was a big issue that presented itself during the first round of testing. Despite the usage of hot glue and other remedies, nothing was able to stop the water from leaking. The team shifted their approach to create a single 3D printed body in which the plant xylem sits at the bottom blocking the opening. This new body acts as a container and water can be poured into the top opening, sitting there until all the water passes through the xylem.

A coliform bacteria test was performed to assess the contamination levels of the filtered sample. The client provided a structured testing schedule wherein the CHE undergraduate lab would be used in Wilsdorf Hall to test the prototype. The first step of testing involved collecting 20–100 milliliters of water from a nearby unfiltered water source, such as a creek or pond, which would then be filtered by the team before they tested it in the Wilsdorf lab. The water collected for this test was from the Dell Pond. In the lab, the team conducted tests with the proper PPE to determine the coliform bacteria concentration in samples of the water. These tests involved pouring the filtered sample into a vacuum pump apparatus, which held a microfilter (with a pore size of 3 nanometers) to catch all the E. coli present in the filtered sample. These microfilters were then transferred to a provided lactose agar plate, on which the E. coli absorbed a pink dye in the sugars in the plate. These plates were then left overnight to incubate, and the next day, bacteria colonies and solid material would be observed and documented based on the resulting difference in color. These tests were repeated for two separate samples of filtered water from the same source to ensure the validity of the results. The team tested six samples in total, in two separate rounds. The first round included two control tests of 10mL and 50mL, and two filtered tests (also 10 mL and 50mL) using the initial design. The second round was only filtered tests using the final design, and they were 1mL and 5mL tests. The resulting differences in the contamination concentration between the tests were then used to judge the effectiveness of the filters. It is important to note that any trace of E. coli bacteria in the filtered water makes the sample unsafe for drinking, according to the National Institutes of Health (Odonkor, S. T., & Mahami, T., 2020). Some variables that can impact the quantity of E. coli present can be temperature, turbidity and coexisting microbes. In addition to the bacteria testing, the water was also tested for turbidity. Because the team did not have access to a full turbidity testing kit, this was done visually by comparing the samples to the control dirty water sample and a clean water sample.

The other two tests were physical in nature on the filtering device itself, with a stress test to simulate an impact on the filter, and a weight test. For the stress test, the team simulated a force of 250.0 N around the main storage area of the filter using Fusion. The weight of the force used was determined by a combination of factors, from average grip strength to the possibility of

being impacted by other large mass objects by accidents, the goal being to simulate a scenario in which the filter would be tested just past a realistic extent to account for unexpected circumstances. For the filter to be considered “safe” in the simulation, the minimum safety factor had to remain above 1. For the test of the two weights of the filters, the primary aim of the project was to create a portable and convenient product for campers on the go, meaning durability and a low weight being imperative for meeting this success criteria.

Unfortunately, the team was unable to test a couple of factors that were mentioned in Chapter 3, due to time and manufacturing capability. The original plan was to test how both wood type and wood thickness affected the performance of the filter, attempting to try and optimize the amount of time it takes for the water to run through the filter, as well as the thickness needed to make sure the water was filtered well. Due to limitations on how many lab tests were run, these factors were not able to be tested.

Full procedures for the different tests can be found in Appendix B.

4.2 Testing Results and Analysis

4.2.1 E. coli and Turbidity Test

The original test results stated that the control and filtered samples were practically identical in E. coli concentration, as shown in Figure 9 and 10. This was due to a manufacturing malfunction of the filter resulting in leakage that did not go through the xylem, resulting in almost no water passing through the filter. The samples of 50 mL had even more CFUs (colony forming unit) as an increase in sample will increase the bacteria concentration as well. Numerous attempts to use software to count the amount of CFUs were tried, but due to bacteria crossing the software’s threshold, results were determined as TNTC (too numerous to count). After the second round of testing, the amount of E. coli in the filtered water decreased significantly. The second round of testing showed zero E. coli in the filtered water, with no pink colonies to find. This is observed in Figures 11 and 12. Despite the filter success, it took around 24 hours for just a small amount of water to pass through the filter, it ultimately resulted in an effectively filtered product. After the E. coli test, a quick visual turbidity test was conducted. The turbidity of the two filtered samples were compared with images online, and the team consulted Dr. Prpich who confirmed that the turbidity of both samples was near zero NTU.

5. SUMMARY OF FINAL DESIGN

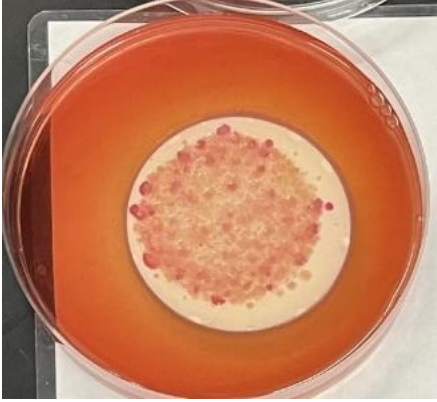


Figure 9: 10mL of filtered sample results with first iteration

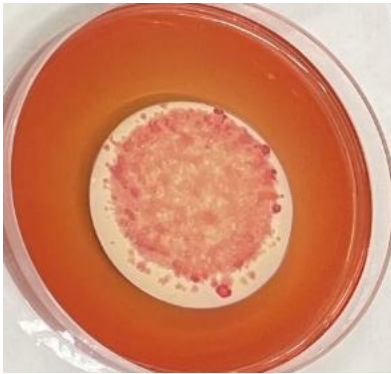


Figure 10: 10mL of unfiltered sample result with first iteration

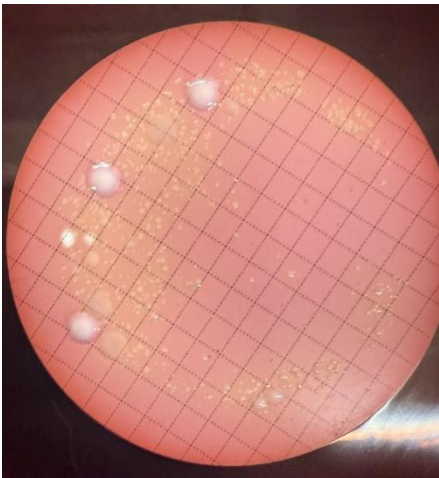


Figure 11: 1mL of filtered sample result with second iteration

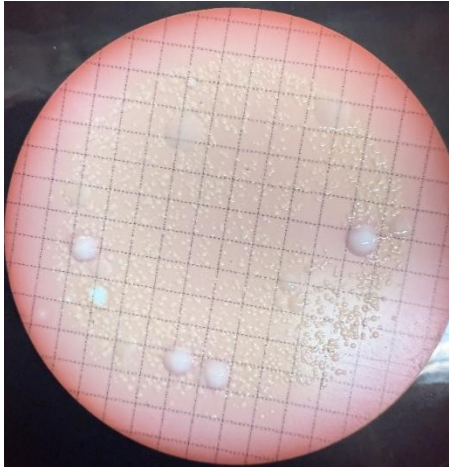


Figure 12: 5mL of filtered sample result with second iteration



Figure 13: Turbidity test of the two filters

Table 4: Summary of Bacteria and Turbidity Tests

	Turbidity	E. coli Concentration
Iteration #1	<1 NTU	TNTC
Iteration #2	<1 NTU	0 colonies detected

4.2.2 Weight Test

A comparative mass analysis was conducted between the initial and final filter prototypes to assess improvements in portability. The final design demonstrated a reduction of 11.2 grams in mass relative to the original, with images of what was weighted shown in Figures 14 and 15, and the tabulated weights in Table 5. Although the revised filter retains a slightly lower water capacity, the decreased weight presents a significant advantage in field applications where gear load is a critical consideration. For users, such as hikers, minimizing equipment weight can

5. SUMMARY OF FINAL DESIGN

enhance mobility and reduce physical strain during extended use. This design refinement reflects a deliberate effort to improve user ergonomics without compromising the filter's primary function. Future development efforts may focus on further optimizing the balance between mass and filtration capacity to meet the practical demands of end users.



Figure 14: Mass of final design



Figure 15: Mass of initial filtration design

Table 5: Mass Chart

	Mass of Filter (g)
Iteration #1	98.48
Iteration #2	86.66

4.2.3 Durability Test

For the durability test, a load of 250.00 N was applied all around the outer section with the largest diameter, the portion that would be most prone to compression or collisions. The reason for this was meant to generalize the strength of the filtration system, and the results for this are shown in Figure 16, where both the minimum and maximum safety factors are 15.00. This safety factor is well above 1, ensuring that any day-to-day forces that may be applied to the body will not result in fracturing, as 250.00 N is more than any force that would normally be applied to it.

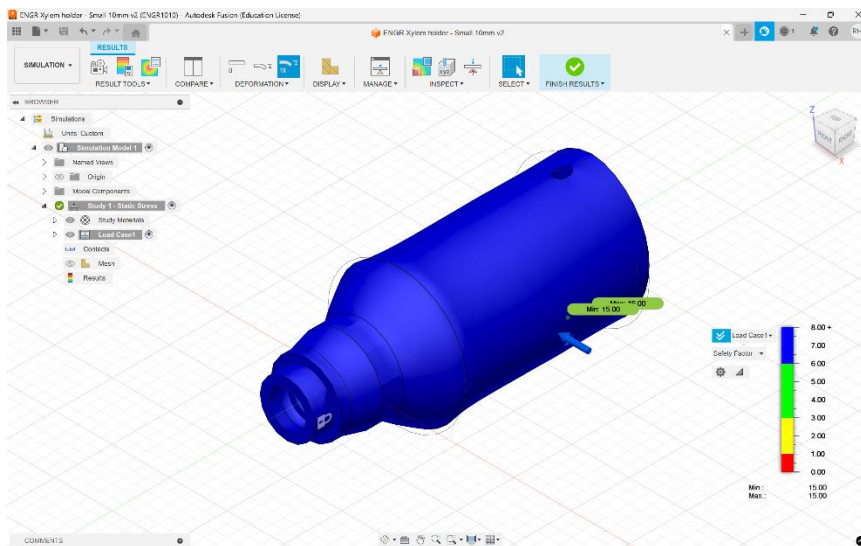


Figure 16: Durability/load test

4.2.4 Summary of Results

The original filter test revealed that both the control and filtered samples had nearly identical *E. coli* concentrations. This indicated a failure in the filter design, specifically a manufacturing defect that caused leakage and allowed water to bypass the xylem entirely. As a result, filtration did not occur. To confirm this, the team ran CFU tests using 10 mL and 50 mL samples. The 50 mL samples produced higher CFU counts, as expected with larger volumes, but reflected the same filtration failure. Therefore, only the data from the 10mL trial was reported above. Initial attempts to use image analysis software to count CFUs failed, as the bacterial colonies exceeded detection limits and were categorized as TNTC. After identifying the leakage as the primary issue, the team redesigned the filter to ensure that all water flowed directly through the xylem. New tests were performed. The filtered samples showed complete removal of CFUs compared to the control, indicating successful bacterial removal. There were no colonies to detect, as can be seen in Figures 11 and 12. These improvements confirm that the redesign addressed the previous issues, and the filter is now much more effective and reliable for real-world use. Despite this however, the slow mass flow rate through the filter remains a limitation

5. SUMMARY OF FINAL DESIGN

for field use. In addition, further testing under varying environmental conditions would help enhance reliability across many different ecosystems.

The team compared the mass of two filter prototypes and found that the final design is 11.2 grams lighter than the original. While the final filter holds less water, the reduced weight offers a practical advantage for users. For hikers on extended trips, lighter gear contributes to greater comfort and efficiency. Although the weight difference may seem minor, over long distances, the cumulative effect can be significant. In addition, the second iteration is much smaller than the first, making it easier to store it in a backpack. In future iterations, the team may consider optimizing both weight and capacity to further improve usability without compromising performance.

A durability test was also conducted, revealing that the design had a minimum mechanical safety factor of 15 all around from a 250 Newton force. This shows that the design can be used without fracturing from minor forces. This structural integrity ensures that the design can endure any sort of day-to-day activity that the user might come across.

4.3 Informed Design Revision

4.3.1 Justification based on data

The testing results indicated that the previous xylem design did not work, most likely due to a leak between the xylem chamber and the water bladder. The adhesives were deemed futile. Furthermore, the E. coli test showed that there were practically no differences between the control and filtered, further proving the filter's inadequacy. The team decided to fix this problem by changing the filter from an attachment on a bag to one that simply holds the water itself, preventing any leaks (shown below). The same process utilizing gravity is then used to push the water through the filter.

4.3.2 Design revisions

During the first week of fabrication, the team planned to design the xylem holder to accommodate the size and threading of the cap of the water bladder. However, a design capable of being able to seal water properly was not achievable initially, due to the specifics of dimensions not being clear on the website. The team brainstormed many designs prioritizing the holding/placement of the xylem, as well as the process of utilizing the coagulant prior to the xylem filtration process. The team spent 2 weeks making and testing the fit of 4 xylem holder designs, 2 for each size of water bladders. After getting the two ordered water bladders, the dimensions of both the components containing the inner and outer threads were taken for each bladder. It was found that the larger cap had a diameter of 40mm, ~1mm threading thickness, and a 10.5mm height, not including the flat top of the said cap. The number of threads were counted, and this average was used to create threading that would replace the cap for the bladder.

5. SUMMARY OF FINAL DESIGN

To produce the xylem holder for the smaller water bladder, because the diameter of the cap was around 30mm and the thread count was the same, the CAD for the larger bladder was simply scaled down. Figure 17 shows the piece that would be screwed on to the water bladder. An internal extruded ring is present with a chamfer intending to hold the xylem, where the water expanding the wood piece would effectively seal the piece in place, not allowing water to flow around the sides unfiltered.

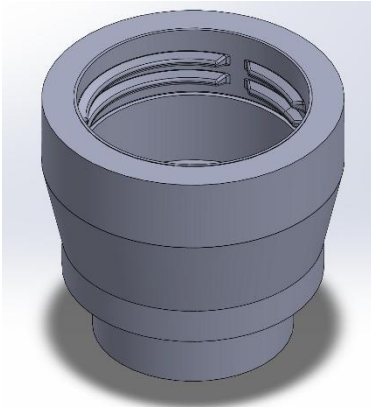


Figure 17: Initial CAD attachment for water bladder with threading

With each test fitting the CAD piece to the large and small water bladders, it was found that dimensioning the threading proved to be too intricate and difficult to get a proper seal, so after the second week of fabrication and needing to move on to a position to start testing, the team collectively returned to the general design and decided to remove the threading altogether and look towards friction/gasket fitting to seal water. *Figure 18* shows smooth internals, as well as the small change in inner diameter in the upper portion (above the chamfered cylinder), which was manipulated with respect to the thickness of xylem to be used. Two iterations of each print were made when testing, one with the second differing diameter to have a height of 10mm, and another with a height of 5mm.

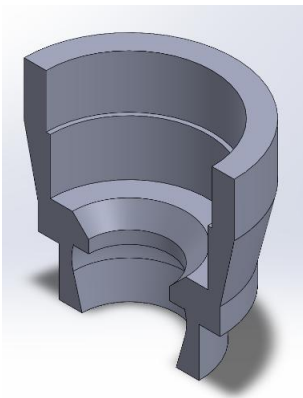


Figure 18: CAD with removed threading - shows chamfered ring

5. SUMMARY OF FINAL DESIGN

At this point of the fabrication stage, neither bladder sizes were decided to be the primary design consideration, and the designs were modified to accommodate each separately. For the larger bladder, sharp indents were located where the threading ended, and an idea came up to include a clipping mechanism, where if the xylem holder was clipped onto the bladder, it would solve the issue of holding the xylem in place, working in conjunction with the friction fitting. Especially since a primary concern for this design was the slow rate of water flowing through the wood piece, the design for *Figure 19* would also allow the consideration of the addition of a pressure system to speed up the process later.

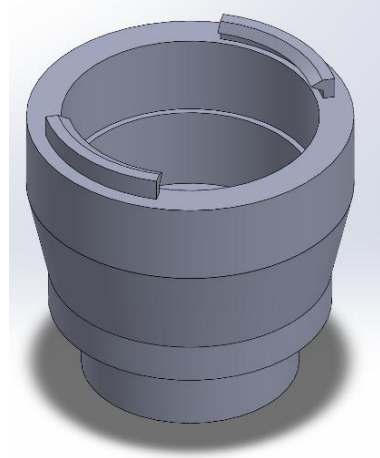


Figure 19: CAD with clips for large bladder

The week after, when the testing iteration was produced and a testing date was scheduled, substantial/usable amount of water was not projected to be available after initially starting the filtration process, and so it was left to filter overnight. 50mL of the control water was filtered by the next day, and tests were run. The turbidity of the large particles was seen to have drastically reduced, but the *E. coli* count did not show a noticeable difference from the control, unfiltered sample. Further small sample testing showed water leakage where adhesive was added to hold together the xylem holder and the water bladder in addition to the rubber strip. From this data, alternative designs were looked at, such as a singular rigid body that would act as the xylem holder as well as the water container as opposed to a multi-piece system, where leakage would be prone. *Figure 19* shows this updated design and opens the opportunity to explore a pressure system, such as a French-Press mechanism, which would potentially speed up the filtration process. 2 holes were added near the top of the design to enable it to be suspended in the air while an external container catches the filtered water.

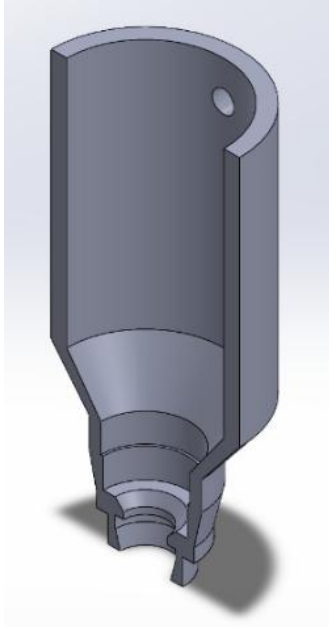


Figure 20: CAD cropped view of 1-piece design

While leakage is difficult to identify in regions where water is expected to exit, observations from the latest iteration provided compelling evidence of no leakage. Notably, the flow rate was significantly slower than in prior trials, where water escaped through unintended gaps. This decrease in flow velocity suggests that the redesign successfully minimized/eliminated major leakage points, particularly between the xylem holder and the water bladder. The slower filtration rate implies that water was being properly routed through the xylem rather than bypassing them, indicating that the adhesive and structural modifications were effective. The behavior of the system aligns with that of a properly sealed filtration mechanism. These findings support the conclusion that water exiting the system had passed through the intended filter medium, thereby increasing probability of the functional integrity of the revised design. Further testing under varied volumes and conditions will be necessary to fully validate this outcome.

5. Summary of Final Design

5.1 Description of Final Design

5.1.1 Detailed Description of Final Design

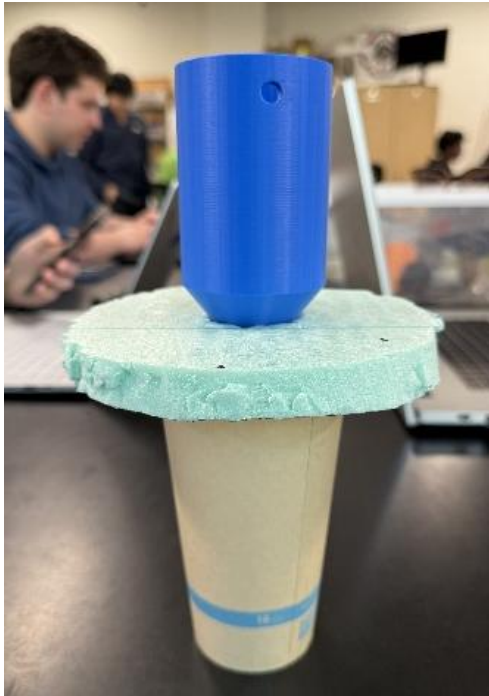


Figure 21: Final design

The final design for the water purification device is shown above in Figure 21 and consists of 2 main components: the xylem filter chamber, and the receiving container. The top cylindrical portion is used to store the contaminated water from a natural source. Once the water has been mixed with the coagulant, it is directed toward the blue filtration chamber, which is supported and stabilized by a surrounding Styrofoam frame. This filter chamber features a cavity designed to hold the xylem wood, which acts as the primary filtration medium. As gravity pulls the water downwards, it passes through the porous structure of the xylem, where contaminants such as bacteria and fine particles are removed. The clean water then exits the bottom of the chamber and is collected in a receiving container—typically a cup or water bottle positioned directly below the filter. The use of gravity eliminates the need for pumps or mechanical pressure, making the system ideal for low-resource or emergency settings. The modular nature of the components also allows for easy assembly and potential reuse of certain parts, such as the chamber and Styrofoam support.

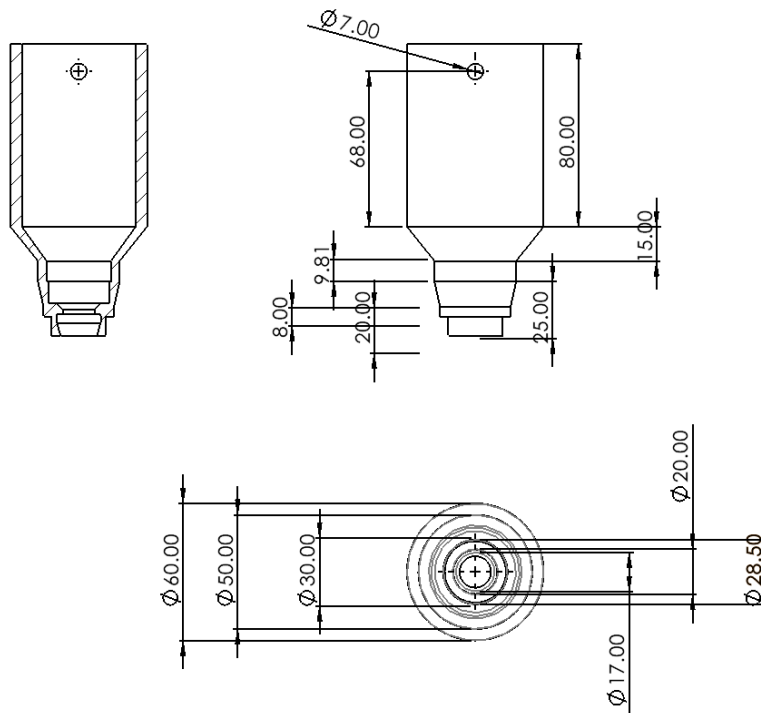


Figure 22: Dimensioned Final Design

For the xylem filter housing, the final design was 3D printed as a single, modular container to house the xylem disc, as shown in Figure 22. The container itself measures approximately 130 mm in height and narrows from the 80 mm height portion with an internal diameter of 50 mm to hold the water to the bottom section small enough to hold a 1 to 10 mm height xylem piece. The piece, which serves as the primary filtration element, fits within the container with a diameter of 20 mm, allowing for stable and secure placement, and coupled with expansion of the wood due to water, excessive gaps are minimized that could potentially lead to water leakage.

A 7 mm hole through the top of the filter device was added to enable it to hang in place while the water filters through. The 15 mm height portion in the middle of the design was tapered to use less PLA and lessen the weight and materials used. Near the water exit hole, there is a chamfered indent which was implemented to prevent as much water from leaking from the sides as possible, while not restricting the surface area of the xylem used to filter the water.

The most notable difference between the planned design in Chapter 3 and the final design lies in the container structure and the overall filtration mechanism. Initially, the container was to be constructed using a water bladder and a single PLA segment to house the filtration xylem. However, during prototyping, this configuration proved ineffective—there was substantial leakage at the bladder to casing connection. Due to these issues, the final design was modified to incorporate a 3D-printed container specifically engineered to hold natural materials like xylem in

addition to the water that was to be filtered, therefore minimizing leaks and maintaining structural fit.

In addition to changes in housing, the filtration approach was also simplified. The final prototype relied solely on a xylem disc as the filtration layer, placed within a 3D-printed container designed to hold the said disc securely in place. Although the use of coagulants was initially considered to reduce turbidity and extend the functional life of the xylem, coagulation was ultimately excluded from final testing. While effective, coagulation requires significant time for particles to cluster and settle, which would have further slowed an already time-consuming filtration process. As a result, testing focused on evaluating the standalone performance of the xylem, prioritizing simplicity and feasibility within project constraints.

Additionally, the modular container housing for the xylem, though a necessary improvement for consistent testing, was simpler than initially planned. The final design did not include additional materials such as a screw-on cap or a support mesh, which would have further improved stability and ease of use. These changes, made due to material availability and time limitations, still met the project's core objective of providing a low-cost, natural filtration solution, but future improvements could include reintroducing the coagulant layer or exploring alternative methods like a French press system to improve filtration efficiency.

5.1.2 Design Performance

The design's performance was down the middle in terms of the success criteria presented by the client. While the design was able to produce a clean sample of water, the sample was extremely small for the time frame that it took to produce it. The client had a competition between teams to see who had the cleanest and fastest filter, and while the design did well in the cleanliness race, the volumetric race was extremely far from successful. A person on a camping trip typically needs around two gallons of water per person per day for cooking, cleaning, and drinking, and at the current pace it would have taken over six years to reach that point with just one filter working. This does not mean that the filter was a failure however, as there are many positives from the final design, but there are also many possibilities for improvement, which will be discussed in the next chapter.

5.2 Design Solution Addressing Customer Needs

5.2.1 Fulfillment Objectives and Customer Needs

The customer's main need was a low-cost, eco-friendly water filtration system for hikers that was effective against bacteria and protozoa. The final product fulfills the customer's needs by featuring a 3D-printed container housing a xylem disc that filters water naturally, without the need for chemicals or heat. The filtration system is secure and effective at removing larger contaminants and sediment. However, one of the main concerns that impacts the filtration efficiency is the slow rate at which water passes through the xylem. During testing, it was found that while the xylem filtered water quite well, the slow filtration time was a limiting factor.

Future work could involve integrating a French press system to help accelerate the filtration process. This would increase the pressure on the water as it passes through the xylem, improving the flow rate while maintaining the natural filtration properties. This adjustment would help to meet the goal of faster filtration without compromising the eco-friendly design.

Additionally, the final design addresses all the necessary criteria. The 3D-printed container, combined with the xylem filtration layer, ensures that the system remains simple yet effective. The modular design makes the system easy to assemble, and the xylem's natural filtering properties allow it to efficiently remove contaminants. While the filtration speed is still a concern, the design is effective at removing large particles and sediment. Based on stress tests done during the design process, the final product is durable enough to withstand typical field conditions, even with frequent handling. The materials used to construct the filter—such as PLA filament and locally sourced xylem—are also inexpensive, ensuring the final product remains affordable, likely costing under \$20 to build. This affordability aligns with the goal of providing a low-cost, eco-friendly solution for hikers in need of clean water.

5.2.2 Sociotechnical Considerations in Final Design

The final design incorporates many sociotechnical considerations, which were carefully integrated into the design process and approach throughout the entire semester long process. While the use of chemical cleaning was prohibited by the client, the fact that the filter system does not rely on some form of chemicals makes it a less expensive and safer option for use in nature. Incorporating biodegradable materials and plant-based filtration makes the filter extremely easy to manufacture and reduces reliance on synthetic materials. Additionally, the fact that the filter is 3D printed makes it easy to manufacture around the world, as 3D printing has become such a common practice. The small size and lightweight nature of the device make it easy to transport, which is perfect for the intended user group (hikers on the go). Because it only requires two components (the filter holder and the xylem piece), the design is simple and straightforward to use, meaning using it does not require any technical training or expertise. This increases the accessibility of the filter, because it ensures that the possible user base is not limited in any way. Keeping the cost of materials low also helps make sure that whoever needs access to this kind of filter will be able to have it.

Beyond individual use, the simplicity of the design also means that it can be used in a variety of different situations. The fact that it only relies on gravity to filter water means that it can be set up anywhere if there is a way to hold it up. Finally, its environmentally friendly materials and minimal waste generation help align the design with growing global efforts toward sustainability, making it a responsible choice not just for users, but for the planet as well.

6. Recommendations and Future Work

Although the current design has some notable successful attributes, there are many possibilities for improvement of the overall product. Throughout the project process the team was able to identify multiple areas of possible improvement, which are present in the entire project process. These improvements can be extended to the design of the actual filter, the manufacturing process, the testing process, and the iteration process.

The first problem that was encountered with the iteration process was that the original filter mount did not fit, since the threading on the original water bladder used did not match. Because this was the first problem that the group encountered, it took longer than expected to find a useful fix. In the end it took three separate attachment designs to find one that worked, and even the one that was tested ended up having a leak. Having the ability to make sure that the first attachment works correctly the first time would be ideal, and this could be achieved in a couple of ways. The first possible fix would be with the use of a 3D sensor like a laser scanner. This would make the dimensions of the threading clear, making it easy to match the filter holder with the bladder without leaks. Another way to fix this problem would be to do what the group eventually did, which was make the filter into a single body. There were problems with this design as well, however, since it was not able to hold or filter much water at a time. If sticking to a single body design in the future, it would be important to scale the design so that it would be able to filter more water at once.

The primary problem with the filter was in the speed of filtration. The filter only managed to produce four milliliters of water in twenty-four hours, a speed that effectively makes the product useless in situations that it was designed be used in. When someone is on a hike or camping trip and needs water, it is needed in large amounts. This is both because humans need at least three and a half liters per day of drinking water and the fact that cooking often requires large amounts of water as well. To try to counteract this, an external pressure system would have been added after researching how to best implement one. A common example of this would be a pump, plunger, or a piston-style press, like a French Press that is used to make coffee. Although this would take away some of the usability of the system, as it would now require some form of human work rather than just relying on gravity, it would make up for it with a much higher amount of clean water produced.

In tandem with the problem of filtration time, a factor that the group wanted to test but were unable to due to time restraints was the optimum thickness of the piece of wood. In Chapter 3 the possibility of testing this variable was discussed, but the overall manufacturing process took much longer than anticipated, leaving little time for the testing that was done. Optimizing the thickness of the wood would have involved a consideration between time of filtration and cleanliness of the produced water, as a thinner piece of wood would allow for a higher mass flow rate, though it would also be at the expense of a less clean resultant product. The current size, ~5mm, worked well in terms of cleanliness but had such a low mass flow rate that it did not matter how clean the water was, because there was simply so little of it. Future experiments

could benefit from testing a series of thicknesses, perhaps ranging from 2 mm to 10 mm, to determine if there is a “sweet spot” where filtration speed and water purity are balanced.

Another factor that was not considered was different types of woods. This was another factor which was proposed as part of testing in Chapter 3 but could not be tested due to time restraints. The filters that were tested only contained one type of wood, pine. Pine wood is classified as softwood, which is good for filtration as they naturally have small xylem pores, letting water run through but keeping contaminants out. The effectiveness of the filtration for different tree species will depend on its tracheid size, resin content, and density. Different types of pine wood, but also different species of tree should be tested to find the best medium for filtration, as well as testing fresh on top of dry xylem pieces. In fresh wood, its vascular tissue is still intact which ensures the function and structure of the xylem pores. When wood dries out its vessels will collapse and clog up, reducing its effectiveness for filtration. It would also be valuable to test how environmental factors such as temperature, water turbidity, and elevation impact the system’s performance, since real-world conditions often differ from lab settings. Gathering this type of data would strengthen the product’s design and reliability.

Overall, while the initial prototype provided valuable insight into the challenges of xylem filtration, significant improvements are both necessary and possible. With more time dedicated to testing, material exploration, and mechanical enhancements, this project has the potential to produce a practical, user-friendly, and efficient water filtration system that could be used in a variety of outdoor and emergency settings.

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Appendix A: Client interview

Client interview Notes:

Common contaminants that affect drinking water quality:

- Pollution like trash, metals
- Bad bacteria: E. coli
- Parasites, e.g. Giardia, tiny parasite that cause diarrhea, causes beaver fever
- Algae
- Microbes (#1 leading cause of waterborne illness)
- Oil, hydrocarbon pollution

Water to Test

- Water from the dell because that will be used for final test

How:

- Filter out microbes and sediment
- Absorb microbes and containments
- Sterilize contaminants
- Low-cost, widely available

Success:

- Reduces turbidity: little sediments
 - o What high turbidity looks like: lots of dirt, mud, silt, algae, organic material, and murky.
- Reduces **coliform** numbers (important quantitative indicator for success)
- Performs well in indicators of potential contamination and water quality & tests for E. coli bacteria.
- Low cost: perhaps something that can be built on demand.

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- Physical interactions
- Competition for cleanest, largest volume, lowest cost will be held.

Other notes:

- Life straw is expensive and not able to be built by user
- Can assemble out on field, or bring compact materials
- Stuff that can be a source: sand, gravel, char, etc.
- Ideally not a slow drip
- Easily reusable, could be good
- Water purity: look up safety standards

5. SUMMARY OF FINAL DESIGN

- Does not need to be marketable, up to team interpretation of how marketable final product is,
- Do not need to only think about the 2 quantitative measures (indicator and cost): can make own criteria
- Imagine Shenandoah Mountain environments as the control and test
 - o e.g. Creeks, springs, no big lakes

Typical problems:

- Clogging
- Homemade built device/project may cause other contaminants, be mindful
- Variability: range of contaminants there could be like depending on season and weather
- Could be multiple processes, anything, open to interpretation and creativity of design

What resources can be used

- Container can be made of anything, but the things put inside should be readily available
- Can use heat indirectly
- Needs to push things through tiny holes, or needs bad stuff to stick to walls, so it's filtered out. Sand and charcoal are good options. (Porous rocks maybe)
- Look to air filtration as an example as well
- Birch bark might be an idea.
- Can use premade things (like water bottles)
- Clay is good at cleaning contaminants (but also maybe not?)
- Gravity feed system
- Can be flexible with many plants' species
- Look at UVA Guatemala water-filtration

Appendix B: Testing Procedures

Procedure for E. coli Testing:

1. Measure out specified amount of water into a graduated cylinder and set up vacuum pump with 3nm microfilter over Erlenmeyer flask.
2. Pour filtered water into vacuum pump setup, and let the pump run until all the water has run through the microfilter.
3. Pick up microfilter using tongs and place directly on to pre-prepared lactose agar plate.
4. Label plate and place into oven, letting it sit for at least twenty-four hours.
5. Remove plate from oven and record results.

Procedure for turbidity testing:

1. Place the control unfiltered water, filtered water, and clean water and put them in test tubes.
2. Compare the clarity of the filtered sample between the clean and the dirty water, using online images as a reference.

Procedure for weight testing:

1. Use the scale to weigh the two different filters, making sure to zero the scale before each one to ensure consistency.
2. Compare the results to see how the iterations affected the overall weight.

Procedure for durability testing:

1. After creating the single bodied prototype in fusion switch the workplace from to simulation and select the static stress study.
2. Create a structural load of 250 N around the main cylindrical portion of the prototype.
3. Create a constraint by selecting the very bottom cylinder of the prototype to keep the object in place.
4. Select solve and wait for results to generate. 1 is the minimum safety factor

